PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

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SEMAINE D'ETUDE

SUR LE THEME

L'EMPLOI DES FERTILISANTS ET LEUR EFFET SUR L'ACCROISSEMENT DES RECOLTES, NOTAMMENT PAR RAPPORT A LA QUALITE ET A L'ECONOMIE

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STUDY WEEK

ON

USE OF FERTILIZERS AND ITS EFFECT IN INCREASING YIELD WITH PARTICULAR ATTENTION TO QUALITY AND ECONOMY

April 10-16, 1972

SECOND PART

PONTIFICIA
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SOIL FERTILITY AND FERTILIZING OF CULTIVATED PLANTS

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A Study Week on the use of fertilizers demands in the first place a preliminary Survey covering both the concept of fertility and our new knowledge of plant nutrition in connection with the absorbing process and the transport of nutritive constituents by cultivated plants. This demand, of course, has become more and more important with the progress and deepening of knowledge concerning soil and plants.

Modern concepts of root absorption, the numerous correlations which on the physiological and agronomical level condition the development and productiveness of crops, and especially the rapid change of the different fertilizers that industries put at the disposal of farmers, require from technicians and practical farmers a careful consideration for the pedological and physiological appropriateness of these fertilizers, and for the way and limits of their application.

More than half of the fertilizers used immediately after the war are no longer to be found on the market, and today there are products in use which at that time did not exist. For this reason both the concept of fertility and the fertilizing processes acquire new and more precise agronomical significances.

To oppose soil fertility to the practice of manuring which, in its general acceptance means today chemical fertilizing, is in my opinion a formulation that is not quite correct and is open to some dangerous interpretation, because it may easily favour the illusory conviction that soil fertility may be increased only through the administration of chemical fertilizers.

Apart from this consideration the subject of my paper would require not forty minutes for its presentation but a whole course of lessons. Therefore, I shall limit myself to handling the theme in a summarized way, emphasizing particularly the more significant aspect of fertility and fertilizing in relation to the actual conditions of agronomical practice.

First I would spend a few moments on the definition of the concept of fertility, which represents a complex function of many variables, most of which are neither simple nor independent.

Many renowned agronomists, among others Demolon, maintain that fertility is not susceptible of a precise and absolute definition, but that it constitutes the expression of an experimental ascertainment referable to the propensity of a soil to favour more or less high yields.

Without entering into detail and considering it in a global sense, the concept of fertility corresponds to what COSIMO RIDOLFI defined at his time as "the admirable propensity of the soil to produce". Evidently this is a rather polyvalent concept which led agricultural chemists to consider a whole series of factors, the intervention of which tends to modify the productiveness of the soil by means of specific effects which, being temporary and manifesting their efficacy within certain limits, determine almost always essentially dynamic situations, capable of changing more or less rapidly. Thus fertility turns out to be the component of a vast series of factors which have the capacity to increase the unit production (i.e. production per hectare) of cultivated plants, and which cannot all be modified through the intervention of man.

The *location*, *latitude* and *altitude* of the soil, and above all *climatic conditions*, which influence the ground and with which the farmer can by no practical means interfere, constitute parameters of particular importance for determining numerical indices for the expert to make use of for establishing in a certain territory a scale which may facilitate the evaluation of its fertility in accordance with experimental results.

The *lie of the land* which can be modified with levelling and terracing works; the *depth of the cultivable stratum*, which can be increased by trenching works, and the presence of abundant *gross skeleton* which today can in certain cases be satisfactorily altered, form on the other hand a category of factors susceptible of possible and substantial ameliorations.

But what I would particularly take into consideration, together with land clearing, is the state of the *superficial disposition of the ground* which, apart from other fertility factors, very often conditions the productiveness of agricultural crops.

When the ground is not well levelled, the first rain after sowing — especially when the soil contains organic or inorganic colloidal constituents — will deprive it of permeability, and there will be a formation of stagnant water capable of provoking asphyxia of the seed and resulting in a conspicuous decrease of the unit yields.

It is not difficult to observe even in European agriculture, in places where the soil cultivation is not carried out very effectually, neglecting for example the levelling of the ground, that the unit yields are inexplicably low even when there is no deficiency of other fertility elements, as a consequence just of this constitutional defect.

While we are discussing the superficial disposition of the ground, besides surface levelling, there has to be considered the subsequent correction of the slopes so that a well scattered system of drainage may prevent destructive consequences at lower levels.

The availability of water in sufficient quantity for the hydric needs of the plant, or the excess of humidity determining difficult life conditions for the root system of the plants, that is the general hydric state of the soil, are essential factors regarding fertility, factors, however, which generally can be modified more or less easily by the farmer in proportion to the means available and the territorial situation in a favourable sense for the vegetal development, and thus for the promotion of a higher level of fertility.

So far, we have pointed to that series of factors concerning essentially the fertility of position or the general fertility of the soil, which in part can be easily modified. Now I would like to dwell on texture and structure, with which the ground's capacity for water and air appears to be linked, and which activate the so-called physical fertility that seems to be of prior importance and to condition constitutional fertility.

As is known, the physical properties of the soil are fundamentally linked with its texture and structure. The significance of the texture is frequently confounded with the significance of the structure without taking into account their profound diversity. The texture is in fact linked to the size of the elementary particles and corresponds to the so-called granulometric composition. The structure instead concerns the way the particles are grouped among themselves.

As already mentioned, on these two factors depends the behaviour of the soil with regard to air and water. While in the definition of texture the dimensional principle dominates, in that of structure prevails the principle of distribution of the single constituant elements in space. In the texture the units are represented by fundamental particles, coarse sand, fine sand, slime and clay, but it is useful to remember that the physico-mechanical characteristics of the soil do not depend on the dimensional factor; they are furthermore linked to the type of slime and especially to the type of clay contained in the soil.

When the soil is too light or too heavy as concerns its physico-mechanical constitution, one provides for its amendment which consists in the addition of sandy material to too heavy soils or of clayey material to too light soils, that is, of course, when one recognizes the objective and economic possibility of their realization.

The soil structure, on the other hand, contains as funda mental units the elementary aggregates which can also combine one with another so as to form structural units of higher dimensions. The structure is extremely important for fertility because it influences the capacity of accumulating water and air and plays a considerable role in resistance of the soil to erosion by conditioning the process of leaching and the permeability. The new agricultural techniques, the ever increasing use of machines for the cultivation of the soil, and above all the reduced supply of organic substances have during the last decades led to a general decay of the structure of agricultural fields.

Insufficient structural stability (which stability depends on the tenacity of the organic and inorganic binding means in the larger part of cultivated soils) makes the disastrous effect of hydro-meteoric erosion more severe, and this within a short time can determine the loss of the surface stratum where the larger part of the chemical fertility of agricultural soil is located.

There is no need here to dwell on the subject of the aggregates and the binding means which contribute to the stability of the aggregates, however, I deem it necessary to mention that quite a series of factors can regenerate the structure and heighten the structural stability, which will lead to an increase in porosity. By incorporating mechanical work that has the effect of raising the center of gravity of the active thickness of the soil in increasing its apparent specific weight, one provokes the occurrence of certain phenomena which can condition positively the formation of binding means. It is known that the production of binding materials is favoured by abundant administrations of organic substances and by well directed microbiological transformations of the organic substance itself, or also by adding conditioners like "Flotal", once used in Italy, or some synthetic polymers, like Krilium and Vama, and finally by means of some natural compounds of plant origin found in the soil which by their nature contain substances provided with a constitution and functions analogous to those of synthetic polymers.

The full fertility of agricultural soil requires that this soil manifest, in the right measure, certain catalytic and enzymatic activities capable of provoking and accelerating a whole series of transformations directed to the formation of numerous metabolites that characterize the active chemistry of the soil. Among the catalytic activities mention should be made of the oxidasic activity prevailingly linked to the presence of hydrated manganese oxide, which determines the transformation of carbon monoxide into carbon dioxide, and of cyanamid into urea, according to the CELSO ULPIANI's classical scheme. Therefore, in a soil that is not provided with such activity, as for example the heavy calcareous Grisolera soils (Venice), this transformation of the cyanamid into more easily assimilable products will not take place on the part of the plants.

Furthermore, the oxidation of ammonia provoked by manganese dioxide, studied in 1904 by FAUSTO SESTINI and later by DE ROSSI and by RUSSEL and SMITH, constitutes an activity of the soil capable of forming nitric acid and then putting this nitric matter at free disposal of the plant. It is known that the processes of catalytic oxidation proceed in considerable measure in agricultural soil when the action of metallic oxides becomes manifest under the iufluences of luminous radiations.

In this connection we may mention the researches made by GOPAL RAO and by DHAR on photochemical oxidation in the soil; they attributed this power also to titanium, aluminium and silicon oxides.

Enzymatic activities manifest themselves in the soil by the presence of tissual enzymes, which plant residues convey into the soil, and those of bacterial and fungous origin. They include the catalase activity, the urease activity, particularly responsible for the rapid transformation of fertilizing urea into ammonia, and furthermore the cellulase, phosphatase, amylase, protease and depolymerization activities. The latter assumes great importance for the transformation of polyphosphates, now largely used in agriculture, and for the degradation of surfactents, the accumulation and persistence of which would finally lead to unfavourable effects for the soil structure together with antimitotic actions capable of reducing the development of plant roots.

I would like to refer in detail also to the phytase and lecithinase activities which contribute to the mobility of organic phosphorus contained in the soil; but to me it appears sufficient to have mentioned these essential characterictics of the soil which are intimately linked to the transformation of certain insoluble compounds into forms more easily assimilable by plants, and which consequently constitute an important factor of fertility.

I deem it convenient just to mention the microbial fertility of the soil, without which the cycles of mineralization of the organic substance, of the atmospheric nitrogen fixation and of the nitrification process would not develop in an economic and timely way, with serious damage for the nutritional absorption of plants.

Before considering the constitutional fertility factors including the chemophysical and chemical state, I would like to emphasize that modern agricultural development has led us during the last decades to a form of husbandry that makes use of special inert substrates, or as it is generally expressed by a term not always legitimate, hydroponic culture.

In this connection it should be pointed out that owing to the transformations suffered by the solid material in the course of time, the concept of physical fertility, which might appear simplified because of the absolute absence of colloids of organic and inorganic nature, on the contrary reacquires almost all of its strictly pedological dimensions as a result of the pedogenetic transformations manifested in the substrate. Therefore, when using easily decomposable material as a substrate for hydroponic plants, there arise again all of the problems concerning the correlations between fertility and the general characteristics of agricultural soil.

The relation between physicochemical properties and soil fertility is marked by the hydrogenionic concentration value or by the pH index. It is known that plants do not tolerate acidity degrees below the acidity of vinegar and above the alkalinity of calcium carbonates.

On the other hand, the chemical macro and micro nutritive elements can become insoluble in a soil with anomalous reaction; and so even when the plant is able to tolerate the reaction of the milieu, it will for this reason yet be unable to benefit from the chemical fertilizing.

These pedological conditions, though, are in many cases easily susceptible of correction. The correctives of acid and alkalinic soils succeed in most cases in modifying favourably the anomalous reaction of the soil. These operations are by now largely introduced in agricultural practice, and I think it is sufficient to have just mentioned them.

Concerning real chemical fertility, apart from all other fertility factors already discussed, it should be emphasized that the chemical composition of the nutritive means operates on the aspect and the growing velocity of the plants, on their morphology and composition, and thus on the configuration of the vegetable landscape as well as on the useful production of agricultural crops.

The attempts to put plant biochemistry in relation to the mineral components of the soil leads back to the dawning of research and belongs to the first meditations of the naturalists; a rational explanation of the various influences exerted by the inorganic components on plant life, however, represents a rather recent, and under certain aspects not yet entirely definitive achievement.

The spreading of ashes on the ground is besides a very old practice and was already characterictic of the first agricultural initiatives. BERNARD PALISSY in 1563 wrote that the remarkable variety of mineral salts which plants require for their development, is drawn from the earth through the root system; but the Georgics had already much earlier realized that fertilizing substances added to the soil restore what plants withdraw during their developing cycle.

The origin and the significance of the mineral salts contained in plants remained nevertheless for a long time subject of controversy, and only in the course of the centuries has it been clearly demonstrated that certain mineral elements are indispensable to plant life.

For the first experiment on mineral plant nutrition we are indebted to VAN HELMONT, but it was not until 1699 that the English scientist Woodward started an interesting experiment which brought the problem of mineral plant nutrition on the right track. He shows in detail, in the first place, that plants can live with their roots immersed in water, drawing from it the elements useful for their growth, and by means of a series of rather subtle experiments he demonstrated that such growth is different according to whether the plant is immersed in river water or in rain water, or in water extracted from the soil.

On the strength of these interesting observations, WOODWARD contested decisively VAN HELMONT's conclusions, and he writes fairly logically — even though not quite legitimately and correctly that "earth and not water is the matter that constitutes plants".

In 1727, some decades later, Hales carried out another series of researches converging rather on the same subject.

But it was not until 1804 that De Saussure expressed the opinion that the soil furnishes small but essential contributions to the nourishment of plants, and he demonstrated experimentally that if a plant grows in water devoid of mineral substances, the content of such substances will increase only proportionally to the small quantities of inorganic matter that may come to the plants from the seed or from atmospheric dust deposits. In spite of these clear experimental results, there persisted the opinion that the inorganic substances, present in plants, are simple accidental inclusions or else mysterious stimulants rather than nutritive factors. The results of De Saussure's experiments were only taken into their just consideration 50 years later. The theory of the humists indeed was finally demolished by Justus v. Liebig with perspicacious criticism, in a famous address presented in 1840 at the British Association for the Progress of Sciences.

Agricultural practice had in part already anticipated these conclusions. Ammonium sulfate from coke ovens, saltpeter from the Chilean caliches, guana from Peru, bone meal and phosphorites had already been largely introduced, together with dung, in the manuring of agricultural crops. It is evident that after the formulation of the new doctrine of mineral plant nutrition, the utilization of these substances would strongly increase, and the chemical industry would thus be pushed towards that series of fruitful experiments which followed one another near the end of the century, and which led to the production of the new synthetic fertilizers.

The doctrine of mineral plant nutrition, established in its essential aspects by J. v. Liebig in 1840, finds its definitive formulation after careful researches regarding the composition of ashes and after the further study of the relations existing between plant development and the absorption of inorganic elements present in the soil or in nutritive solutions.

Boussingault and Wolf, Wiegner, Polstorff and Knop participated in these important works, and a final conclusion about the indispensability of mineral elements for the development and growtn of plants was reached only after 1840, when the cultivation method of plants in nutritive solution was introduced, a method which permits this problem to be solved by legitimating the substance itself of the new doctrine.

These achievements resulted in determining clearly the function of the soil as source of inorganic salts for plants, and the experimental data on plant growth in nutritive solution led to the conclusion that when the medium is lacking in one of the organogenic elements, such as carbon, hydrogen, nitrogen or phosphorus, sulphur, potassium, calcium, magnesium and iron, the plants show defects and are unable to complete fully their vegetative cycle.

It is on these ten pillars that the doctrine of mineral nutrition and chemical fertility was based for some decades. It should be pointed out, however, that in these classical experiments no attention had been paid to the great importance and the usefulness of certain inorganic elements absorbed by the plant in extremely small quantity, and almost always present in the impurities of the reagents and the receptacles used for conducting the tests.

Later researches and the new achievements of modern plant physiology, especially those concerning the role of enzymes in the chemistry of the metabolic processes, demonstrated that besides LIEBIG's ten macroelements there are still others that plants absorb only in traces and which are likewise indispensable for their development.

These elements have been named minor elements or microelements. A hundred years after the important discovery by LIEBIG, we are today witnesses of a second renaissance of the mineral nutrition of plants. The series of the elements indispensable for plants has remarkably increased, and in the course of these last decades, there has been clearly put in evidence the agronomical importance of manganese, molybdenum, zinc, boron, copper, cobalt, viz. of all the micro-nutritive or oligodynamic elements connected with the names of BERTRAND, of SCHARRER, and also of the Italian GIOACCHINO CARRADORI. The latter already in 1749, even before the doctrine of mineral plant nutrition had been affirmed, had already foreseen the importance of certain microelements, not so much for their specific action on plant metabolism as for their influence on the general development of plants and the productiveness of agricultural crops.

There is now opening a third period of the science of mineral plant nutrition: that of the simple and complex alimentary interactions, the knowledge of which has already suggested profound modifications in the fertilizing management of crops.

Passing now to the second part of my paper concerning the fertilizing of plants, I must say that more than a hundred years after the formulation of the doctrine of mineral plant nutrition, there still persist together two opposed attitudes as regards chemical fertilizing.

There is the attitude of the agronomists who are especially concerned about the unitary yield, and they reasonably see in the manuring of their crops, no matter how it will be applied, the fundamental instrument to obtain a higher agronomical result. There is then the attitude of the hygienists, who see in the chemical fertilizing a forcing of the productive capacity of plants with disadvantages on the qualitative and health level.

I cannot associate myself either with the one or with the other attitude. Each one is in part right and in part wrong. In fact, so as to respond fully to the exigencies of agricultural crops, a manuring must be complete and equilibrated. The assessment of the quality of agricultural crops for the alimentation of man and domestic animals, today must take into account the play of the nutritional balances which condition the global productiveness of the crops and at the same time have a profound effect on the quality of the production itself.

In plants, the will to feed, and the preference expressed by their selective root absorption, even though they are not coordinated by a rational intelligence, manifest themselves none the less in a framework of strictly coordinated and interdependent actions and reactions. The knowledge of these actions and reactions appears to be an indispensable condition for being able to complete on a solid basis the science of plant nutrition, and for the rules to follow for the sake of an economic and productive manuring of the soil.

On its part the mechanism of absorption and transport of the elements of fertility involves the existence of a strict coordination between the different factors which determine the growth of plants and their specific yield.

After all it must be kept in mind that the role of a particular fertility element does not depend only on the direct effects of its concentration, but also on the repercussions that it exerts on all of the other factors existing in the system.

In practical agriculture fertilizers constitute without any doubt, if not the major, one of the most efficacious technical factors to increase the productiveness of the earth.

The science of genetics, the mechanization of agricultural work, irrigation, the defence of crops against noxious factors, together with the manuring of the soil have exerted, during these last decades, a remarkable influence on the entire agricultural production throughout the world. There is no doubt, however, that the large increase recorded in the production of cereals in the course of the last half of the century depends greatly on the total quantity of the soluble fertilizers administered to the crops.

Also, the considerable production in overseas countries, which has determined a great availability of food products for international consumption, is linked to an extensive application of soluble fertilizers to the plants. On the other hand, countries that still use peat or natural organic fertilizers of various nature — neglecting fertilizers of prompt effect have achieved rather modest increases in their global and unit production in spite of the progress made in improving other factors of their production.

In this connection it is interesting to point out that, on the physiological level, the plant can feed even if the fertility elements are given to the medium in extremely small concentrations; but in order to correspond to the exigencies of agricultural and economic character, the concentrations of the soil solutions relatively to the single macro and micro nutritional elements, must not diminish below fixed levels.

From this exigency follows the necessity to apply to the soil the fertility elements needed by the crops in the quantity and form capable of creating in the agricultural ground excellent concentration conditions of each nutritive element.

And seeing that the development of agricultural crops takes place relatively to the ratio of the various nutritive elements present in the soil, the problem of plant needs must therefore be considered comparatively rather than in an absolute sense, because the lack of a given element may show itself even when it is administered in conspicuous quantities if its quantity is out of proportion compared with the other elements or does not correspond to the general needs of the mineral nutrition of the plant.

The levels of unit productiveness of the various crops show very sensible differences in different countries and different agricultural regions throughout the world. In 40 countries chosen from among the most important, the mean wheat production during the period 1956/58, has shown variations ranging from a minimum of 6.64 quintals to a maximum of 36.33 quintals per hectare, i.e. in a ratio of one to six.

This remarkable oscillation of the unit yields does not find sufficient justification in the different characteristics of the physical environment; it appears indeed connected in the first place with agricultural and economic development, and in an equally important measure with technical means. Even the increase during the last decades seem to be clearly connected with the genetic improvement, the control and the defence of the crops, irrigation and technological or cultural improvement, but especially with the use of fertilizers.

Evidently the application of these factors requires also an adequate structuration of farms as well as economical and social conditions favourable to the development of the productive process. The researches conducted in the larger countries of the world have in fact demonstrated that high unit yields are observed mainly in those countries where modern agricultural techniques are employed with great care, and where the cultural level of the rural world, besides being elevated, goes hand in hand with a clear efficiency in the technological sector.

As concern the reserves of the hygienists, it should be emphasized that the experiments made by ZEILER and coworkers, and by GERICKE in Germany, have shown that when soils are rationally fertilized, by respecting the nutritional balances, the agricultural products present higher alimentary characteristics than those deriving from unfertilized soils.

We consider now shortly the complex problem of the choice of criteria and methods for the measure of chemical soil fertility.

In spite of the experimental researches carried on for more than a century on this difficult subject, the approximate agreement between the different methods, namely the statistical correlation index between the results obtained, cannot be considered as a definitive solution of the problem, but only as a proof of a satisfying convergence between the methods that are today more largely employed. In fact, neither the abundance of nutritive elements nor even their solubility can assume full significance, these being generally elements like phosphorus, potassium, calcium and magnesium which, being retained in the absorption compounds, present a changeable agricultural behaviour.

With regard to nitrogen, to the elaboration of which contributes also the microbiological activity of the soil — in which in spite of a richness in organic nitrogen there may at times be observed a lack of nitrogen because of the soil's anomalous reaction or of its reducing capacity — the appraisement of the concept of fertility becomes still more difficult.

Analogous considerations are valid also for phosphorus, potassium, iron and the other elements of macro and micro nutritive fertility.

When the evaluation of chemical soil fertility becomes a guiding instrument for dunging techniques, the decisive method for practical aims is the direct or agronomical method of dung tests carried out in the fields or in pots according to the position of the problem.

Also indirect, physiological, chemical, biochemical extraction methods etc., may present a certain reliability for practical aims provided their results agree with those of the direct agronomical method.

Regarding the fertilizing technique, I shall limit myself just to hinting at two general problems, having to do with the production and use of chemical fertilizers.

Production as technical fact, particularly for the sector of nitrogens, could not present a more satisfying panorama than the present one. The same cannot be said of the phosphatics, the production of which — except in the United States where the polyphosphate industry has greatly developed — still sticks to the old technologies and to the old products. These latter, though having played an important role in the past, present certain serious inconveniences when applied to acid and subacid soil, where phosphoric anhydride becomes easily insoluble forming ferric and aluminium phosphate.

The experiences of these last decades moreover have shown that among the deficiencies of agricultural practice on the technological level, the way and the limits of fertilizing the soil are rather important.

It is known that the global volume of agricultural production depends fundamentally on the ability of the cultivated species to adapt themselves to pedoclimatic conditions, on their resistance to noxious agents, and on the capacities of the crops to take advantage of the fertility of the soil.

But the lack of information on these questions is still far from being negligible, and I daresay that this insufficiency costs the economy of the different countries very dear. In the interest of all, it appears useful to free certain specialists from the illusion that to solve agricultural production problems, and consequently those of the food supply for the whole of humanity, it is sufficient to increase agricultural machinery and the consumption of fertilizers or pesticides, whereas it is absolutely necessary to improve in the first place the limits, the times and the ways of employing these endogenous factors of production in order to adapt them to the real necessities of the crops and of farm management.

Nobody thinks that there might be expected a strict correlation between the quantity of fertilizer employed and the agricultural production, since the water availability, the climate, the tillage, the choice of the varieties and seeds as well as the farming practices constitute together with fertilizers equally factors capable of conditioning crop productiveness. There is no doubt, however, that when a further administration of fertilizer does not bring about an adequate increase in production, as happens almost throughout the world, the reason can only be looked for in the way, the times or the limits according to which the dunging is carried out.

This shows that with great efforts there are obtained small results, meaning that it is still necessary to work in the sector of soil fertility and the technique of dunging in order to adapt the fertilizer to the soil and to the crop, in the framework of a deeper knowledge of mineral plant nutrition.

There have always been many difficult problems in the field of crop fertilizing, and in spite of the progress achieved during the last decades there remain still those with regard to causes of physiological, pedological and economic nature.

Therefore, we must clarify still more accurately the validity of the so-called complex fertilizers, know better the various nitrogen forms, furthermore respect the relations and the nutritional balances between the different fertility elements and, finally, consider with more scientific and practical depth the correlations existing between fertilizer-soil and plant.

These problems require precise solutions which will enlighten farmers and become useful for agricultural productiveness only if the researches be set up in a correct way and above all carried out with full methodological rigour.

The old factors of production are today in competition with a vaster series of scientific factors concerning the development cycle of plant life in connection with environmental conditions and in the framework of the complex correlations existing between all of the physiological factors operating in the multiform play of the natural balances.

Agronomical science has until today pursued almost exclusively objectives of quantitative character, but in future it will be necessary to look more into the influence of fertilizers on the quality of crops and of livestock, so as to correspond more strictly with the exigencies of the consumers.

It is known that the influences of qualitative order depend essentially on the ratio according to which the different fertility elements are available for absorption by agricultural crops. Therefore, an equilibrated dunging is the first condition for agricultural success and for the largest agricultural productiveness.

A deeper knowledge af these ratios will certainly facilitate also the better use of fertilizers, making of this important instrument of agricultural technique a factor of progress and economic prosperity for farmers and for national communities.

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THE LIQUID FERTILIZING

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Of the two papers indicated in the program I shall present only the second, and perhaps I should explain the philosophy which led me to present this paper. When a year ago, together with VALENTINO HERNANDO I had to choose one of the two papers I had proposed, namely: "On Soil Fertility and Fertilizing of agricultural croppings" and "On liquid Fertilizing", we decided to present that on liquid fertilizing. Later on I travelled to France and the United States to study this problem, and my enthusiasm for the one on liquid fertilizing soon died down for reasons I shall explain later. On my return from these journeys, it appeared to me that it was not worth while to developing a subject which presented so many uncertainties, and I decided for the subject on fertility. I thought that it might be necessary, on a philosophical level, to explain the different elements which share in the formation of soil fertility. It is generally believed that the chemical fertility coincides perfectly with the general fertility of the soil, i.e. the agronomical fertility. In my opinion this is a great error, because it may lead agriculturists to false interpretations, making them believe that it is sufficient to add chemical fertilizers in order to raise the agronomical fertility of the soil. This does not correspond to reality, because the agronomical fertility, the fertility of the soil, includes different components. There exists in the first place a physical fertility of the soil which is linked with the texture and the structure of the ground. A ground not well structured, a ground that does not have a structure resistant to the course of time, lends itself badly to a rational manuring, because in such ground the manure will not be able to exert its entire influence. A soil without a certain physico-chemical fertility lends itself little in tolerating heavy manures because in that case the soil is in a certain degree unable to manifest the absorbing power capable of retaining the ammonium ions, potassium ions and phosphoric acid anhydride ions which otherwise are whashed away by meteoric waters. In the first place the earth should be fairly neutral because, if it presents anomalous reactions, which happens when the pH passes below the acid acidity and above the alkalinity of calcium carbonate, it is difficult to obtain economically efficient results from the manuring. In such case the pH of the soil must first be reduced within the right limits and only then will it be possible to apply fertilizers in a useful way. These were the subjects I intended to develop.

On the other hand, besides the physical and physico-chemical fertility, there are also other components which are not always duly taken into account. For example, if the chemical, catalytic, enzymatic and microbiological activities are lacking, not only do they render less efficient the manuring of the cultivations, but in certain cases the application of fertilizers when such activities are lacking may even bring about results that are diametrically opposed to those expected from the manuring. I would like to advance only two examples in order to explain this interesting aspect. By applying organic products to a soil which is not provided with a sufficient microbial quantity, the organic substance will not transform itself, it remains mummified. This occurs, for example, in strongly clayey, reducing soils in which happen to lack, amongst other elements those binding elements which contribute to the formation of the micella structures of the soil. I agree with the Colleague Colwell who the other day joined in the discussion on this subject to stress the importance of the organic fertilizing. When, in the absence of organic binding elements the land plots are not firmly compact so as to form solid structures, the earth does not present a good structure nor sufficient stability of structure, and in such case there will never be a soil with sufficient capacity for air, and thus for oxygen, as WELTE deemed it to be reasonably necessary, and for water. We know how the agricultural production progresses without water. We all know very well that for the formation of one gram of organic substance, there must pass through the plant stalk from 300/350 to 1.000/1.200 g of water. Water consumptions are extremely high. I think that these problems must be carefully examined, otherwise it will be very difficult to get a proper picture of the fertility of the soil, and it will be even more difficult to draw useful knowledge for manuring the cultivations. Another example I wish to illustrate concerns the use of urea as a nitrogenous fertilizer. Today very high quantities of urea are employed throughout the world. Sometimes I ask myself if all soils are provided with a sufficient quantity of urease in order to transform the urea rapidly in ammonium carbonate. When the soil is well provided with urease, the fertilizing urea decomposes itself rapidly and the ureic manuring assumes the volume of an ammoniacal manuring. But if by chance we have to do with a soil of old fertility which contains no or but a small quantity of urease, the ureolytic transformation, instead of becoming manifest with a velocity that in normal cases lasts from 4 to 5 days — meaning that within 4 to 5 days the urea will be transformed in ammonia — proceeds very slowly or stops altogether. Then instead of changing into ammonium carbonate, the urea takes another direction pointed out by WÖHLER in 1828, a century and a half ago. The urea changes into ammonium cyanate on account of an isomerization action, and with the appearance of the cyanide ion, which is terribly antimitotic with concentrations of the order of 0,0001%, the roots and small plants will be destroyed with consequent mortification of the cultivations. I gave these examples to put in evidence that it is important to consider not only the chemical, physical, physicochemical or chemophysical fertility, but likewise all those activities of chemical, catalytic, enzymatic and microbiological nature normally existing in the soil which, however, may be lacking in sterile soils and in those where the farmer with irrational spreading of insecticides, fungicides or herbicides, contributes in destroying or mortifying those activities with the result of reducing the efficacity of the manures beyond the necessary measure.

The first part of my paper which was distributed beforehand, summerizes these meditations on the concept of global fertility which, I trust might explain the philosophical sense of the different single components of soil fertility. The second part has been prepared because the Colleague VALENTINO HERNANDO thought it right that in a Study Week, where the fertilizing problems are discussed, the problems of liquid manuring ought to be debated. This is the reason why it was decided to illustrate the second and not the first one of my two papers. The paper of liquid manuring deals mainly with anhydrous ammonia which in my opinion presents aspects of larger economical convenience for countries which, like Italy, need to obtain a certain economy in the manuring of the crops. I would like to point out that my paper intends above all to arouse a discussion among the Colleagues. Of course, I mentioned already that for this new form of manuring there are certain favourable elements and other less favourable elements, in short there are lights and shadows, the intensity of which varies profoundly with the conditions of the various agricultures; therefore, while it may be considered advisable in certain countries, it may appear less so in others.

1. In the United States and in several European countries there has recently been diffused a new way of fertilizing agricultural crops which, under certain aspects, recalls the so-called "fertirrigation" already applied for a long time in mountain farms where sufficient water under natural pressure is available and also considerable quantity of manure.

In this case it is a question of utilizing not only the manure, i.e. the solid dejections added to the litter, but also the liquid fecal matter possessing high fertilizing value due to their nitrogen, potassium and auxins content.

GINO FRIEDMANN, around the twenties, had devoted himself to this agronomical practice on farms in the Alps using chiefly a method with a mixing apparatus of fixed and variable dosage, consisting in an hydraulic injector capable of drawing an organic manuring liquid, formed by urines and manure slime collected in special and separated vats. In small farms the "fertirrigation" was effected with barrel carts containing the manuring liquid drawn by a tractor which commanded a booster pump connected with the irrigator installed in the same barrel cart.

On the other hand, specimes of fertirrigation of meadows and seedplots with ammonia solutions had already been used in 1853 on the initiative of the English SCHUSTON, and also in Italy in 1920, by FRANCO SAMARANI, then Director of the Agricultural Station in Crema.

Today this new way of manuring the soil is called "liquid fertilizing", but maybe it would be better to say "fluid fertilizing", thus including also the administration of gaseous fertilizing products, like anhydrous ammonia, and also those in form of solid suspensions when using materials with high concentrations containing little soluble nitrogenous, phosphatic and potassic compounds.

The benefits of this fertilizing irrigation, realized by means of fluid of various nature, present certain advantages of general order like:

a) the greater facility with which the fertilizer can at any time be distributed on the fields during the developing cycle of agriculture;

b) its agreeing with a criterion of greater speed by making the single fertility elements available to the crops;

c) the increase of the fertilizing efficacy thanks to a quicker action and an intenser potential of the process of mineral nutrition, also through the practice of the leaf absorption;

d) the reduction of the cost of the fertilizer unit, and subordinately of the distribution expenses, especially when the fertirrigation method is applied. According to American experiences, the labour cost for the administration of fluid fertilizers amounts to 5% of the cost of the fertilizer, and does not differ much from that of solid fertilizers;

e) saving of labour on the part of the farmer. Evidently the pumping of the liquid is much easier and less toilsome than the transporting of sacks or even loose quantities of solid products. Because of the state of aggregation characterictic of the material used, it is obvious that the fluid manuring permits an entirely mechanized manipulation and distribution;

f) the realization of a more uniform distribution of the fertilizing elements which permits a more homogenous vegetative development of the cultivations;

g) the possibility of uniformly mixing and administering with the same operation, and thus with a notable saving of time and labour, secondary elements: microelements, herbicides, insecticides and anticryptogamics. In any case working times are remarkably shortened;

h) the combination of these advantages with those of the much easier storage and dosage, and others of psychological nature, such as to interest and attract those farmers who want to put in practice a more favourable and advanced technique.

There are still more advantages like the greater economy in packing up, loading, unloading and transport of the fertilizer, less labour for the farm worker, and last not least, less cost per unit of fertilizer compared with the same unit contained in conventional compounds.

2) During these last decades fluid manuring has indeed experienced an unusual expansion in several countries, but whereas at the beginning it was pushed by the necessity and the convenience of introducing less onerous and more easily used fertilizing systems, the initiative passed later into the hands of productive and commercial organizations aiming mainly at the intensification of selling larger quantities of phosphatic and potassic mixtnres, according to the case, losing sight of what had been the original intention.

Now while the use of liquid fertilizers developed rapidly in the U.S.A. where the application of fluid forms had reached 53% by 1961, i.e. about ten years after their introduction, in Italy and generally in all of the European countries, the time has been spent on trials or tests of preliminary character.

Both in the U.S.A. and in France, the basis of fertilizing with liquid manures is the availability (besides ammonia, urea and ammonium nitrate), of several raw materials like superphosphoric acid and polyphosphates, not produced in every country.

The lack of the industrial preparation of superphosphoric acid and polyphosphates certainly handicaps the development of a larger and extended application of liquid manuring.

The preparation of superphosphoric acid and its ammoniacal salts has been developed by the Tennessee Valley Authority; it is an acid that contains 76% phosphoric anhydride, whereas orthophosphoric acid contains only 54%.

The melting point of this acid is sufficiently low to render it fluid at room temperature, and the advantage of its use consists in the fact that its ammonium salts are much more soluble than those of orthophosphate. The development and use of polyphosphates obtained by various methods make possible the availability of products containing up to 79% of phosphoric anhydride, and according to recent preparations realized by the T.V.A., a compound has been obtained in which the 79% of phosphoric anhydride is formed by: 19% orthophosphoric acid, 44% pyrophosphoric acid, 21% triphosphoric acid, 10% tetraphosphoric acid and 6% acid of a still longer chain.

I do not want to go on any longer on illustrating the particular properties of these compounds, i.e. their solubility, hydrolysability and possibility of binding certain oligoelements of great interest for plant nutrition, but I would like to point out that it will not be possible to develop the expansion of liquid manuring in those countries where the industries of phosphatic fertilizers are not embarked on aiming decidedly at the preparation of these important products.

As concerns Italy, I believe that the delay in the realization of liquid fertilizers is linked with three different reasons:

1) First of all, phosphorous compounds with high concentration of soluble phosphoric anhydride, indispensable for the preparation of compound fertilizer solutions, are not available to us.

2) We have no distribution structure, that is organizations of a capillary agronomical service which could take the place of the initiative of the individual farmers who as a rule do not have the necessary means to provide for it directly for themselves.

3) Finally, the structure of Italian agriculture is up to the present time based on farms of dimensions inadequate for realizations of this type.

As to the conditions of agriculture in Italy, where rather big structural problems relevant to phosphatic products have to be solved in the agricultural and in the industrial field, it appears advisible, at least at the beginning, to direct liquid manuring towards the use of products like gaseous ammonia the market price of which per fertilizing unit is lower than that of a unit of nitrogen present in the traditional nitrogenous fertilizers.

It is known that the production cost per unit of nitrogenous fertilizers is almost twice as much as that of anhydrous ammonia or ammonia in solution which has also the advantage of not being burdened with extra charges for operations of drying processes, granulation and storing, characteristic of solid products.

3. The realization of fluid fertilizing with anhydrous ammonia has the advantage, amongst others, of utilizing a product that contains 87% nitrogen and constitutes, as is known, the raw material for the preparation of almost the whole of the fluids and for the larger part of the solids.

The use of the ammoniacal solutions presents certain advantages concerning the distribution apparatuses, but in spite of this, in the U.S.A. anhydrous ammonia continues to be the main fluid nitrogenous fertilizer.

The corrosion of the tanks and the equipment are no problem as concerns anhydrous ammonia which requests only a few particular precautions because of its toxicity and its burning effect. Considering, however, that the applications are made in the open air, it will not be difficult to prevent such type of incidents, when observing the usual safety measures.

Anhydrous ammonia is generally injected into the soil at a depth varying from 10 to 20 cm. in relation to the texture and the other physico-mechanical characteristics of the soil. The operation consists in producing in the soil a narrow furrow which will be rapidly closed in order to cover the gaseous ammonia in such a way as to limit the losses to a minimum.

Sohn and Peach have studied the absorption of ammonia on clay and on organic substances of the soil arriving at the conclusion that this process develops more easily in slimy-clayey and in acid soils. Also in subalkaline soils with pH up to 7.3, the earth absorbs likewise considerable quantities of ammonia, almost the whole of which spreads from the application point in a range of 5 cm.

The experiment has demonstrated that even by giving nitrogen quantities of 100-120 kg/ha, the losses are economically unimportant.

Mac Intoh and Frederick found that the diffusion of anhydrous ammonia takes place with a different velocity, according to the content, in empty spaces of the earth. The gravity does not seem to have any effect on its diffusion which does not appreciably vary either above or below the point of injection. Under the same humidity conditions, the ammonia requires eight hours for its diffusion in an area of 27,5 cm. of range with 40% empty spaces, whereas with 50% it takes only 6,5 hours to diffuse in the same environment.

Goring and Martin have investigated the behaviour of anhydrous ammonia in a sandy soil under different conditions of humidity. The diffusing velocity of ammonia diminishes with the increase of the humidity on the soil.

For its diffusion on 12.5 cm. from the point of injection, anhydrous ammonia takes $1^{hr}30'$ in dry earth, $2^{hr}30'$ in earth containing 1.5% humidity, $4^{hr}20'$ if it contains 3.5% and $4^{hr}30'$ if it contains 6%.

With change in temperature the velocity of diffusion varies, and obviously this velocity increases with higher temperature: in a tract of 14.5 cm length it takes $3^{hr}30'$ at 7°C, $1^{hr}30'$ at 20°C, and only one hour at 28°C.

The diffusing velocity of the gas, however, diminishes when the content of organic substances in the earth increases, while the other conditions remain the same.

According to GIFFORD and STRICKLING anhydrous ammonia would exert a certain effect on the stabilization of the soil aggregates, in relation to a certain specific interaction of the ammonia with several organic constituents not yet well identified, and which — after being dissolved by the ammonia — would subsequently reprecipitate and spread in a more homogenous way in the soil.

According to ANDREWS the manuring with anhydrous ammonia produces the best effect when duly taken into account together with the most favourable depth of injection, humidity of the soil, ventilating conditions, spacing of the rows and the temperature at the time of the administration.

There are then still the experiments concerning the toxicity of the gaseous ammonia. As a matter of fact, ENO and BLUE have ascertained that the nitrifying power of the soil decreases only by 10% even when the alkalinity increases to pH 9,6. It is evident that the mortification of the nitrifying process is connected with the toxic effect of the ammonia on the nitrifying microorganism. The effects of the gaseous ammonia explain themselves also in comparison with the other members of the microbial population of the earth.

When 100-120 kg. nitrogen per hectare are given as anhydrous ammonia, one notices also a reduction in the number of the bacteria, hyphomycetes and actinomycetes, but the toxic effect is limited to those found in the earth at 6 or 7 cm. from the point of the injection.

The same researches, however, have shown that 3 or 4 days after the treatment, the bacterial and actinomycetic load of the earth returns about the same as at the beginning, whereas the toxic effect on the fungi lasts longer and may persist for several weeks. When the concentration of the nitrogen increases to 600 p.p.m., the pH reaches 9,4, and its effect on the fungi population and on the nematodes becomes rather drastic; this activity, however, is only temporary and has not the slightest consequence on the normal course of the cultivation. When the concentration of the ammonia reaches 608 p.p.m., corresponding to a hydrogenionic concentration of pH 9.4, almost all the microorganisms succumb, but concentrations of this kind occur only in zones where anhydrous ammonia invades a relatively small portion of the ground. Obviously the effect is only temporary because the pH reached will not last for a long time; but according to BONGESS and HAWKINS a few days after the nitrification process the conditions return to be normal and in certain cases there may be even a drop below the original pH.

Perhaps I should here recall the series of researches carried out by STANLEY and SMITH who have shown that an application of 100 to 120 kg. of gaseous ammonia per hectare causes a remarkable increase in the quantity of phosphoric anhydride and in assimilable potassium oxide thanks to the action that the ammonia exerts on the phosphoric and potassic components absorbed or fixed by the constituents of the soil.

This detailed examination of the behaviour of anhydrous ammonia in the soil, in relation to the different conditions of humidity, structural stability etc., is of great importance for the sake of ascertaining the best conditions for the administration of the fertilizer: the quantity, the depth of injection, the distance between the injector cogs, and the exigency of reducing the loss to a minimum.

4. The agronomical researches on the effects of the manuring with anhydrous ammonia have shown that there is no sensible difference between the fluid and the solid form of nitrogen. The fertilizing with anhydrous ammonia has given the same productive yield as under all the other conditions. Evidently this happens also when the nitrogen is applied under other forms, like the ureic or the nitroammoniacal form. In spite of some difference between the various nitrogenous forms, no difference is recorded when they are administered in fluids or in solid state.

A careful examination of the other fluid fertilizers does not seem timely to me in consideration of the preliminary remarks. I am convinced that in view of the objective conditions of the Italian situation, we are not yet mature for the full introduction of the fluid fertilizing except for the Po Valley and the other alluvial districts in the center and in the south which, however, represent a rather reduced section of the entire agricultural surface.

At any rate, the fluid manuring needs for its development:

1) a network of farm units of larger dimensions which allow for an easier development of agricultural mechanization. The practising of fluid fertilizing forms part of the mechanized operations and therefore needs for its expansion that the real conditions of the mechanization itself be carried into effect. The reduced volume of the single farm units and the modest extension of the cultivated plots certainly constitute a handicap in the process of mechanization and a delay in the introduction of liquid fertilizing.

2) There will then be needed an efficient organization of agricultural services for the numerous farms which do not have the convenience or the possibility of investing important sums for equipment. Therefore they must resort to these specialized services, capable of carrying out essential agricultural operations like that of liquid manuring.

3) Finally the advantage of technological order characteristic of liquid fertilizing discussed previously, must go together with a certain economical advantage which, under the present conditions may be obtained only with the use of anhydrous ammonia.

Later on, when the organization conditions render more efficient the network of agricultural services, and when all the raw materials necessary for the preparation of other fluid fertilizers are available, we may pass from manuring with anhydrous ammonia to the realization of liquid manuring in other ways.

Evidently the costs of liquid fertilizing depend also upon the extension of its application; thus the more it is used the more consistent will be the productiveness of this agricultural practice. Moreover the improvement of equipment and the perfectioning of technique will render the applications easier and more economical, also with less waste.

By now the new system has been firmly established in more advanced agriculture, and the experience of operators promises that a new epoch is going to open up for the manuring of the fields, and in spite of certain technical problems not yet solved, this will constitute an important progress compared with the techniques of the past.

In concluding I should like to emphasize that liquid manuring constitutes the only and the most economical means for fertilizing the soil and the cultures of a large agricultural farm where the process of mechanization has arrived at its full application.

In countries where organization conditions do not yet permit that they proceed straightforward in this direction, the first applications of liquid manuring with anhydrous ammonia might be reserved for cultivations like maize which requests considerable quantities of nitrogen. This will represent an important progress in comparison with the present reality, and certainly an eventual evolution will be possible towards fertilizer solutions which will mark another step forward to more advanced forms in the process of field manuring.

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DISCUSSION

Chairman: Y. ARATEN

ARATEN

On page 8, Professor ROTINI wrote that the super phosphoric acid of TVA contains 76% phosphoric anhydride (P_2O_5) whereas orthophosphoric acid contains only 54% (P_2O_5). This is true for « wet phosphoric acid » which is not 100% phosphoric acid and which is impure. Thermal acid, or so called furnace acid, contains about between 69 and 70% P_2O_5, and I.M.I. acid, which is made by digesting phosphate rock with hydhochloric acid and consequent solvent extraction contains the same amount of 69%.

On page 6, Professor ROTINI wrote that ammonia is the cheapest nitrogen fertiliser. This is correct, however the various classes of nitrogen solution fertilisers, acqua-ammonia, urea, ammonium nitrate solution or both, owe their existence and popularity to lower investment for storage, handling and application equipment, and to lower application costs because of the power required for pulling injectors through the soil.

ROTINI

L'acido fosforico ad altissima concentrazione ha da noi un costo così elevato che non può trovare economica applicazione nella produzione dei fertilizzanti. Il rapporto dei costi da me citato nella mia relazione si riferisce tanto per l'acido superfosforico quanto per l'acido orto-fosforico ai prodotti tecnici e non a quelli concentrati.

Non ho creduto opportuno estendere la trattazione all'acqua ammonia, prodotto già largamente impiegato in Francia, perché nelle condizioni dell'agricoltura italiana reputa sia più armonicamente conveniente cominciare con l'ammonia anidra ed anche perché dall'acqua ammonia si passa facilmente alle soluzioni miste, le quali accanto all'azoto contengono anche prodotti fosfatici e potassici e cioè componenti che hanno differente coerenza pedologica e fisiologica e che non sempre è opportuno legare insieme.

In our country phosphoric acid at highest concentration is so expensive that it is not economical to use it in the fertilizer production. The cost relation which I mentioned in my paper refers for both superphosphoric acid and orthophosphoric acid to technical and not to concentrated products.

I did not deem it suitable to extend the treatment to water ammonia, already largely employed in France, because in reputed Italian agricultural conditions it is harmoniously more convenient to begin with anhydride ammonia and also because from water ammonia it is easy to pass over to mixte solutions which, besides nitrogen contain also phosphatic and potassic products, i.e. compounds with different pedological and physiological coherence and which it is not always appropriate to bind together.

HERNANDO

I should like to explain that when I had the idea of assembling here specialists with different points of view on problems regarding the use of fertilizers, I thought it might be interesting to have with us a personality with a very good knowledge about fertilizer materials, knowledge which Prof. ARATEN will explain to us tomorrow. The idea is to try to get here conclusions for the future. My opinion is that in future we may be using new fertilizer types as Professor ARATEN will show us, and we may use also more ferti-irrigation for several reasons. The main one being the reduction of labor cost. Labor cost is increasing quite heavily and so the cost of yields, especially for intensive cultivation since we use high amounts of fertilizers, and we must reduce the cost.

On the other hand the problem illustrated by Professor ROTINI shows that many countries have difficulties in preparing fertilizers with high phosphate levels and with the problem of the equipment for the use of the ammonia. I am of the opinion that this is not a real problem. In Spain f.i. for the time being we do not prepare fertilizer with a high phosphate content. On the other hand, however, the price of 18.54.00 ammoniated triple-superphosphate fertilizer is surely the cheapest in Spain although it is imported from other countries. This means that in future the developing countries may not have possibilities to produce their own needs, and they may receive fertilizing materials from the more developed countries, where highly concentrated substances, like pure phosphoric acid can be prepared for mixed or complex fertilizers. This will reduce the price for shipment and especially the handling charges. In certain cases these products can also be applied in higher quantities without increasing the labor costs. With water irrigation it is also possible to apply soluble fertilizers in any areas of the more intensive cropping of the world.

ARATEN

I would like to draw the attention of Professor HERNANDO to a factory in Sevilla which during the last year has been producing concentrated phosphoric acid according to the I.M.I. method on a commercial scale, that is a beginning.

EWELL

I would like to set the record straight about the chronology of the development of the use of liquid fertilisers. In the United States we began to use liquid ammonia in 1937, 35 years ago.

The use of liquid ammonia was developed by two people in different parts of the country, by Dr. ANDREWS in the State of Mississippi, and by Dr. LEAVELL in California, at almost the same time in 1937. The United States today uses something like 65 percent of all of its nitrogen in the form of liquids and an increasing amount of both phosphate and potash are used in liquid form also. In the rest of the world, Mexico is now using liquid fertilisers to a large extent, particularly ammonia, but also other liquid fertilisers. The Soviet Union and Japan have made a very good start in the use of liquid fertilisers, and several countries in Europe I believe are doing so, particularly France. We use so much liquid ammonia in the United States that we now have two pipelines running from Texas up to the Middle West area in the general neighbourhood of Iowa, Just like we transport petroleum and gas in pipelines, we transport liquid ammonia in pipelines a distance of around 2,500 kms. This liquid ammonia comes into large storage areas and then it goes into refrigerated or pressurised trucks and is taken out to the different distribution areas where a farmer can go with his own tank, just like you go to a gasoline filling station, and fill up with liquid ammonia or other liquid fertilisers. For a good many years liquid ammonia was the only liquid fertiliser used in the United States, but about 1950, or maybe a little before, the use of nitrogen solutions became quite widespread. These are solutions of ammonia and either urea or ammonium nitrate in water. This is now a very large business. And in the middle of the 1950's we began to use NPK liquid fertilisers, and also aqua ammonia (a 20 percent solution of ammonia in water at zero pressure). So I just wanted to set the record straight on how long we have been using these types of fertilisers in the United States.

PRIMAVESI

Je vous présente mes compliments, pour l'excellent travail présenté. En particulier je veux vous dire que nos expériences nous font croire qu'un des facteurs fondamentaux pour obtenir continuellement des hautes rentes dans l'agriculture dans les tropiques et subtropiques, où l'agriculture pratique est plus difficile et plus compliquée que dans les régions de climat temperé, c'est de soigner une bonne structure du sol. Sans doute, le cher collègue fut très heureux avec son explication sur la structure du sol, et je rappelle spécialement ce que vous dites dans ce sens, dans les page 7 et 8 de votre travail, sur l'importance de la structure du sol. Sans amener en compte ces considérations fondamentales de physique et de microbiologie du sol les meilleures connaissances purement chimiques, ou soit des meilleures applications des fertilisant, après peu d'années de succès initial, se rendent toujours plus insuffisants jusqu'à ce que donnent des réponses anti-économiques, car la décadence du sol provoquée par la destruction de la structure du sol le rend, en peu d'années d'usage et manièrement incorrect du sol tropical et subtropical, infertile. Tandis que nous pouvons maltraiter pendant bien des années les sols des régions de climat tempéré, jusqu'à ce que sa structure entre en décadence; généralement cela se passe très vite aux tropiques et subtropiques où, pour cette raison, l'importance du soin de la structure du sol est plus grande.

Digne d'être noté de son formidable travail, à cause de son importance pour l'agriculture pratique dans les tropiques et subtropiques, c'est encore ce que vous dites sur la fertilité microbienne du terrain. Il s'agit de deux grandes vérités, que malheureusement sont souvent tout à fait oubliées, spécialement quand des techniciens des régions de climat tempéré, parfois des techniciens fameux, viennent aux tropiques pour rendre leur collaboration.

Pour l'agriculture pratique dans les tropiques c'est important à noter que notre éminent collègue dit que les changements rapides des différents engrais à la disposition des paysans, réclament, de la part des techniciens et des pratiques de la fertilisation, une grande considération pour la cohérence pédologique et physiologique des engrais et pour l'emploi à propos de leur distribution. Et encore, de la nécessité d'administrer au sol les éléments de fertilité nécessaires aux cultures dans la mesure et dans la forme capables de déterminer dans le sol agricole des conditions excellentes de concentration de chaque élément nutritif. »

Le manque de considération des facteurs ici détachés, cités dans votre travail, peut être considéré dans la majorité des cas comme les raisons principales pourquoi les rendements agricoles dans les tropiques et subtropiques sont si bas tandis que dans la majorité des pays de climat tempéré on a déjà obtenu de hauts, et même excellents, rendements. C'est pourquoi le professeur dit avec toute raison que dans la pratique « malgré de gros efforts on obtient de petit résultats ». On doit intensifier beaucoup plus l'investigation expérimentale, mais pas seulement sur le champ de la chimie du sol mais aussi sur le champ de la physique et la microbiologie du sol, et étudier beaucoup plus des facteurs limitants de la production agricole. Beaucoup de messieurs seront surpris de ce que nous avons déjà vérifié, toujours de nouveau, que les études de la physique du sol, par exemple, sont au moins de la même importance que ceux de la chimie du sol, quand nous cherchons d'augmenter continuellement les récoltes agricoles dans les tropiques et subtropiques.

I pay you my compliments for your excellent paper. In particular I may say that our experiments make us believe that one of the fundamental factors for obtaining continually high profits in tropic and subtropic agriculture, where the practical agriculture is more difficult and more complicated than in regions with temperate climate, is to take care of a good soil structure. No doubt the Colleague was very happy with his explication on soil structure, and I remember particularly what you say in this sense on page 7 and 8 of your work on the importance of the soil structure. Without taking into account these fundamental physical and microbiological considerations of the soil, the best, purely chemical knowledges or the best fertilizer applications, after a few years of initial success become ever more insufficient until they give anti-economical responses, because the deterioration of the soil provoked by the destruction of the soil structure renders it within a few years of use and incorrect treatment of tropical and subtropical soil infertile. While in regions of temperate climate the soils may be badly treated for years until its structure declines, this happens generally rather quickly in the tropics and subtropics, where for this reason the curing of the soil structure is of greater importance.

Worth of particular mention of your excellent work is also what you say about the microbial fertility of the soil, on account of its importance for the practical agriculture in the tropics and subtropics. There are two important facts which unfortunately are often quite forgotten, especially when techniciens from temperate climatic regions come for collaboration.

For practical agriculture in the tropics it is important to note, as pointed out by our Collegue, that the rapid changes of the different fertilizers at the disposal of the farmers request from the techniciens and from the fertilizing practices great consideration for the pedological and physiological coherence of the fertilizers and for the way of their distribution. Furthermore the necessity to apply to the soil nutrients of fertility necessary to the cultures to an extent and in a form capable of determining in the agricultural soil excellent conditions of concentration of each nutritional element. The lack of consideration of the factors, here singled out, mentioned in your work, in the majority of the cases may be regarded as the main reasons for the low agricultural yields in the tropics and subtropics which, on the contrary, in most of the countries with temperate climate have already obtained high and even excellent yields. That is why Prof. ROTINI says quite rightly that in practice "in spite of great efforts one obtains small results". The experimental investigation should much more be intensified, not only in the field of soil chemistry but also in the field of physics and microbiology of the soil, besides, by studying much more the factors limiting the agricultural production. Many of you will be surprised of what we have already reached, and that the studies of soil physics, for instance are of no less importance than those of soil chemistry when we try to increase continually the agricultural yields in the tropics and subtropics.

SAALBACH

On the German market there are on sale nitrogen solutions and anhydrous ammonia but no NPK solutions. One reason for this is that the highly concentrated phosphoric acid is too expensive and it is cheaper for the farmer to fertilize with nitrogen solution and to give solid phosphate and potash dressings. The other reason is that the nutrient content of the NPK solutions is very low and you have to transport very much water.

ROTINI

Sono d'accordo che convenga in paesi come l'Italia e la Germania incominciare in fertilizzazione fluide con i soli azotati in alcune colture, come, per esempio, il mais, che richiede alte somministrazioni di azoto da fornire in diversi momenti del ciclo di sviluppo della pianta, interrando per contro i concimi fosfatici e potassici in forma solida al momento della preparazione del terreno o alla semina.

I agree that in countries like Italy and Germany it is convenient to start the fluid fertilization with nitrogens only on a few cultures, as for instance on maize which requests high nitrogen supplies at different times of the developing cycle of the plant, while on the other hand phosphatic and potassic fertilizers are given to the soil in solid form at the time of the field preparation or at the sowing season.

FERTILIZERS - THE LIMITING FACTOR IN THE SUCCESS OR FAILURE OF THE GREEN REVOLUTION

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Theses of This Paper

The theses to be presented and defended in this paper are the following:

1. Of the three primary agricultural inputs - seeds, water and fertilizer - fertilizer is the most critical input since it involves the greatest investment both by individual farmers and by the national economy.

2. Very large quantities of fertilizer will be required by the developing countries during the next decade in order for agricultural production to keep pace with population growth.

3. Under-utilization of fertilizer is likely to be the limiting factor in increasing agricultural production in the developing couutries during the next decade.

4. Under-utilization of fertilizer in the developing countries, if it occurs, may be due to inadequate demand by farmers or due to inadequate supply of fertilizer.

5. Supply of adequate quantities of fertilizer in the developing countries will require enormous sums of money during the next decade, possibly as much as U.S. $ 28 billion or more (including both local currencies and foreign exchange).

The Green Revolution

What is the Green Revolution? What do I mean by the "success or failure of the Green Revolution"?

The Green Revolution is the improvement of agricultural yields in tropical and sub-tropical regions of the world by the application of scientific principles and agricultural techniques which have been used in the temperate regions for the past 50 or more years. The tropical and sub-tropical regions referred to correspond roughly to the group of countries in Asia, Africa and Latin America usually called the "developing countries". The Green Revolution is a development of the past 30 years, and particularly the past 20 years. The Green Revolution had its origin in the agricultural improvement program on wheat and maize in Mexico initiated by the Rockefeller Foundation in 1942. This program began to have a significant impact on wheat and maize yields in Mexico by the mid—1950's. The wheat and maize improvement program in Mexico is now being operated as the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). The Mexican experience was later transferred to other Latin American countries and to Asian countries, notably India and Pakistan, in the middle 1960's. *Figure 1* shows the remarkable increase in wheat yields in Mexico since 1955 and the beginning of increased wheat yields in India since 1966. *Figure 2* compares wheat yields in 18 countries in 1970.

In 1963 the Rockefeller and Ford Foundations established the International Rice Research Institute (IRRI) in the Philippines with the objective of improving rice culture in tropical regions. Many new varieties of rice designed to give high

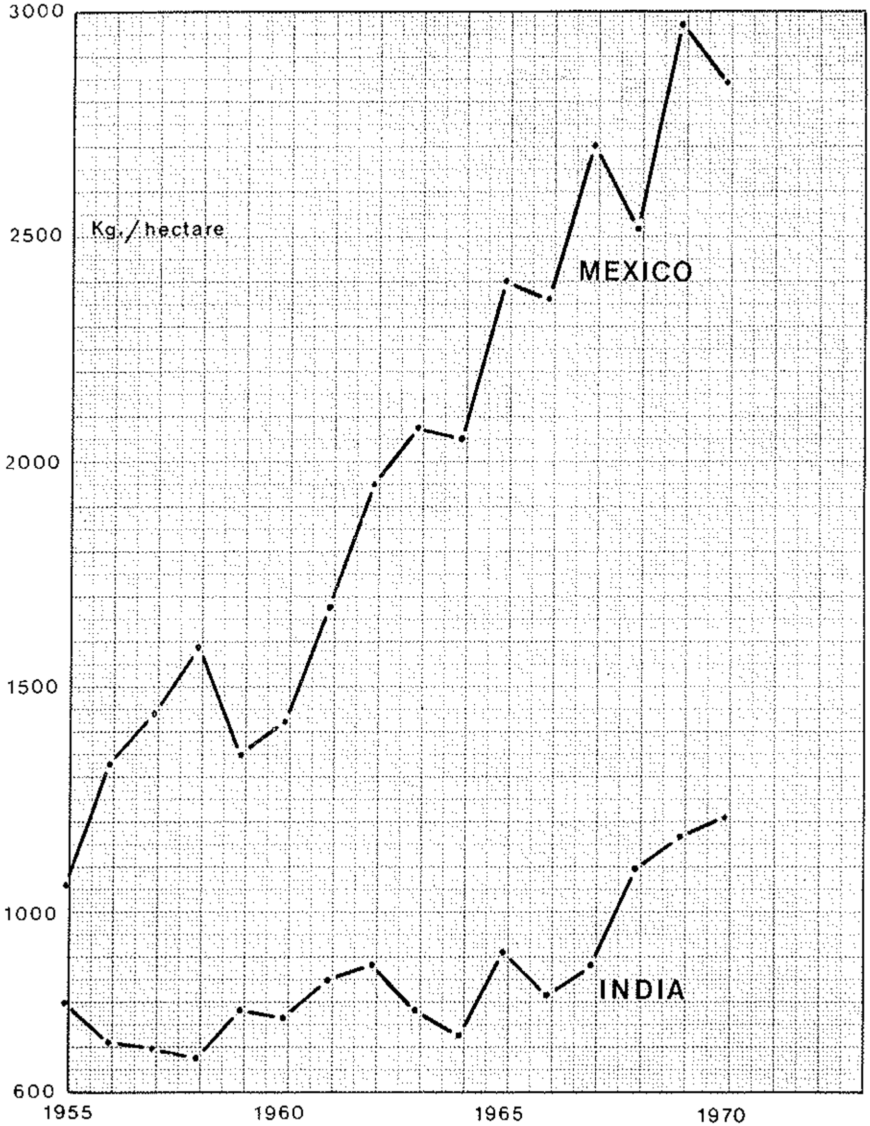


FIG. 1 — Yield of wheat.

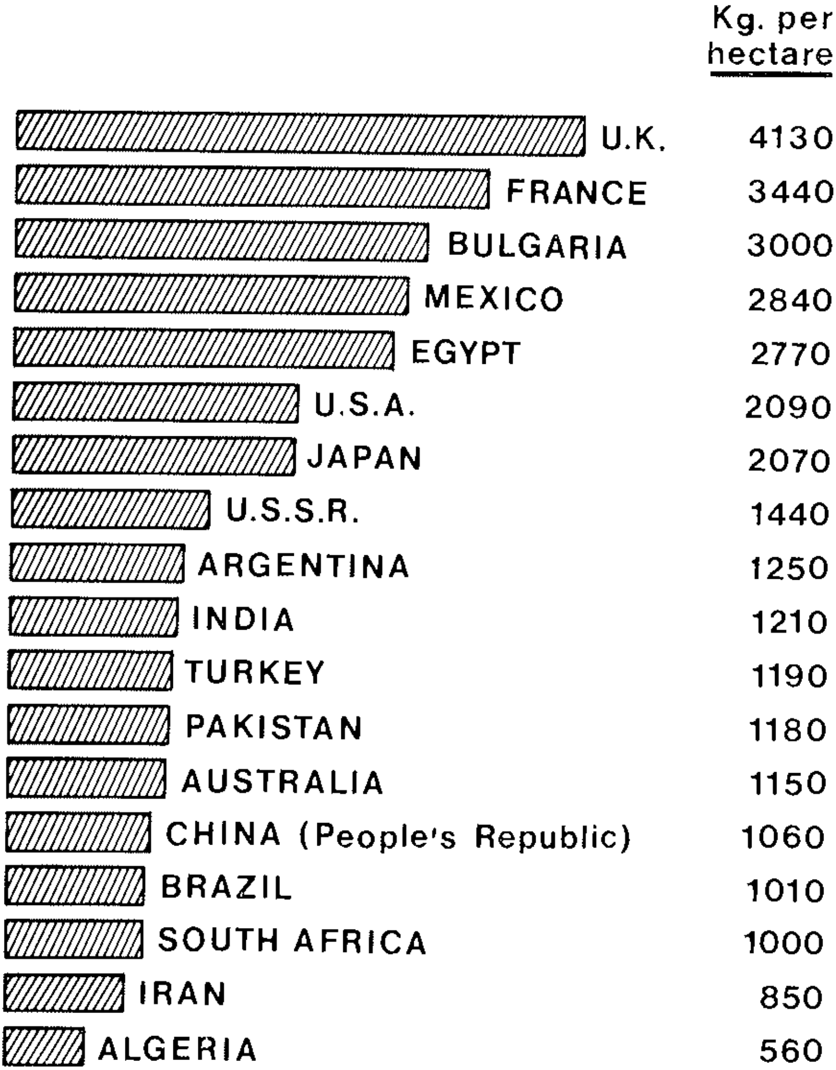


FIG. 2 — Yield of wheat 1970.

yields of rice under tropical conditions have been developed by IRRI and are now widely used throughout Asia. Also, important advances in rice-growing technology have been made by indigenous research institutions in India, Taiwan and other South Asian countries. Rice yields have been substantially increased in Taiwan, South Korea, Philippines, Ceylon and West Pakistan, but there has been little improvement in rice yields in India, Bangla Desh, Indonesia, Burma, Thailand, Malaysia and most other South Asian countries. *Figure 3* shows trends in rice yields in Taiwan and India during the period 1955 to 1970. *Figure 4* compares rice yields in 18 countries in 1970.

New research institutions have recently been established in Colombia and Nigeria with the objective of repeating the wheat/maize/rice successes of CIMMYT and IRRI on other tropical crops.

How will we know whether the Green Revolution has been a success or a failure, say 25 years from now? Since the population of the developing countries — 2.7 billion in 1972 — is now increasing at the rate of 2.5 percent per year and therefore will double in 28 years if this rate of growth continues, *success of the Green Revolution* might well be defined as at least a doubling of agricultural production during the next 28 years. The area under cultivation will, of course, increase to some extent during the next 20 years, possibly by 15 to 20 percent, judging from the increase in agricultural area during the past 20 years. Therefore it is clear that the larger part of the increase in agricultural output during the next 28 years will have to come from increased yields.

Figures 5, 6 and 7 show the increases in grain production in Mexico, India and Brazil during the period 1955 to 1970. In Mexico and India most of the increases in grain production have come from factors other than area increase, including improved seed varieties, water supply, fertilizer and other factors. The increase of grain production in Mexico from 5.8

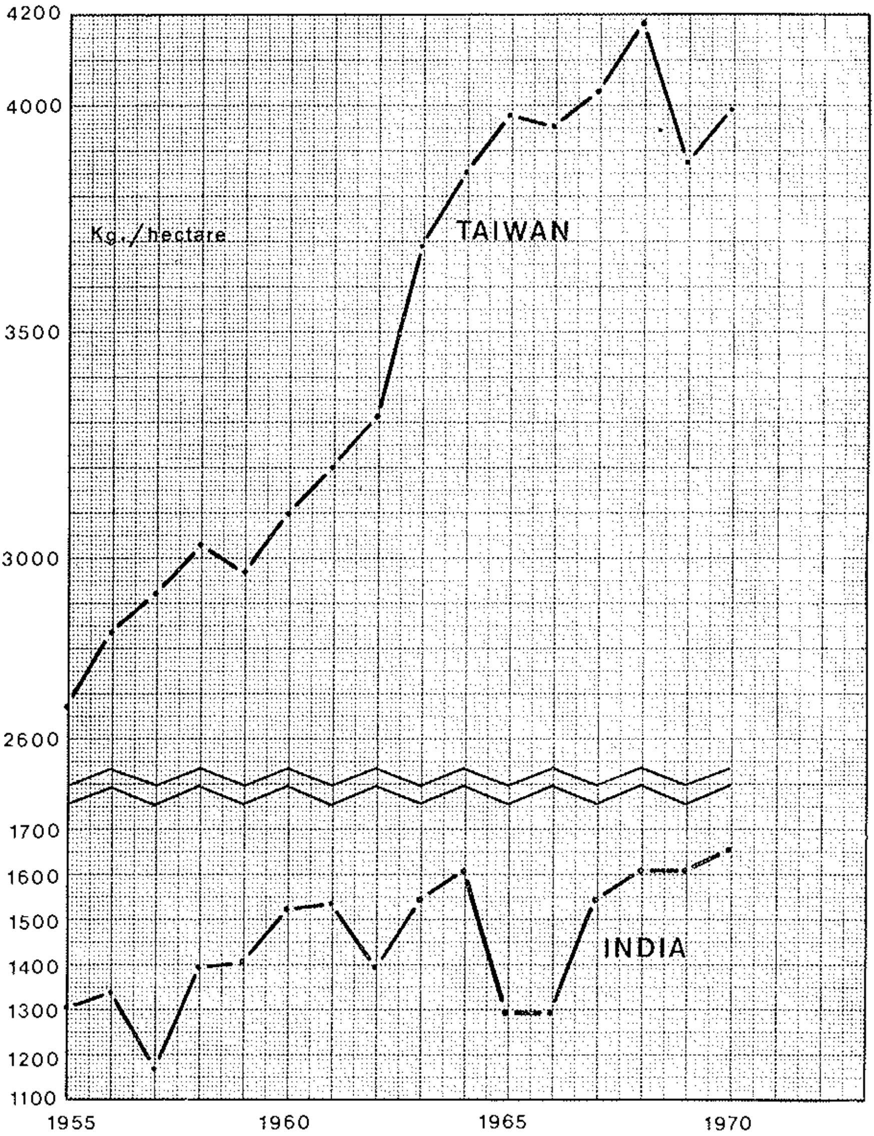


FIG. 3 — Yield of rice (paddy).

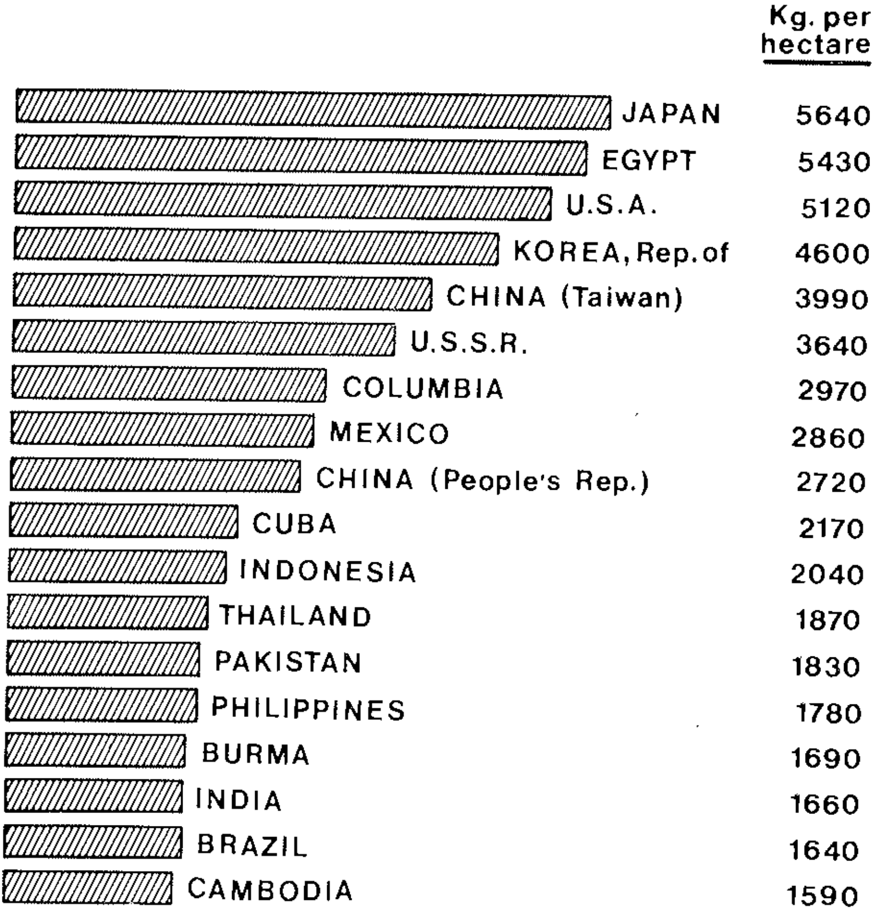


FIG. 4 — Yield of rice (paddy) 1970.

million tons in 1955 to 15.2 million tons in 1970 is probably the greatest success story in the history of agriculture in the developing countries. The effect of the 1965 and 1966 droughts in India shows up dramatically in Figure 6. Fortunately for India she has had very favorable weather for the past five

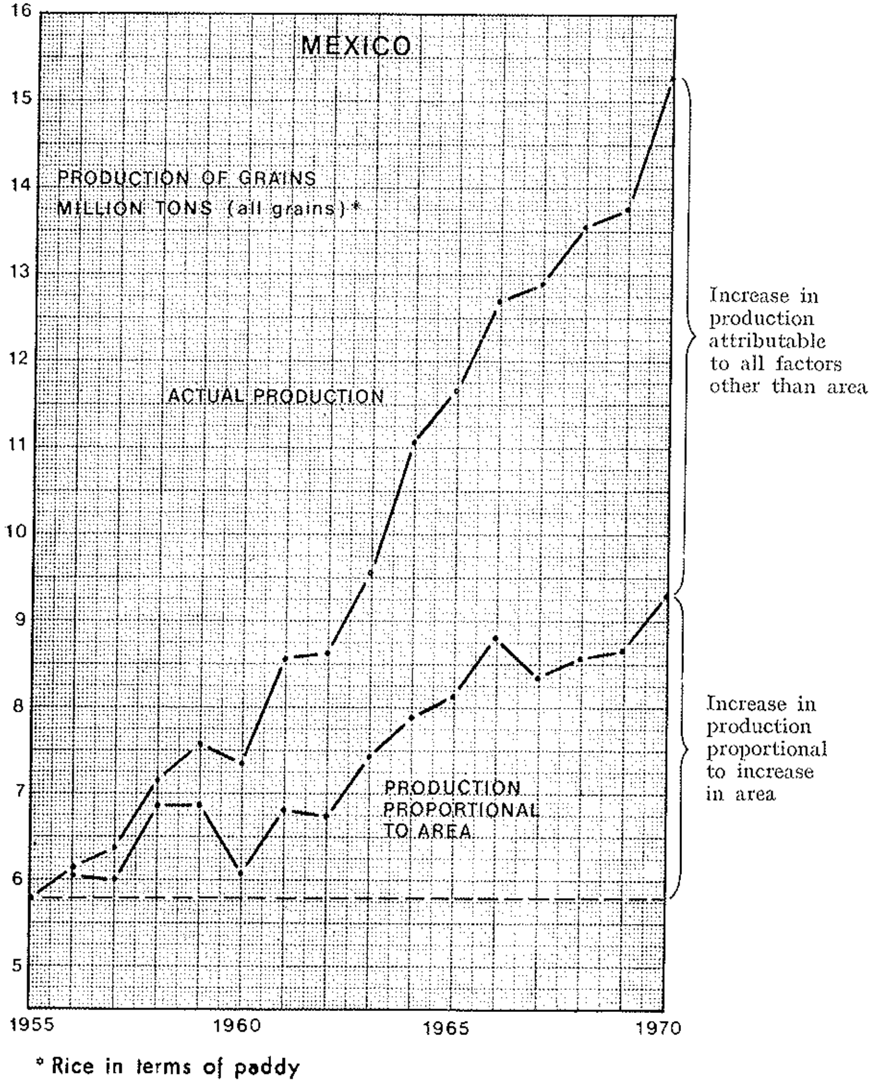


FIG. 5 — Production of grain as function of area and other factors.

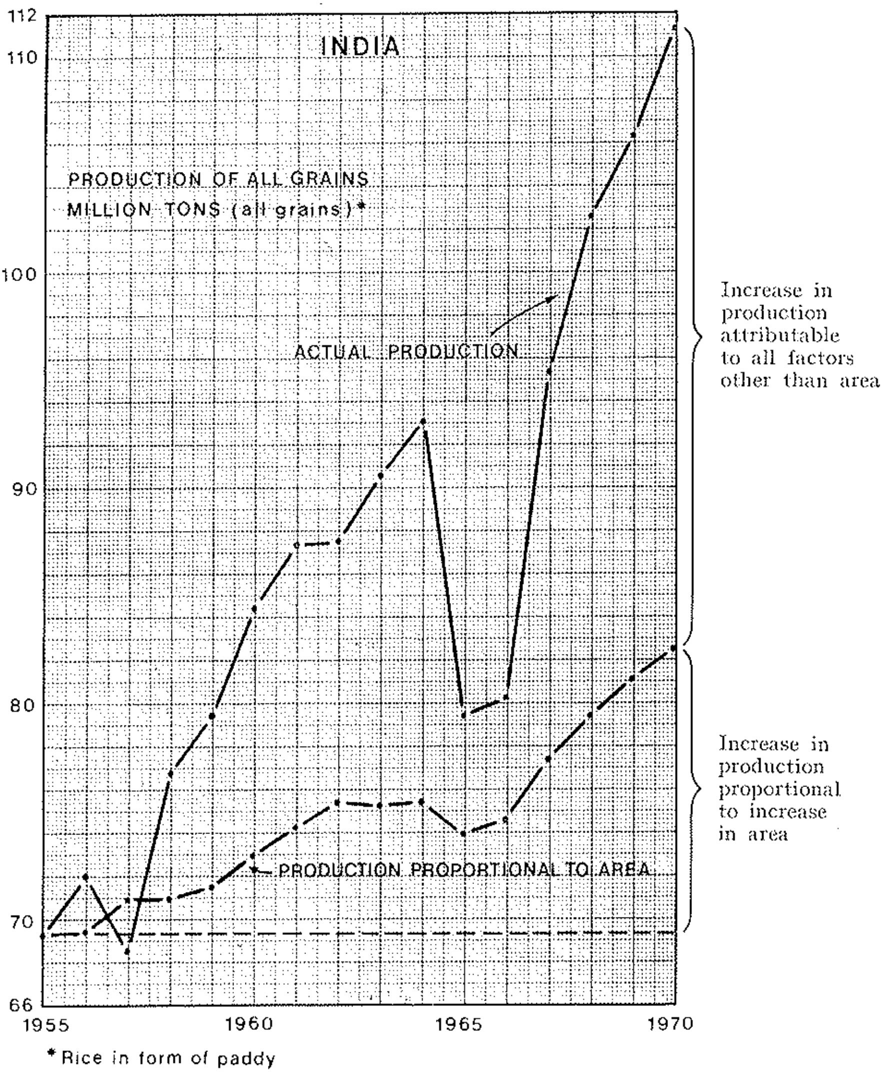


FIG. 6 — Production of grain as function of area and other factors.

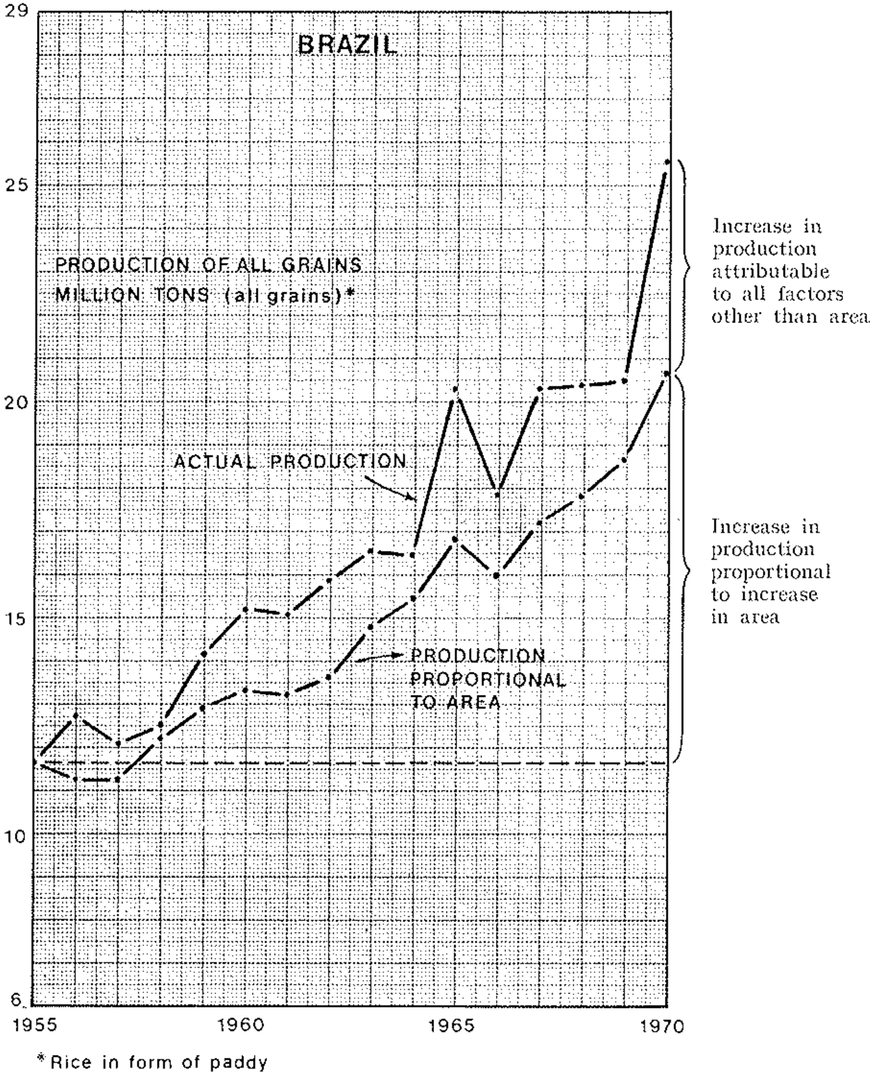


FIG. 7 — Production of grain as function of area and other factors.

years and grain production has increased substantially. In Brazil on the other hand most of the increase in grain production has come from increased use of land rather than from improved technology.

Anything less than a doubling of agricultural production in the developing countries during the next 28 years would have to be considered as a *failure of the Green Revolution.*

An even greater increase in agricultural production than doubling in 28 years would be needed if the developing countries were to improve their nutritional levels during this period. Many writers have suggested that the developing countries need to increase total food production by a factor of three and protein production by a factor of five during the next 28-30 years in order for these countries to realize even a modest improvement in nutrition. The following data on two representative countries in 1969 illustrate the enormous difference in nutritional level between developed and developing countries:

	France	India
Calories per person per day	3270	1940
Total protein, kg. per person per year	37.8	17.5
Animal protein, kg. per person per year	23.5	2.0

Most of the developed countries have approximately the same nutritional picture as France, although Japan is considerably lower in both calories and protein than other developed countries. Many of the developing countries have approximately the same nutritional picture as India, although a few such as Argentina, Uruguay, South Korea, Taiwan and Turkey are considerably better than India.

However, this writer suggests the more modest target of doubling food production in the developing countries between 1972 and 2000. In the case of grains this would mean increasing production from possibly 650 million tons to something around 1,300 million tons in 2000. This would appear to be a colossal achievement, but yet it would be consistent with growth trends of the past 20 years. Grain production in the developing countries increased from 318 million tons in 1950 to 597 million tons in 1970 — an increase of 88 percent in 20 years (*Table I*). Probably 20-25 percent of this increase came from increased land under cultivation and 75-80 percent from increased yields. Therefore an increase of 100% in 28 years seems quite within the realm of possibility.

Figure 8 shows grain production in the world, developed countries and developing countries in 1955 to 1970. Graphical extrapolation of these data (including 1950 data, also) give the projections of grain production in 1975 and 1980 shown in Table I. *Figure 9* shows the derived data on grain production per capita. The difference between grain production per capita in the developed and developing countries is striking. The production of grain is increasing quite rapidly in the developing countries, but the population is increasing rapidly, also, so that the production per capita increases very slowly. According to my projections, grain production per capita is likely to increase very slowly in the developing countries during the next decade.

There is, of course, a net movement of grain from the developed countries to the developing countries — circa 15 to 20 million tons per year in recent years — but this is small compared with the total magnitudes. Therefore it seems clear that the developing countries will have to depend largely on their own resources to meet their requirements for grain and other basic foods.

In this paper "grain production" is used more or less synonymously with "food production". This is common practice among writers on the world food problem since production of various grains can be added together with a reasonable degree of homogeneity, whereas it is difficult to add grains, potatoes, beans, sugarcane, ground nuts, bananas, etc. in a meaningful way. *Table II* shows that grains occupy 50 percent of all arable land and an even larger percentage of land

TABLE I — *Population, grain production and fertilizer consumption 1950-1980.*

TOTAL WORLD	Population, billions	Grain production, million tons	Fertilizer consumption, million tons (1)	Grain production per capita, kg./capita	Fertilizer consumption per capita, kg./capita
1950	2.49	692 (2)	14.9 (2)	278	6.0
1955	2.71	825	22.0	304	8.1
1960	2.98	963	29.6	323	9.9
1965	3.29	1,021	45.6	311	13.9
1970	3.63	1,198	68.1	331	18.8
1975	4.00	1,385 (3)	99.4 (4)	347	24.7
1980	4.46	1,570 (3)	133.5 (4)	352	30.0
DEVELOPED COUNTRIES					
1950	0.83	374 (2)	13.7 (2)	450	16.5
1955	0.88	440	19.8	500	22.5
1960	0.94	515	25.5	548	27.1
1965	1.00	528	39.1	528	39.1
1970	1.04	601	54.0	578	52.0
1975	1.10	710 (3)	75.9 (4)	645	69.0
1980	1.16	800 (3)	100.2 (4)	690	86.5
DEVELOPING COUNTRIES					
1950	1.66	318 (2)	1.2 (2)	192	0.7
1955	1.83	385	2.2	210	1.2
1960	2.04	448	4.1	220	2.0
1965	2.29	493	6.5	215	2.8
1970	2.59	597	14.1	231	5.4
1975	2.90	675 (3)	23.5 (4)	232	6.0
1980	3.30	770 (3)	33.3 (4)	233	10.0

Notes and Sources of Data

(1) Developed countries include U.S.A., Canada, Europe, U.S.S.R., Japan, Australia, New Zealand.

(2) Developing countries include all other countries and dependent territories.

(3) Population data 1950-1985 are from "Total Population Estimates of World, Regions and Countries Each Year, 1950-1985", report ESA/P/WP.34, Population Division, Department of Economic and Social Affairs, United Nations, New York, 16 October 1970.

(4) Population data for 1990 were estimated as 1985 plus 1.0 percent per year for developed countries, 1985 plus 2.4 percent per year for developing countries (2.4 percent per year is the growth rate in 1980-85 indicated in the reference in note 3).

(5) Grain production data and fertilizer consumption data, 1950-1970, are from FAO Production Yearbook, annual, FAO, Rome.

(6) Grain productions and fertilizer consumptions for 1950 are the average of 1948/49 to 1952/53.

(7) Grain production estimates for 1975, 1980, 1985 and 1990 made by projection of production data from 1950 to 1970 by use of Gompertz equation (see explanation on page 17 of text).

(8) Fertilizer consumptions are for the lst half of the split years in which fertilizer data are reported by FAO, e.g. data for 1970 given above are for the split year 1970/71.

(9) Fertilizer consumption in 1975 and 1980 are projections published by UNIDO in 1971 (Kiev Symposium paper ID/WG.99/4). Fertilizer consumption in developing countries in 1985 and 1990 given in Table I are rough "guesstimates" and not based on any analytical or graphical method.

TABLE II — *Arable Areas and Production of Major Crops World-Wide 1970).*

	Area, million hectares	Production million metric tons
Wheat	210.3	311.6
Rice (paddy) (1)	135.5	306.8
Sorghum & millet	112.3	92.5
Maize	110.8	266.8
Barley	78.1	128.5
Oats	32.0	52.6
Rye	20.0	30.8
Other cereals	4.8	7.9
TOTAL CEREALS	703.8	1,197.5
Dry pulses (2)	63.3	42.6
Soybeans	35.0	46.5
Cotton	33.2	11.8 + 22 m. tons cotton seed
Oilseeds (five) (3)	31.9	39.7
Potatoes	22.5	299.5
Ground nuts	19.1	18.1
Sweet potatoes & yams	16.0	135.9
Sugar cane	11.3	581.0
Grapes	9.9	51.6
Cassava	9.7	91.0
Coffee	8.0	4.0
Sugar beets	7.7	219.6
Industrial fibers (4)	5.1	5.0
Tobacco	4.0	4.7
Bananas	1.7	26.2
Flax fiber	1.6	0.7
Tomatoes	1.3	27.3
Tea	1.3	1.3
Onions	0.9	11.0
Hops	0.6	0.1
TOTAL, ABOVE CROPS	988	
All other crops (5)	436	
TOTAL CROPPED AREA	1424	

(1) Production of milled rice = 0.65 × paddy.

(2) "Dry pulses" includes dry beans, dry peas, dry broad beans, chick peas, lentils, pigeon peas, cow peas, vetch, lupins, and other minor pulses.

(3) "Five Oilseeds" includes linseed, rapeseed (mustard), sesame seed, sunflower seed and castor beans.

(4) "Industrial fibers" includes hemp, jute, kenaf, abaca (Manila hemp), sisal, henequen, letona, cantala, ixtle, caroa, fique, Mauritius fibre, formio, and others. Of these, jute and sisal are by far the largest.

(5) "All other crops" includes vegetables, fruits, melons, berries, hay (various species), a number of tree crops (coconuts, cacao, oil palms, olives, tung nuts, etc.), and many other crops on which specific data are not available. Of these, vegetables, fruits and hay are by far the largest. Among fruits, grapes and bananas are listed specifically above, but no specific data are available on apples, apricots, peaches, pears, plums, prunes, cherries, citrus fruits, pineapples, figs, dates, mangoes, papayas, etc. Also, a substantial part of this area is fallow each year, even though it is classified and reported by FAO as « arable area ».

Source: "FAO Production Yearbook, 1970", FAO, Rome, 1971.

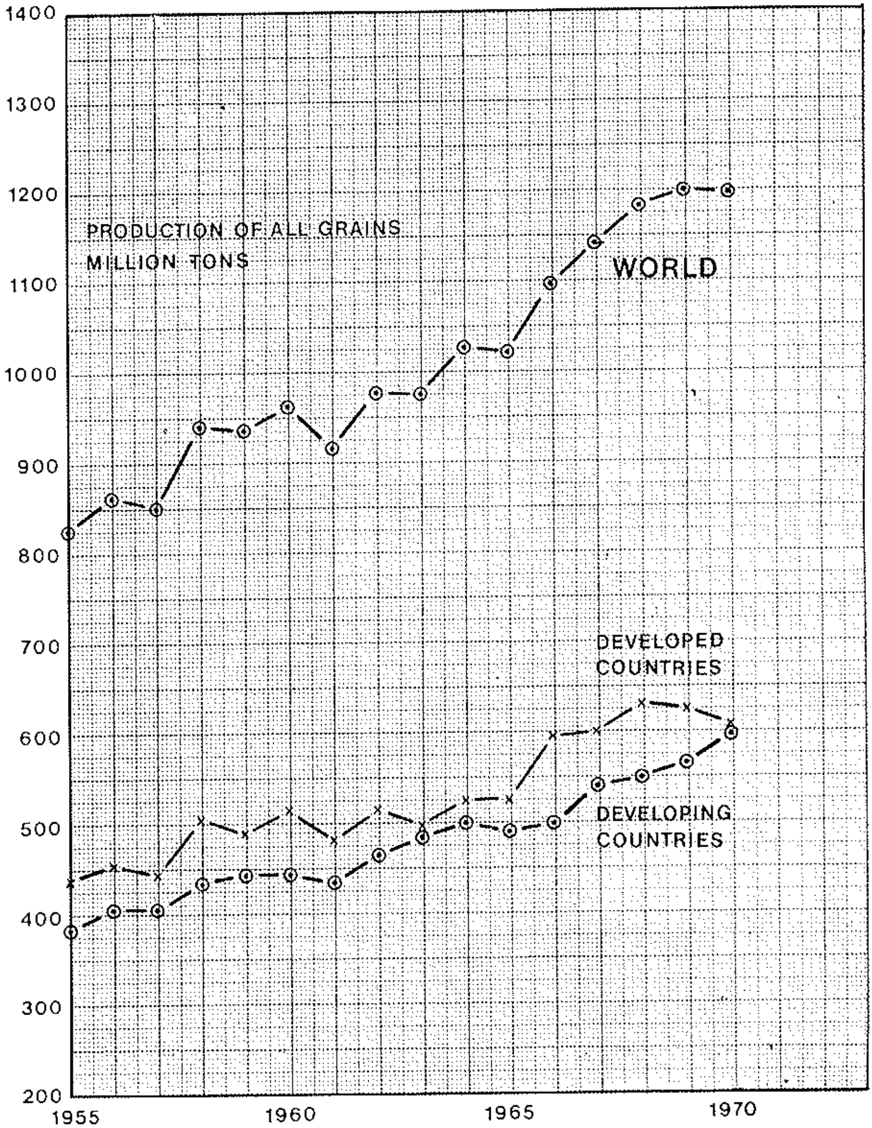


FIG. 8 — Production of grain - 1955 to 1970.

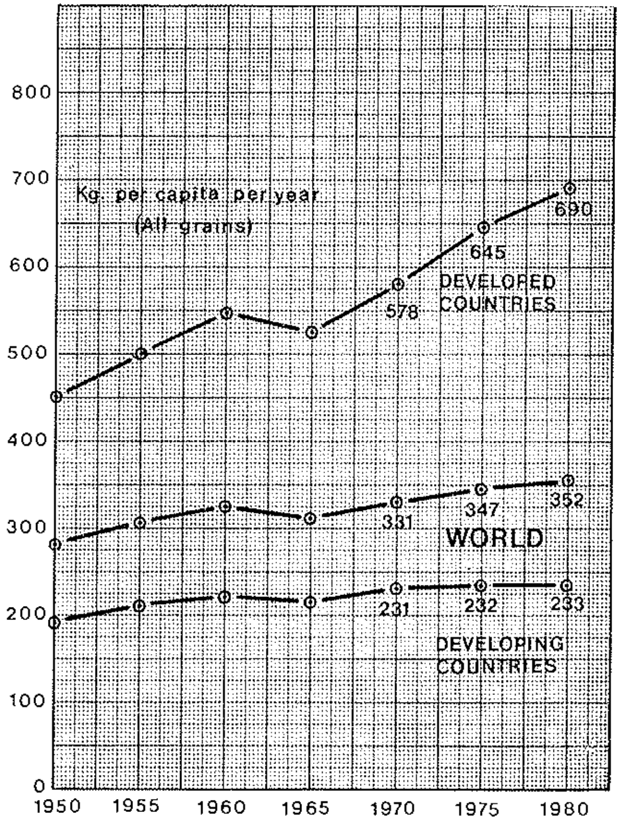


FIG. 9 — Grain production per capita.

actually cropped, i.e. excluding fallow land. Also, it may be noted that in the developing countries grains supply probably 60 to 70 percent of all calories and most of the protein. Moreover, something like 50 to 60 percent of all fertilizer is used on grains and this percentage seems likely to increase in the future.

The distribution of food supplies in the world is very uneven at present – as it has been for at least the past 200 years. The 28 percent of the world's population in USA, Canada, Europe, USSR, Japan, Australia and New Zealand consume more than half of the world's food production and the other 72 percent of the world's population in Asia, Africa and Latin America consume less than half (see Table I and Figure 6). The people in the developed countries eat very little of the grain they produce, but feed most of the grain to animals for production of meat, eggs and milk products. On the other hand, the people in the developing countries eat most of their grain directly as food and feed very little to animals. The people in these countries are so poor they can't afford to feed grain to animals. As a result, they eat very little animal protein as illustrated by the above data on India.

Table III shows the production of major foods in 1970 in the 27 most populous countries in the world plus Australia (because Australia is a major producer of wheat and sugar).

Agricultural Inputs

The physical and biological inputs to agriculture may be summarized by the following diagram:

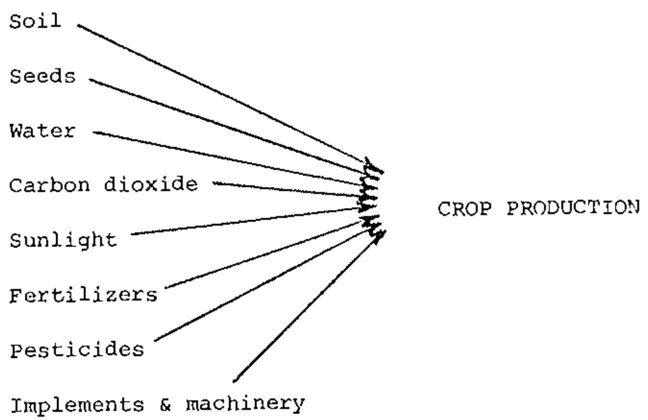


TABLE III — *Production of major foods in the larger countries - 1970* (Population in millions; production data in million metric tons).

	Population 1971	Wheat	Rice (paddy)	Maize	Sorghum & Millet	Barley	Dry pulses	Soy beans	Potatoes	Sweet potatoes	Cassava	Peanuts	Sugar
China	773	30	100	28	21	19	8.0	12	33	94	—	2.4	3.2
India	570	20	62	6.5	19	2.7	12	—	4.1	1.6	4.6	6.4	4.4
U.S.S.R.	245	94	1.2	13	3.0	28	7.3	0.6	97	—	—	—	9.3
U.S.A.	207	38	3.7	104	18	8.9	1.0	30	15	0.7	—	1.4	5.4
Pakistan	142	7.3	22	0.7	0.6	0.1	1.1	—	1.0	0.5	—	0.1	0.8
Indonesia	125	—	17	2.5	—	—	—	0.4	—	1.9	11	0.5	0.8
Japan	105	0.5	16	0.1	—	0.6	0.2	0.1	3.7	2.8	—	0.1	0.4
Brazil	96	1.8	7.6	16	—	—	2.5	1.5	1.7	2.2	30	0.9	5.4
W. Germany	59	5.7	—	0.5	—	4.7	0.1	—	16	—	—	—	2.0
Nigeria	57	—	0.4	1.2	6.3	—	0.7	—	—	12	6.8	1.2	—
U.K.	56	4.2	—	—	—	7.5	0.3	—	6.5	—	—	—	1.0
Italy	54	9.6	0.9	4.8	—	0.3	0.6	—	3.8	—	—	—	1.2
Mexico	53	2.1	0.5	10	2.3	0.2	1.5	0.3	0.5	0.2	—	0.1	2.4
France	52	13	0.1	7.5	0.2	8.0	0.1	—	9.0	—	—	—	2.6
Philippines	39	—	5.6	2.4	—	—	—	—	—	0.7	0.5	—	2.2
Thailand	37	—	14	1.7	0.1	—	0.1	0.1	—	0.2	1.9	0.2	0.5
Turkey	37	10	0.2	1.0	0.1	3.2	0.5	—	1.9	—	—	—	0.6
Egypt	35	1.5	2.6	2.3	0.9	0.1	0.3	—	0.5	0.1	—	—	0.5
Spain	34	4.0	0.4	1.8	0.1	3.1	0.6	—	4.4	—	—	—	0.9
Poland	33	4.6	—	—	—	2.0	0.2	—	43	—	—	—	1.6
S. Korea	33	0.4	5.9	0.1	0.1	2.2	—	0.2	0.6	2.1	—	—	—
Iran	29	4.0	1.1	—	—	1.0	0.1	—	0.2	—	—	—	0.6
Burma	28	—	8.1	0.1	0.1	—	0.2	—	—	—	—	0.5	0.1
Ethiopia	26	0.8	—	0.9	2.7	1.5	0.6	—	0.1	0.2	—	—	0.1
Argentina	25	4.2	0.4	9.4	4.2	0.6	—	—	2.3	0.5	0.3	0.2	1.0
Colombia	22	0.1	0.7	0.8	0.1	—	—	0.1	1.1	0.1	0.9	—	0.9
Canada	22	9.0	—	2.5	—	9.0	—	0.3	2.4	—	—	—	0.1
Australia (*)	13	8.0	0.2	0.2	0.6	2.3	—	—	0.6	—	—	—	2.5
WORLD	3,706	312	307	267	93	129	43	47	300	136	91	18	73

(*) Australia included even though small population because Australia is a major producer of wheat and sugar.

The basic chemical reaction which takes place in the growth of plants is photosynthesis in which carbon dioxide and water are combined, under the influence of sunlight, to form glucose:

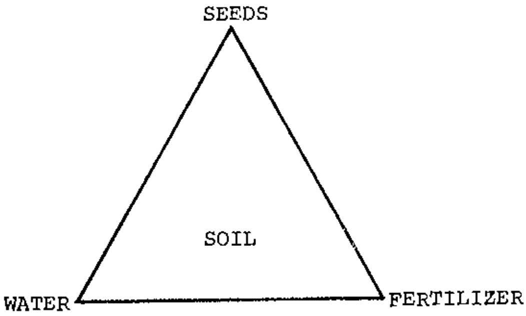
$$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$$

Glucose then forms starch and cellulose. Therefore carbon dioxide and water are the basic raw materials of plant growth, but many other elements are required for high crop yields, including nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, iron, manganese, boron and some 8 or 10 other elements. The chemical role of these elements in plant growth is too complex to discuss in this paper, but obviously nitrogen plays a key role in the production of plant proteins.

Seeds, water and fertilizer are the three primary agricultural inputs. Pesticides and machinery are secondary agricultural inputs. Pesticides are needed — and needed badly — if a crop is attacked by a disease or an insect pest, but if there is no pest, pesticides are not needed — wheat in North India, for example. In other words, pesticides are not fundamental to plant growth. Agricultural machinery is largely concerned with reducing labor requirements, although in many crop situations the use of mechanized equipment will increase yields over and above what could be obtained by hand labor alone by carrying out the various farm operations more rapidly.

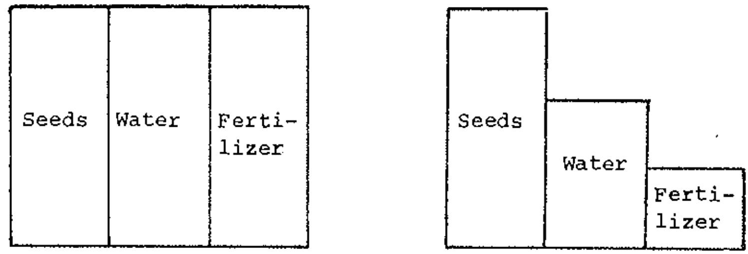
In addition to physical and biological inputs, there are many economic, political and cultural factors which affect agricultural production, including education of farmers, land ownership, farm credit, prices of agricultural products, prices of inputs, subsidies for products and inputs, marketing systems, transportation facilities and many more. However, this paper will focus primarily on the physical and biological inputs.

The three primary agricultural inputs — seeds, water and fertilizers — acting within the milieu of the soil, constitute the triangular base of agriculture:



This three-way relationship is like a three-legged stool. Unless these three inputs are balanced, yields will not be maximized. Japan is the world's master in balancing these three inputs. Among the developing countries, Taiwan, South Korea, North Korea, Egypt and Mexico are very efficient in this regard. Also, Western and Eastern European countries are very good at balancing these inputs and obtaining high yields. The United States, the Soviet Union and China obtain high yields in some crops but not so high yields in other crops. India, Brazil, Indonesia, Turkey and most other developing countries do not balance these inputs properly and therefore have generally poor yields (although India has improved her wheat yields during the last five years). Figures 2 and 4 illustrate the wide variations in wheat and rice yields among countries.

India and Japan may be compared in their success in balancing the three primary inputs by the following diagram:



JAPAN
Good balance of inputs
High crop yields

INDIA
Poor balance of inputs
Low crop yields

India now has a good supply of high quality seeds, at least of wheat, rice, maize and sorghum (jowar). Also, India has 30 million hectares of irrigated land and additional millions of hectares of adequately rain-fed land so that India could effectively use many times as much fertilizer as she is now using. *The big factor holding back higher agricultural production in India today is under-utilization of fertilizer.* This point will be discussed in greater detail in a later section of this paper.

Fertilizer the Most Critical Input

It is not possible to say that any one of the three primary agricultural inputs — seeds, water, fertilizer — is more important than the other two. All three are essential for crop production, and it is necessary to attain an optimum balance among these three inputs in order to obtain high yields. However, it is possible to say that fertilizer is the *most critical* of the three primary inputs because it is the most costly of the inputs — at least this is the case in most countries, developed and developing. Providing enough fertilizer is more costly than supplying high quality seeds or enough irrigation water or any other input. And yet the use of enough fertilizer is absolutely essential to high agricultural production. Moreover, the use of fertilizer usually yields a good economic return. Fertilizer is, therefore, the *most-critical* agricultural input (1) to the farmer because it strains his financial resources and (2) to the nation because it requires much foreign exchange either to import fertilizer or to buy machinery with which to equip indigenous fertilizer factories.

This point may be illustrated by an operating cost analysis of a typical wheat farm in an irrigated area shown in *Table IV*. This farm might be in India, Iran, Turkey, Algeria, Mexico or any other country growing wheat under irrigation. In this example, total ont-of-pocket costs to the farmer are $ 69 per hectare (not including interest on invested capital and depreciation). Out of the $ 69 out-of-pocket costs per hectare, fertilizer takes $ 30, water $ 20 and seeds $ 10. These costs will, of course, vary widely in different countries and regions. Therefore, in this example, fertilizer is the most costly input to the farmer and pnts the greatest strain on his financial resources. However, much more important is the financial strain on the national economy to provide this fertilizer because this reqnires much foreign exchange either to buy the fertilizer on the world market or to buy machinery from the developed countries with which to equip indigenous fertilizer factories.

On the other hand, providing the farmer with high qnality seeds and irrigation water can be accomplished largely by the investment of local currencies. Providing high quality seeds requires investment in research institutions and seed multiplication farms which need only local currencies, although a small initial investment of foreign exchange might have to be made to buy high quality seeds from some other country, as India and Pakistan bought high-yielding wheat seeds from

TABLE IV — *Economics of a typical wheat farm in an irrigated area (in India, for example).*

— using high yielding varieties of wheat
— using moderate amounts of fertilizer
— using irrigation water
— using pesticides if and when necessary
Yield = 3000 kg./hectare

	Production costs per hectare, U.S. dollars
Seed (saved from previous year's crop), 100 kg. @ 10¢/kg. (*)	10
Irrigation Water, 4000 cu.m. @ ½¢/cu.m. (**)	20
Fertilizer:	
100 kg. N @ 20¢/kg. 50 kg. P_2O_5 @ 15¢/kg. 25 kg. K_2O @ 10¢/kg.	30
Pesticides (maybe required, maybe not)	?
Labor (outside family), 6 man-days @ 67¢/man-day	4
Maintenance of equipment, 5% of $100/ha.	5
Interest on capital invested in land, 10% of $1000/ha.	100
Interest on capital invested in equipment, 10% of $100/ha.	10
Depreciation on equipment, 10% of $100/ha.	10
Total production costs per hectare	189
Income, 3000 kg. wheat @ 10¢/kg.	300
Profit (***)	111
Cash flow (profit + two interest items + depreciation)	231

(*) Even though seed is saved from the farmer's own crop, it must be considered an out-of-pocket cost since it could be sold in the market for cash. If the farmer buys seed, the price would probably be higher than that given above.

(**) Water @ ½¢/cu.m. = 2¢1000 gallons (1 cu.m. = 264 gallons) 4000 cu.m./ha. = 16 inches of water.

(***) Profit subsumes the labor of owner and family.

Note: The above figures are illustrative only. All the figures in the above calculation will vary greatly from one country to another and from one region to another within a country.

Mexico several years ago. Providing irrigation water involves building dams and irrigation canals which can be done with local labour and local building materials, although some expenditure of foreign exchange may be made to buy earth-moving equipment, explosives, etc. from the developed countries.

Table V shows the operating cost analysis of a typical wheat farm in a non-irrigated area for comparison with Table IV.

Many agricultural observers have made statements that this developing country or that developing country, or all developing countries, should use more fertilizer. Why? What is the basis for such statements? What is the optimum amount of fertilizer that a nation, or an individual farmer, should use? How can a nation or an individual farmer know whether the current usage of fertilizer is optimum or not? The answer to these questions lies in a complex array of economic, technological and social factors.

In general, it can be said that agricultural areas which use large amounts of fertilizer per hectare have higher agricultural yields than comparable areas using smaller amounts of fertilizer per hectare. Also, countries which use large amounts of fertilizer per capita usually have better nutrition than countries using smaller amounts of fertilizer per capita. However, there are exceptions to this generalization resulting from other agricultural and economic factors. These exceptions reflect the fact that agriculture is a very complex activity involving many variables.

Figure 10 shows the percentage of irrigated land in 20 countries. Egypt is unique in having 100 percent irrigated agricultural land; this fact is a major reason why Egypt has some of the highest agricultural yields among developing countries. However, greater use of fertilizer would increase Egypt's yields still more. China has 69 percent irrigated land, and this is a major reason why China is able to feed her 770 million people on 110 million hectares at least as well as India

Table V — *Economics of a typical wheat farm in a non-irrigated area (in India, for example).*

— using traditional varieties of wheat
— using no fertilizer (or very little)
— using no irrigation water
— using no pesticides
Yield = 1000 kg./hectare

	Production costs per hectare, U.S. dollars
Seed (saved from previous year's crop), 100 kg. @ 10¢/kg. (*)	10
Irrigation water	0
Fertilizer	0
Pesticides	0
Labor (outside family)	0
Maintenance of equipment, 5% of $13/ha.	0.7
Interest on capital invested in land, 10% of $200/ha.	20
Interest on capital invested in equipment, 10% of $13/ha.	1.3
Depreciation on equipment, 10% of $13/ha.	1.3
Total production costs per hectare	33
Income, 1000 kg. wheat @ 10¢/kg.	100
Profit (**)	67
Cash flow (profit + two interest items + depreciation)	90

(*) Even though seed is saved from the farmer's own crop, it must be considered an out-of-pocket cost since it could be sold in the market for cash. If the farmer buys seed, the price would probably be higher than that given above.

(**) Profit subsumes the labor of owner and his family.

Note: The above figures are illustrative only. All the figures in the above calculation will vary greatly from one country to another and from one region to another within a country.

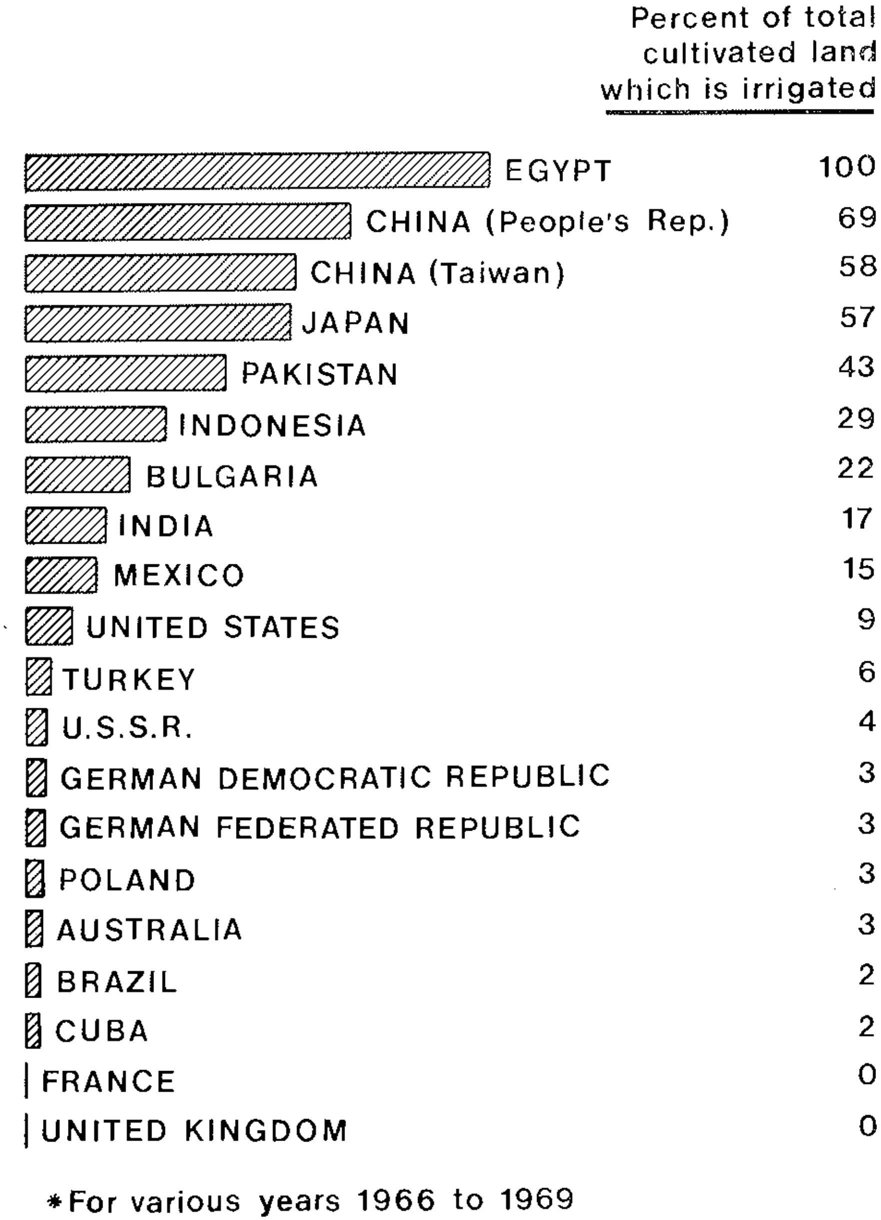


FIG. 10 — Percentage of irrigated agricultural land selected countries*.

feeds her 570 million people on 162 million hectares. Greater use of fertilizer would increase yields in both China and India. Most European countries have little irrigated land, for example, 23,000 ha. in France and 107,000 ha. in U.K. The five highest countries in Europe percentagewise are Bulgaria 22 percent, Greece 20 percent, Italy 16 percent, Portugal 15 percent, Spain 11 percent.

Fertilizer, Population and Grain Production

The basic driving force for increased use of fertilizer, and other agricultural inputs as well, is the growth of population and the resulting increased demand for food and other agricultural products. Thus there is a basic relationship between population growth and fertilizer consumption.

This relationship is illustrated by *Figures 11, 12 and 13*. Figure 11 compares population growth, grain production and fertilizer consumption in the world during the period 1950 to 1969 with projections to 1975 and 1980. Figure 12 makes the same comparison for the developing countries (including the Asian communist countries). The conclusions to be drawn from Figures 11 and 12 are (1) that grain production increased slightly more rapidly than population during the 1950-1970 period, both in the world as a whole and in the developing countries as a group, and (2) that fertilizer consumption has been increasing much more rapidly than either population or grain production. All the data shown in Figures 11 and 12 are from Table I.

Figure 13 shows a correlation of population growth and fertilizer consumption in the developing countries during the period 1950 to 1969 and also forecasts for 1975 and 1980 which will be discussed in the next section. Figure 13 shows that fertilizer consumption has been increasing much more rapidly

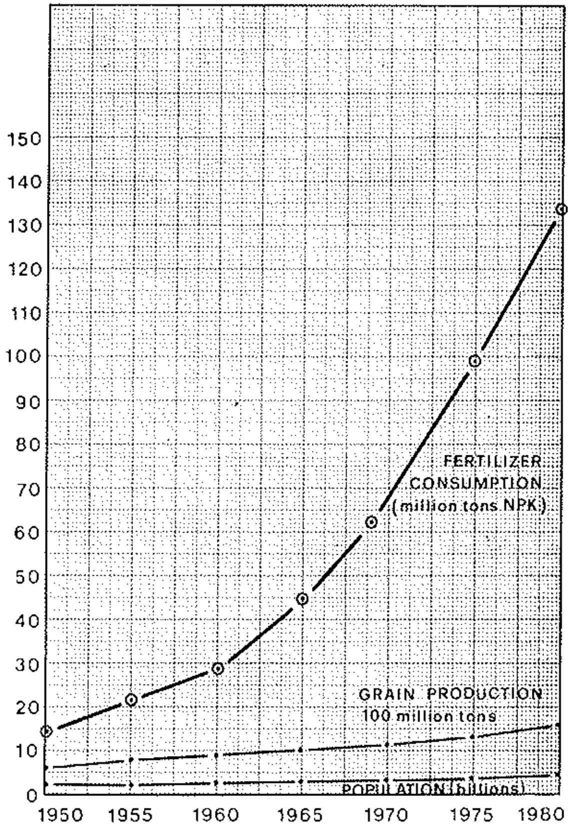


FIG. 11 — Growth of population, grain production and fertilizer consumption - Total world.

than population. For example, from 1950 to 1969 population of the developing countries increased by 52 percent whereas fertilizer consumption increased from 1.2 to 12.4 million tons or 930 percent. In fact, fertilizer consumption has been increasing only slightly less than exponentially with population. The forecast of fertilizer consumption in 1975 lies on the projected curve, but the forecast for 1980 is well below

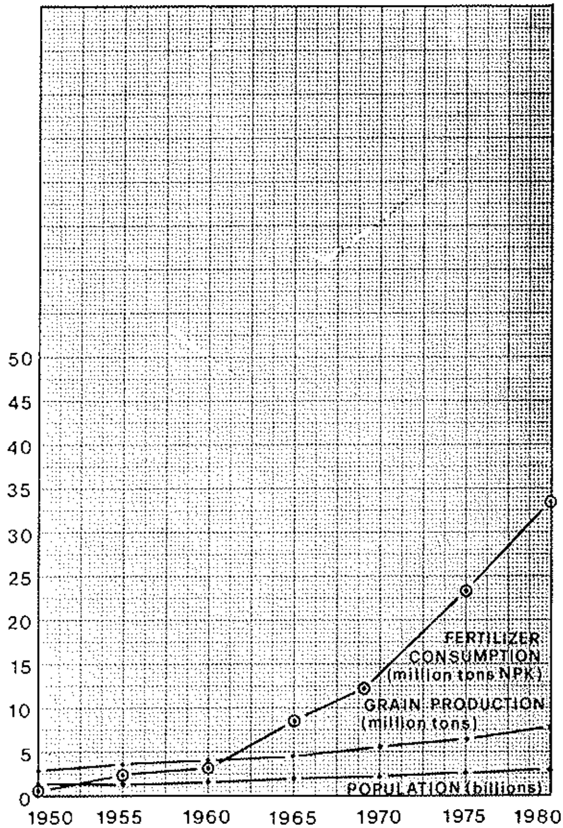


FIG. 12 — Growth of population, grain production and fertilizer consumption - Developing countries.

the curve. This raises the question that possibly the 1980 forecast of fertilizer consumption may be too low.

Basic Statistics on Fertilizer Production and Consumption

World production and consumption of commercial fertilizers have increased rapidly throughout this century as indi-

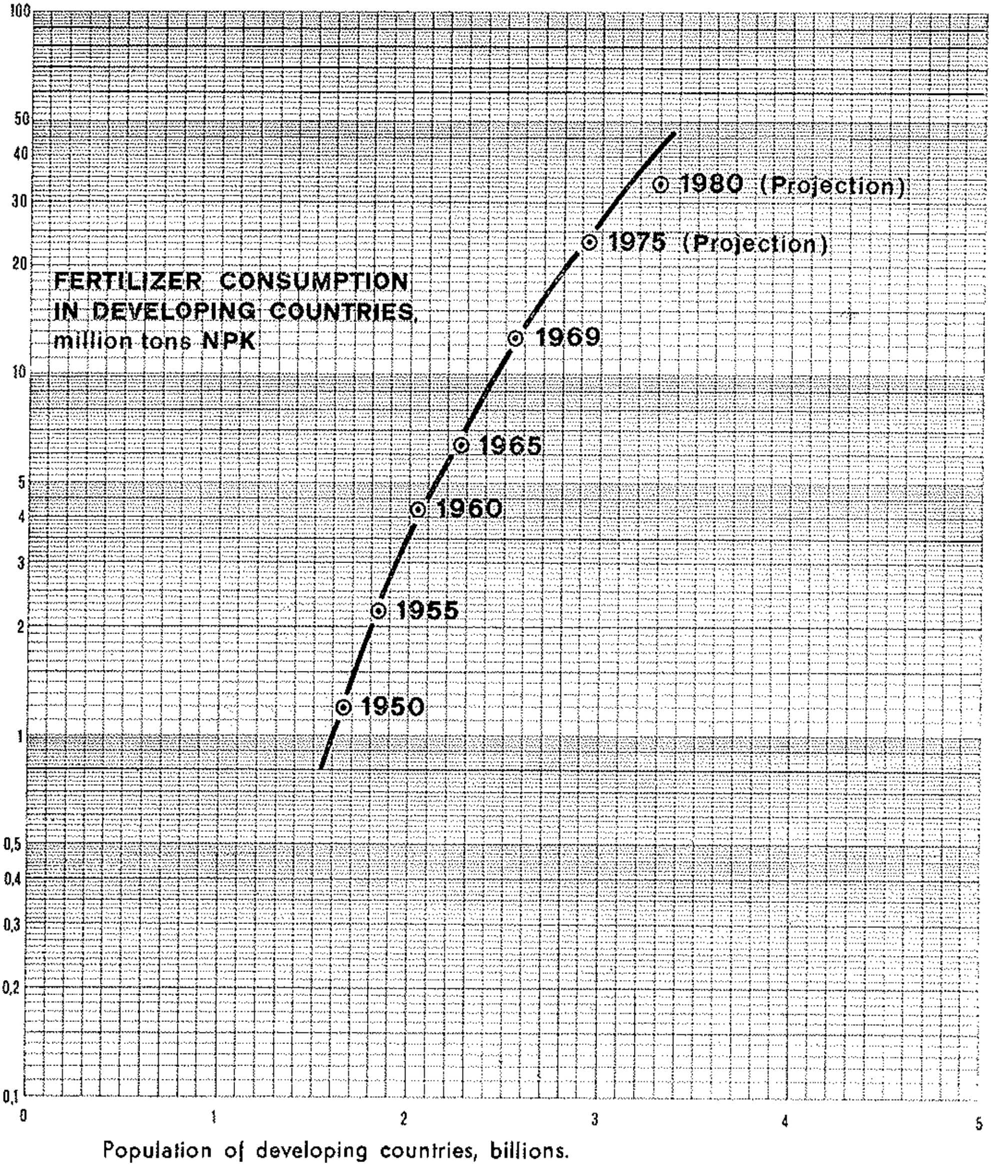


FIG. 13 — Correlation of population growth and fertilizer consumption in developing countries.

cated by the following data on *fertilizer consumption* (in million tons of nutrients):

	N	P_2O_5	K_2O	Total
1905/06	0.4	1.0	0.5	1.9
1913/14	0.7	2.1	1.0	3.8
----- Decline during World War I -----				
1919/20	0.8	1.7	1.1	3.6
1938/39	2.7	3.6	2.9	9.2
----- Decline during World War II -----				
1945/46	2.0	3.4	2.1	7.5
1947/48	3.1	5.0	3.1	11.2
1960/61	11.0	10.1	8.6	29.7
1970/71	31.6	19.8	16.8	68.2

Fertilizer production would be parallel to the above data but about five percent higher in each year. The above data include the Asian communist countries in 1960/61 and 1970/71, but not in the earlier years. These data do not include organic fertilizers except organic fertilizers processed in factories and sold as commercial fertilizers. Organic materials were a substantial part of commercial fertilizer production up to about 1930, but today they are only a small fraction of one percent of total commercial fertilizers.

Despite the great increase in world fertilizer production, the majority of developing countries in 1970 did not produce any fertilizer at all and many others did not produce enough to meet their needs. Both these categories of developing countries, therefore, have to import fertilizers. On the other hand, nearly all developed countries produce chemical fertilizers and many of them produce surplus fertilizer which they export.

For example, in nitrogen fertilizer many European countries, U.S.A., U.S.S.R., Canada and Japan are exporters, whereas among the developing countries only Chile, South Korea, Kuwait, Saudi Arabia, South Africa and Trinidad were significant exporters in 1970/71.

Similar situations exist in phosphate and potash fertilizers. In phosphate fertilizer, many European countries, U.S.A., U.S.S.R., Canada and Japan are exporters, while among the developing countries only Tunisia, Morocco and South Africa were significant exporters in 1970/71. In addition, Mexico, Iran and Israel will soon become large exporters of phosphoric acid.

In potash fertilizer, production is dominated by U.S.S.R., Canada, U.S.A. and several European countries, with Israel and Congo (Brazzaville) also producing significant amounts. Israel and Congo (Brazzaville) export nearly all of their production.

Tables VI, VII, VIII illustrate the facts outlined in the last three paragraphs.

In 1970/71 the developing countries produced 8.0 million tons of fertilizer (nutrient basis) and consumed 14.1 million tons, indicating an apparent deficit of 6.1 million tons. The largest deficits among the developing countries were People's Republic of China 2.0 million tons, India 1.1. million tons, Brazil 777,000 tons, Cuba 391,000 tons, Turkey 287,000 tons, Pakistan 243,000 tons, Indonesia 206,000 tons, Egypt 172,000 tons. These eight countries comprised 85 percent of the total deficits of the developing countries in 1970/71.

Figures 14, 15 and 16 show the past history of the consumption of fertilizers in developed and developing countries with projections to 1975/76 and 1980/81. Figures 15 and 16 are semi-logarithmic graphs so that all slopes are proportional to rates of growth. The rate of growth of fertilizer consumption is higher in the developing countries than in the

TABLE VI — *Largest Producers, Consumers, Exporters and Importers of Nitrogen Fertilizer in 1969/70* (all data in thousand tons of nitrogen).

Largest Producers	Production	Largest Consumers	Consumption
1. USA	7,632	1. USA	6,679
2. USSR	4,509	2. USSR	3,798
3. Japan	2,152	3. China (Mainland)	2,495
4. FRG	1,574	4. India	1,244
5. France	1,313	5. France	1,243
6. China (Mainland)	1,040	6. FRG	1,085
7. Italy	960	7. Japan	897
8. Poland	938	8. Poland	790
9. Netherlands	906	9. United Kingdom	650
10. India	731	10. Spain	604
11. United Kingdom	710	11. Italy	550
12. Canada	605	12. GDR	487
13. Bulgaria	586	13. Bulgaria	402
14. Spain	543	14. Mexico	388
15. Belgium	514	15. Netherlands	385
16. Romania	494	16. Romania	380
17. GDR	391	17. Hungary	348
18. Norway	371	18. Czechoslovakia	330
19. Mexico	359	19. Korea, Republic of	320
20. Korea, Republic of	356	20. Pakistan	320

Largest Exporters	Apparent Exports (*)	Largest Importers	Apparent Imports (*)
1. Japan	1,255	1. China (Mainland)	1,455
2. USA	953	2. India	513
3. USSR	711	3. Denmark	200
4. Netherlands	521	4. Turkey	179
5. FRG	489	5. Cuba	179
6. Italy	410	6. United Arab Republic	160
7. Canada	360	7. Brazil	158
8. Belgium	337	8. Pakistan	146
9. Norway	296	9. Vietnam, Republic of	122
10. Bulgaria	184	10. Indonesia	122
11. Poland	148	11. Yugoslavia	100
12. Austria	127	12. GDR	96
13. Romania	114	13. Ceylon	62
14. Kuwait	75	14. Spain	61
15. Trinidad & Tobago	70	15. Sweden	61
16. France	70	16. Hungary	48
17. United Kingdom	60	17. Thailand	47
18. Chile	59	18. Greece	45
19. South Africa	54	19. Sudan	39
20. Korea, Republic of	36	20. Peru	35

(*) Apparent exports estimated as Production - Consumption; apparent imports estimated as Consumption - Production. This is a rough method of estimating apparent exports and apparent imports, but it should be reasonably accurate except for stock changes and losses. Since stocks of fertilizer tend to increase in step with the steady increase in consumption and since losses in transportation and storage do occur, apparent exports calculated in this manner tend to be too high by a few percent and apparent imports tend to be too low by a few percent.

SOURCE: FAO Monthly Bulletin of Agricultural Economics and Statistics, Rome, February 1971.

TABLE VII — *Largest Producers, Consumers, Exporters and Importers of Phosphate Fertilizer in 1969/70* (all data in thousand tons of P_2O_5).

Largest Producers	Production	Largest Consumers	Consumption
1. USA	4,721	1. USA	4,177
2. USSR	2,071	2. USSR	1,916
3. France	1,400	3. France	1,681
4. FRG	919	4. FRG	857
5. Australia	792	5. Australia	830
6. Japan	745	6. Japan	689
7. Belgium	616	7. Poland	600
8. Italy	540	8. China (Mainland)	511
9. Poland	534	9. Italy	486
10. China (Mainland)	507	10. United Kingdom	460
11. Canada	450	11. Spain	406
12. United Kingdom	434	12. GDR	389
13. Spain	375	13. New Zealand	341
14. GDR	369	14. India	315
15. New Zealand	330	15. Canada	320
16. South Africa	312	16. Czechoslovakia	300
17. Czechoslovakia	289	17. South Africa	261
18. Netherlands	284	18. Bulgaria	256
19. India	224	19. Brazil	237
20. Romania	221	20. Turkey	201

Largest Exporters	Apparent Exports (*)	Largest Importers	Apparent Imports (*)
1. USA	544	1. France	281
2. Belgium	460	2. Turkey	157
3. Netherlands	176	3. Brazil	118
4. Tunisia	162	4. Bulgaria	117
5. USSR	155	5. Cuba	112
6. Luxembourg	140	6. India	91
7. Canada	130	7. Chile	81
8. Morocco	87	8. Poland	66
9. FRG	63	9. Indonesia	53
10. Japan	56	10. Pakistan	48
11. Italy	54	11. Colombia	48
12. South Africa	51	12. Thailand	45
13. Norway	49	13. Ireland	45
14. Romania	41	14. Yugoslavia	39
15. Lebanon	16	15. Australia	39
16. Korea, Republic of	16	16. Switzerland	38
17. United Arab Republic	10	17. Denmark	33
18. Greece	6.6	18. Spain	31
19. Senegal	5.9	19. Iran	30
20. Uganda	3.4	20. Vietnam, Republic of	28

(*) Apparent exports estimated as Production - Consumption; apparent imports estimated as Consumption - Production. This is a rough method of estimating apparent exports and apparent imports, but it should be reasonably accurate except for stock changes and losses. Since stocks of fertilizer tend to increase in step with the steady increase in consumption and since losses in transportation and storage do occur, apparent exports calculated in this manner tend to be too high by a few percent and apparent imports tend to be too low by a few percent.

SOURCE: FAO Monthly Bulletin of Agricultural Economics and Statistics, Rome, February 1971.

TABLE VIII — *Largest Producers, Consumers, Exporters and Importers of Potash Fertilizer in 1969/70* (all data in thousand tons of K_2O).

Largest Producers	Production	Largest Consumers	Consumption
1. Canada	3,500	1. USA	3,625
2. USSR	3,244	2. USSR	2,319
3. USA	2,487	3. France	1,279
4. GDR	2,346	4. FRG	1,120
5. FRG	2,212	5. Poland	1,050
6. France	1,750	6. Japan	690
7. Spain	519	7. GDR	624
8. Israel	437	8. Czechoslovakia	500
9. Italy	166	9. UK	462
10. China (Mainland)	140	10. China (Mainland)	240
11. Congo (Brazzaville)	67	11. Spain	224
12. Chile	15	12. Brazil	200
		13. Italy	195
(No other significant producers).		14. Canada	190
		15. Belgium	186
		16. Cuba	185
		17. Denmark	184
		18. Yugoslavia	180
		19. Austria	169
		20. Hungary	169

Largest Exporters	Apparent Exports (*)	Largest Importers	Apparent Imports (*)
1. Canada	3,310	1. USA	1,138
2. GDR	1,722	2. Poland	1,050
3. FRG	1,092	3. Japan	690
4. USSR	925	4. Czechoslovakia	500
5. France	471	5. UK	462
6. Israel	428	6. Brazil	200
7. Spain	295	7. Belgium	186
8. Congo (Brazzaville)	63	8. Cuba	185
		9. Denmark	184
(No other exporters)		10. Yugoslavia	180
		11. Austria	169
		12. Hungary	169
		13. India	151
		14. Ireland	141
		15. Finland	132
		16. Sweden	129
		17. Netherlands	121
		18. China (Mainland)	100
		19. New Zealand	99
		20. Australia	95

(*) Apparent exports estimated as Production - Consumption; apparent imports estimated as Consumption - Production. This is a rough method of estimating apparent exports and apparent imports, but it should be reasonably accurate except for stock changes and losses. Since stocks of fertilizer tend to increase in step with the steady increase in consumption and since losses in transportation and storage do occur, apparent exports calculated in this manner tend to be too high by a few percent and apparent imports tend to be too low by a few percent.

SOURCE: FAO Monthly Bulletin of Agricultural Economics and Statistics, Rome, February 1971.

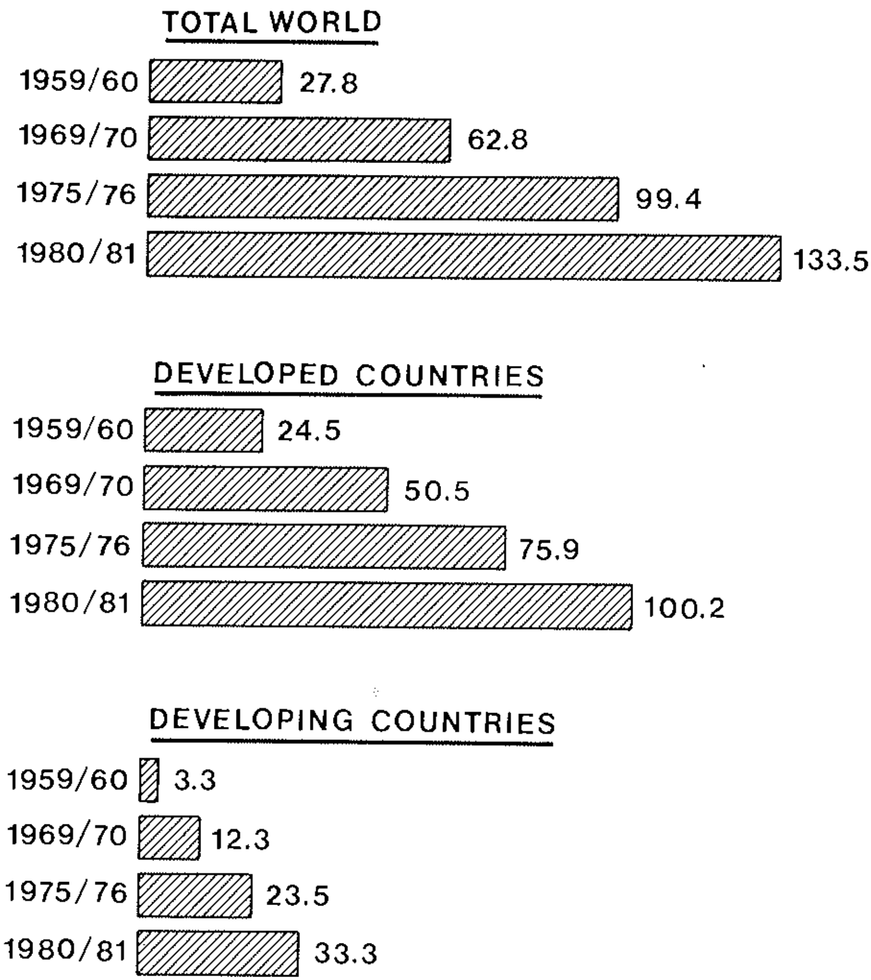


FIG. 14 — Consumption of fertilizers 1959/60, 1969/70, 1975/76, 1980/81, (million tons NPK) (including Mainland China, North Korea, North Vietnam).

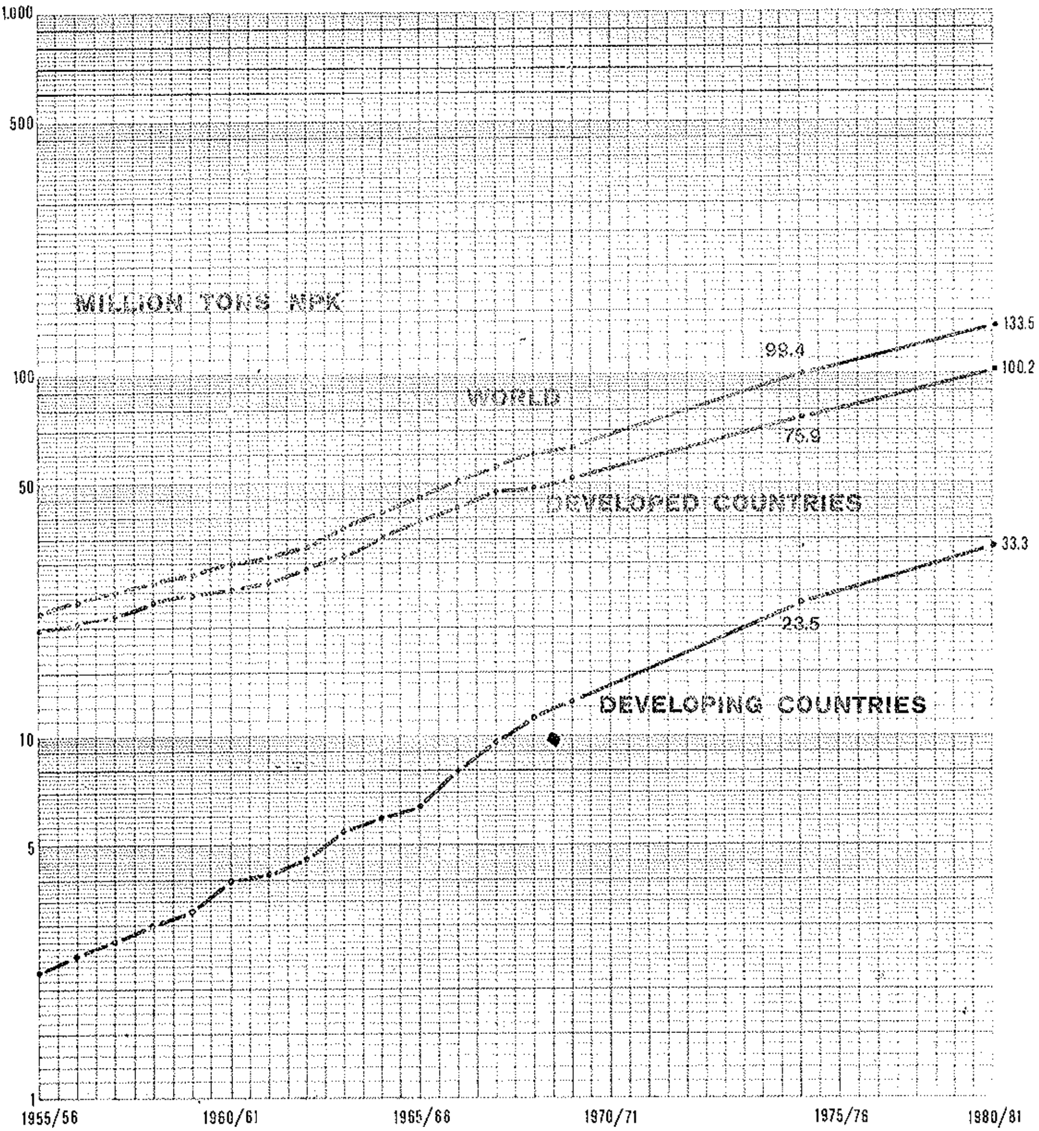


FIG. 15 — World consumption of fertilizers (including Mainland China, North Korea, North Vietnam).

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developed countries. The same is true of rates of growth of fertilizer production.

Figure 16 shows the consumption of fertilizer in the developing countries of Asia, Africa and Latin America. It is clear that Asia has had the highest growth rate among the three continental regions, Latin America has the next highest growth rate and Africa has the lowest growth rate.

Figure 17 shows the growth of both production and consumption of fertilizers in developed and developing countries. It may be noted that in the developed countries production exceeds consumption, but in the developing countries consumption exceeds production. The apparent deficit of the developing countries in 1970/71 amounted to 6.1 million tons NPK and the indicated deficit in 1980/81 is 9.1 million tons NPK.

Figure 18 shows the history of the consumption of nitrogen, phosphate and potash fertilizers. Nitrogen has been growing more rapidly than phosphate or potash fertilizers. The trends of the past 15 years appear to be heading towards the following ratios of the three major nutrients by 1980:

Developed countries $N\text{-}P_2O_5\text{-}K_2O = 1\text{-}0.55\text{-}0.45$

Developing countries $N\text{-}P_2O_5\text{-}K_2O = 1\text{-}0.50\text{-}0.30$

These are averages, of course, for the two groups of countries.

Tables IX and X give some of the numerical data shown graphically in Figures 14 to 18.

Growth Rate of Fertilizer

World production and consumption of fertilizer have shown high rates of growth throughout this century, except during the First and Second World Wars, when both production and consumption declined greatly. The following data

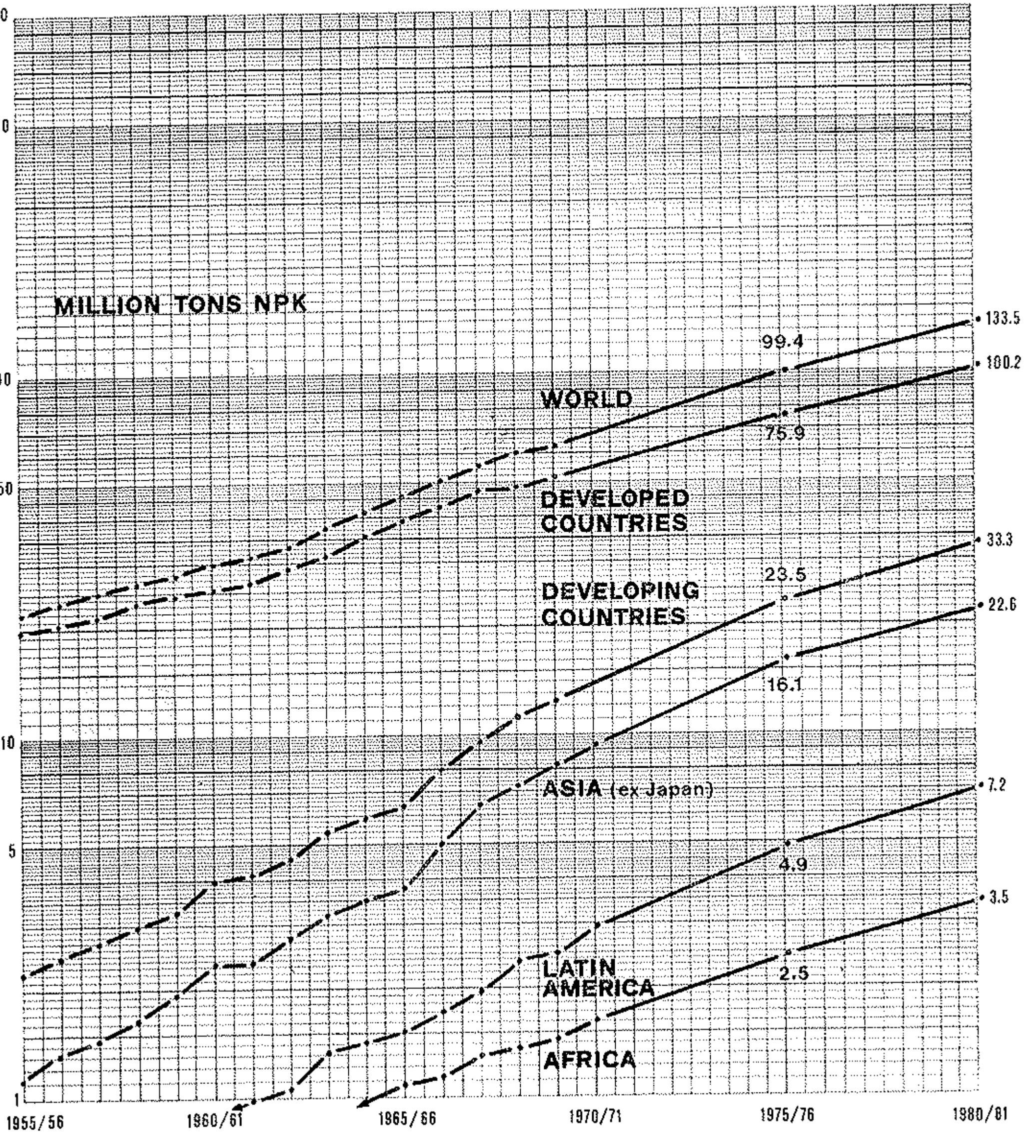
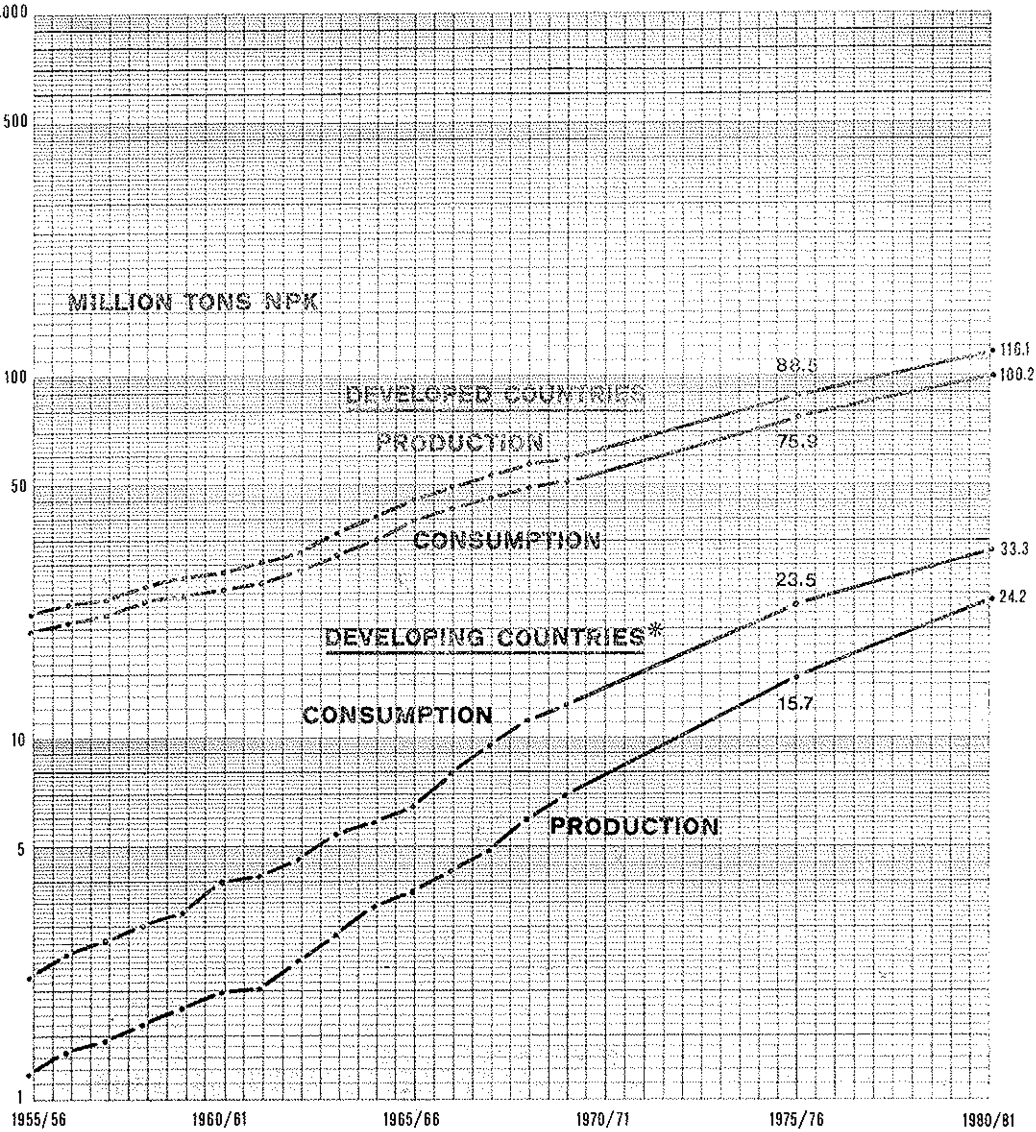


FIG. 16 — World consumption of fertilizers (Breakdown by continental areas).



*DEVELOPING COUNTRIES include Mainland China, North Korea, North Vietnam

FIG. 17 — Production and consumption of fertilizers in developed and developing countries.

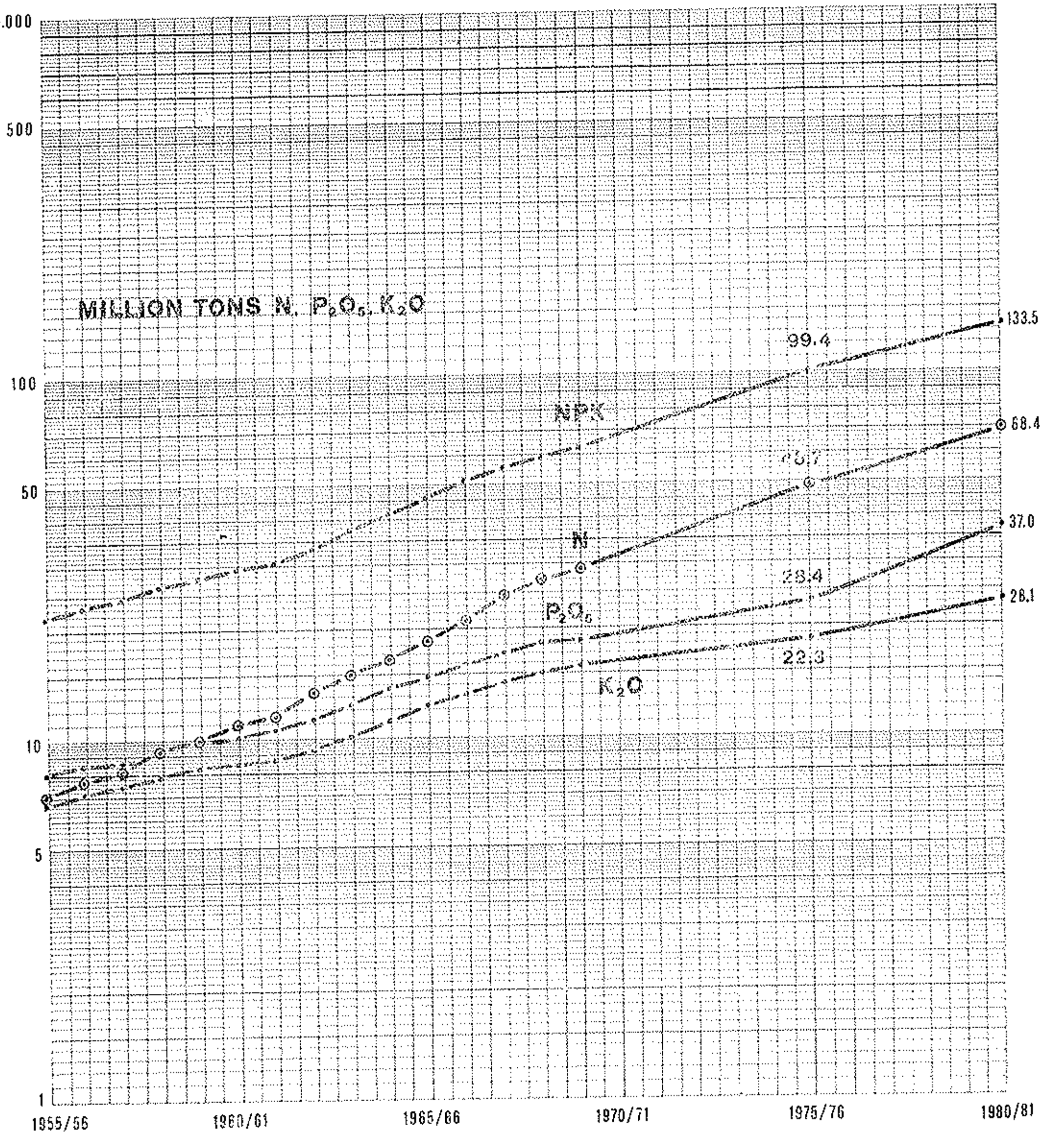


FIG. 18 — World consumption of fertilizers (including Mainland China, North Korea, North Vietnam).

Table IX — *World Production and Consumption of Fertilizers Breakdown by developed and developing countries* (million tons NPK).

	Production			Consumption		
	Developed Countries	Developing Countries	World Total	Developed Countries	Developing Countries	World Total
1945/46	n.a.	n.a.	7.9	n.a.	n.a.	7.5
1946/47	»	»	10.1	»	»	9.6
1947/48	»	»	11.8	»	»	11.2
1948/49	»	»	13.0	»	»	12.4
1949/50	»	»	14.2	»	»	13.5
1950/51	»	»	15.7	»	»	14.9
1951/52	»	»	16.6	»	»	15.8
1952/53	»	»	18.1	»	»	17.2
1953/54	»	»	20.0	»	»	19.1
1954/55	»	»	21.3	»	»	20.3
1955/56	21.8	1.1	22.9	19.8	2.2	22.0
1956/57	23.1	1.3	24.4	20.7	2.5	23.2
1957/58	24.1	1.5	25.6	21.6	2.8	24.4
1958/59	25.9	1.6	27.5	23.4	3.0	26.4
1959/60	27.3	1.8	29.1	24.6	3.3	27.9
1960/61	28.6	2.0	30.6	25.5	4.2	29.7
1961/62	30.2	2.1	32.3	26.8	4.2	31.0
1962/63	32.3	2.5	34.8	29.3	4.6	33.9
1963/64	36.2	2.9	39.1	32.1	5.4	37.5
1964/65	40.3	3.5	43.8	35.2	5.9	41.1
1965/66	45.3	3.8	49.1	39.1	6.5	45.6
1966/67	49.1	4.3	53.4	42.4	8.0	50.4
1967/68	53.2	4.9	58.1	45.9	9.7	55.6
1968/69	56.6	6.0	12.6	48.3	11.2	59.5
1969/70	59.0	7.0	66.0	50.4	12.4	62.8
1970/71	63.2	8.0	71.2	54.1	14.1	68.2
1975/76	88.5	15.7	104.2	75.9	23.5	99.4
1980/81	116.1	24.2	140.3	100.2	33.3	133.5

Sources:

1945/46 to 1969/70 data from FAO Production Yearbook.

1970/71 data from FAO Monthly Bulletin of Agricultural and Economic Statistics, February 1972.

1975/76 and 1980/81 estimates are from UNIDO paper ID/WG.99/4, « Review of World Production, Consumption and International Trade in Fertilizers with Projections to 1975 and 1980 », presented at the Second Interregional Fertilizer Symposium, Kiev, U.S.S.R., September 1971.

ABLE X — *Production and consumption of fertilizer 1960/61 to 1980/81.*

	Nitrogen fertilizer (million tons N)							
	Production			Consumption			Deficit or (Surp	
	1960/61	1970/71	1980/81	1960/61	1970/71	1980/81	1960/61	1970/71
eveloped countries (1)	10.4	28.1	57.2	8.5	22.8	48.5	(1.9)	(5.3)
eveloping countries (2)	1.0	4.6	14.8	2.5	8.8	19.9	1.5	4.2
Asia (ex. Japan & CA) (3)	0.2	2.0	7.5	0.9	3.3	8.5	0.7	1.3
Asia, Communist (CA) (3)	0.4	1.4	3.0	0.8	3.2	6.0	0.4	1.8
Africa	0.1	0.4	1.2	0.3	0.9	1.8	0.2	0.5
Latin America	0.3	0.8	3.1	0.5	1.4	3.6	0.2	0.6
orld total	11.4	32.7	72.0	11.0	31.6	68.4	(0.4)	(1.1)

	Phosphate fertilizer (million tons P_2O_5)							
	Production			Consumption			Deficit or (Surp	
	1960/61	1970/71	1980/81	1960/61	1970/71	1980/81	1960/61	1970/71
eveloped countries	9.5	18.3	31.6	9.0	16.4	28.5	(0.5)	(1.9)
eveloping countries	0.8	2.5	7.2	1.1	3.4	8.5	0.3	0.9
Asia (ex. Japan & CA)	0.1	0.6	1.9	0.3	1.2	3.8	0.2	0.6
Asia, Communist (CA)	0.2	0.7	1.5	0.2	0.7	1.5	—	—
Africa	0.3	0.8	2.5	0.3	0.6	1.1	—	(0.2)
Latin America	0.2	0.4	1.3	0.3	0.9	2.1	0.1	0.5
orld total	10.3	20.8	38.8	10.1	19.8	37.0	(0.2)	(1.0)

	Potash fertilizer (million tons K_2O)							
	Production			Consumption			Deficit or (Surp	
	1960/61	1970/71	1980/81	1960/61	1970/71	1980/81	1960/61	1970/71
eveloped countries	8.7	16.8	27.3	8.0	14.9	23.2	(0.7)	(1.9)
eveloping countries	0.2	0.9	2.2	0.6	1.9	4.9	0.4	1.0
Asia (ex. Japan & CA)	0.1	0.6	1 0	0.2	0.6	2.1	0.1	—
Asia, Communist (CA)	0.1	0.1	0.3	0.1	0.3	0.7	—	0.2
Africa	—	0.2	0.8	0.1	0.3	0.6	0.1	0.1
Latin America	—	—	0.1	0.2	0.7	1.5	0.2	0.7
orld total	8.9	17.7	29.5	8.6	16.8	28.1	(0.3)	(0.9)

	Total fertilizer (million tons N + P_2O_5 + K_2O)							
	Production			Consumption			Deficit or (Surp	
	1960/61	1970/71	1980/81	1960/61	1970/71	1980/81	1960/61	1970/71
eveloped countries	28.6	63.2	116.1	25.5	54.1	100.2	(3.1)	(9.1)
eveloping countries	2.0	8.0	24.2	4.2	14.1	33.3	2.2	6.1
Asia (ex. Japan & CA)	0.4	3.2	10.4	1.4	5.1	14.4	1.0	1.9
Asia, Communist (CA)	0.7	2.2	4.8	1.1	4.2	8.2	0.4	2.0
Africa	0.4	1.4	4.5	0.7	1.8	3.5	0.3	0.4
Latin America	0.5	1.2	4.5	1.0	3.0	7.2	0.5	1.8
orld total	30.6	71.2	140.3	29.7	68.2	133.5	(0.9)	(3.0)

otes

(1) Developed countries include U.S.A., Canada, Europe, U.S.S.R., Japan and Oceania.

(2) Developing countries include all countries of Asia (except Japan), Africa and Latin America. Latin A all of North and South America except U.S.A. and Canada.

(3) CA = Communist Asia = People's Republic of China, North Korea, North Vietnam, Mongolia.

ource:

1960/61 data from FAO Production Yearbook.

1970/71 data from FAO Monthly Bulletin of Agricultural and Economic Statistics, February 1972.

1980/81 estimates are from UNIDO paper ID/WG.99/4, "Review of World Production, Consumption and national Trade in Fertilizers with Projections to 1975 and 1980", presented at the Second Intern Fertilizer Symposium, Kiev, U.S.S.R., September 1971.

show the rates of growth of production and consumption during several periods of time:

Average annual rates of growth	Percent per year N	P_2O_5	K_2O	Total
1905/06 to 1913/14 (8 years)	8.5%	9.3%	9.0%	9.0%
1919/20 to 1938/39 (19 years)	6.9%	4.0%	5.4%	5.1%
1947/48 to 1960/61 (13 years)	10.2%	5.6%	8.1%	7.8%
1960/61 to 1971/71 (10 years)	11.1%	7.0%	7.0%	8.7%

The relatively low growth rate during the 1919/20 to 1938/39 period was caused by the economic depression of the early 1930's when fertilizer consumption remained constant for several years.

One of the most important facts concerning the world fertilizer picture is that both production and consumption of fertilizers have been growing nearly twice as rapidly in the developing countries as in the developed countries. This is illustrated by the following data:

Growth of fertilizer production and consumption in developed and developing countries during ten-year period 1960/61 to 1970/71 (in million tons $N + P_2O_5 + K_2O$)

	Developed Countries	Developing Countries	World Total
Production, 1960/61	28.7	2.0	30.7
» , 1970/71	63.3	7.9	71.2
Annual rate of increase	8.2%	14.7%	8.8%
Consumption, 1960/61	25.4	4.2	29.6
» , 1970/71	54.0	14.1	68.1
Annual rate of increase	7.8%	13.0%	8.7%

Future Projections of Production and Consumption

Projections of future fertilizer production and consumption up to 1980/81 were made by the staff of the United Nations Industrial Development Organization for all countries in the world based on the historical data from 1950/51 to 1969/70. This analysis was presented at the Second Interregional Fertilizer Symposium in Kiev, U.S.S.R. in September 1971 (paper ID/WG.99/4). The projection method used was a visual, graphical adaptation of the Gompertz growth curve, as illustrated in Figures 15, 16, 17, 18. The data for 1970/71, which became available from FAO in February 1972, fit precisely on the projection lines developed a year earlier. The projections made in the UNIDO report for 1980/81 are summarized as follows:

Total fertilizer (million tons $N + P_2O_5 + K_2O$)

	Production		Consumption		Apparent deficit (Apparent surplus)	
	1970/71	1980/81	1970/71	1980/81	1970/71	1980/81
Developed countries	63.3	116.1	54.0	100.2	(9.3)	(15.9)
Developing countries	8.00	24.2	14.1	33.3	6.1	9.1
Total world	71.3	140.3	68.1	133.5	(3.2)	(6.8)

The apparent world surpluses are the result of increased stocks as the volume of trade in fertilizers increases and also losses.

Apparent deficits of the developing countries are, therefore, projected to increase from 6.1 million tons in 1969/70 to 9.1 million tons in 1980/81. The two largest deficits indicated by the projections are People's Republic of China 3.1 million tons and India 2.65 million tons.

Fertilizer Consumption per Capita and per Hectare

Figure 19 and *Table XI* give detailed data on fertilizer consumption per capita in various countries in 1969/70. Fertilizer consumption per capita varies from East Germany at 92.6 kg./capita down to Ethiopia at 0.1 kg./capita. The top 21 countries include 16 European countries plus Australia,

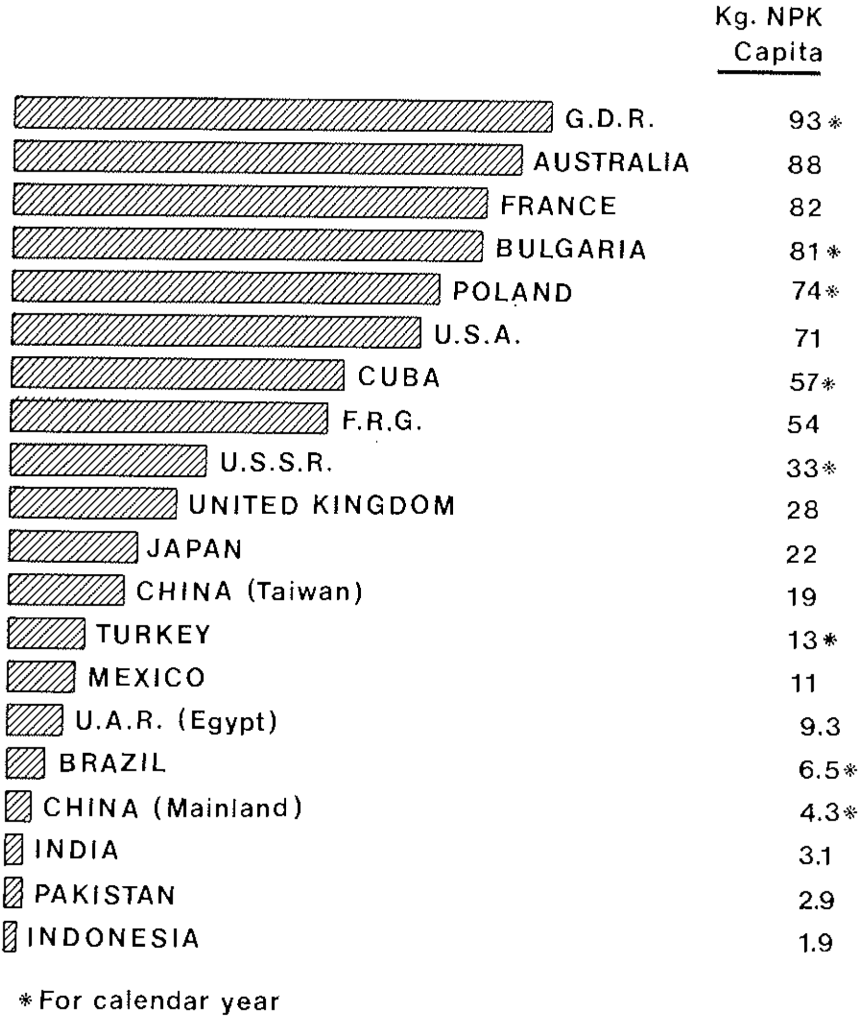


FIG. 19 — Fertilizer consumption per capita - 1969/70 (selected countries).

TABLE XI — *Classification of Countries in Fertilizer Consumption per Capita* (Including all countries over 5,000,000 population in 1970) (in kg./capita of $N + P_2O_5 + K_2O$ in 1969/70 crop year).

Developed Countries		Developing Countries	
Very High — 50-100 kg./capita			
Australia	Germany (East)	Cuba	
Austria	Germany (West)		
Belgium	Hungary		
Bulgaria	Poland		
Czechoslovakia	Sweden		
France	United States		
High — 25-50 kg./capita			
Canada	Soviet Union	None	
Greece	Spain		
Netherlands	United Kingdom		
Romania	Yugoslavia		
Moderate — 10-25 kg./capita			
Italy		Central America (*)	Mexico
Japan		Chile	Rhodesia
Portugal		China (Taiwan)	South Africa
Switzerland		Korea (North)	Turkey
		Korea (South)	
Low — 5-10 kg./capita			
	None	Algeria	Malaysia
		Brazil	Morocco
		Ceylon	Peru
		Colombia	Tunisia
		Ecuador	Vietnam (South)
		Egypt	
Very low — 0-5 kg./capita			
	None	Afghanistan	Madagascar
		Angola	Mali
		Argentina	Mozambique
		Burma	Nepal
		Cambodia	Nigeria
		Cameroon	Pakistan
		China (Mainland)	Philippines
		Congo (Dem. Rep.)	Saudi Arabia
		Ethiopia	Sudan
		Ghana	Syria
		Haiti	Tanzania
		India	Thailand
		Indonesia	Uganda
		Iran	Upper Volta
		Iraq	Venezuela
		Kenya	Vietnam (North)

(*) Central America includes Guatemala, Nicaragua, Honduras, El Salvador, Costa Rica and Panama.

U.S.A., Cuba, Canada and U.S.S.R. Cuba is the only developing country in the Very High or High Categories. All countries in the Low and Very Low Categories are developing countries.

Figure 20 and *Table XII* give similar data on fertilizer consumption per hectare. Fertilizer consumption per hectare varies from Japan at 400 kg./hectare down to Upper Volta at 0.1 kg./hectare. The top 19 countries include 13 European countries plus Japan, China (Taiwan), Cuba, South Korea, North Korea and Egypt.

Actually, Netherlands and Belgium appear to be the two highest on a per hectare basis with 675 and 583 kg./hectare, respectively. However, these are fictitious figures since a majority of the fertilizer in both these countries is used on pastures rather than on crop land. The same thing is true to a lesser extent in West Germany, Switzerland, East Germany and other northern European countries. Kg./hectare data are usually calculated by dividing total fertilizer consumption by total arable land (which does not include permanent pastures), and therefore if a large part of the fertilizer is used on permanent pastures the calculated ratio is fictitious. For this reason it is believed that Japan has the highest kg./hectare application of fertilizer on crops and is so shown in Figure 20.

Fertilizer consumption per capita is the important economic variable related to planning the development of the fertilizer industry in any country rather than fertilizer consumption per hectare. In other words, fertilizer consumption per capita is an economic variable whereas fertilizer consumption per hectare is an agro-technical variable. A ton of fertilizer will produce so much additional food whether it is used on 10 hectares or 20 hectares or even possibly 40 hectares. This generalization is true only within limits, of course, and it implies a linear yield-fertilizer response curve, which is not exactly true. But within limits this is a valid generalization —

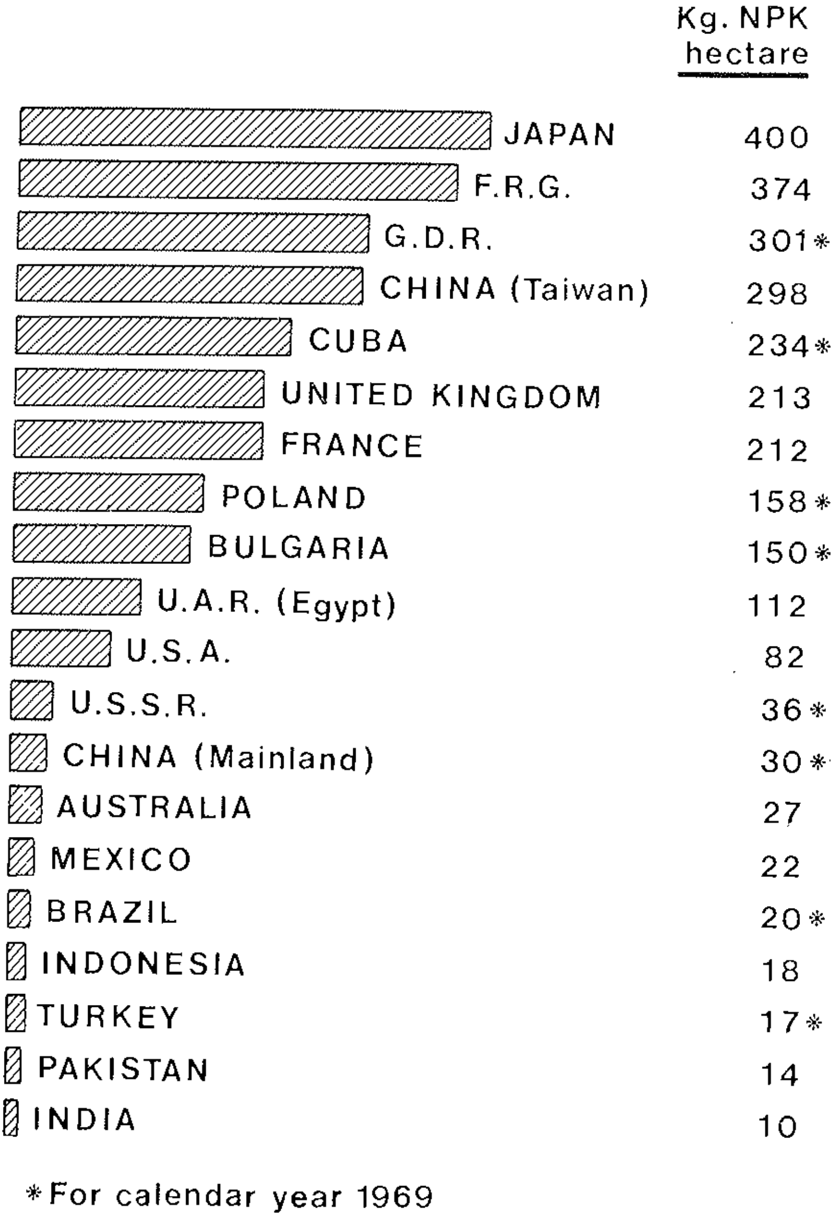


FIG. 20 — Fertilizer consumption per hectare - 1969/70 (selected countries).

TABLE XII — *Classification of Countries in Fertilizer Consumption per Hectare* (Including all countries over 5,000,000 population in 1970) (In kg./hectare of $N + P_2O_5 + K_2O$ in 1969/70 crop year).

Developed Countries		Developing Countries	
Very High — over 200 kg./hectare			
Austria	Germany, West	China (Taiwan)	
Belgium	Japan	Cuba	
Czechoslavakia	Netherlands	Korea (South)	
France	Switzerland		
Germany, East	United Kingdom		
High — 100-200 kg./hectare			
Bulgaria	Poland	Egypt	
Hungary	Sweden	Korea (North)	
Moderate — 50-100 kg./hectare			
Greece	Spain	Ceylon	
Italy	United States	Rhodesia	
Romania	Yugoslavia	Vietnam (South)	
Low — 25-50 kg./hectare			
Australia		Central America (*)	Malaysia
Portugal		Chile	Peru
Soviet Union		China (Mainland)	South Africa
		Colombia	Vietnam (North)
Very low — 0-25 kg./hectare			
Canada		Afghanistan	Mali
		Algeria	Mexico
		Angola	Morocco
		Argentina	Mozambique
		Brazil	Nepal
		Burma	Nigeria
		Cambodia	Pakistan
		Cameroon	Philippines
		Congo, Dem. Rep.	Saudi Arabia
		Ecuador	Sudan
		Ethiopia	Syria
		Ghana	Tanzania
		Haiti	Thailand
		India	Tunisia
		Indonesia	Turkey
		Iran	Uganda
		Iraq	Upper Volta
		Kenya	Venezuela
		Madagascar	

(*) Central America includes Guatemala, Nicaragua, Honduras, El Salvador, Costa Rica and Panama.

in fact, many yield-fertilizer response curves are approximately linear over wide ranges of fertilizer application.

Therefore fertilizer consumption per capita is the variable on which national planners should focus their attention. Fertilizer consumption per hectare is of great importance to the economics of a particular farm, and indeed to the economics of the nation, but in planning the development of the fertilizer industry, fertilizer consumption per capita is the key variable.

Fertilizer and Crop Yields

The purpose of using fertilizer in agriculture is, of course, to increase crop yields. The effect of fertilizer on crop yields may be represented by a fertilizer response curve or in a more complex way by fertilizer response surfaces. *Figure 21* gives a schematic picture of some types of response curves comparing the fertilizer response of the new high-yielding, fertilizer-responsive varieties of wheat and rice with the old traditional non-fertilizer-responsive varieties. These curves represent the essence of the Green Revolution. The old traditional varieties of wheat and rice respond to low applications of fertilizer, but at high levels of fertilizer application the plants fall over or "lodge" which reduces the yields drastically. The maximum yield with the old traditional varieties is usually reached somewhere in the range of 75 to 125 kg./hectare of NPK.

By contrast the new high-yielding, fertilizer-responsive varieties increase yields steadily with increased fertilizer application up to at least 200 kg./hectare and even up to as high as 400 or more kg./hectare. Figure 21 indicates a yield at 200 kg./hectare about double the yield at zero fertilizer. This is very conservative since many instances of increasing wheat and rice yields by factors of 3, 4 and 5 by increased use of fertilizer are reported in the literature. The response to fertilizer in any particular situation is, of course, influenced

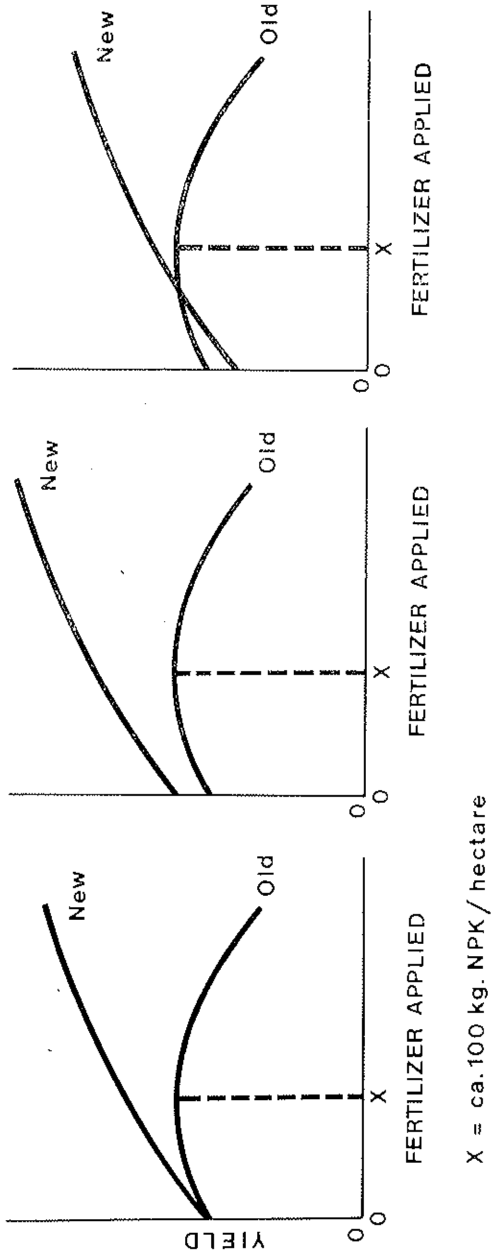


Fig. 21 — Types of fertilizer response curves comparing new high-yielding varieties with traditional varieties.

very much by the natural fertility of the soil — soils of low fertility give higher responses to fertilizer than soils of high fertility. However, soils of low fertility are the usual situation in developing countries.

Also, it must be kept in mind that fertilizer application has to be accompanied by an adequate supply of water to be effective and economical. However, many of the developing countries have enough irrigated land and adequately rain-fed land to use effectively much greater quantities of fertilizer than they are now using. For example, India has 30 million hectares of irrigated land and if India were to use an average of 200 kg. NPK/hectare on all these acres, this would amount to 6 million tons NPK, compared with India's total consumption of 2.1 million tons NPK in 1970/71. By contrast Japan uses 400 kg. NPK/hectare as *an average for the entire country*, and Taiwan and South Korea used 298 kg./hectare and 230 kg./hectare, respectively, in 1969/70. In addition, India has another 10-15 million hectares which have good water supplies without irrigation, which could also use more fertilizer effectively. The large area of agricultural land with inadequate or marginal water supplies is a major problem in India and in many other developing countries. This will continue to be a problem, but in the meantime India and other developing countries are not using their well-watered lands to maximum effectiveness.

The basic biological feature that distinguishes the new high-yielding, fertilizer-responsive varieties of wheat and rice is that they are dwarf varieties, growing to a height about half the height of the old traditional varieties. This desirable characteristic has been obtained by the application of the science of plant genetics to cross-breeding of thousands of strains of wheat and rice at CIMMYT, IRRI and other research institutions.

The intense interest in the new high-yielding varieties has resulted in thousands of experiments involving various combinations of seeds, water and fertilizer which have generated millions of response curves. It has been this writer's observation that no two response curves are ever identical. Response curves vary widely under seemingly identical conditions. That is why I presented some schematic response curves in Figure 21 rather than actual experimental curves.

In fertilizer experiments on wheat, rice, maize, sorghum, beans and ground nuts, response ratios of 6 to 10 are quite common, but in many experiments response ratios as high as 15 to 20 or even higher have been observed. The general picture is that more fertilizer gives higher yields, with value/cost ratios frequently in the range of 3 to 5, i.e. $ 3 to $ 5 value of additional crop per $ 1 cost of fertilizer.

Figure 22 shows the correlation of rice yields and fertilizer consumption in Taiwan during the period 1955 to 1970. The decreases in rice yields in 1959, 1966 and 1969 were undoubtedly due to weather fluctuations. The yield-fertilizer ratio is about 10 for the period 1955-68, but the ratio drops to about 8 if 1969 is included. The fertilizer figures are for all crops in Taiwan (rice, sugarcane, pineapple, banana, etc.), but rice is the main crop.

Figure 23 shows a similar correlation in Taiwan for earlier years, 1930 to 1957, published by FAO in 1962. The first years in Figure 22 fit exactly with the last years in Figure 23. The yield-fertilizer ratio seems to be about 8 during the period 1945/47 to 1957/59.

Figure 24 is a well-known curve published by FAO in 1960 correlating grain yield and fertilizer use in 40 countries. What this curve says, again, is that greater use of fertilizer increases yields. The slopes of this curve are:

0 - 50	kg. NPK/hectare		Average	slope	=	16	kg. grain/kg.	NPK
50 - 100	»	»	»	»	=	9	»	»
100 - 150	»	»	»	»	=	6.5	»	»
150 - 200	»	»	»	»	=	5.5	»	»
200 - 250	»	»	»	»	=	5.0	»	»
250 - 300	»	»	»	»	=	4.6	»	»
300 - 350	»	»	»	»	=	4.3	»	»

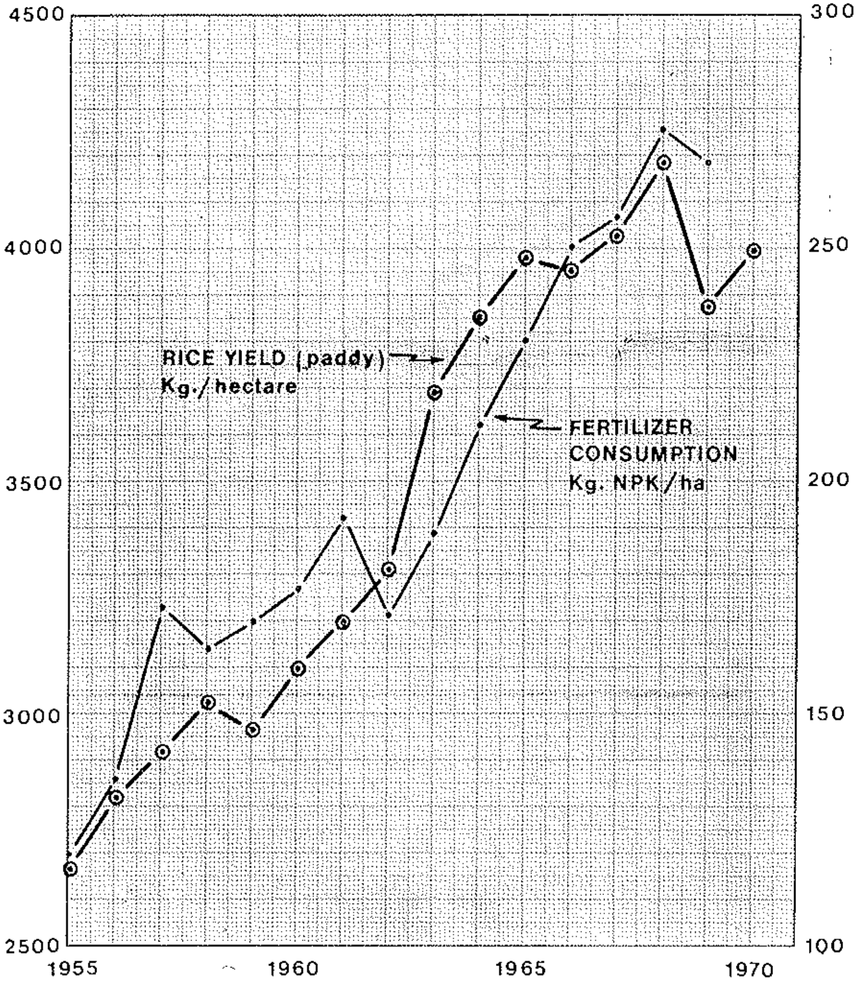


FIG. 22 — Rice yield compared with fertilizer consumption Taiwan.

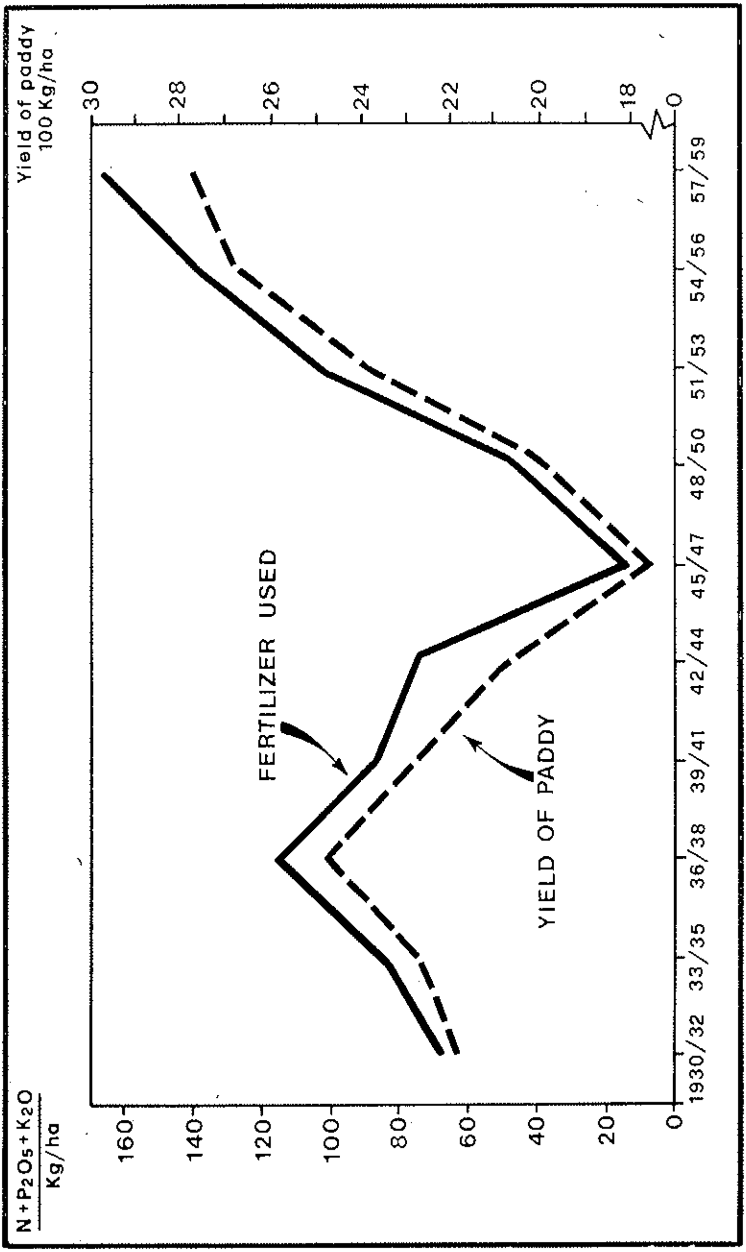


FIG. 23 — Relationship between yield of paddy and fertilizer use (nutrient), Taiwan, 1930-59 (3-year averages).

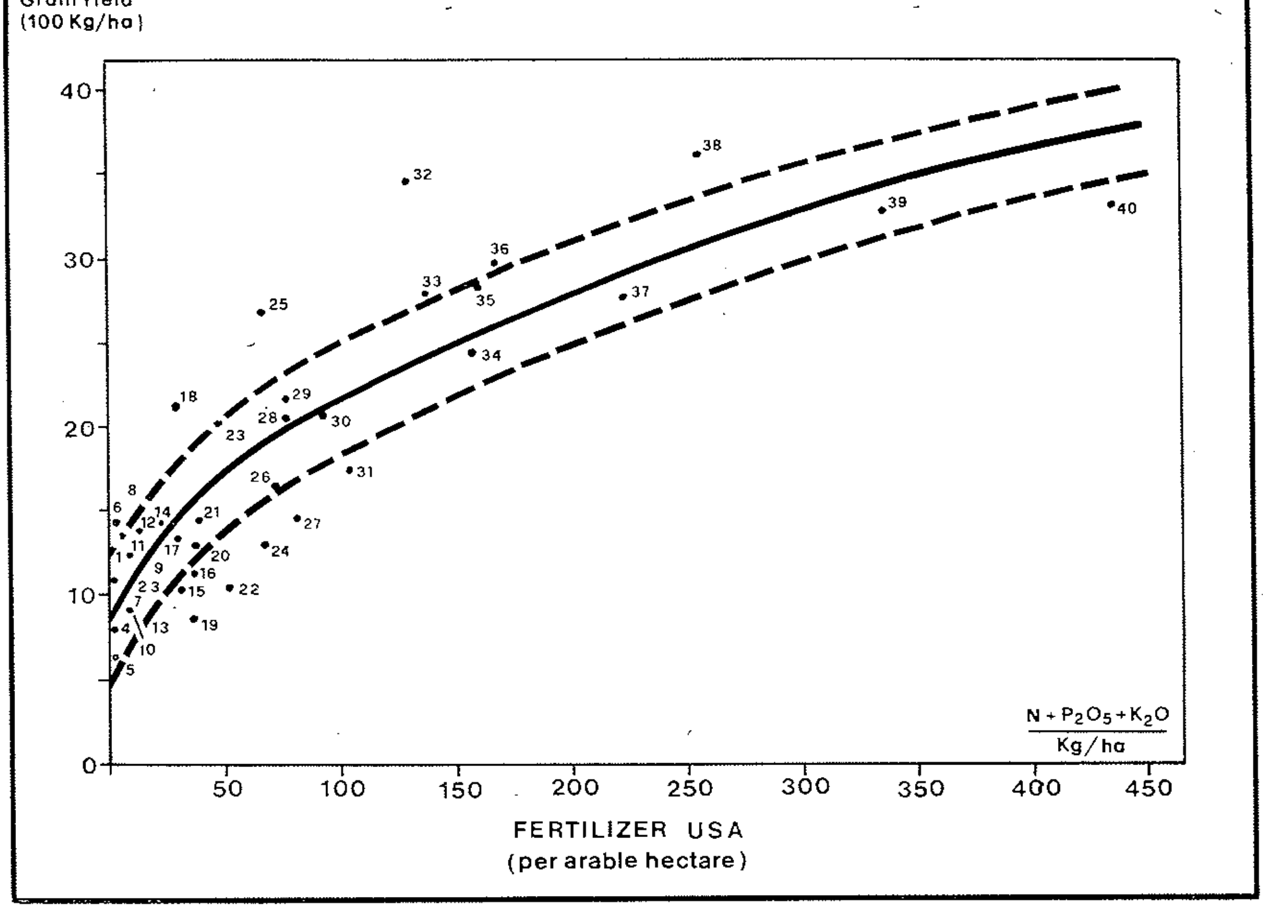


FIG. 24 — National use of fertilizers and yield of grains (per hectare, 40 countries, 1956-58).

1. Argentina
2. Pakistan
3. Turkey
4. India
5. Syria
6. Indonesia
7. Philippines
8. Canada

11. Brazil
12. Chile
13. South Africa
14. Yugoslavia
15. El Salvador
16. Spain
17. Greece
18. United States

21. Poland
22. Australia
23. Italy
24. Peru
25. United Arab Rep.
26. Finland
27. Israel
28. Sweden

31. Republic of Korea
32. Denmark
33. United Kingdom
34. Norway
35. Taiwan
36. Switzerland
37. Germany, Fed. Rep.
38. Japan

These slopes are consistent with response ratios reported in the literature. The fertilizer dosages indicated in Figure 24 are the averages of all crops in each country, which may account for some of the wide variations. As noted earlier in this paper, the kg. NPK/hectare figures for Netherlands and Belgium are fictitious and not comparable with other countries.

Figure 25 shows a correlation of grain production and fertilizer consumption in four countries over a 14-year period from 1955 to 1969. This correlation is similar to Figure 24 but the correlation is for a particular country over a period of years rather than for a number of countries in a given year. The production-fertilizer ratios of 8.4 to 12.7 shown in Figure 25 are consistent with response ratios reported in the literature.

Financial Requirements of the Developing Countries to Meet Their Fertilizer Needs During the 1970-80 Decade

Let us start with an analysis of crop production. Table I presented data on grain production in the developing countries during the period 1950-70 with projections to 1975 and 1980, which may be summarized as follows:

Projected grain production in 1980	770	million	tons
Actual grain production in 1970	597	»	»
Projected increase 1970 to 1980	173	»	»

As explained in an earlier section of this paper the projected grain productions in 1975 and 1980 were obtained by graphical projection of the data for the developed and developing countries, separately, using the Gompertz equation. These projections are, of course, subject to question and disagreement like any projections into the future.

Using an average response ratio of 10 would give a requirement of 17.3 million tons of additional fertilizer (NPK)

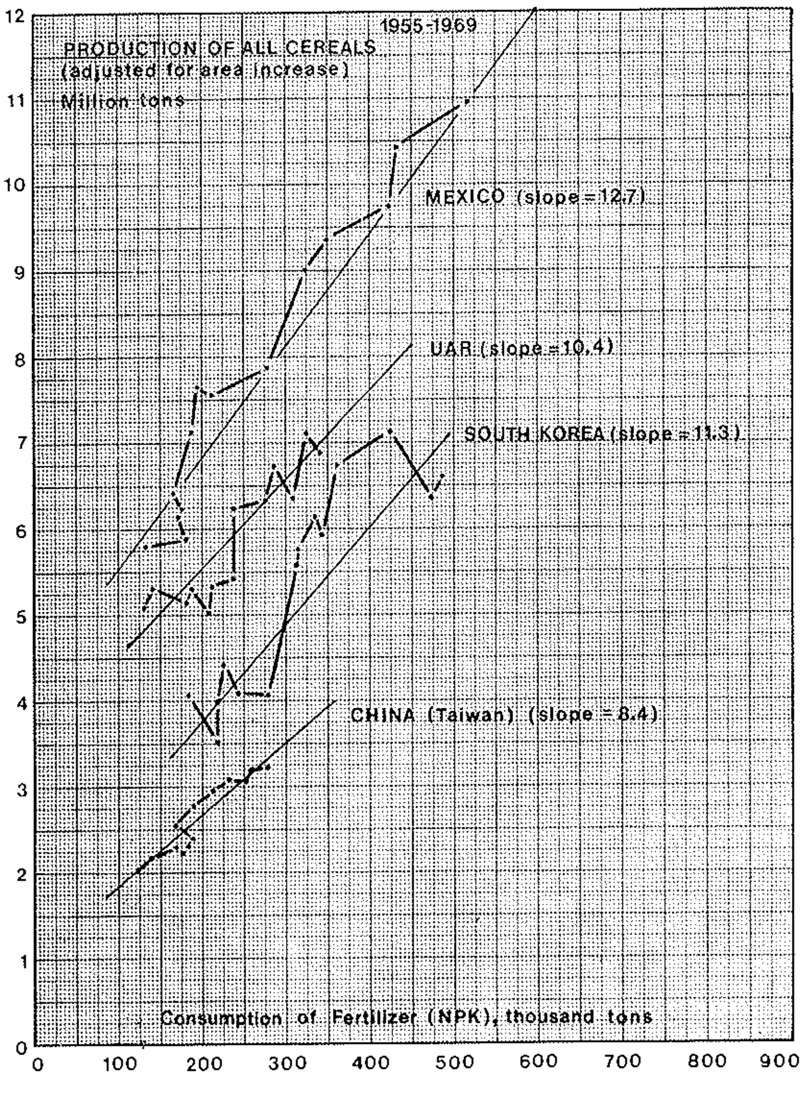


FIG. 25 — Correlation of production of cereals with consumption of fertilizers.

to increase grain production by 173 million tons. Next if we assume that 67% of the additional fertilizer used by the developing countries is used on grain and 33% on other crops, this approach gives an estimated requirement for additional fertilizer (compared with 1970) of 26 million tons NPK. However, part of the increased production of grains and other crops would be the result of increased land under cultivation, increased irrigation, wider use of improved seed varieties and greater use of pesticides. Therefore the requirement for additional fertilizer (compared with 1970) would be somewhat less than 26 million tons, possibly of the order of 20 million tons.

Tables I, IX and X give the following data for fertilizer consumption in the developing countries in 1970 and 1980:

Projected fertilizer consumption in 1980	33.3	million	tons	NPK
Actual fertilizer consumption in 1970	14.1	»	»	»
Projected increase 1970 to 1980	19.2	»	»	»

The agreement with the calculation based on increased grain production is interesting, but subject to the usual doubts of such an exercise in futurism.

Assuming that the developing countries will need, and will in fact obtain and use, an increase of 19.2 million tons of fertilizer in 1980 (compared to 1970), what will be the cost of this much fertilizer and auxiliary costs associated with distributing this much fertilizer. Table XIII presents an analysis of these costs which *total $ 28.2 billion over the 10-year period 1970 to 1980* — or it might be any other 10-year period such as 1972 to 1982. The analysis in Table XIII is based on a recent paper by E. Becker-Boost, World Bank Group, presented at the Second Interregional Fertilizer Symposium in New Delhi, India, in October 1971 (UNIDO paper ID/WG. 99/6), but with some modifications and refinements based on further research and discussion since October 1971.

TABLE XIII — *Financial Requirements of the Developing Countries to Meet Their Fertilizer Needs During the 1970-80 Decade.*

Capital costs (to increase indigenous production to the levels indicated in Table X)

Nitrogen plants	10.2 m. tons × \$400/ton =	\$ 4.1 billion
Phosphate plants	4.7 m. tons × \$300/ton =	1.4 »
Potash mines and plants	1.3 m. tons × \$200/ton =	0.3 »
Total capital investment in plants		\$ 5.8 »

Additional infrastructure needed to transport raw materials and fertilizer and to market finished fertilizers

Transportation facilities	\$ 3.0 billion
Marketing facilities	3.0 »
Total capital investment in infrastructure	\$ 6.0 »

Annual costs, cumulative for the 10-year period 1970-80

Imported fertilizers (to make up deficits)	\$ 8.0 billion (*)
Raw materials (to operate indigenous plants)	7.0 »
Spare parts, catalysts, chemicals, etc.	1.4 »
	16.4 »
Total costs during 10-year period 1970-80	\$28.2 billion

(*) Based on the following average landed costs of fertilizers:

\$150 per ton N
100 per ton P_2O_5
50 per ton K_2O

The estimations in Table XIII are summarized briefly as follows:

New fertilizer plants	$	5.8 billion
Transportation facilities		3.0 »
Marketing facilities		3.0 »
Imported fertilizer (to make up deficits)		8.0 »
Raw materials (to operate indigenous plants)		7.0 »
Spare parts, catalysts, chemicals, etc.		1.4 »
	$	28.2 billion

The capital cost of new fertilizer plants is needed to increase indigenous production from 8.0 million tons NPK in 1970/71 to 24.2 million tons NPK as projected in Table X. The calculation of these items in Table XIII is, I believe, clear.

Transportation facilities comprise (1) port unloading facilities for imported fertilizer, phosphate rock, potash, sulphur, and imported machinery for fertilizer plants, (2) railroad equipment and heavy-duty road vehicles to transport these items from the ports to the fertilizer plants and to transport finished fertilizer from the plants to various points along the distribution pipeline.

Marketing facilities comprise (1) storage warehouses of various sizes along the distribution pipeline, (2) soil testing stations, (3) agronomic research institutions, all of which are necessary parts of the marketing process.

There are no good guide-lines for estimating these infrastructure costs, and it must be admitted that the figure of $ 6 billion is only a wild guess.

The bill for imported fertilizer is estimated at $ 8 billion to make up the projected deficits of the developing countries beginning at 6.1 million tons in 1970/71 and getting larger each year to a projected level of 9.1 million tons in 1980/81. This is a cumulative figure for the entire 10-year period.

The cost of raw materials for the 10-year period comes to $ 7 billion. These are the raw materials required to operate the indigenous fertilizer plants in the developing countries which are projected to produce 24.2 million tons NPK in 1980/81. These raw materials include natural gas, petroleum products (particularly naphtha), coal, phosphate rock, potash, sulphur and also intermediates including ammonia, phosphoric acid and ammonium phosphates. The figure of $ 7 billion may be considerably too low.

The estimated overall cost of $ 28 billion will be comprised of both local currencies and foreign exchange. Many of the required items are produced in the developing countries, particularly in the more advanced countries, and these can be purchased with local currencies. But many items will have to be purchased from the developed countries with foreign exchange, by the extension of credit by the developed countries, or through barter deals.

A good guess is that about 50% of all these costs can be paid for with local currencies and about 50% with foreign exchange (or credits or barters). Following is a general picture of how these items might be procured:

New fertilizer plants

— equipment can be produced indigenously to some extent in the more advanced developing countries, such as China, India, Egypt, South Africa, Brazil, Mexico, but not all equipment even in these countries — the remainder would have to be bought from the developed countries

— buildings can be built indigenously although structural steel and other construction items would have to be imported in many cases

Transportation facilities

— same picture as equipment for fertilizer plants

Marketing facilities —

— same picture as buildings for fertilizer plants

Imported fertilizers

— all would have to be bought with foreign exchange (or through credit or barter deals)

Raw materials

— many developing countries have indigenous supplies of natural gas, petroleum products, coal, phosphate rock, potash and sulphur, but many countries do not have these raw materials and would have to buy them with foreign exchange (or through credit or barter deals)

Spare parts, catalysts, chemicals, etc.

— most of this would have to be bought with foreign exchange

Part of the fertilizer deficits of some developing countries will be met by exports from other developing countries which have surpluses, but this is included in the overall projected deficit of 9.1 million tons NPK for the developing countries as a group, including countries with deficits and those with surpluses. Table XIV lists the developing countries which are likely to have deficits, those likely to have surpluses and those likely to be in balance in 1980.

Also, there will be some sale of fertilizers from the surplus developing countries to developed countries, such as the following:

Nitrogen	from	Algeria and Libya to Europe
»	»	Kuwait, Iran, Saudi Arabia and Qatar to Japan
»	»	Trinidad and Venezuela to U.S.A.

Phosphate from Morocco, Algeria, Tunisia and Senegal to Europe

» » Israel to Europe and Japan

Potash from Israel and Congo (B) to Europe and Japan

However, to the extent that such sales take place, the overall deficit of the developing countries as a group will be even larger than the 9.1 million tons projected in Table X and this additional deficit will have to be made up by additional purchases from the developed countries.

A very large question facing the developing countries is where are they going to obtain the foreign exchange (or credit) to finance something like $ 14 billion of purchases from the developed countries during the next 10 years. Even the local currency requirements of another $ 14 billion (equivalent) may put a considerable financial strain on some developing countries.

The estimation of $ 28 billion in Table XIII is probably an understatement since it does not make any allowance for the following:

— the estimation of capital costs is based on operation of all new fertilizer plants in the developing countries at 100 percent of capacity, whereas in many developing countries existing plants operate at 50 to 75 percent of capacity

— the estimation does not include anything for development of production of natural gas, petroleum, coal, phosphate rock and sulphur in these countries

— the estimation does not include anything for additional infrastructure for transportation, marketing and storage of additional food production (this is not directly a part of the fertilizer picture, but is indirectly connected with it).

TABLE XIV — *Classification of Developing Countries re Fertilizer Supply in 1980.*

	Developing countries likely to have fertilizer deficits in 1980	Developing countries likely to be in balance in fertilizer in 1980	Developing countries likely to have fertilizer surpluses in 1980
ASIA	Cambodia Ceylon China Cyprus India Indonesia Jordan Nepal Pakistan Philippines Thailand Turkey Vietnam, North Vietnam, South	Afghanistan Burma Iraq Korea, North Korea, South Lebanon Madagascar Malaysia Syria Taiwan	Kuwait (N only) Iran (N and P) Israel (P only) Qatar (P. only) Saudi Arabia (N only)
AFRICA	Egypt Ethiopia Ghana Kenya Rhodesia Sudan Tanzania Uganda Zaire	Mauritius Zambia	Algeria (N and P) Libya (N only) Morocco (P only) Nigeria (N. only) Senegal (P. only) South Africa (N and P) Tunisia (P only)
LATIN AMERICA	Argentina Bolivia Brazil Central America (6 countries) Cuba Dominican Republic Ecuador Jamaica Mexico Paraguay Peru Uruguay	Colombia	Chile (N only) Trinidad (N only) Venezuela (N only)

Limiting Factors in Agricultural Production

At any point in time in a particular region one of the agricultural inputs will be the factor limiting agricultural production in that season in that region. In one crop season the limiting factor may be shortage of high quality seeds. In another crop season the limiting factor may be water supply. In another crop season the limiting factor may be shortage of fertilizer. In another crop season the limiting factor may be the lack of effective pesticides to combat some new disease, for example, the fungus disease which struck the United States maize crop in 1970. Or the limiting factor may be a lack of understanding or interest by farmers in using these agricultural inputs even when they are available.

Each of these agricultural inputs has been the limiting factor in one region or another in past years. For example, lack of high quality seeds has been the limiting factor in agricultural production in most of the developing countries for many decades and this is still the limiting factor in many of the developing countries.

As another example, water supply was the limiting factor in India in the great drought years of 1965 and 1966 (note Figure 6). Since 1966 India has been blessed with good to excellent monsoons for five successive years and agricultural production has increased steadily from the 1966 low point. However, India is still vulnerable to a shortage in water supply and another poor monsoon, such as 1965 or 1966, could be expected to reduce India's agricultural output by 15 to 20 percent as it did in 1965 compared to 1964. Such a reduction, if it should occur, would be from a much higher base level of agricultural output, but also India has a much larger population to feed than she had in 1965 and 1966.

Shortage of water is a perennial limiting factor in Egypt, Syria, Iran, Algeria, Morocco, Peru, Australia, southwestern U.S.A. and other countries in arid regions. Egypt has compensated for her basic water shortage by using relatively high dosages of fertilizer so that Egypt in recent years has had high yields of wheat, rice, cotton and other crops. Other arid countries, especially in North Africa and the Middle East, are moving in this same direction.

However, Egypt does not produce enough fertilizer to meet her needs and must import over half of her fertilizer requirements at great cost in foreign exchange. Moreover, Egypt could use much more fertilizer, effectively and economically, if she could afford to buy it. Egypt is still using only 9 kg. NPK/capita compared to Cuba at 57 kg./capita and China (Taiwan) at 19 kg./capita. On a per hectare basis, Egypt is using 112 kg. NPK/hectare compared to China (Taiwan) at 298 kg./hectare and Cuba at 234 kg./hectare.

Lack of effective pesticides, when they are needed, can also be the limiting factor in agricultural production, for example, in rice in the Philippines in 1970 and in maize in the United States in 1970.

However, the most widespread limiting factor in agricultural production in most of the developing countries has been, and still is, *the low usage of fertilizer*. The low usage of fertilizer is due, in many of the developing countries, to a lack of understanding or interest by farmers in using more fertilizer. In many other countries there is an actual shortage of fertilizer due to limited indigenous capacity for manufacturing fertilizers and/or to limited foreign exchange with which to buy fertilizer on the world market. There is a large surplus capacity for manufacturing fertilizers in the developed countries, but the developing countries which need it cannot afford to buy it except on very liberal credit terms. In still other countries, there is an adequate supply of fertilizer and the farmers have an interest in using more fertilizer but they are deterred by unfavourable economic conditions, such as low prices for agricultural products, high prices of fertilizer, poor marketing facilities, etc.

Conclusions

1. Under-utilization of fertilizer is likely to be the limiting factor in agricultural production in the developing countries during the 1970's and 1980's, rather than under-utilization of improved seed varieties or under-utilization of agricultural water.

2. Under-utilization of fertilizer in the developing countries is the most likely cause of the Green Revolution falling short of the expectations the world's people now have for it, if that should happen.

3. The developed and developing countries and international organizations, such as the United Nations and the World Bank, should work together to supply the quantities of fertilizer and other agricultural inputs needed by the developing countries during the 1970's and 1980's and to educate and motivate farmers in the developing countries to use optimum levels of fertilizer and other agricultural inputs.

The discussion of this paper, for matter of time, was postponed. It was included in the Joint Discussion of the papers: EWELL, ARATEN *and* BRAMÃO.

NEW FERTILIZERS, THEIR AGRICULTURAL AND ECONOMIC IMPORTANCE

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INTRODUCTION

I feel honoured to participate in the study week organized by the Pontifical Academy of Sciences, an academy that is unique because of its universal nature. At the time of its foundation, the academy already comprised Catholic, Protestant and Jewish scientists from twenty-two nations.

I also appreciate the privilege that enables me to address you on the subject of New Fertilizers, their Agricultural and Economic Importance especially as there are scientists here who are responsible for much of our knowledge in this field.

This review had to be prepared in a compactness dictated both by the abundance of subject matter and by the limitation of space. It was necessary to bring into focus at least a number of developments, and in making the choice of these, I am aware of various unavoidable omissions.

Most of the participants here have addressed you on specific topics to which they personally contributed a great part of our knowledge; my report, however, deals mainly with work done by others in various research institutes, universities, agricultural experimental stations and the like, and my own part in this vast area of research has enabled me to pinpoint the highlights of all their work, so that I hope to be able to give you an over-all picture.

Science, of course, is forward-looking but has its basis in past work. So it is interesting to take a swift look backwards and rid ourselves of any delusion that this idea of feeding the soil, so that it may feed us, is something that belongs entirely to our modern world! The Bible itself gives us one of our earliest pieces of information about conserving the properties of the soil: the Children of Israel were commanded to let the land lie fallow every seventh year. In this way, nutrients from the plants that were growing but were neither removed nor used during this Sabbatical year partly counterbalanced those nutrients lost while the land was being cultivated and made to give up its fruits.

Going farther East, somewhat later accounts tell us about the Indians who had already learnt that burying a fish under a corn hill produced better plants, and that corn grew better when a brush pile had been burned. These people did not realize that what they were doing was fertilizing the soil with nitrogen and phosphates from the fish and with potash from the wood ashes. All that mattered was that there should be enough fish and ashes for the little corn needed then by the much smaller population.

In Western Europe, up to the end of the nineteenth century, agriculture was practised mainly with animal manure without chemical fertilizers. An interesting sidelight on farming methods in the Middle Ages was given recently by Prof. DE WITT of Holland who tells us how the St. Symphorian Monastery in Antver, France, fed its fifteen monks: the hundred farmer families in the neighbourhood, with a maximum gross yield of 800 kg. grain per hectare (compare this with Holland's present harvest of 5000 kg. per ha!) gave their surplus crops to the monks. And this is how they laid out their 800 kg: on account of the inferior quality and the many weeds they contained, no less than 200 kg. per ha. had to be set aside for seeds; 150 kg was required for the beasts of burden and for the production of beer (the quality of drinking water was inferior and the meat was salty, for it had to be preserved); and the farmers were left (after supplying the monks) with just 300 kg of grain/ha for their own needs for a whole year. Today, 100 farmer families are able to produce food for more than 1000 families.

This, of course, is vast progress, and by understanding how it has come about, we shall also be able to plan for the future, because much of our world is still hungry and ill-clad, and the populations are expanding.

Why did our Medieval farmers get such low yields? The reason was not the lack of water or the unfavourable climate, but the shortage of available plant nutrients. We know that only about 25 kg of nutrients were available per hectare per annum from organic waste, and with this amount, plants cannot produce more dry matter than 1500 kg/ha. If we deduct the amount of dry matter consumed by the leaves and the stems, about half (some 750 kg) will be obtained as seeds.

Compare this quantity of 25 kg nutrients with the almost 400 kg used in our times in such countries as Japan and W. Germany! Today we know that efficient agriculture *can* supply the needful food and clothing; and since crops require nutrition if man is to benefit from them, it follows that efficient agriculture needs i.e. chemical fertilizers be efficiently produced. Thus my subject-matter resolves itself into a number of well-defined aspects:

How much fertilizer does the world use, and is likely to use in the future?

Which types of fertilizer have been used so far?

Which types are being produced today, and in what are these different from the conventional kinds used in the past?

These are the questions that I shall attempt to answer in this review.

WORLD CONSUMPTION OF FERTILIZERS.

The use of inorganic fertilizers is, of course, extremely young in the history of agriculture. The first shipment of Chilean nitrate to Europe was despatched in 1830, superphosphate production began in 1843, and potash fertilizers in 1861, while nitrogenous fertilizers were first manufactured in 1902.

A continually expanding world population means that more food is always required; this has been reflected in the growth of fertilizer consumption which increased from about 2 million tons in 1905 to 63 million tons in 1969/70. Except for the war periods, 1914-1918 and 1940-1945, production and consumption have doubled or trebled in each decade.

By 1969/70, we see that the use of nutrients has become an integral part of farming.

Figure 1 shows that farmers used in 1969/70

70	times	as	much	N	(0.4	million	tons	→ 28.5)	
17	»	»	»	P_2O_5	(1.1	»	»	→ 18.5)	and
31	»	»	»	K_2O	(2	»	»	→ 63)	

as in 1905/06.

The increase in the yields of crops per hectare was astounding, and led naturally to popularizing the use of fertilizers on the one hand, and to greater discrimination in the various types on the other.

Until the late 1950's the principal fertilizers available in commercial quantities were: sodium nitrate, ammonium sulphate, single superphosphate and kainite ($MgSO_4 \cdot KCl$ $3H_2O$) with a nutrient content within the range of 15-20%.

However, hand in hand with the increase in the fertilizer

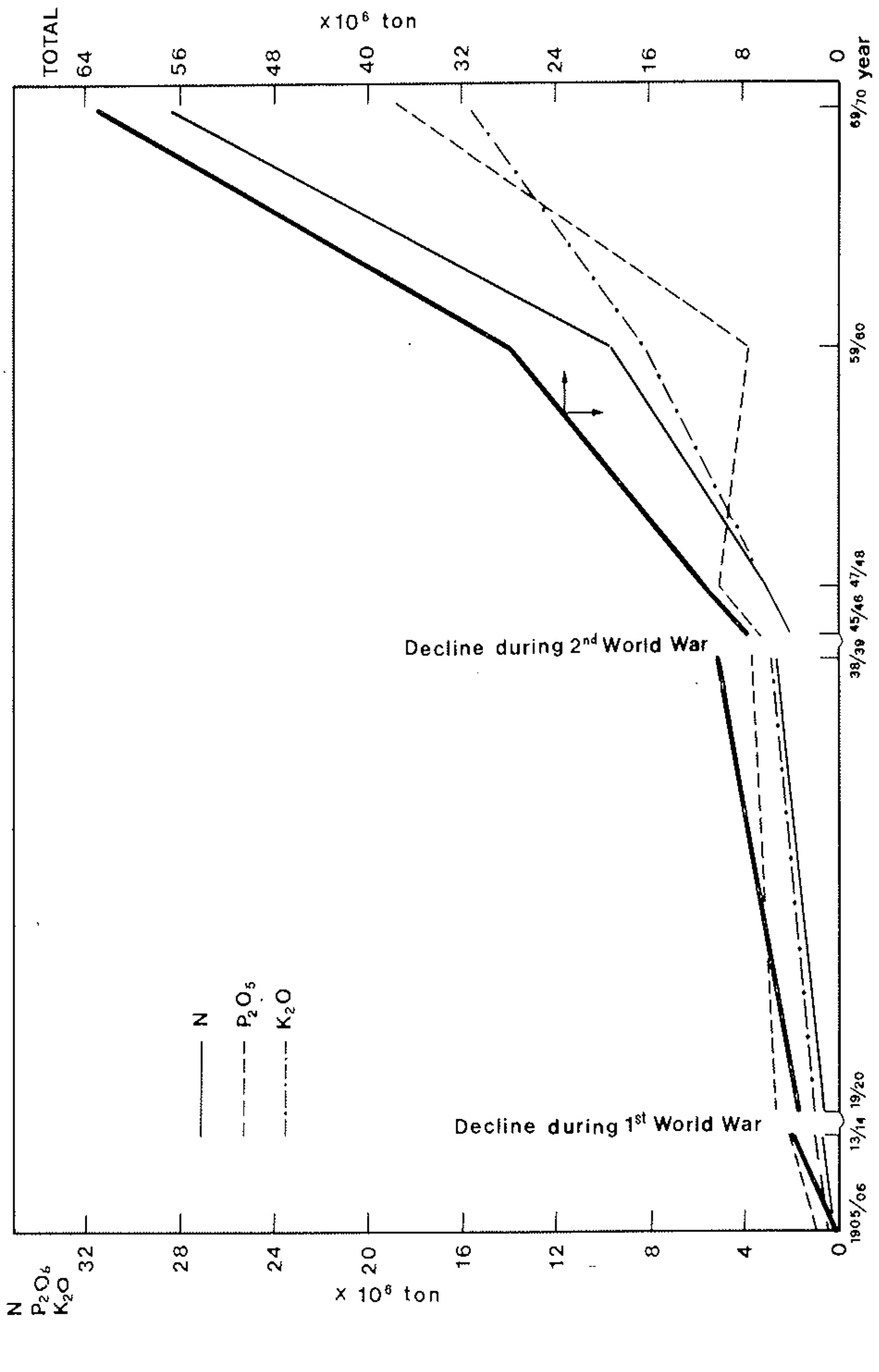

FIG. 1 — Growth of World Fertilizer Consumption 1905/06 to 1969/70 in million tons.

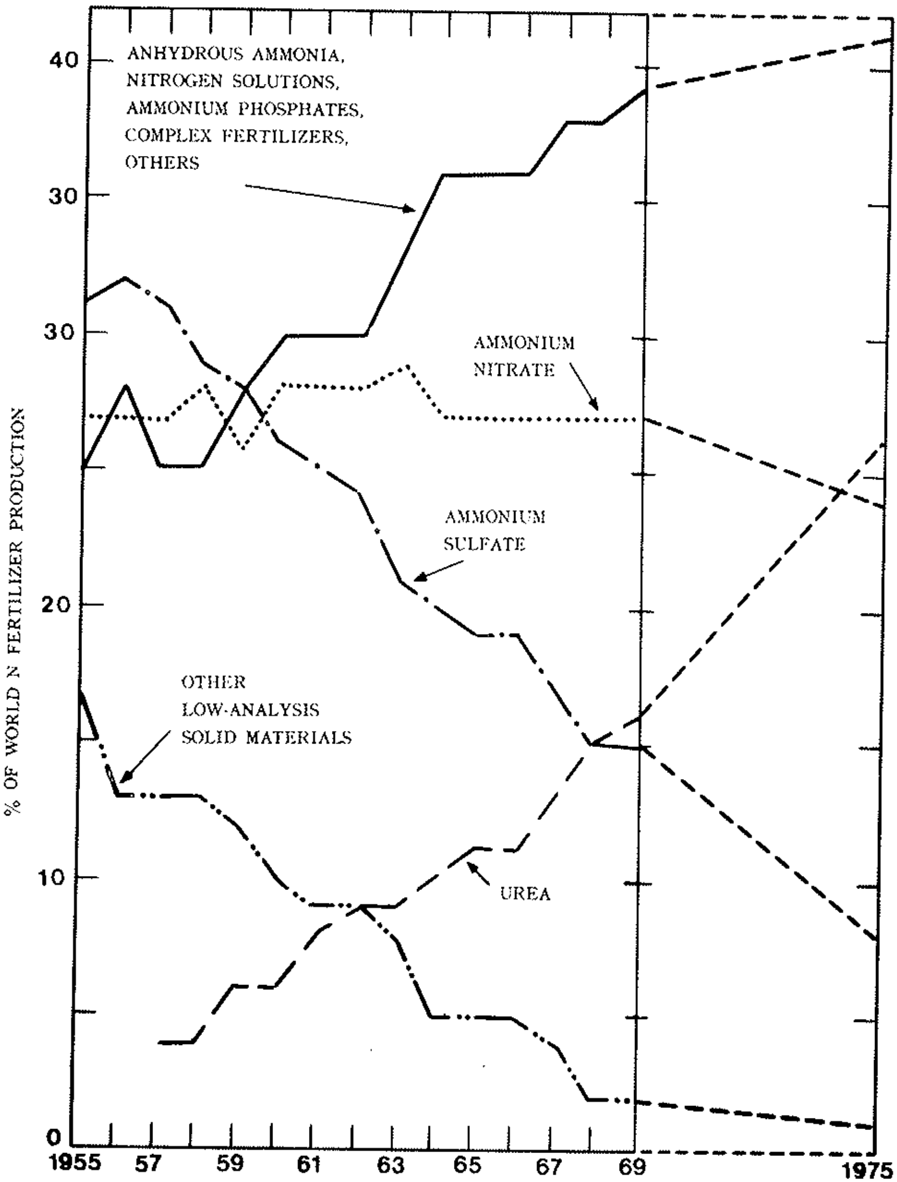

FIG. 2 — World Trends in Types of Nitrogenous Fertilizer Materials.

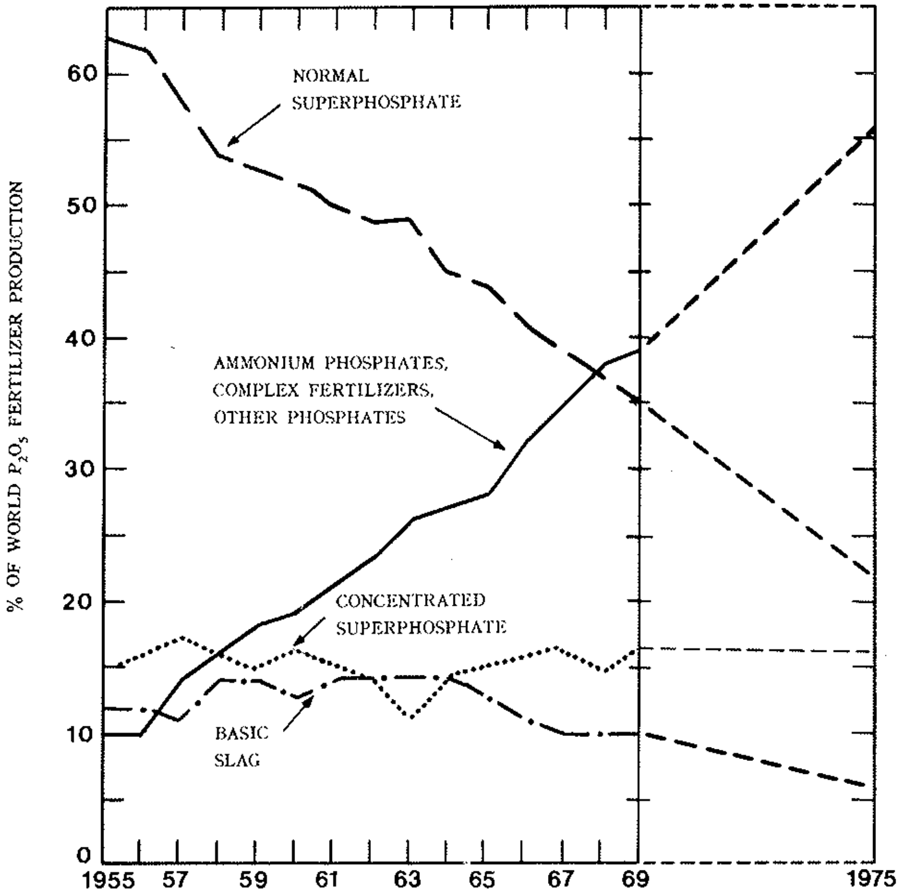

FIG. 3 — World Trends in Types of Phosphatic Fertilizer Materials.

consumption went the decline in the use of conventional fertilizer materials, while new fertilizer materials rose to popularity, as can be seen from Figures 2 and 3:

Thus, *sodium nitrate* — i.e. Chilean nitrate — which in the twenties had 33% of the nitrogen market, dropped at present to less than 1%.

Ammonium sulphate which had, a decade ago, 30% of the nitrogen market dropped to 15% in 1969, and may decline to 8% in 1975.

Normal superphosphate, formerly the most popular of the phosphatic materials, which was supplying 63% of the phosphate fertilizer market in 1955, dropped to 35% and is likely to dwindle to 22% by 1975.

Basic slag dropped from 16% in 1960 to 10% of the total in 1969.

This brings us to our main question and the actual subject of this lecture:

TYPES OF NEW FERTILIZER MATERIALS.

The basic materials are anhydrous ammonia, wet process phosphoric acid and potash.

Anhydrous ammonia, with 82% nitrogen, has become the basic building block for nitrogen fertilizers, while *wet process phosphoric* acid became the major source of phosphate fertilizers.

Little change has taken place in the processing of *potassium chloride,* which remains the principal type of potash fertilizers.

Urea, with 46% nitrogen, has the greatest popularity within nitrogenous fertilizers, as shown in Figure 2, having risen from less than 5% in 1955 to 16% in 1969. This does not include the urea content of solutions and of complex fertilizers, which may bring its use to 40% of world nitrogen fertilizer production.

Ammonium phosphates and complex fertilizers increased from 10 to 39% of the total during the same period.

What has brought about these changes? Let us examine the purport of the new fertilizer materials that are ousting the old traditional ones.

AGRICULTURAL SIGNIFICANCE.

From an agricultural point of view, the use of new fertilizer materials, with their high concentration, precludes the unnecessary addition of soluble salts and ballast to the soil that occurred with the type of fertilizers formerly used.

The amounts of nutrients applied were increased in many areas from 20 kg/ha to 300 kg/ha. Applying the low analysis soluble fertilizer with 20% nutrients means adding 1200 kg ballast and salts per hectare, whereas concentrated fertilizers with 60% nutrient leave only 200 kg non-nutrients, which often consist of water and oxygen only. Low analysis fertilizers applied in large quantities increase the salt content of the soil and may reduce crop yields.

In the case of nitrogen fertilizers there are additional reasons for the decline in the use of conventional fertilizers ammonium sulphate and ammonium chloride: both ammonium sulphate and ammonium chloride deplete reserves of bases and make soil acid. It is true that the ammonia itself, urea and ammonium nitrate also accelerate the loss of cations from soil but ammonium sulphate and ammonium chloride have the greatest effects and it is necessary to supply extra lime to all non-calcareous soils when these fertilizers are used.

Losses of soluble nutrients from surface soils caused by leaching may be reduced by some new fertilizer materials or by inhibitors.

Economic Significance.

Fertilizers cannot always be produced where they are needed. Geographical distances separate the sources of major raw material phosphate rock, potash and hydrocarbon fuels from the principal fertilizer consuming areas. Hence, marketing, shipping, storage and distribution are required. In view of the population explosion in developing parts of the world, large amounts of fertilizers have to be transported far away from the production centres. The estimated cost of marketing, shipping and distribution in various areas of the U.S.A. already amounts to 50% of the price the farmer pays for his fertilizer. In developing countries these costs reach 70 to 80% when we use low analysis fertilizers, like ammonium suphate or single superphosphate, containing 20% nutrients.

The production of high analysis fertilizers meant that the high production costs per unit of nutrient in high analysis fertilizers could be out-balanced by the cheaper freight, storage and distribution costs per unit of nutrient.

New Forms of Fertilizers.

Four different forms are being produced:

- o Multinutrients and
- o Liquid fertilizers, both on a large commercial scale
- o Suspension fertilizers and
- o Controlled release fertilizers with varying degrees of commercial success.

Multinutrients.

a) *Nitrogen and phosphorus.* — It was in the field of phosphatic fertilizers that the multinutrient was used for the first time: this combines high concentration, water soluble P_2O_5, and the presence of nitrogen and phosphorus in a single compound. There is a considerable mass of evidence relating to the interaction of nitrogenous and phosphatic fertilizers. This can lead to greater uptake of phosphorus and to higher crop yields.

This group includes diammonium phosphate (21-53-0), ammonium polyphosphate (15-62-0) mainly for the production of liquid fertilizers, and nitrophosphates up to 20-30-0 with over 80% of the P_2O_5 water soluble, however, the range of grades in nitrophosphates is limited.

b) *Potassium and phosphorus, potassium and nitrogen.* — There has been much less research and development in the potash area than in that of nitrogen and phosphate. Potassium chloride of a high concentration, up to 62% K_2O, available in large quantities, supplies about 90% of the fertilizer potash. Potassium chloride holds its key position because of its low production costs and high concentration, and its excellence as a source of potash for crops in general. However, on account of the detrimental effects of excessive chlorine for various crops, the demand for other carriers of potash is growing. Potassium sulphate is the classical non-chloride potassium fertilizer.

This group includes: monopotassium phosphate (0-52-32), monopotassium phosphate·monoammonium phosphate (6-57-18), potassium polyphosphate (0-57-37), potassium metaphosphate (0-58-33) and potassium nitrate (13-0-44).

A few words about the properties of those fertilizers:

o *Monopotassium phosphate* and its ammoniated double salt *monopotassium phosphate·monoammonium phosphate* produced on pilot plant scale are obtained as dry free-flowing non-hygroscopic powder that can be dry-mixed, granulated or compounded with such materials as ammonium nitrate, urea, ammonium phosphate and with other fertilizer materials making up the principal fertilizers used in the main crops in various countries; grades up to 20-20-20 can be obtained in this way. In greenhouse experiments their performance was proven to be as great as, or in some cases greater than, that of phosphorus and potassium in monocalcium phosphate and potassium nitrate.

Monopotassium phosphate and monopotassium phosphate· monoammonium phosphate have the following advantages:

— They combine solubility with congruent dissolution, which means that the solution phase contains the same species as the solid phase.

— They are virtually free of chloride ions, which is of special importance for crops like tobacco and potatoes.

— Phosphorus and potassium in potassium phosphates diffuse at approximately the same rate in sandy soils. This is rather important because most of the phosphorus and potassium that crops take up reaches the roots by diffusion.

Monopotassium phosphate and monopotassium phosphate· monoammonium phosphate will probably be available to agriculture, in the near future, in commercial quantities. Liquid grades, produced on pilot plant scale, contain 40% more plant food than the grades produced from potash.

o *Potassium polyphosphates* have several attractive features, including high nutrient content, absence of chloride, high solubility for liquid fertilizer, and low solubility, when made at high temperature.

There are difficulties, however, in getting the optimum combination of processing conditions and product properties. Unless further research advances are made, commercial production seems at present unlikely.

o *Potassium metaphosphate.* Many studies indicate the long run fertilizer value of potassium metaphosphate in certain areas despite its low solubility. However, so far, production on pilot plant scale in the U.K. and in Israel has not succeeded in converting it into a commercial product.

o *Potassium nitrate.* A full scale commercial production started in the U.S.A. in 1963, and in Israel in 1969. The U.S. plant has lately discontinued its production.

Mr. A. V. Slack of T.V.A., summarized the pros and cons of potassium nitrate as follows:

Advantages

— Excellent physical condition.

— Granulation aid for mixed fertilizers. High solubility of potassium nitrate, at elevated temperatures, makes possible to granulate with less water, thereby increasing the capacity of granulating units.

— Useful as additive in stabilization of ammonium nitrate.

— Absence of chloride.

— Reduced burning of plants.

Disadvantages

— Processes are expensive.

— Economics depend on adequate return from a co-product.

— Economics are further adversely affected by the fact that all the nitrogen comes from nitric acid, a relatively expensive source.

There is also an economic reason for the production of multinutrients. Mixtures of NPK were formerly made, using straight fertilizers which were manufactured by different companies, and despatched to a mixing plant for mixing and for eventual granulating.

Such mixing and granulation entail additional expense which can partly be avoided if multinutrients are manufactured in integrated plants.

Liquid Fertilizers

The main advantages of liquid fertilizers are:

o Lower production costs for the same types.

o More economical handling by use of pumps and pipes rather than the more cumbersome equipment that handles solids.

o Convenience of labour saving in application.

o They provide means for the uniform application of plant nutrients, including micronutrients.

o Herbicides and insecticides may be uniformly mixed and applied in liquid fertilizers.

o Investment cost in a fluid mixed fertilizer plant is often less than that of a plant producing dry-mixed fertilizer.

o Fluid mixed fertilizers can be produced with a minimum of air and stream pollution.

The consumption of liquid fertilizers in 1965 in the U.S.A., as you can see from Figure 4, was *5.1 million tons* including *1 million ton* liquid mixed fertilizer and rose to *9.8 million tons* in 1970 incl. *2.7 million tons* liquid mixed fertilizers, which is about 30% of the total N, P_2O_5 and K_2O.

The various classes of nitrogen solution fertilizers — aqua ammonia, urea and ammonium nitrate solution or both — obviously cost more than anhydrous ammonia. They owe their existence and popularity to lower investment for storage, handling and application equipment, and to lower application costs because of the power required for pulling injectors through the soil.

A disadvantage of clear liquid mixed fertilizers is that they cannot contain a high percentage of potash.

Suspension Fertilizers.

Suspension fertilizers, containing a suspending agent, can overcome this disadvantage of liquid mixed fertilizers, and grades available are up to 10-20-20, 15-15-15 etc.

Solutions and suspensions save labour and time required for transportation and application, and avoid segregation problems, which exist in bulk blended materials. In addition solutions and suspensions are useful as carriers of micronutrients and sources of sulphur solutions, such as ammonium thiosulphate.

Controlled or Slow Release Fertilizers.

Slow release fertilizers have the following advantages:

o One application of the material can take the place of split applications of soluble fertilizers. This applies especially to sandy soils and high rainfall or irrigation throughout the growing season.

o Minimization of losses by leaching, fixation or decomposition.

o The chance of water pollution is lessened.

So far, experiments with controlled-release phosphate and potassium materials have not been promising; however, good results have been obtained with some controlled-release nitrogen materials. Because of their cost, they have, so far only been used in gardening.

A particular example of the advantages of fertilizers which release nitrogen at a controlled and varying rate during the growth of the plant is in the growing practice of mulching with a membrane of plastics or other materials. The entire

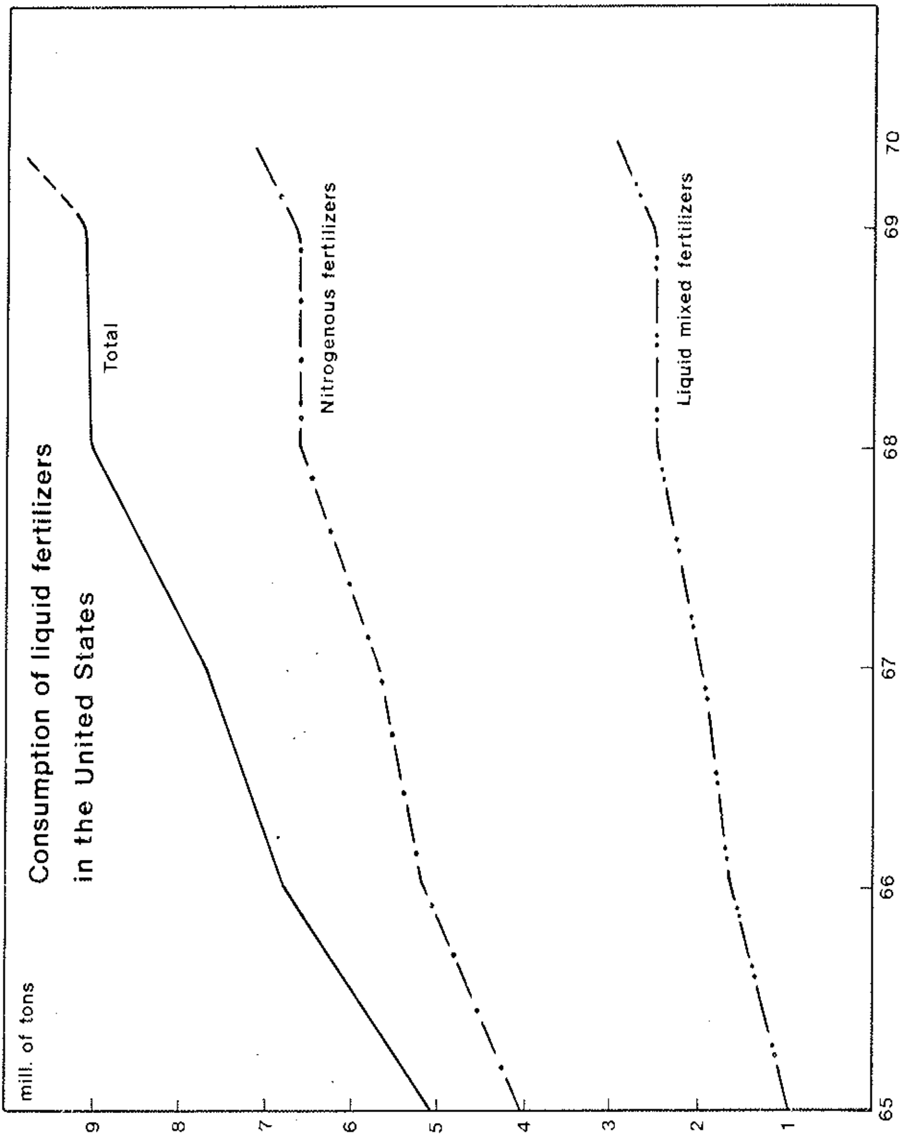
Consumption of liquid fertilizers
in the United States
mill. of tons
Total
Nitrogenous fertilizers
Liquid mixed fertilizers
9
8
7
6
5
4
3
2
1
65
66
67
68
69
70

FIG. 4

quantity of fertilizer must be applied before the membrane is placed, and since the crops that justify this expensive practice are those with high yields, such as vegetables and fruits, large amounts of fertilizers are used. Under these conditions, a reduced rate of release during the early development is of considerable value.

Thus, briefly, we see what these new types of fertilizers do, and we have to make some comparison with the traditional ones.

New Fertilizers versus Traditional Fertilizers.

The introduction of new fertilizers to replace the older types did not come about without encountering objections. One of the arguments used against concentrated fertilizers was that they were incomplete in comparison with low analysis fertilizers; they contain little or no secondary elements and very few trace elements. This argument was valid as long as the amount of nutrients applied per hectare and the respective crop yield per hectare was relatively small. The increased amounts of nutrients applied as well as the large yields of crops which removed substantial quantities of secondary and trace elements from the soil made it imperative to determine the amounts of secondary and trace elements required for a certain crop in a certain area.

Controlled amounts, which can often be incorporated in fertilizers, can be added. For intensive agriculture this is more efficient, and the object of avoiding deficiencies is better secured than in the case of uncontrolled quantities of these elements in the traditional fertilizers.

Another reason in favour of concentrated fertilizers versus low analysis was given recently by Dr. Raistrick of the U.K., who finds that as fertilizer dressings increase, so also does the quantity of any toxic material present in the fertilizer. Some of the heavy metals are particularly toxic, especially when potentiated by known means, for example by chelate materials both natural and chemical. A case in point is cadmium, which has done so much damage to human health in Japan. Even though the quantities of these heavy metals in raw materials, for example, phosphate rock, are relatively small, the tonnage of rock used in fertilizers is now so great that hundreds of tons of toxic elements are processed every year.

High analysis fertilizers contain less heavy metals; however, if they contain chelating agents (polyphosphates) they must be watched.

Phosphate rock containing minimal quantities of toxic metals will probably occupy a more favourable position in the market with the coming years.

Merchant Phosphoric Acid.

Let us now take a look at the world trends in new phosphatic fertilizers:

The trend in the phosphate industry is to remove calcium from phosphatic fertilizers in order to increase their nutrient content, reduce ballast and raise the water solubility of phosphates. This trend has reached its peak: ammonium phosphate, ammonium polyphosphate and potassium phosphate contain no calcium at all.

In order to produce them, large amounts of phosphoric acid are required. Until a few years ago, phosphoric acid was a captive commodity, and limited amounts were produced. However, in 1969, phosphoric acid already accounted for 45% of total phosphate rock consumption. World production in 1963, was 6.3 million tons P_2O_5, and total world production in 1970 reached 11 million tons P_2O_5 in the form of wet phosphoric acid and 2.4 million tons in the form of furnace acid. Fertilizer firms started to buy phosphoric acid for use in high analysis fertilizers in addition to what they themselves produced, and large wet phosphoric acid plants came on stream, the output of which is designed for sale as merchant acid.

The trade in phosphoric acid has increased for the following reasons: About 3.5 tons of phosphate rock and nearly 1 ton of sulphur are required to make 1 ton of P_2O_5 as phosphoric acid. Thus, the weight of the raw materials is about 4.5 tons per ton P_2O_5, whereas the weight of the acid is 1.85 tons for acid of 54% concentration, or 1.4 tons for acid of 72% concentration. So one advantage of shipment of acid rather than raw materials is the reduction in weight of material transported. Another advantage is the economy of production of the acid in large-scale plants located at the phosphate mine or at the source of sulphuric acid.

Upgrading of wet phosphoric acid.

In addition to the increased use of wet phosphoric acid for concentrated phosphate-based chemicals in the fertilizer industry, various firms have developed upgrading technologies for crude wet process phosphoric acid to meet the increasing demand for upgraded, concentrated, phosphate-based chemicals.

The upgraded acid is expected partly to replace thermal acid in the manufacture of industrial products such as: liquid fertilizers, high concentration phosphate fertilizers, animal feed phosphates, detergent and other industrial phosphates.

So far, the IMI Cleaning Process is the only one which has been implemented on a commercial scale by Fertilizantes Fosfatados Mexicanos (FFM) producing several hundreds of tons P_2O_5 per day as liquid fertilizer grade acid, and detergent grade acid. The Clean Acid can easily be concentrated to 69% P_2O_5 or even further without scale formation or aerosol losses. Total Cleaning recovery of wet phosphoric acid can reach 95% P_2O_5.

A simple version of the Cleaning Process splits 60% of the feed P_2O_5 into the Clean Acid product, the balance being available as a residual acid stream, containing about 40% P_2O_5, and the bulk of the impurities in the raw phosphoric acid. This version of the process is attractive if an outlet for the residual stream is available.

On account of the decreasing price of sulphur — the raw material required for the production of wet phosphoric acid, and the increasing price of electricity consumed in large quantities by furnace acid — the trend of upgrading the wet process phosphoric acid is increasing.

Details about magnesium and sulphur fertilizers are given in the report.

Outlook.

Future of new fertilizers.

High analysis fertilizers will undoubtedly be an increasingly important factor in the world's agricultural economy. Very few additions are likely to be made to the list of elements known to be required for the growth of plants; substitutions among these elements are impossible, since each of them performs specific functions. Thus, the essence of fertilizers is not subject to change, but their form, concentration and combination may change.

Future research and development.

Basic agronomic studies in plant nutrition together with technological research will eventually cause the nutrients to be supplied in their most efficient and economic forms; more specifically:

o New processes will be developed and new kinds of combinations will reach the market.

o The average nutrient content of fertilizer materials will rise.

o Physical conditions will be improved.

o Fertilizers for specific crops and for specific soils will be developed.

o More attention will be paid to the influence of fertilizers and their accompanying ions on the quality of crops.

Production and marketing.

o In the next 15 years there will be 1.5 billion more people in the world to feed. The increase in the use of fertilizers will be staggering.

o The increased consumption of fertilizers means that giant plants for the production of intermediates become feasible. These intermediates will be produced at locations where raw material costs are low and low-cost transportation methods can be used.

In order to save transportation costs, those intermediates — ammonia, urea, elemental phosphorus, phosphoric acid, potassium phosphates, polyphosphates — will be high analysis fertilizer materials which will minimize transportation, storage, and handling costs.

o These intermediates will be shipped to smaller plants, which will serve local markets, for the production of the final product. Plants in local areas can satisfy specific needs of local farmers regarding grades, addition of secondary elements and micronutrients.

o Consumption of liquid fertilizers will increase and again concentrated base solutions will be shipped to small plants for the production of various grades.

Many farmers prefer liquids due to absence of caking, dustiness, hygroscopicity and inhomogeneity.

If the shortage of agricultural labour in W. Europe increases — liquid fertilizers will be used on a much larger scale because less labour is required for application.

* * *

I have been able to give but a small aspect of this important subject; may I thank you for the privilege.

DISCUSSION

Chairman: E. W. Russell

Russell

I would like to take comments only on points of detail of Dr. Araten's paper, and leave general points of principle until after the coffee break when we will be having a general discussion on fertilizer requirements, future types of fertilizers and so on. So points of detail please, not of general principle.

Rotini

Io desidero precisare che alcuni dissensi che si verificano tra di noi dipendono dal fatto che ognuno di noi vede le cose nelle particolari condizioni di ambiente in cui noi operiamo. Io desidero confermare la mia perplessità nei riguardi dei concimi complessi, per due ragioni: la prima ragione è di carattere economico; la seconda ragione è di carattere tecnico. In Italia la vendita dei concimi chimici è regolata dalla commissione centrale dei prezzi. E' il consiglio dei ministri che stabilisce i prezzi dei concimi chimici. A questa disciplina sono legati tutti i concimi semplici, mentre non sono legati i concimi complessi. La ragione per cui in Italia ci sono diversi complessi è perché con i complessi il commercio riesce a realizzare un prezzo superiore a quello dei concimi semplici. L'agricoltore che concima le proprie colture con i concimi complessi spende molto di più di quel che si spende concimando con i concimi semplici. Io non desidero annoiarvi con le cifre, ma vi posso dire che la concimazione di un ettaro di frumento con i concimi complessi costa dalle 20.000 alle 25.000 lire in più della stessa concimazione fatta con i concimi semplici. Per questa ragione alcuni di noi non sono molto d'accordo con la estensione dei concimi complessi. Accanto a questa ragione di carattere economico, c'è un'altra ragione di carattere tecnico. Si comprende come i concimi complessi possano avere una grande diffusione in paesi come gli Stati Uniti di America dove in interi stati come la Florida, il Wisconsin, ricorrono terreni molto omogenei. Quando il terreno di un vasto territorio è omogeneo e quando vi si pratica la monocoltura è estremamente facile stabilire alcune formule di concimazione idonee per quel terreno e per quella coltura. Ma in Italia, la composizione del terreno cambia ogni 50 metri, dato che la geologia del territorio è molto complessa, e credo che la Francia e la Germania si trovano su per giù nelle stesse condizioni. In Italia poi non viene praticata la monocoltura perché ogni agricoltore nel suo piccolo podere vuol coltivare un po' di tutto; io penso perciò che non si possa dare l'avvio ai concimi complessi. Quindi, non è che esista un contrasto tra la vostra opinione e la mia. Noi abbiamo delle opinioni diverse perché ognuno di noi opera in condizioni economiche e tecniche profondamente diverse.

I wish to explain that certain dissensions happening between us depend upon the fact that every one of us looks at the things under the particular environmental conditions in which we work. I wish to confirm my perplexity in regard to complex fertilizers for two reasons: the first one being of economical character, the second of technical character. In Italy the sale of chemical fertilizers is regulated by the central price commission. The chemical fertilizer prices are fixed by the Council of the Ministers. All simple fertilizers are bound to this discipline, whereas complex fertilizers are not bound. The reason for the existence of different complex fertilizers is because in trade it is possible to realize a higher price for complex fertilizers than for simple fertilizers. The farmer who uses complex fertilizers for his cultures spends much more than what is spent when using simple fertilizers. I do not want to annoy you with figures, but I may say that the manuring of a hectare of wheat with complex fertilizers costs from 20.000 to 25.000 lire more than the same manuring with simple fertilizers. For this reason some of us are not much in agreement with the extension of the complex fertilizers.

Besides this reason of economical character, there is another one of technical character. It is understandable that complex fertilizers may have a large diffusion in countries like the United States of America, where entire states like Florida, Wisconsin dispose of many homogeneous pieces of land.

When the land of a vast territory is homogeneous and when the monoculture is practised there, it is extremely easy to establish certain formulas of manuring suitable for such land and for such culture. In Italy, however, the composition of the ground changes every 50 meters since the geology of our country is very complex, and I believe that France and Germany find themselves more or less in the same conditions. In Italy the monoculture is not practised, because each farmer likes to cultivate a little of everything on his small farm, therefore I think that it is not possible to start with complex fertilizers. So it is not that there exists a contrast between your and my opinion. We have different opinions because each one of us works under profoundly different economical and technical conditions.

ARATEN

I would like only to make a few general remarks to what Prof. ROTINI said. Of course a group of fertilizers is not a thing you can introduce in all areas in all soils and in all countries. However, regarding Prof. ROTINI's objections to new fertilizers and liquid fertilizers for Italy, I would be ready to prepare a table for Prof. ROTINI about fertilizers in Italy - 1960 and at present. I visited Italy in 1960 and the late Prof. MORANI, who was then the head of the research station in Rome, told me that it is impossible to change the structure of Italian agriculture and that there were in 1960, 46 percent of the working population engaged in agriculture. I don't know what today's figure is but I am ready to find out and I am ready to give you a table comparing the situation of 1960 with '72. You will see what was considered then impossible was reached — Italy made great progress in agriculture during those 12 years and I do hope that the next great progress will be in producing, on a large scale, the concentrated intermediates and combining those small farmers to cooperatives, like we have in Israel.

HERNANDO

I should like to take part in this discussion. Five years ago we had in Spain the same problem Prof. ROTINI presented, but now the situation is completely different. We find that farmers and technicians are in complete agreement, that the prices and applications of high complex fertilizers are cheaper than the normal fertilizer. The reason is that we must not think of the price of 100 kgs of material but of the price of the nutrients. In this connection we must consider three factors: price per unit, transportation costs and labour application. In areas where very low amounts of fertilizers are applied, it may be cheaper to use normal fertilizer. By increasing the application of fertilizer, also in the central areas of Spain where the total application is on the level of developed countries, the cost on the whole is lower, because we do not think in the price of the product only, but in the three aspects just mentioned. The joint effect of these three aspects is to get a cheaper price. I suppose that in future years this difference will be greater, i.e. every time we can get fertilizers closer to the pure chemical substances. I believe that this will be the best effort to help the developing countries. As Prof. EWELL yesterday told us, the developing countries need to receive quite large amounts of fertilizer substances from the developed countries. And if they have the possibility to receive these pure chemicals and prepare the fertilizer they need themselves, they will considerably reduce the need of funds to import these products.

ROTINI

Vorrei cogliere l'occasione per commentare brevemente alla replica del Professore ARATEN, ed a quello che ha detto il professor HERNANDO. Per quanto riguarda le osservazioni fatte dal collega ARATEN, che ha citato il Prof. MORANI, vorrei sottolineare che in qualsiasi paese per un tecnico talvolta è estremamente difficile esprimere liberamente il proprio pensiero. Le organizzazioni industriali e commerciali, dalle quali dipendono molte cose, sono molto potenti e non tutti hanno il coraggio di dire quello che va detto. Io mi onore appartenere a quel gruppo di chimici agrari che desiderano dire quello che pensano. Non mi meraviglio che altri possano comportarsi in modo diametralmente opposto. Per quanto riguarda le osservazioni del collega VALENTINO HERNANDO, io vorrei sottolineare che, dal punto di vista tecnico costituisce a mio avviso un grave errore dare insieme acido nitrico, potassio e anidride fosforica, perché un complesso di questo tipo contiene tre elementi fertilizzanti di differente coerenza pedologica e fisiologica. Se un tale concime complesso viene dato alla semina, cioè all'impianto della coltura, l'acido nitrico durante l'inverno si perde perché viene dilavato dalle acque. Se il complesso viene dato in primavera in apertura, viene utilizzato l'acido nitrico, ma la potassa e l'anidride fosforica, che vengono fortemente assorbite dai costituenti colloidali del terreno, non entrano in giuoco nel processo di nutrizione della pianta, rimanendo in superficie. E positivo che ci sono delle ragioni di carattere tecnico che non consigliano di preparare sempre il piatto unico delle colture, cioè di mescolare la minestra, il primo piatto e la frutta. C'è poi un'altra ragione di notevole validità, e cioè che il fosforo, il potassio e l'azoto, vengono utilizzate in diversi momenti nel ciclo di sviluppo della pianta. Il fosforo deve essere disponibile sin dall'inizio, perché la pianta utilizza direttamente le forme del fosforo presenti nei fertilizzanti, ma gli esteri fosforici ed i composti organici del fosforo, si formano durante il primo periodo dello sviluppo e costituiscono il vero patrimonio fosfatico della pianta. Per tale ragione il fosforo va dato all'inizio della coltura. Mentre l'azoto viene soprattutto richiesto quando la pianta esplode e cioè durante la stagione primaverile. A mio avviso, anche per tale ragione ritengo che non sia conveniente consigliare agli agricoltori il piatto unico delle colture.

I would like to comment briefly on Professor ARATEN's answer and to what Professor HERNANDO said. As concerns the observations made by the colleague ARATEN who cited Professor MORANI, I may point out that in any country it is very difficult for a technicien to express freely his own opinion. The industrial and commercial organizations, on whom depend many things, are very powerful and not all have the courage to say what ought to be said. I am proud of belonging to those group of agrarian chemists who want to say what they think. I am not surprised that others may behave in a diametrically opposed way. Regarding the observations of the colleague VALENTINO HERNANDO, I would emphasize that from the technical point of view I consider it a serious error to give at the same time nitric acid, potassium and phosphoric anhydride, because a complex of this type contains three fertilizing elements of different pedological and physiological coherence. If such a complex fertilizer is given to the sowing, that is to the implantation of the culture, the nitric acid gets lost during the winter because it will be washed away by the water. If the complex fertilizer will be given at the beginning of spring, the nitric acid will be used, but potash and phosphoric anhydride, which will be strongly absorbed by the colloidal constituents of the soil, will not join the nutritional process of the plant and remain on the surface. As a matter of fact there are reasons of technical character which do not advise to prepare always the unique dish for the cultures, i.e. to mix the soup with the main dish and the fruit.

There is still another reason of remarkable validity, and that is that phosphorus, potassium and nitrogen will be utilized at different times in the developing cycle of the plant. Phosphorus must be available as from the beginning, because the plant utilizes directly the forms of the phosphorus present in the fertilizers, but the phosphoric esters and the organic compounds of phosphorus form themselves during the first developing period and constitute the real phosphatic patrimony of the plant. For this reason phosphorus ought to be given at the beginning of the culture. On the other hand the nitrogen is mainly requested when the plant explodes that is during the spring season. According to me also for this reason I think that it is not convenient to advise the farmers to serve the unique dish to the plants.

THE PLACE OF SOIL FERTILITY AND LAND RESOURCES IN THE FUTURE OF AGRICULTURAL PRODUCTION

LUIS BRAMÃO
Former chief of the FAO's World Soil Resources Office and coordinator of the FAO/UNESCO Soil Map of the World Project and now Senior Research Professor, The Agricultural Research Center
Oeiras - Portugal

The various aspects of soil fertility, fertilizer uses and crop production have been referred to here already in great detail and with the greatest competence. I now wish to refer here to some aspects of land resources, development problems concerned with soil fertility and crop production and give an idea, although very general and modest, of the present position of the matter and future trends. My international experience, during the last twenty years, was mainly in the field of soil science, particularly soil classification and geography related to climate, topography and agricultural production. I witnessed, cooperated and sometimes participated in studies carried out to promote agricultural development at the national and international levels, not only in developed countries but often, because of my duties, in the developing ones. The earliest of these studies of a global nature was The Plan for Agricultural Development of Portugal launched in 1949 and which aimed at coordinating technically and economically the activities related to the promotion of agricultural production.

Later I had the opportunity of participating in the FAO Indicative World Plan for Agricultural Development (IWP) as chairman of the Inter Division Production and Resources Unit and also as the coordinator of the FAO/UNESCO Soil Map of the World Project. During this period I became deeply interested in the so-called phenomenon of population explosion in relation to the food production potentialities of the different regions of the world.

Future trends

After the Second World War the economic, social, political and cultural conditions of the world have changed much and this change has been much more rapid than was foreseen. The new technological advances are deeply influencing agricultural production and above all the philosophy of the farmer himself. His concepts are changing fast and his requests to have a share in modern life are becoming very pressing. However, at the present time traditional agriculture is still predominating in the world as a whole, sometimes contrasting sharply with highly sophisticated enterprises, where the farmer is already artificially controlling the climate, temperature, moisture and even light to provide ideal conditions for his particular product. He may use totally artificial conditions in which plant nutrients are supplied to his plants with much the same accuracy and scientific rigor that a diet may be administered to a patient, or better to an athlete, in a specialized institution.

In the developed countries *marketing* largely controls agricultural production. Technical skill plus capital investment, including equipment, other inputs, and infrastructures are now responsible for the success of the enterprise. The pre-war agriculture is being replaced quickly in the most advanced countries by this enterprise agriculture, and the developing countries are trying to follow the example pretty closely. The labour force of the production sector, whether in industry or agriculture, is shrinking. The trend is for it to be reduced to a small percentage of the total population of the country and there will be less and less place for unspecialized labour which will tend to disappear with increased level of education. We are witnessing a large-scale migration of the rural population into the towns. The new agricultural production methods are therefore designed to employ a small number of highly specialized hands and to absorb considerable capital investments. This seems to be the dominant trend in modern agriculture. I would even dare to say that it is an irreversible trend and agricultural production must adapt itself to the new conditions.

According to the FAO State of Food and Agriculture for 1970, during the last fifteen years the population working in agriculture has decreased considerably, Belgium being the country in Europe, that employs the least people in agriculture (about 6% of its population). The shrinking of the agricultural population is not due only to the increased production per capita (1) but to the general phenomenon of exodus from the land into urban areas which occurs more or less everywhere. Many of the agricultural labourers prefer to go and try their opportunities in the urban centres, and this seems to be an irreversible process, and modern agriculture can no longer afford to employ so much labour anyway. Curiously enough, there is also the reverse process of the urban people moving to the country, not as agriculturists, but to establish their residence, from which they travel every day to work, or for retirement outside the confusion of the big cities. This return to the land seems to be a phenomenon which represents an important trend for the future. Perhaps with social and economic consequences too.

(1) In the United States however, in the production of wheat, productivity per capita has increased considerably whilst per unit area it is still low.

The land resources of the world.

The inventory of the land resources which I am referring to here was based on information coming from the FAO/UNESCO Soil Map of the World Project, analyses of Land Forms and on crop-climate relationships in addition to information coming from experimental fields and farmers the world over.

Let me consider first, although very briefly, the FAO/UNESCO Soil Map of the World Project which provided the main bulk of information for the land resources inventories. Other world soil maps have been published previously, however, only this one was thoroughly the result of an international effort and the integration of all available knowledge on soil classification and geography prepared by the participating countries — approximately 70 (2) — in cooperation with the project centre.

The project accumulated an enormous amount of information in the project centre in Rome. The project centre and its *advisory panel* established a uniform criteria for the map legend and the definitions of the mapping units. This was the result of many meetings and field excursions with the participation of the advisory panel, the members of the Soil Correlation Committees and other consulting soil scientists until the legend and the definitions of the mapping units reached the publication stage in 1968. Several international soil expeditions were made in different countries and across continents to warrant uniformity of concepts, of methodology and of boundry definitions. It is important to explain here that the criteria adopted for the separation of the soil units and their identification included a *strong agricultural element,* relating soils with land use. In this way the units of the legend reflect relationships between soil conditions and the agricultural capabilities of the land.

(2) All the countries that had soil scientists.

The studies on Land Form were prepared by classifying land according to a few classes of topography, related to the suitability of the area for mechanized agriculture, and the crop-climate regions on the basis of Papadakis climatic studies.

Potential Land Area Estimated to be Suitable for Crop Production (3)

Region	Area Mill. Ha	As % of Total Land Area
Africa South of Sahara	304	19
Asia and the Far East	252	47
Latin America	570	29
North West Africa	19	6
Total or average	1145	26

The combination of soil characteristics, relief classes and crop climate information resulted in the Inventory of Land

(3) IWP, Vol. I, 1970.
(The experience of advanced countries shows that the place of soils in development planning remains important indeed, but not as important as in pre-war subsistence agriculture. I wish to mention an example here. On the kind invitation of Prof. HERNANDO I visited an interesting experimental strawberry farm near Malaga in Spain (La Mayora). It is a pilot farm and farmers in southern Spain and Portugal are following with great success the methods developed. Here some strawberries are produced in fields conquered from the hilly country by bulldozers which levelled the hill tops to create a favourable topography. The surface of the land has no soil, so to speak, and remains covered with rock fragments and rock debris which are used as strawberry beds with the addition of peat and the necessary plant nutrients).

Resources and in the appraisal of their suitability for agriculture, forestry and animal production.

Arable land in 1962 (4)

Region	Area Mill. Ha	As % of Total Potential Land Area
Africa South of Sahara	172	50
Asia and the Far East	211	84
Latin America	130	23
North West Africa	19	100
Total or average	512	45

The accuracy of this inventory varies considerably according to the accuracy of the basic information. However, this was the first attempt to actually measure land resources from field information rather than from statistics.

The studies of land resources showed that the amount of land available for agriculture was considerably higher than that being used, at least in certain regions such as Latin America and Africa South of Sahara. The studies also showed that often the best soils are not being used. They may be located far from the population centres and general advancement and population pressure have not yet stimulated the farmers to search for them. Of course, in these regions population pressure and economic conditions are too low for the farmers to

(4) IWP, Vol. 1, 1970.

expand their arable land. This situation occurs more often than is generally recognized. I agree with Prof. BAADE, when he writes in his very interesting paper that there is no reason to fear that world population will soon become too big to be adequately fed by world agriculture, provided that agriculture is developed to what is now considered its fullest possibilities.

The analysis of the two tables gives an idea of the relative population pressure in the different regions concerned. Europe, North America and Australia were not included in these tables because their position is better known and we had in mind to stress the situation as it is at present in the developing world.

The same source shows that the average utilization of the land in the developing countries is only 11% for arable land and permanent crops, 21% for permanent pastures and 28% for forestry. There remain 40% of the area which is not used for any agricultural or forestry purposes. This high percentage accounts for the deserts, inland lakes and very high mountains. These average values are percentages of the total land surface. The situation differs between regions, the highest percentage of arable land being 39% for Asia and the Far East and the lowest 6% for the Near East and North West Africa.

Since the fallow usually takes several years, *the harvest land* is only a percentage of the arable land. The ratio between the two is the cropping intensity. The fallow has been used to store up water for the following crop and also to increase the natural soil fertility. In the irrigated areas as well as in technological agriculture the fallow can be reduced or eliminated altogether and crop intensity increased up to 100%.

Technical advances in food production.

Crop intensity is usually very low throughout the developing regions and efforts should be directed towards increasing crop intensity and productivity per unit area and per worker. How then can food production be increased, Essentially it can be done by:

a) expanding the arable area;

b) increasing crop yields;

c) reducing the fallow, or;

d) increasing the number of crops grown on each field per year.

a) It is usually difficult and expensive to *expand the arable land*. Modern land settlement requires expensive infrastructures, including medical services, to make life attractive and safe to the new settler. In the future, even if the resources of the soil, water and climate are favourable to a prosperous agricultural enterprise, occupation of new lands may not automatically follow. A pioneering spirit of a few settlers will not be sufficient. It is my strong belief that only carefully planned multi-disciplinary settlement projects will guarantee a successful undertaking.

b) *An increase of the yield of crops per unit can be achieved,* and has in fact been achieved in a spectacular manner, by applying the knowledge gained by scientists in such fields as genetics, soil science, physiology, plant pathology, entomology and fertilizers, which in combined action can bring about the full genetic potential of new varieties. In this connection I would like to mention the work carried out by the ROCKEFELLER and FORD Foundation and FAO. I had the opportunity of following closely the development of some of the outstanding results achieved by these Organizations and which helped to widen considerably the horizons and perspectives of agriculture in the developing countries. I had the good fortune of being closely acquainted, for the last 30 years, with some of the scientists engaged in this very successful work. In this connection I would like to mention the name of Dr. J. HARRAR of the Rockefeller Foundation, who initiated at the request of the Mexican Government the Mexican Program for the production of wheat and maize in 1943. This became an enormous success crowned by the awarding of the Nobel Prize for Peace to Dr. NORMAN BORLAUGH for the creation of the so-called "miracle wheat". The Rockefeller Foundation in association with the Ford Foundation launched the International Rice Research Institute in the Philippines to improve the production of rice in the so-called "Rice Bowl". Dr. CHANDLER was given the leadership of the Institute, which after only six years of work produced the famous IR 8 rice. This new variety is already enormously increasing the supply of this staple food in Asia and consequently the economy of the farmers.

The great quality of the IR 8 is to have a short, stiff straw, resistant to lodging, capable of absorbing large quantities of fertilizers. It increased local production from the average 1-2 tons per hectare to 4-10 tons per hectare. These high yields were obtained, disturbing as little as possible the general traditional system of rice production in the Far East with only the necessary innovations in agricultural practices, such as pest control and adequate fertilizer dressings.

The IR 8 is not the final answer. The breeding process is continuing in order to improve the variety's resistance to disease and also to make it more palatable to the very exigent taste of the local consumer.

Beginning in the late forties and early fifties Dr. W. FITTS and other American scientists were working to help the farmers in North Carolina and Iowa to obtain the most efficient results from their fertilizer inputs, particularly in relation to the production of hybrid corn. Dr. FITTS during this long period has developed and improved (as you heard from his lecture) suitable tests that are not only much faster but often more accurate than conventional analytical methods.

Meanwhile FAO started its famous Fertilizer Program. This was the first international field soil fertility program with experiments in many developing countries; yon had an excellent account of the program by Dr. HAUSER. In this connection I would like to mention the names of the pioneers Drs. H. L. RICHARDSON, F. W. PARKER and G. VERMAT. Dr. G. HAUSER is also a pioneer in this Program.

Finally, I would like to mention in the international field the experiments carried out by Dr. FRIED, whose lecture will show us clearly the potentialities of his work and its consequences for the economy of production.

Since the times of LAWS and GILBERT, LIEBIG and MITSCHERLICH a long way has been covered. Fertilizers are indispensable plant foods but expensive materials. Their volume of application will continue to increase fast in the years to come. They must therefore be applied accurately with regard to quality, quantity, location and timing for maximum usefulness. From the contributions presented to this Study Week it is clear that there are already many answers, which when put into practice would significantly improve the output and economy of agricultural production.

c) *Reducing the fallow*. According to the IWP, there are the grass fallows and bush fallows in the tropical forest zones and the bare fallows in the low rainfall areas. Although fallows had a place in traditional agriculture to help build up soil moisture and soil fertility for the next crop, they represent an important waste of land area. They are, however, difficult to eliminate. In the tropical humid areas they usually occur in the soils with the lowest fertility and as we will see further on, such soils are difficult to recover.

In the arid zones the bare fallow is the result of low rainfall and the intensification of agriculture in such lands is also very difficult because of water as a limiting factor. Australia seems to be the country which has achieved the greater success in the intensification of production of such arid grass lands. This was accomplished in part through tbe Australian strains of the "subclover" — Trifolium subterraneum, the ancestors of which came from plants collected in southern Europe.

d) Increasing the number of crops grown on each field per year. Dr Richard Bradfield in his important work for the IRRI in the Phillipines has shown opportunities for increasing food production in tropical regions by intensive, multiple cropping. He calls attention to the fact that solar energy is much higher in the tropics than in temperate regions. Because of this higher temperature and the absence of a cold winter, crop production can take place all year round. The cumulative temperature throughout the year is also much higher in the tropics, 3 to 5 times that of the temperate regions. This cumulative temperature is a useful measure of solar energy. It helps to predict the amount of dry matter that could be produced per unit area, if the farmer could keep his fields covered with crops all year round and supply them with the necessary inputs. Theoretically, he could produce 3 to 5 times more than his counterpart in the temperate regions. Dr. Bradfield reports growing 4 to 5 crops on the same piece of land per year, thus amply confirming the possibility of taking full advantage of the whole year as a growing season.

Farmers in the Mediterranean climate of southern Europe, where solar energy is also plentiful, have since time immemorial used three to four crops per unit area and per year with reasonable success. However, in the humid tropics, as for instance in certain parts of the Amazons, the cloud cast is too thick and permanent all year round that there is evidence that solar energy may become a limiting factor for increasing crop yields.

* * *

The agriculture of the future for the developing countries will be modelled after the technological agriculture already established in some advanced countries.

Its production must:

a) satisfy the market requirements for quality, size and shape of the products,

b) be in large enough quantities to be marketable on a commercial basis (so that distribution is feasible and clients can count upon a steady supply). Therefore, it must be produced out of reasonably large land units with modern techniques and needed inputs.

c) employ the minimal possible labour, highly specialized,

d) utilize specialized equipment to replace labour, abundant in traditional agriculture.

This will give opportunities to the highly organized entrepreneurs with sufficient capital to face the inevitably high overhead costs and expensive production techniques. On a business-like basis such an entrepreneur will select a field, in the right climatic area for the crop, of the required size for the volume of production and with suitable topography. He must invest heavily in inputs of which fertilizers, one of the chief expenditures, must be used to their maximum efficiency.

Traditional agriculture eventually will have great difficulties in surviving because of production costs, since labour will become the most expensive input. However, the replacement of one type of agriculture by another will be slow, but not as slow as people thought ten years ago. In fact there are at present plenty of symptoms of agricultural crises and traditional (artisanat) agriculture is already dying in many countries.

Together with this field-crop production there is the highly sophisticated production of vegetables, fruits and flowers in totally artificial conditions in hot-houses, in a kind of hydroponic culture. In this type of production capital investments may reach the magnitude of the industrial level. But returns are correspondent and often these enterprises are very rentable. *Hot-house* production is extending rapidly in Europe, not only in the North but also in the southern countries. The latter wish to compete on the northern markets with earlier and earlier products, which fetch the best prices, particularly fruits and vegetables. The production and marketing of flowers is even better organized. Some producers just root the cuttings of certain plants and retain them in cold storage until the right moment comes for export. How much the agriculture of the future is going to develop along this particular line, is difficult to foresee. However, I presume that since the system has proved its economic viability, it is bound to continue and take a more important place in the general agricultural production pattern.

Soil Conditions and Soil Productivity.

Although, in modern farming, equipment and other inputs may overcome certain soil limitation, soil conditions, however, may bring serious problems to agricultural production. I would like to mention just a couple of examples regarding soils of the humid tropics and the arid zones.

There is no need to refer to the well-known problem of phosphorus fixation by the soil in the humid tropics, so much discussed during the past twenty years. What I would like to mention is the lack of bases in certain soils of the forests and savannahs of the large flat table lands of South America. These soils are called, in the nomenclature used in the FAO/UNESCO Soil Map of the World Project, Acric Ferralsols (cerrado phase). They are extremely deficient in nutrients and particularly low in calcium in the subsoil. Although high in clay, they also lack active silicate clay minerals. They are very ancient, inherited from another geological era and the product of climatic conditions which have since long disappeared. Their vegetation is living on a very limited mineral cycle. Once destroyed, usually by burning, the minerals are lost. To build up the fertility of the Acric Ferralsols (cerrado phase) and make them suitable for food production may prove very difficult and expensive. Some progress has been made with balanced nutrient treatment; good response to zinc. Their economical utilization is still a question mark because of the difficulty of incorporating the necessary minerals in the soils to ensure normal plant growth. In addition, limestone quarries are scarce over large areas in the tropics and certainly in South America, which means transport over large distances of these materials. This is just to mention one problem of soil fertility and productivity in the humid tropics and the savannah countries.

In the arid zones the soil problems are different. Rainfall and its characteristically bad distribution have created throughout time adverse soil conditions through water-lagging and salinity. There is often too much water over a short period of the year with the consequent problems of soil hydromorphism, bad drainage, erosion and salinity. During the rest of the year there is not enough moisture in the soil for rentable, rain-fed crops. The alluvial plains are often subject to flooding. Strictly speaking, the amount of Fluvisols (alluvial soils) in these plains is small. They exist in association with Gleysols and Halosols. If not properly protected against the floods, there will be no possibility of introducing the modern high-yielding varieties and all the inputs, including the expensive fertilizers, that must go with them. When protected and developed through irrigation and drainage, conditions for maximum productivity are created since solar energy is at its maximum. It is interesting to note that the alluvial valleys in the humid tropics, and I would like to bring as an example the Amazon valley, do not contain but small portions of Distric Fluvisols. Most soils are Gleysols of different kinds with a narrow suitability for agricultural production. And again, they must be defended from flooding. This applies to most river valleys in the wet tropics, which contain the Plinthic

Gleysols, Histic Gleysols and often, in the mouth of the rivers, the Thionic Gleysols.

The soil limitations of the alluvial valleys, both in the humid tropics and the arid zones, are of considerable importance and often escape the attention of the planners in Europe and North America, because of the different association of soils in their own river valleys.

Conclusions

Soil fertility and fertilizer use are indispensable components of modern agricultural production. Without proper application of fertilizers no high yields can be expected. Even the very best strains and highest yielding varieties developed recently, when placed in conditions of traditional farming will give low yields. However, currently much money is wasted in the application of wrong fertilizers in the wrong place and at the wrong time. Studies concerning response to fertilizers by crops, such as those referred to here during this Study Week, are obviously of utmost importance in understanding crop-soil-climate-fertilizer relationship and eventually in guiding the farmers to obtain maximum economic results.

I think it is important to stress in these conclusions that very little scientific application of fertilizers in terms of area percentage occurs in the present-day world. With the exception of some European countries and North America only a few progressive farmers throughout the rest of the world utilize fertilizers efficiently (see the situation in Central and South America regarding fertilizer use as stated by Dr. BORNEMISZA in his lecture here). In the large majority of the countries of the world infrastructures are missing, marketing information is not currently available and losses before and after harvest are not controlled. I believe that modern technological agriculture occurs only in a very small percentage of the world and that therefore world production could be increased manyfold. For instance, the Amazon region, which is ten times the size of France, has a population of slightly above one million most of it concentrated in two towns, BELEM and MANAUS. There are, so to speak, no farmers in this enormous region that alone could produce more rice than all the rice needed at present by the world.

Much is already known about crops, their environments and what could be done to obtain high yields of basic foods from the world's land. It is my believe that if agricultural production and food distribution were given higher priority by world leaders, food could be made plentiful and hunger and malnutrition conquered. It is up to the leaders of humanity to rechannel resources and energy and initiate what could be called a "Food Production Race"! by improving research, experimentation and demonstration wherever needed, infrastructures, education and extension, credit and marketing to assist farmers in producing and selling their products, on national and international markets in a nutshell to make agriculture and food production attractive enough to compete with other activities.

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JOINT DISCUSSION

of papers EWELL, ARATEN and BRAMAO

Chairman: E. W. RUSSELL

RUSSELL

I suggest that the following problems could be discussed at this session. First of all, whether slow acting nitrogen fertilizers have a place in the agriculture of developed countries where high levels of nitrogen fertilizer are used, leading to the possibility of causing high levels of nitrates in the drainage waters. This is a point of great interest to the environmentalists. Another point of interest to environmentalists is the conservation of natural resources. Should more attention be paid to developing new methods of making phosphate fertilizers that do not need sulphuric acid; for in general the calcium sulphate produced is an unwanted waste product. Another point I would like to hear comments on is the possibility of polyphosphate fertilizer mobilizing trace elements toxic to human or animal health, so increasing their content in the crops. I think we should also distinguish in our discussions between problems of fertilizer technology and fertilizer formulation in developed and developing countries and in different agricultural systems. Thus has liquid fertilizer any real place under systems of farming involving small fields. Further whether developing countries should be encouraged to import ammonia and phosphoric acid and to use them to produce the fertilizer formulations locally needed. With these introductory remarks, I now open the subject for discussion.

HERNANDO

I would ask Prof. ARATEN something about his paper. Have you some special knowledge on the use of NPK components which release nutrients very slowly and are recommended for citrus trees' growing areas, especially when we start planting?

The other point is in relation to Prof. ROTINI's paper. Prof. ROTINI spoke about the problems of using NPK in high concentration. We have had the same problems in Spain about five years ago, but now it has been resolved because it is important, to use highly concentrated fertilizer, but not necessarily NPK. It could be PK only which is mostly used for wheat or barley growing areas where nitrates and ammonia must be applied after sowing. Sometimes, however, it is necessary to apply, for example, N and P. In such case we use treble-super phosphate and ammonia. I do not think that this is harmful to the plant's growth, because their fertilizers lend themselves for any possible use. The important matter is the high concentration level.

SAALBACH

I am of the the same opinion as Dr. ARATEN in relation to the main trends in the development and use of new fertilizers. The speed of the development and the extent of the use of the new products will be different in each country.

PRIMAVESI

First I will congratulate Prof. BRAMAO on his excellent paper and will take the occasion to thank him for all he has done for Brazil. He has realized a very great work for the development of the agricultural situation in Brazil.

Your work, Professor ARATEN, is without doubt an excellent explanation of the theme you have chosen.

May I ask you to kindly explain me one thing. I did not quite understand, referring to paragraph 8 « Outlook »: If addition or lack of silicon increased the yields of sugar cane in Hawaii and of rice in Japan?

ARATEN

Mr. T. P. HIGNETT of T.V.A. cited an example of silicon, which, in the form of assimilable silicones, dramatically increased yields of sugar cane in Hawai or of rice in Japan, when the supply of silicon from the soil was inadequate.

WALSH

Having heard the contributions in this session I feel it desirable to draw attention to an important matter which seems to have been overlooked. It is very nice to have highly concentrated formulations and have fertilizer technology well developed but when it comes to farmer use, efficiency will be considerably determined by the way the nutrients are distributed in the soil. Uneven distribution will result in uneven yields, uneven crops and a consequential effect on the economics of fertilizer use. This was clearly shown at the FAO/EEC meeting in Geneva in December 1970. Indeed much of the matter covered at that meeting is very relevant to this meeting here. Perhaps Mr. HAUSER from FAO could make available to this group the conclusions of that meeting because I do not think we should sit down here at a meeting and duplicate or repeat the conclusions of that meeting. What we are talking about now, has been thoroughly worked over at Geneva. It was concluded there that there should be far more attention paid to the mechanism of fertilizer distribution at farm level, because there could be major losses in efficiency. At that meeting I gave the results of work from our own country and the United Kingdom which showed clearly the substantial losses in efficiency due to uneven distribution. Many of the machines that are available not only in my country but in your countries for distributing fertilizers may not be efficient. I trust that this point will not be overlooked in the conclusions of this study week.

HAUSER

I am sorry, maybe I have heard about that meeting but I was not there and I think the Economic Department of FAO was involved there. I cannot give you any details about that meeting because I do not have them, but if you would like it I can find out of course. It could have been a meeting of the Economic Commission of Europe.

FITTS

I would agree with Dr. WALSH on this, this is a real problem and one we are interested in as we begin to approach these second and third generation problems beyond the primary elements. A lot of comments have been made here on sources of fertilizer. We know that fertilizer technology in the last two decades has made tremendous progress, and I am sure that in the next decade there will be even more progress. I believe that the soil scientists and agronomists need to keep up with these changes to see what is happening. We have mentioned here about the exploding population, and what the population is going to be in the year 2000. We must remember that as population increases that many other things increase too. We will have more cars or some other form of transportation, and more other sources of pollution. This is something I think we have got to look at. This question of more people means more pollution. The environmentalists are now having a « field day », they are trying to have conditions like they were 50 years ago, but it is very difficult to go back to where we were 50 years ago in environment if population continues to increase at a rapid rate. I think we have to look at this from the viewpoint of increase of population. This means we are going to change the environment, and if we are going to change environment how is the best way to do it which would be most satisfactory to everyone and still have a higher standard of living. I think this is a question as we begin to use increased quantities of fertilizer. The old philosophy of a little is good, much more is better, will not hold. We are going to have to have much closer fit of fertilizers to plant needs to avoid contamination of our streams, pollution and other conditions. I think that we have the responsibility relative to, how do we distribute fertilizer uniformerly, how do we get the greatest efficiency from it, not only from the product itself but from its distribution. In respect to this problem we are looking more and more at slurries or suspension fertilizer, and not much mention of that has been made here. The slurry fertilizers are becoming more popular in our part of the United States anyway, and it does offer us a cheaper source of materials to put in a slurry, for more uniform distribution. It also makes it possible for us to use cheaper sources of micro-nutrients to put in the slurry. Some of these micro-nutrients are rather expensive but we can get them cheaper with slurry forms.

BRAMAO

I would just like to support Dr. WALSH's remarks. I think it is very important to have the conclusions of the Geneva meeting before ours are drawn so that there is some coordination, and I am absolutely sure that the paper on this meeting must be at FAO, either in the Agricultural Department's technical section or in the Economic Department. If we could have a copy it would be important to see the conclusions before ours are finalized.

RUSSELL

This problem of the non-uniform application of fertilizer over the land due to the inefficiency of fertilizer distributors has always been with us, and in spite of much work by manufacturers they are still relatively inefficient.

HERNANDO

I would like to comment on the paper of Prof. BRAMAO in relation to the problem of lime in some areas of Brazil, I think it will be interesting to use natural rock phosphate that is available in the areas around Sao Paulo. It is not necessary to import, and at the same time there is transportation from one part to another and the distribution price is used for both calcium and phosphate. I don't know if you would like to answer on that.

BRAMAO

I think it is a very good suggestion. Rock phosphate is also abundant in the north-east of Brazil in the state of Pernambuco. Another suggestion that has been made sometime in the past, was to ground basic igneos rocks and use that material for liming and providing other minerals to the soil.

HERNANDO

Now I would like to make some comment on the paper of Dr. EWELL. I have many questions for you but I try to make some comments first and later to ask my questions. The comment is in relation to figure 4. You present there the yield per hectare of many countries producing rice in the world. I am surprised you don't have news about Spain, because Spain is the country which does not have a large area but the highest yield in the whole world. We have an average of more than 7,000 kg per hectare and in some areas near Valencia we arrive, with normal varieties, to 9,000 kg. The next point is related to a comment you made on page 62, but this is in relation to a table. I don't remember now the table, but I will try to explain the point. The point is that you don't take into account that the family work is a farming cost. I was surprised that you separated the family work from the work of people employed and paid. I think the family work also is a cost that you must include.

EWELL

With respect to the yields of rice, I only included the major producers. Spain, Italy and Australia have the three highest yields of rice in the world, but they are all very small producers in terms of total production, and therefore all three of these countries are not included in this list. I should have indicated that, I think I used a minimum of 2 million tons a year of rice production. While the yields in Australia, Italy and Spain are extremely high, the total production is quite low. On the second point, including or not including the cost of family labour in farming, it is the usual mode of thinking in the developing countries that they do not consider the family labour as a cost. In the developed countries this would be true because there is a shortage of labour. In most of the developed countries if a member of a farm family works on the farm, he is not able to work in a factory or some other paying position, but in the developing countries there is almost always a surplus of labour so countries like India and Indonesia, the Philippines and Thailand, family labour on the farm is just considered as part of everyday living. They live and they work on the farm, but if they have to hire somebody from the neighbourhood to work they have to pay them as an out-of-pocket cost. I mentioned yesterday that the cost analysis of the wheat farm in India I actually obtained from a farmer in northern India. This is the custom in India that they do not consider the labour of the family as part of the operating cost of the farm.

RUSSELL

I would like to make an additional comment here. There are parts of Africa where there is a great surplus of labour on the land during most of the year, yet there can be short periods, such as planting time and weeding as critical periods in the growth of the crop when there is a shortage of labour. There is a strong case for developing simple labour-saving equipment for these bottleneck periods.

HERNANDO

I think you are right in this moment, I think as you do. Maybe this income will be important to keep in mind when you think in the future of the developing countries. This is an important fact to take into account.

EWELL

It is just a question of surplus or shortage of labour and at least in a country like India, which I know the best, there will be a surplus of labour for the next 1,000 years.

ARATEN

Professor EWELL, in your figure mentioned of 26 or 28 million dollars required for the provision of fertilizers needed in underdeveloped countries, there is included a figure of 5.8 million dollars for new fertilizer plants. I would like to know if you took into consideration that fertilizer plants in underdeveloped countries are working at an average rate of 50% capacity. It is therefore of importance to spend funds on education of engineers and technicians able to run the plants efficiently at full capacity.

There is a problem in India which I would like to mention; the Ford Foundation Team several years ago sent a team and made a review of the agricultural situation in India. One of the members. a Californian professor came to a village lying in a zone where the government of India distributed fertilizers free of charge, and when the professor enquired about what were the results of using fertilizers, the farmer did not know what a fertilizer was. They thought they were stones sent by the government and they wouldn't touch them. When I told this story to an Indian extension officer who was visiting Israel, and I said it was a pity that they don't have more extension officers to tell the farmer what a fertilizer is, he said to me; « you are wrong, I am of a higher class, I would never speak to a farmer ». May be this is not the rule but education in this respect is also of great importance.

EWELL

It is true that most of the fertilizer factories in the developing countries operate at low efficiencies. The average for all the fertilizer factories in all the developing countries is probably in the range of 60-70 percent operation. This is a very important problem and countries such as India are working on this problem. They all have hopes of bringing these efficiencies up to 80 or 90 percent within the next 5-6 years. In fact the World Bank has recently established a new special program of loans to developing countries for the specific purpose of improving the efficiency of fertilizer plants, what is called in the trade « de-bottlenecking », i.e. removing the neck from the bottle. The World Bank is prepared to make loans to any developing country which can offer a plan for adding new equipment or improving maintenance or training personnel which will increase or up-grade the efficiency of their plant. I think they have earmarked something like 100 million dollars a year for the next five years for this purpose. The second point you made, Dr. ARATEN, was the reaction of extension officers in India. Now I question wether this is a universal reaction. I have met hundreds of extension officers in India and I never heard this reaction before. There might be a few very self-conscious high-caste Brahmins who would have this reaction, but most of the extension officers in India are very hard-working, down-to-earth people who do their best to help the farmer.

OBERLÄNDER

I should like to comment on one of Prof. EWELL's graphs, concerning the prediction of a linear increase of fertilizer consumption in the highly industrialized countries for the next decades. I assume this prediction was based on the assumption of a constant size of the cultivated area. However we know that at least in the highly industrialized countries of north western Europe, this cultivated area is continuously reduced, and if this trend of reduction does not continue spontaneously, it will be enforced; so if we assume that the cultivated area will be reduced, and we still want to predict a linear increase of fertilizer consumption for some decades, we must necessarily come to such extremely high rates of application per unit of area that I do not think they would be physiologically tolerable. Would you, please, comment on this point.

EWELL

The future consumption of fertilizer in the developed countries is a very controversial issue. As a matter of fact the projections which we made in UNIDO in Vienna during the past year are about the highest that there are. The other principal group which has done this type of projecting is TVA in the United States. The Tennessee Valley Authority, and their projections are substantially lower for the developed countries than the UNIDO projections. There is a controversy going on about this now. Personally, I like the projections that we made in Vienna, but the TVA thinks they are too high and we think theirs are too low. As regards the ultimate possibility of fertilizer consumption from the standpoint of plant physiology, I would not know about that, but there must be some level at which plants just can't absorb any more. Just like human beings can only eat so much. But I prefer to accept the projections that we made at UNIDO for the time being.

BUSSLER

Dr. OBERLÄNDER and Dr. EWELL mentioned the physiological discrimination. I am sure it is to be feared the more salt we give the most dangerous is a single salt solution. It is not more so with two different salts and it even diminishes if you give all the nutrients. How much salts are to be given depends on the examination of soils, or of plants by sap or leaf analysis. We cannot give the amounts statistically calculated for a continent or a single place. We must have analysis for each place. We add these high amounts of nutrients because we want high yields. We should have real knowledge about what is to be given on each place.

BLANCHET

Justement, je pense que ces questions nous ramènent un peu au problème de la carte des sols dont le docteur BRAMAO a présenté une excellente réalisation tout à l'heure, malgré les difficultés qui ont été rencontrées pour son établissement à cause des bases de classification différentes au départ. Je pense que cette carte des sols doit être maintenant un point de départ de nouvelles études plus agronomiques qui concernent à la fois les possibilités de dévelopment et de production des plantes dans ces différents types de sols, dans leur contexte climatique, de manière à pouvoir mieux définir les potentialités de production, et les conditions de cette production, qu'il s'agisse de structure physique des sols, de régime de l'eau et de systèmes de cultures possibles, de manière à bien voir quelle est, dans tous ces différents types de sols et leur contexte climatique, l'efficacité des éléments fertilisants. Aussi je crois que quand dans des points bien précis, bien caractéristique, indiqués par les cartes, ces études ont pu être faites, la carte devient alors le moyen de généralisation de ces données agronomiques, alors que cette généralisation serait très difficilement possible quand on ne dispose pas de ces cartes nécessaires.

Exactly, I think that these questions lead us somewhat to the problem of the soil map of which Dr. Bramao has presented an excellent realisation just now, in spite of the difficulties met with in its establishing on account of the different classification bases at the beginning. In my opinion this soil map should now serve as starting point of new more agrarian studies which concern at the same time the possibilities of plant development and plant production in these different soil types, in their climatic context, so that the production potentiality may better be defined, and the conditions of this production, i.e. whether it is a question of the physical structure of the soils, of the water flow and of the system of possible cultures, so as to be able to see in all these different soil types and their climatic context the efficacity of the fertilizing elements. I also believe that when under precise and well characterized points, indicated by these maps, these studies can have been made, the map becomes the means of generalization of these agrarian data when this generalization would hardly be possible if these necessary maps were not available.

Bramao

I would like to inform you Dr. Blanchet, that your points were really the points that persuaded FAO to undertake the preparation of The Soil Map of the World. Therefore I appreciated very much your comments.

Oberländer

I am afraid I used the word « physiological », I did not want to confuse anybody who is not a physiologist. Maybe I should have said « reaching the plateau of the Mitscherlich curve » where any further fertilizer increment just does not make any sense. If you predict linear increase of fertilizer consumption on reduced areas of application you would try to do something that would be useless, I mean you'd be applying rates which would not have any more effect on cropping.

PESEK

I have watched the fluid fertilizer development over the past 15 years or a little bit more in the central United States. I admit readily that anhydrous ammonia is by far the least expensive source of nitrogen, at least delivered to a farm, and I do not choose to discuss this one. However, I still fail to see the economy of either nitrogen solutions, or complete fertilizer solutions, as compared to handling the dry materials in the equivalent amounts involved. I wonder if either Prof. ARATEN or Prof. ROTINI would explain how conditions which exist elsewhere might make these fertilizers less expensive — contrary to my experience.

RUSSELL

I'd just like to make a remark. If contractors in England could supply liquid fertilizer cheaper than solid fertilizer, the formers would use liquid fertilizer.

FITTS

I would say Dr. PESEK, that North Carolina is a little different than Iowa. Nitrogen solutions, liquid fertilizers and slurries are more popular than anhydrous ammonia. There is little anhydrous ammonia used for our soils. Almost all of nitrogen is applied in liquid fertilizers. They find it more economical both from the work distribution stand-point and from ease of application.

PESEK

I think that this answers my question. He said popular and I asked if there is any similarity between popularity and economics, and he went on to say that people « feel » it is more economical. Our evidence indicates they really are not, but people do use them, even though it is not as economical to use them. We are certain that the people who use these in planting corn-belt soils, use them at a significant loss for added convenience, and whatever prestige they secure by using them.

EWELL

I am not very familiar with Iowa, but Dr. PESEK I am absolutely amazed to hear you say this, because the consumption of liquid fertilizers of all types, including liquid ammonia, nitrogen solutions and NPK solutions, has been going up constantly in the United States for 20 years now and there must be an economic reason for it. At least I am told by various fertilizer distribution experts that it is a matter of lower cost. Now I believe it's true that the principal consumption of liquid ammonia and possibly other liquid fertilizers is in the Far West, in California, in Arizona and in the South, throughout the cotton-growing area. On the other hand there are these two ammonia pipelines running right up to Iowa from Texas and the ammonia which comes out at the end of those pipelines is certainly being used for something.

PESEK

I excempted a discussion of ammonia from my question. I agree on ammonia, but not on complete solutions or nitrogen solutions.

HERNANDO

On page 68 of your paper at the end of the page you talk about the lack of effective pesticides when they are needed. This can also be a limiting factor in agricultural production. I would like to make a comment on that. I think in many occasions it is really due to the lack of pesticides, but some climatic condition affect the absorption of the nutrient element by the plant thus producing the spreading of the disease. Several times during tbe meeting I have pointed out that it is very important to know if there is a shortage of mineral elements in the plant before applying pesticides, and in this connection I would like to present a clear example. In the province of Guadalajara to the north of Madrid the rainfall is rather variable every year. Sometimes we have a rainfall in the winter of 400 mm and sometimes of 10 mm only. With such very low rainfall the plants look like this. There is deficiency in phosphate but the soil test does not show shortage of phosphate and we get there a fungus disease. In normal years we found a normal phosphate level in the plant and no disease. The only problem or difficulty of absorption of the phosphate by the plant in this case is water deficiency. Therefore, I suggested to study the soil directly independently of environmental conditions. It may thus be possible to get a clear idea of the potentiality of the soil and to supply a nutrient element to the plant, independently of the climatic conditions.

COÏC

Je reviens sur le problème de l'augmentation de la consommation des engrais dans les pays à cultures intensives. Nous pensons que l'augmentation de cette consommation d'engrais dans les années futures dépendra, pour beaucoup, des résultats obtenus par les chercheurs. Par exemple quelle sont les principales causes d'augmentation de la consommation d'engrais dans l'ouest de l'Europe ces dernières années? D'une meilleure utilisation des engrais; mais aussi du travail des généticiens de l'amélioration des plantes. C'est le cas du maïs; c'est le cas des plantes de prairies. En France, je pense que la meilleure assurance du besoin en eau de nos cultures (irrigation d'appoint) sera une cause importante de la consommation d'engrais dans les prochaines années.

I return to the problem of the increase of fertilizer consumption in the countries with intensive cultures. We think that the increase of such fertilizer consumption in future years will for many depend upon the results obtained by the researchers. For example, what arè the main causes for the increase of the fertilizer consumption in Western Europe during these last years? A better fertilizer use, but also the work of the geneticists of plant amelioration. This is the case with maize and with grassland plants. In France, I think that the best assurance of water needs of our cultures (odd irrigation) will be an important motive of the fertilizer consumption in the next years.

RUSSELL

There is one point I would like to raise here on irrigation. Inland water can be a scarce commodity. Every farmer in eastern England would like to irrigate his land, but he cannot because he has not got the water. In parts of western Europe there are also probably areas where intensive agricultural production is practised but where there is not enough water available for irrigation.

HERNANDO

I would like to make another comment to the paper of Prof. BRAMAO.

FITTS

I just wanted to come back to your outline a moment relative to the item, slow acting nitrogen fertilizer. I wondered what you had in mind that we might take up in this discussion. Several studies on slow acting nitrogen fertilizer have been done by TVA and commercial companies around the world. One thing that we have noted with slow release nitrogen fertilizers — the nitrogen has to be released before the plant can take it up and that which is in a soluble form will leach as rapidly as if it were in the inorganic form when you added it. Then for a short time after the rain there is a problem of getting enough nitrogen for the plant needs. There are special conditions, particularly on rice, when some of the sulphur coated nitrogen fertilizer looks like it has possibilities, but I wondered if you had any specific points in mind that anybody could give us additional advice?

RUSSELL

The possible advantages of using urea-sulphur slow release fertilizers compared with a single dressing of a readily available nitrogen fertilizer are that there should be lower losses of nitrates from the soil if there are heavy rains shortly after the fertilizer has been applied. The urea-sulphur prills or granules are formulated so that they will be releasing nitrates fairly evenly over a matter of 2-3 months. The value of these fertilizers was discussed a few weeks ago at an FAO working group in the context of developing nitrogen fertilizers which would give a minimum risk of raising the nitrate content of the drainage water leaving the farm.

PESEK

I have one more question on fertilizer materials and this deals with the use of urea on lays or meadows. Urea is rapidly transformed to ammonia and carbon-dioxide by the action of urease which is universally present and particularly present on the surfaces of some plants and in soils. I wonder if any of the people in Europe, who have had experience with the use of urea containing fertilizers under such conditions where they have to be top dressed would indicate what they feel about the possible losses and what their experience has been with urea.

RUSSELL

In Great Britain we purposely use ammonium nitrate on our short-period grass pastures. Has anybody else experience regarding ammonium nitrate versus urea on such pastures?

PESEK

In my opinion ammonium nitrate is the perfect nitrogen fertiliser for aereated soils because it is virtually impossible to make an error in using it.

COÏC

La difficulté dans l'utilisation de l'urée est que cette substance, avant d'être transformée en carbonate d'ammoniaque peut traverser très rapidement le sol, n'étant pas retenue énergiquement par les Coloïdes argilo-humiques de sorte que la méthode d'emploi de l'urée est évidemment un peu délicate et peu amener plus d'erreurs que celle du nitrate d'ammoniaque mais je ne pense pas que ce soit très grave.

The difficulty in utilizing urea is that this substance, before being transformed in ammonium carbonate, can get through the soil very quickly since it is energetically not retained by argil-humic colloids so that the method of using ura is somewhat delicate and can bring about more errors than the one of ammonium carbonate. I think, however, that this is not very serious.

HAUSER

I just want to make a remark about the comment of Professor BLANCHET on Dr. BRAMAO's presentation. What Professor BLANCHET said that the World Soils Map and the data related to it should be used efficiently, is done at the moment by FAO, and I mentioned it very briefly in my presentation. FAO is now developing a storage and retrieval system for computerisation of all the soil data which are available, and the final goal is to make estimates with these data and with the help of the computer on the production potentialities of the soils which are shown on the Soils Map of the World. We will then know what we can produce in this world and which crops can be produced where, etc., and we shall have more details about the production possibilities in this world.

WALSH

This is as much a remark as it is a question. I would bring you back to Dr. FITTS' contribution as there is, I believe, a conclusion from it which concerns the meeting as a whole. We must look at the question of nutrient conservation. The supply of the world's nutrients is limited, particularly regarding phosphorus. In this context it is obvious that in the development of new fertilisers and new formulations, this question of conservation should receive attention. In the second place new fertilisers should be developed so as to ensure the best conservation of the environment. Here we are concerned with a societal matter of the greatest significance. I think this meeting should take note of this situation, and would hope that Dr. FRIED's committee will take note. We should see clearly where we are going so that the new fertilisers will not be such as to lead to undue contamination in the days ahead, while also conserving nutrient resources.

There is one more remark I want to make about this whole question of slow release nitrogenous fertilisers. I want to bring you back to the views of one of your British colleagues, Dr. COOKE, on this matter. He said that « it seems a hopeless task to design materials that would release nitrate by a biological mechanism at a rate that matches the need for nitrate of another biological system, and that is the crop ». I do not altogether agree with George Cooke on this matter, because I believe progress in designing appropriate slow release fertilisers is possible. We should, through research and its capacity to create new things, be able to do something about this. However, we shall not become over enthusiastic about this whole situation. My other remark is that under our conditions urea for grassland production is 80% as efficient as calcium ammonium nitrate at some 50% of the cost for unit of N, so there is no need to wonder why farmers intensifying their enterprises are tending to use urea increasingly as a source of nitrogen.

RUSSELL

There are one or two points that I think we should bear in mind in this discussion. Dr. BRAMAO, you commented on the amount of land that is not being cultivated. Would you like to comment on how far this is due to the poor system of land ownership that exists in many parts of the world? There is often an over-populated area next to an under-populated area, and there are political reasons why populations cannot move over from one to the other. I don't know how far FAO has looked into this problem. Another problem on development is the availability of agricultural capital and that again comes back to land ownership; for if the farmer is to obtain credit, he must be able to give some security for that credit, and his security is usually land. Another point I would like to comment on is the World Soil Map — to me the greatest contribution that FAO has made, is not on an agreed system of nomenclature but on getting an agreed system of criteria for separating soils into the different categories. I would also like to ask if you are publishing any maps showing the reliability of the soil map? I should also like to make a little comment on Dr. BRADFIELD's work in the Philippines which Dr. BRAMAO quoted. Dr. BRADFIELD has been able to obtain four or five crops per year on some land in the Philippines and is a great enthusiast for multiple cropping. The Philippines have however a climate that exists only in parts of the tropics. There is no cold season and the temperature is always high enough for the growth of tropical crops. There is an adequate water supply available every day of the year. So Dr. BRADFIELD's excellent work cannot be translated directly to many other parts of the tropics. A final point on the tropics which we have already been discussing, but on which I would like to remark again is that on the whole labour is not a scarce commodity on many farms in the tropics. There are bottlenecks but on the whole labour is not scarce. Now I will open this to discussion.

BRAMAO

Land unused in the Tropics. I think there is a bit of everything. All the arguments you used are probably right. However, in addition, there is also very scarce population in many areas in the Tropics. Let us consider South America, for instance, to which we have been giving a little more attention today. We have made an expedition from the border of Peru to Rio de Janeiro, across the whole Amazon area. We found the populated areas were often very small — towns marked on the map would have, sometimes, only 4 or 5 houses. The occupation of the continent really starts at about 500 kms from the coast; in our expedition we covered about 4,000 kms. There is not a minimum of population on the vast central areas of the continent, although there are some very good soil areas. I think shortage of population is often one of the reasons.

I am very glad you mentioned the importance of reaching a unified criteria for soil definitions which was obtained in the population of the Soil Map of the World Project. I appreciated the opportunity you have given me to speak of the reliability of the map. With regard to South America, you may see the small map printed on the same sheet showing the reliability of the basic soil surveys from which the soil map was prepared. The reliability of the soil map of South America is obviously heterogenous, so is its detail. Some soil areas in the Amazon Valley are very large while some others near the coast, where much more is known about the soils, are much more detailed as expected.

Referring to your other question, I do not think I have to explain farther Dr. BRADFIELD's working in the Philippines. We all know of it and have great respect for him.

The question dealing with availability of labour in the Tropics. Labour is scarce, often because the population is also scarce. Take for example the Mato Gross State in Brazil. It is a very large State, about two and a half times the size of France. Its population is only about one million inhabitants. Obviously you do not have enough population to fully develop the land potentials. If you want to start some agricultural production enterprise you find that it is difficult to find help.

HERNANDO

I tried to present two points to Dr. BRAMAO. The first point has already been referred to by Professor RUSSELL and my only remark is to stress the following aspect. It is necessary to prepare the soil capability map or the soil productivity map, I don't mind about the name — separately from the soil survey map, but maybe with the possibility of getting the correlation, soil type — fertilisation needs. The other thing is a comment in regard to the data you showed us on the work in Australia with the subterranean clover. You say that the subterranean clover they have, are species obtained from Spain and Portugal. I would like to add to this point that we are already experimenting in Spain with these varieties, too, and new varieties with very good results. Also, I remember that when I was in Portugal last time they were experimenting along with good results.

BRAMAO

I was informed that with the varieties of clover which they have obtained from Europe, the Australians have developed their own improved varieties. I am afraid I did not understand you well, Professor HERNANDO, when you mentioned the necessity of preparing soil productivity maps independently of the world soil map.

HERNANDO

What I wanted to say was this, that in the world soil map prepared by FAO, many of the countries show details on the needs of fertilisers by soils, but it is not the general rule. There are many countries, one of which is Spain, where there is nothing indicated about this. Therefore I suggested also to Dr. HAUSER, that one of the first things FAO could do in continuation of the world soil map, would be to prepare a map of the whole world in relation to the fertilisation needs of the soil, in correlation to the soil type, as a second part of the work.

WALSH

I was especially pleased to hear Mr. HAUSER saying that FAO were conscious that the soil map of the world would be of value and that the people in the soil fertility end of FAO are going to use it and indeed consider it worth using. Quite candidly, I could never understand the opposition inside FAO to this particular matter and indeed the resistance which those preparing the map encountered generally. To me this opposition was totally unmerited. However we are very glad to hear that it is now accepted that soil maps have distinct advantages for rationalising the use of fertilisers throughout the world and for transferring technology from one area to another. I think that is a major advance. It has taken a long time to achieve.

I was very pleased to hear that FAO are setting up a world soil data bank. This is a most important development which I believe we should definitely put on record here and that it should appear in our final conclusions. It is a development we should support very fully because from that bank I would visualise that even a country like ours is able to benefit very substantially. It has benefits for the retrieval of information for people in developed and under-developed countries alike. May I give a personal instance of how the lack of such a data bank has inhibited development. When I wanted information about an area in Brazil of interest to our national « Freedom from Hunger » organisation, I found it very difficult to get the necessary information.

We should record that this is a major advance and it should be supported by all the countries everywhere that are supporting FAO and who are contributing to the funds of FAO. The service should, of course, be fully computerised. On Dr. BRAMAO's map as such, I think that there are one or two matters we should remember. The world soil map is presented now as an approximation. It does not say it is the final result. A lot of work has to be done to get accuracy in it in a great many countries. In any logical system of soil survey, the soil maps should first be developed, based on a realistic approach where classification is concerned; a meaningtul approach, understanding that the map has to be used for a variety of purposes, not only for soil fertility work but for rural development and for rural area planning.

From basic soil maps we should of course logically develop land use capability maps. We do this normally. The first thing that we do in our own effort is that from the soil map for each area we develop a land use capability map. On the basis of this we set down major series of experiments, recording all relevant data including the traditional experience of farmers. In the final analysis the data can be incorporated in computer programmes. For instance we make such maps as I showed you in my paper on the livestock carrying capacity of a particular region or of the country as a whole. This is based on basic soil information and soil mapping and also of course on experimental work on a chain of experimental farms and practical experience for the particular soils. For instance, livestock carrying capacity per unit area depends on the type of soil. I think that the New Zealanders and ourselves are the only two countries that have approached it in this way, because we are both primarily pastoral countries, and this information is vital to us for planning. I might also say that our soils approach to this problem was conditioned to a considerable degree, by the developments in that very intensive agricultural country, the Netherlands. I have said enough about this matter to express our total conviction that as we begin to rationalise the use of fertilisers and other resources on the basis of good soil maps that we move in a progressive rational fashion removing much confusion and ensuring the use of our resources in the best possible manner.

HAUSER

I fully agree with what Dr. WALSH said, and it is so that in the projects of FAO in the various countries, such land use maps are made, very many of them really because there are quite a few projects now going on, but this happens on another scale. Now the world soil map at the moment is 1:5 million and that is of course a fairly small scale. It is not detailed enough for land une maps for the countries but that doesn't mean that it is not useful because we have land use groups. As regards the precision of the map, I think we should also think here in terms of the scale of the map. It is not very probable if we work with the scientists of the country that they make very big mistakes. On the scale of 1:5 million the map is fairly precise. Less precision comes in when the scale gets bigger, and then of course we will have to make corrections. Already, some countries have come up witb corrections and that is very helpful. In the course of these corrections there were four of five main soil units added; we are now at 106 or 108 although we were under at the beginning, so you can see that this is also a development, it is not one fixed map for ever. The map may change and is corrected as needed.

BRAMAO

I would like to say that I am very much in agreement with Dr. WALSH's point of view. We have tried to make these land capability maps with the information coming from the soil map of the world project. This information does cause varied scales always larger than 1:5000 as you realize. Some cartographic information came at the scale of 100,000 or even larger. My office actually prepared land capability maps of the entire world at the scale of 25 million, because it is practically impossible to do such maps at a larger scale. It would become too confusing due to different uses. A soil with high capability for a given crop may have a low suitability for another crop. In preparing soil capability maps, we did take into consideration the crop climate and topography.

PESEK

I would like to indicate agreement with Dr. BRAMAO's generally optimistic attitude towards the possibility of meeting our food needs in the world, and agree with him also that there is no reason for lack of food in the relatively near future because of the technical inability of soil and crop scientists to show the way to the increased production needed. I think that much depends on the people and governments of the various countries in deciding whether we will or will not be well fed.

DAVIDESCU

En ce qui concerne l'utilisation de la carte du sol pour une application rationnelle des engrais: d'après les expériences faites en Roumanie, on remarque que la carte du sol peut servir pour l'utilisation rationnelle des engrais quand un pays, une région, une ferme utilise de petites quantités d'engrais à l'hectare. Au contraire, quand on utilise de grandes quantité d'engrais il faut faire une carte agro-chimique. L'emploi des fertilisants d'après la carte du sol, dans notre pays, ne donne pas de bons résultats quand il s'agit de culture intensive.

As concerns the utilization of a soil map for a rational fertilizer application: According to the experiences made in Rumania it is observed that the soil map may serve for a rational fertilizer application when a country, a region or a farm use small fertilizer quantities per hectare. On the contrary, when large fertilizer quantities are used there ought to be made an agro-chemical map. The use of fertilizers according to the soil map does not yield good results in our country when dealing with intensive cultures.

VI

EMPLOI DE TECHNIQUE DE CALCUL ET NOUVEAUX SYSTEMES POUR DETERMINER LE BESOIN DE FERTILISANTS

CROP YIELD RESPONSE EQUATIONS AND ECONOMIC LEVELS OF FERTILIZER USE

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The recognition of crop responses to applied fertilizers has accelerated greatly during the past few decades. Experiments have shown that responses are secured in more places, that there are responses to higher rates of fertilizers and that a greater number of the so-called « soil-derived » essential elements is needed for optimum crop yields. There are many factors which have led us to seek and find this increased knowledge; however, the most important one is the need to produce more food and fiber for an expanding world population.

Fertilizer use has grown because fertilizers can be substituted for land and labor and other capital inputs in the production of crops and, in many cases, crop production can be expanded more efficiently by adding fertilizers than by adding the other production factors. This has the dual benefit of providing food at lower costs and of releasing people and resources to provide other items needed for a better living standard for all.

Once it is known that a particular crop will respond to fertilizers at a given location, one must learn how much fertilizer is needed to achieve certain objectives in crop production.

The first requirement for fertilizer use for crop production is that the value of the crop response, Δy, is greater than the cost of the increment of fertilizer applied, ΔF. If the price per unit of each is given as R, this inequality may be written as:

$$(1) \qquad \Delta y\ (R_y) > \Delta F\ (R_F)$$

There is no economic rationale for applying fertilizer unless this inequality exists.

Certain types of factors of production, other than fertilizers, may be employed only in specified units. For example, a crop may be cultivated once or twice, but not one and one-half times and, likewise, it is possible either to spray or not spray for control of pests, but one cannot apply part of a spray. Under these circumstances, equation 1 is adequate to make the decision relative to the application of the factor provided there is no other competitive use for the investment in resource which is more profitable.

But the application of fertilizer can be in any fractional amount chosen and is limited only by the individual's ability to measure and distribute it. Likewise, the increments, ΔF, of fertilizer may be varied in size at will. The question then becomes one of how many increments of fertilizer should be applied to achieve certain economic objectives. One common agronomic objective is that of maximizing tbe economic return per unit of area fertilized. The *optimum rate* of fertilizer is the quantity of fertilizer which achieves this objective.

Let us consider how the optimum rate of fertilizer is derived.

Experience and experiments have shown that whenever there is a response of a crop to fertilizer, and the whole range of responses is studied, the increase in yield per additional increment of fertilizer decreases as follows:

$$(2) \qquad \Delta y_1/\Delta F_1 > \Delta y_2/\Delta F_2 > \ldots > \Delta y_n/\Delta F_n\ .$$

The subscripts 1, 2, ..., *n* represent the increments of response to successive equal increments of fertilizer. This specifies the *law of diminishing returns.*

If the inequalities of (2) hold then the following can also be shown to exist as successive increments of fertilizer are added.

(3a) $$\Delta y \; (R_y) \gg \Delta F \; (R_F) \; ;$$

(3b) $$\Delta y \; (R_y) > \Delta F \; (R_F) \; ;$$

(3c) $$\Delta y \; (R_y) = \Delta F \; (R_F) \; ;$$

(3d) $$\Delta y \; (R_y) < \Delta F \; (R_F) \; ;$$

Clearly, it is profitable to apply increments of fertilizers as long as inequalities such as 3a and 3b prevail. It is also true that the inequality 3d leads to a loss from the use of fertilizer and should not be applied. Generalizing then, it is profitable to add increments of fertilizer until the equality 3c is reached but no more. Every increment of fertilizer up until this one returns some profit. Every increment above this leads to a loss in net revenue.

Inequality 3c may be rewritten as:

(4) $$\Delta y / \Delta F = R_F / Ry \; .$$

As F approaches zero we obtain:

(5) $$dy / dF = R_F / Ry \; .$$

Hence, the optimum rate of fertilizer is defined as that amount at which the marginal product, dy/dF, (first derivative) is equal to the price ratio of the unit of fertilizer to a unit of yield. It can be shown that this quantity of fertilizer is the maximum amount which should be applied under any conditions given the objective of maximizing profit per unit of area of crop produced.

The relationships described in the previous paragraphs may be graphed as in Figure 1. The conditions in equation 5 are defined graphically by drawing a line parallel to the fertilizer cost line, BFC, (expressed in the same units as y) and tangent to the yield response curve, OEA. The amount of fertilizer, x_3, needed to produce this magnitude of yield response at this point of tangency is the optimum rate. The vertical distance, EF, between the fertilizer cost line and the yield response curve is the profit and this distance is greatest at this fertilizer rate.

Yield Response Equations

The previous section indicated that the optimum rate of fertilizer may be determined graphically and also that this graphical relationship can be expressed algebraically. There are rather serious difficulties with graphical solutions of problems of this nature, and an algebraic solution is quicker and reproducible. An algebraic solution, however, requires the expression of the yield response curve as a function of the fertilizer applied. Much effort has been spent in deriving response equations.

Response equations for single nutrients

Perhaps the oldest and probably best known of the response equations was the one proposed by Mitscherlich (1909). In a series of experiments, he observed that the incremental response to fertilizer was proportional to the decrement from maximum yield or:

$$dy/dx = c\ (A - y)\ , \qquad (6)$$

which, upon integration and solving, becomes:

$$\log\ A - \log\ (A - y) = cx \qquad (7)$$

where x is the magnitude of the fertilizer being studied, c is the effect factor, y is the yield obtained at any given level of x, and A is the maximum obtainable yield by adding increasing quantities of x. This equation produces a response curve asymptotic to A: it does not permit reduction in yield due to excessive rates of x. HANWAY and DUMENIL (1955) employed

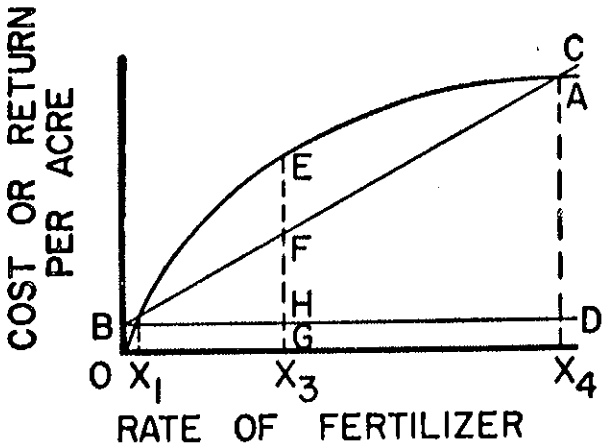

FIG. 1 — Relationship between the response curve, OEA, and the total fertilizer cost line, BFC, and the optimum rate of fertilizer x_3. Line BHD is the fixed cost of applying fertilizer. (After PESEK and HEADY, 1958)

this equation in computing optimum rates of nitrogen fertilizer for maize.

In order to overcome the objection to this equation because of its asymptotic nature, MITSCHERLICH (1928) divided both sides of equation 6 by y and then integrated and simplified to give:

(8) $$y = A\ (1 - 10^{-cx})\ (10^{-kx^2})$$

in which k is a damage factor permitting the equation to turn down if high levels of x do reduce yields.

BAULE (1918) made it easier to apply the MITSCHERLICH equation to certain data by designating an "effect quantity" unit, n, of the applied factor as that quantity which produces one-half of the maximum yield. Two units of this "effect quantity" would produce 0.75 of maximum yield, three units produce 0.875 of maximum yield, etc. With these modifications and y' being the ratio of observed yield to A, equation 7 may be written in natural logarithms as:

(9a) $$y' = 1 - e^{-0.7\ x/h}\ ,$$

or

(9b) $$y' = 1 - e^{-0.7\ v}\ ,$$

because h is the unit of measurement, unity, and x/h is v.

Observing that successive increments in yield resulting from successive equal increments of fertilizer tended to form the terms of a decreasing geometric series, SPILLMAN (1923) derived what has been called the SPILLMAN equation and used widely by economists. This equation may be written as:

(10) $$y = A - MR^x$$

where A is the theoretical maximum yield attainable by adding unlimited quantities of the fertilizer, x, M is the maximum yield increase attainable and R is the ratio of the incremental yield increase resulting from each successive increment of x to the yield increase which results from the previous equal increment of x. The SPILLMAN equation can be shown to be mathematically equivalent to the MITSCHERLICH equation and has the same limitations.

A number of investigators proposed various forms of the hyberbola as a response equation. Among these were BAULE (1918), BRIGGS (1925), BALMUKAND (1928), BORESCH (1928), RAUTERBERG (1934), and BONDORFF and THILAU as quoted by PLESSING (1943). The derivation of these equations and others is summarized by the author in the National Academy of Sciences National Research Council (1961) and by HEADY and DILLON (1961).

NIKLAS and MILLER (1927) admitted that they were not the first to use the parabola to describe yield responses; however, they apparently were the first to set down the conditions necessary to derive the second degree polynomial form (parabola or quadratic equation). They visualized that an optimal supply, h, of a growth factor exists which gives a maximum yield, H. The differential of the incremental response, dy/dx, they postulated is proportional to the difference between the amount of fertilizer, x, applied and h. If c is the proportionality factor than the differential equation may be written as:

$$dy/dx = c\ (h - x)\ . \qquad (11)$$

Following integration and simplication, the yield equation becomes:

$$y = b_0 + b_1 x + b_{11} x^2\ . \qquad (12)$$

When the sign of the coefficient b_{11} is negative the equation specifies diminishing returns, i.e., the graph is concave to the x-axis. It permits positive and negative responses to added increments of x.

Various exponential functions of differing degrees of complexity have been proposed as yield equations for crops responding to fertilizers. These, too, are presented by the National Academy of Sciences National Research Council (1961). The most common of these exponential or power functions is the COBB-DOUGLAS function and is usually written as:

$$y = ax^b \tag{13}$$

where a and b are constants and x again is the variable fertilizer quantity used. The most serious limitation of this function is that it does not provide for a maximum yield and hence cannot describe, adequately, the complete range of responses observed. It is not even asymptotic to a maximum.

Response equations for two or more nutrients

Single nutrient equations are satisfactory for certain purposes but they have only limited application for expressing yield responses to fertilizer under most field conditions. The most important reason is that most soils are simultaneously deficient in more than one nutrient element for most satisfactory crop production. A second reason is that the establishment of a single nutrient response curve in the presence of added adequate quantities of other elements attributes not only the direct effect of that element upon yield, but also attributes to it any favorable or unfavorable effects due to interaction with other elements. Hence, an optimum rate determined on the basis of a single nutrient response curve either over-estimates or under-estimates the optimum if other elements are added at adequate rates and interactions are present. This is a very common situation. A fairly complete treatment of multivariate equations has already been presented by the author in the National Academy of Sciences National Research Council (1961) and by HEADY and DILLON (1961). Some of these will be presented briefly here.

After establishing his concept of "effect quantity", BAULE (1918) was apparently the first to expand the MITSCHERLICH equation to apply to more than one variable. He wrote it as:

$$(14) \qquad y = \mathrm{E}\ (1 - e^{-0.7x'_1/h_1})\ (1 - e^{-0.7x'_2/h_2}) \ \dots\ (1 - e^{-0.7x'_n/h_n})$$

In this equation, E is the maximum attainable yield when all factors, x'_i, are in adequate quantities and h_i are the effect quantities of the respective growth factors. The nature of h has been described previously. When soil is the medium of growth, there are certain quantities of the growth factors, b_i, already present. To accommodate the soil contribution, equation 14 may be modified by substituting $x_i + b_i$ in the numerators of the exponents of e replacing x'_i. (e is the base of the Napierian logarithms).

SPILLMAN (1933), following BAULE'S procedure, expanded his equation as follows:

$$(15) \qquad y = \mathrm{A}\ (1 - \mathrm{R}^{n+a})\ (1 - \mathrm{R}^{p+b})\ (1 - \mathrm{R}^{k+c}) \dots .$$

In this case, R has the same meaning as previously, a, b, and c are units of fertilizer like N, P, and K applied and n, p, and k are the amounts of a, b, and c available in the soil and in the same units. The most difficult problem in applying the MITSCHERLICH-SPILLMAN type of equation is the problem of determining effect quantities in the soil because chemical and biological tests do not yield answers which are in "effect equivalents" to the units supplied in fertilizers.

The COBB-DOUGLAS power function is easily expanded by writing

$$(16) \qquad y = a x_1^{b_1} x_2^{b_2} \ldots x_n^{b_n} .$$

It is fitted by the method of least squares by rewriting it in logarithmic form. Aside from the other problems with the power function mentioned previously, this multivariate form presents the same difficulties related to soil supplies of nutrient elements encountered with the MITSCHERLICH-SPILLMAN equation.

BALMUKAND (1928) expanded the resistance formula proposed by BRIGGS (1925) to more than one factor. The basic hypothesis is that the reciprocal of the yield, $1/y$, is the sum of a constant and several effect functions of the various nutrients. His final equation was written as:

$$(17) \qquad 1/y = C + a_n (n + N)^{-1} + a_p (p + P)^{-1} + a_k (k + K)^{-1} \ldots ,$$

where C is a general constant, a_n, a_p, etc. are constants for the several types of fertilizers, N, P, etc. are the quantities of nutrients added in the fertilizer and n, p, etc. are effect quantities of these nutrients initially present in the soil.

The modified hyperbola equation was also expanded by BAULE (1918) by writing it as:

$$(18) \qquad y = \frac{A}{\sqrt{1 + 3\,[a_1/x_1)^2 + (a_2/x_2)^2 + (a_3/x_3)^2 + \ldots]}}$$

The second degree polynomial is simply expanded by adding terms representing the additional variates and their interactions to give:

$$(19) \qquad \begin{aligned} y = {} & b_0 + b_1 x_1 + b_{11} x_1^2 + b_2 x_2 + b_{22} x_2^2 + b_{12} x_1 x_2 + b_3 x_3 + \ldots \\ & + b^{nn} x^{n2} + b_n x_1 + \ldots + b_{np} x_n x_p \end{aligned}$$

where b_0 is the intercept, x_1, x_2, ... x_n are the nutrient variates or production factors, b_i's are the linear coefficients, b_{ii}'s are the quadratic coefficients, b_{ij}'s the interaction coefficients, and p is equal to $n-1$. The effect quantities of nutrients present in the soil and other soil or environmental growth factors interacting with fertilizers are simply added as additional x variates with corresponding effect coefficients.

The second degree polynomial may be written substituting $x^{0.5}$ for x and simplifying (HEADY et al., 1955). This has been referred to as the square-root transformation of the quadratic equation. The basic polynomial equation also can be expanded to include higher powers of x_i, e.g., x_i^3 (STRITZEL, 1958), and more complex interaction terms, e.g., $b_{122}x_1x_2^2$. Another variation is to write $x^{1.5}$ in place of x^2 (DOLL et al., 1958). These equations like the others can be fitted simply by least squares fitting procedures for multiple curvilinear regressions.

Some properties of multivariate response equations

HEADY and DILLON (1961) have described the properties of the response surfaces generated by the most frequently used response equations with two variates. These are the COBB-DOUGLAS equation, the MITSCHERLICH-SPILLMAN equation, the resistance equation proposed by BALMUKAND, and the quadratic and square root transformation of the quadratic equations.

Experience, experiments, and intuition suggest that responses of crops to fertilizers should be characterized by diminishing returns over at least part of the range of responses, they should exhibit a maximum yield and the yield should decline after the maximum is reached and that the maximum should be achieved at a unique combination of two or more variates used in multivariate experiments. Regression equations which do not provide for these possibilities would not be appropriate to describe the full range of crop responses to fertilizers, although they may be appropriate for other growth responses such as growing or lactating animals.

According to HEADY and DILLON (1961) and as described previously, given the right data, all of these equations provide for the possibility of diminishing returns. However, only the quadratic equation and the square root transformation of the quadratic equation provide for positive and negative responses to additional increments in the same function. Likewise, only these two forms of equations, the two polynomials, provide for a unique combination of two factors to produce a maximum yield or yield response: the other equations provide for response surfaces which either are asymptotic to a plane as in the case of the MITSCHERLICH-SPILLMAN equation or which continue to rise as in the case of the other two.

By elimination, we arrive at having to make a choice between the quadratic equation or the square root transformation of the quadratic equation. (Other transformations of the quadratic equation containing terms with fractional powers have similar properties). One obvious advantage of a simple second order equation is that it is very easy to manipulate algebraically while the differentiation and solution of equations with terms raised to fractional powers involves more computations. There are, however, other reasons why this author prefers the simple second order polynomial equation for studying and specifying economic fertilizer use levels.

It is necessary to consider the properties of the response surface generated by the two types of regressions to present the argument for favoring one over the other. An illustration of a general response surface showing yield as a function of two variates is presented in Figure 2. When fitted to data over a wide range of treatments, both the quadratic and the square root transformation of the quadratic equation provide for a maximum point on the surface; i.e., there can be a real simultaneous solution to

(20a) $$dy/dz = 0$$

and

(20b) $$dy/dx = 0 .$$

Note that on a response surface of this type, any given value of y may be achieved with many combinations of the two independent variates as along the dotted line ab. Different values of y are contours on the surface which are at the same distance above the base plane. When these contours are projected vertically downward to the base plane and graphed, they become a series of more or less parallel curved lines as in figures 3 and 4. These curves, representing equal quantities of yield, are called *isoquants*. The isoquant for the maximum yield reduces to a single point with the unique combination

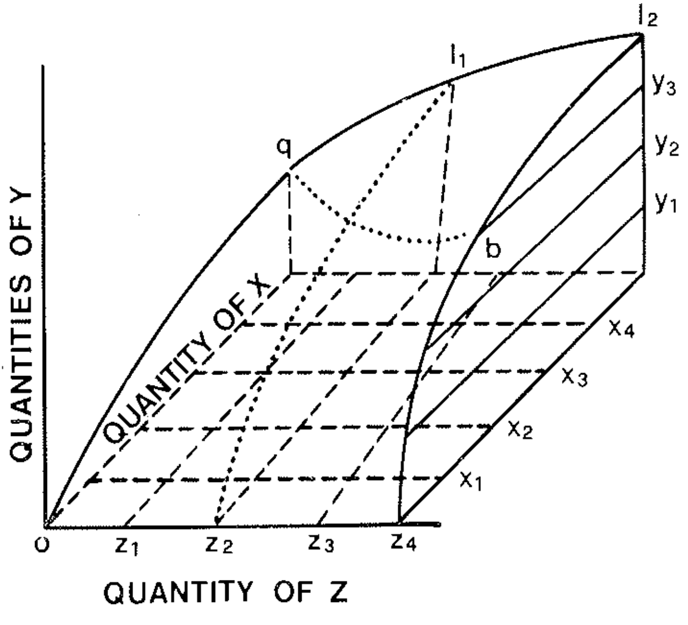

FIG. 2 — A yield surface generated by a yield equation in two independent variables, X and Z. (After HEADY and DILLON, 1961; used by permission from *Agricultural Production Functions* by EARL HEADY and JOHN DILLON, © 1966 by the Iowa State University Press, Ames, Iowa.)

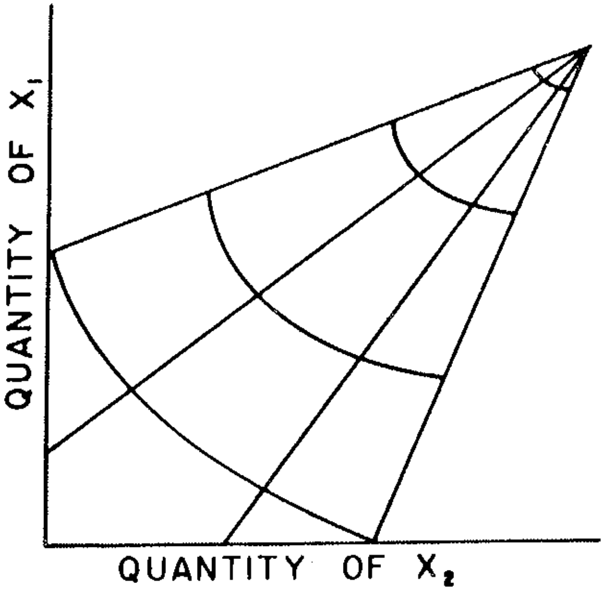

FIG. 3 — Isoquants and isoclines for a quadratic yield equation. (After HEADY and DILLON, 1961; used by permission from *Agricultural Production Functions* by EARL HEADY and JOHN DILLON, © 1966 by The Iowa State University Press, Ames, Iowa.)

of the two variates given by values of the coordinates of this point (the solutions to equations 20a and 20b). Observe also that at yield levels below the maximum, numerous combinations of the two variates are predicted to produce the same yield.

Starting with a simple quadratic equation in x_1 and x_2 such as:

$$y = b_0 + b_1 x_1 + b_{11} x_1^2 + b_2 x_2 + b_{22} x_2^2 + b_{12} x_1 x_2 \tag{21}$$

the isoquant can be calculated by transposing y and solving for either x_1 or x_2 by the quadratic formula. The isoquant equation then becomes:

(22)

$$x = \frac{-(b_1 + b_{12}x_2) \pm [(b_1 + b_{12}x_2)^2 - 4b_{11}(b_2x_2 + b_{22}x_2^2 + b_0 - y)]^{\frac{1}{2}}}{2b_{11}} .$$

By selecting different values for x_2, holding y constant, the values for x_1 may be calculated and the isoquant graphed. A new value for y and a set of values of x_2 will lead to calculations of another isoquant. Computer programs are available for plotting these isoquants.

A simple equation in x_1 and x_2 in the square root transformation is:

$$(23) \qquad y = b_0 + b_1x_1^{\frac{1}{2}} + b_{11}x_1 + b_2x_2^{\frac{1}{2}} + b_{22}x_2 + b_{12}x_1^{\frac{1}{2}}x_2^{\frac{1}{2}} .$$

The isoquant equation is calculated similarly and is as follows:

(24)

$$x_1 = \left[\frac{-(b_1 + b_{12}x_2^{\frac{1}{2}}) \pm [(b_1 + b_{12}x_2^{\frac{1}{2}})^2 - 4b_{11}(b_2x_2^{\frac{1}{2}} + b_{22}\, x_2 + b_0 - y)]^{\frac{1}{2}}}{2b_{11}}\right]^2 .$$

This equation is always a little more cumbersome to use than equation 22. The coefficients b_{11} and b_{22} have negative signs when these equations are fitted to data exhibiting diminishing returns. The isoquants in figures 3 and 4 are characteristic of the general nature of isoquants for equations 21 and 23, respectively.

Observe that for the appropriate values of y, that is, values of y below the maximum, equations 22 and 24 provide for closed curves elliptical in nature. Each curve will therefore be vertical at two points, one nearer the vertical axis and to the left of the maximum point and one to the right of the maximum point. Likewise, each curve will be horizontal at two points, one nearer the horizontal axis and below the maximum point and one above the maximum. The parts of the isoquants graphed are those falling between the vertical point to the left of the maximum and the horizontal point below the maximum. These segments of the curves are said to fall within the "rational" range of choices of fertilizer combinations. The reason is that any given level of y between these two points on the isoquant can be secured with a lower quantity of one or both variables than at points along the same isoquant curve outside of this rational range.

The lines in each figure connecting the points on the isoquants where the isoquants are vertical and where the isoquants are horizontal are called *ridge-lines*. These ridge-lines intersect at the maximum point and, with the two axes, form the boundaries for the rational choices of combinations of the two variates in producing given levels of y.

It is necessary to consider one more concept. This is the concept of economic substitution of one of the variates for the other and selecting the combination which produces a given level of y for the lowest cost. If variate x_1 were "free" then one would produce a given level of y with the greatest amount of x_1 and the least amount of x_2 possible. Hence, one would select combinations of x_1 and x_2 producing the quantity of y along the upper ridge-line. On the contrary, if x_2 were free then one would select combinations of x_1 and x_2 which produce a given quantity of y with selections along the right ridge-line.

But both resources usually have some actual costs to the producer and the problem becomes one of selecting some combination which lies between the two ridge-lines. The least cost combination to produce a given quantity of y is that combination at which the following is realized:

(25a) $$\Delta x_1 \, (C_{x_1}) = \Delta x_2 \, (C_{x_2})$$

(25b) $$\Delta x_1 / \Delta x_2 = C_{x_2} / C_{x_1}$$

(25c) $$dx_1 / dx_2 = C_{x_2} / C_{x_1} \; .$$

Here C is the cost per unit of each variable and the derivation for the equality in equation 25c is the same as for equation 5 presented earlier.

On each isoquant, there will therefore be the solution which satisfies equation 25c and, if one wishes to produce at a higher level of y, he would produce at a point on the higher isoquant which also satisfies this condition. If we calculate the points on a series of isoquants which will satisfy the same cost ratio and connect them, we produce a line which is called an *isocline*. This line connects points on successive isoquants having the same slope or inclination, hence, the name. The significance of the isocline is that it specifies the combination of the two variates which produce a given level of y at least cost. These isoclines all pass through the maximum point and only those falling within the rational range are of interest. If the cost ratio is written simply as c', equations 26 and 27 specify the isoclines for equations 21 and 23, respectively. A different isocline is specified for each value of c'.

$$(26) \qquad \frac{dx_1}{dx_2} = -\frac{b_2 + 2b_{22}X_2 + b_{12}X_1}{b_1 + 2b_{11}X_1 + b_{12}X_2} = c'$$

$$(27) \qquad \frac{dx_1}{dx_2} = -\frac{b_{22} + 0.5b_2x_2^{-\frac{1}{2}} + 0.5b_{12}x_1^{\frac{1}{2}}x_2^{-\frac{1}{2}}}{b_{11} + 0.5b_1x_1^{-\frac{1}{2}} + 0.5b_{12}x_1^{-\frac{1}{2}}x_2^{\frac{1}{2}}} = c'$$

Observe that equation 26 provides for the linear isoclines which are shown in Figure 3. One of these isoclines will pass through origin and only if the least cost combination of x_1 and x_2 for production of y lies along this isocline should higher quantities of y be produced by simply increasing the amount of a fixed mixture of fertilizer. In all other cases, the least cost combinations of x_1 and x_2 for production of increasing quantities will require changing proportions of the two variates gradually approaching the unique combination producing the maximum yield. The square root transformation of the quadratic equation also provides for changing the mixture of the two variates as higher yields are sought. The least cost combinations also converge to the single ratio producing the maximum yield. This is shown in Figure 4.

The big difference between these two equations is that the square root transformation predicts a narrowing of the ratio ranges of the two variates at low yield levels as well as at high yield levels, while the range of ratios permitted by

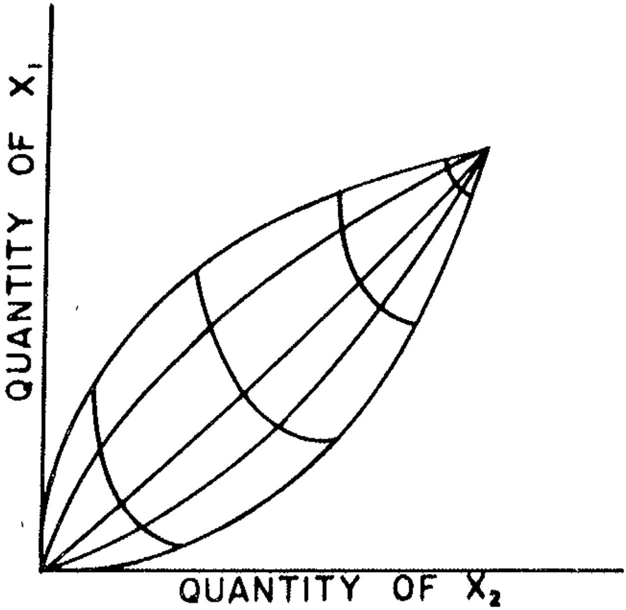

FIG. 4 — Isoquants and isoclines for a square root transformation of the quadratic equation. (After HEADY and DILLON, 1961; used by permission from *Agricultural Production Functions* by EARL HEADY and JOHN DILLON, © 1966 by The Iowa State University Press, Ames, Iowa.)

the quadratic equation is widest at low yield levels. It permits the production of certain low levels of y with only one variate or the other variate. (In practice, even with one but not the other, BROWN et al., 1956.) Experience indicates that, except under unusual conditions, some yield increases can be achieved by the application of only one of several limiting factors in soil systems in the field.

It is because of the nature of the isocline map that this author prefers the quadratic equation over the square root transformation for crop yield functions involving fertilizers. This is in spite of a significant disadvantage. This disadvantage is that, intuitively, the radius of curvature of a response surface should be shortest at low rates of fertilizer inputs becoming longer as fertilizer inputs are increased and becoming longest at the point of maximum yield. The MITSCHERLICH, SPILLMAN, resistance, and the square root transformation all have this property. The quadratic equation does not, having the shortest radius of curvature at the maximum point.

Figure 3 shows the isocline and isoquant map in the presence of a positive interaction. Note that the ridge-lines intersect each other at an acute angle. In the absence of an interaction term, the ridge-lines intersect each other at right angles and when a negative interaction is present, the ridge-lines intersect at an obtuse angle. Interactions between variates applied and with uncontrolled climatic and edaphic variates are a key to generalizing yield equations to make recommendations for economic fertilizer use.

GENERALIZED YIELD EQUATION

The equations given and illustrated in previous sections pertain to responses to fertilizer under a given circumstance — that of a particular experiment in which these yields were measured. Therefore, many potential variables are held constant. If responses to fertilizers always were the same under various soil and climatic conditions, then a few carefully conducted experiments could serve as the foundation for making all fertilizer recommendations. This, of course, is not the case and one must utilize the results of experiments under many different conditions to sample the relevant range of conditions. The problem then becomes one of combining the experiments into a unified system for use in making fertilizer recommendations. In order to fit a quadratic equation in two variates, it is necessary to have an experiment given these two variates with at least three levels of each and in combination with each other if interaction is to be included. Suppose there were n levels of two variates in all combinations and replicated k times. In this case an analysis of variance would be as in Table 1. Note that there are a number of interaction degrees of freedom for interactions and main effects higher than the second degree. The mean square associated with these interactions and higher order main effects is a measure of the failure of the quadratic equation to fit the experimental data.

The main advantage of adding a replication is to provide for an estimate of experimental error. If one is willing to accept deviations from regression as a mesure of experimental error, one need not have replications in experiments for the purpose of fitting yield equations if provision is made for an adequate number of "lack of fit" degrees of freedom. Because three points can be fitted exactly with a curved line without deviations from regression, the minimum number of levels for fitting quadratic equations is four. If at least two levels of each are also applied in all combinations with the other, there will be three interactions of higher order than the second degree.

If the experiment is repeated at s sites, then the analysis

TABLE I — *An analysis of variance of a factorial experiment in two variables, A and B, each at* n *levels and replicated* k *times.*

Source of variation	Degrees of freedom
Total	$n^2k - 1$
Replications (R)	$k^2 - 1$
Treatments (T)	$n^2 - 1$
Main effect of A	$n - 1$
Linear (A_l)	1
Quadratic (A_q)	1
Higher order effects	$n - 3$
Main effect of B	$n - 1$
Linear (B_l)	1
Quadratic (B_q)	1
Higher order effects	$n - 3$
Interaction A × B	$(n - 1)^2$
Linear × linear (A_lB_l)	1
Higher order interactions	$(n - 1)^2 - 1$
Error (R × T)	$(k - 1)(n^2 - 1)$
[Deviation from second order regression	$(n^2 - 1) - 5$]

of variance is as shown in Table 2. The degrees of freedom for sites are the bases for the values of b_0 in equation 21 being different at different sites. The treatment by sites (T × S) interaction represents the failure of treatments to give the same response at all sites.

It is evident that the total yield, y, over all sites is made up of at least three components: (a) the treatment effect, T, including interactions, within sites, (b) the site effect S, and (c) the interaction of the site factors by the applied treatments. This can be written:

$$y = \Sigma T + \Sigma S + \Sigma ST \; . \tag{28}$$

All degrees of freedom for the S terms must come from the "among sites" source of variation. All the T terms degrees of freedom have to come from "within site" sources of variation and the ST degrees of freedom come from the large number of degrees of freedom representend by "treatment by site".

Combining a series of experiments

The stage of agronomic science is such that the major factors affecting yields are known and some of the interactions understood. JENSON and PESEK (1959) have discussed many of the basic considerations needed to generalize response equations to relate response of crops to fertilizers to the initial soil factors and to environment. We are interested in generating a yield equation which could be used to predict fertilizer needs as opposed to determining the presence or absence of response which should already he known. VOSS (1962), VOSS and PESEK (1962), SHAH (1965) and PUENTE (1969) have shown how this might be done.

TABLE 2 — *An analysis of variance of a factorial experiment in two variables, A and B, each at* n *levels, replicated* k *times and conducted at* s *sites.*

Source of variation	Degrees of freedom
Total	$snk - 1$
Sites (S)	$s - 1$
Replications (R) within S	$k - 1$
R × S	$(S - 1)\ (k - 1)$
Treatment (T)	$n^2 - 1$
Main effect of A	$n - 1$
Linear (A_l)	1
Quadratic (A_q)	1
Higher order effects of A	$n - 3$
Main effect of B	$n - 1$
Linear (B_l)	1
Quadratic (B_q)	1
Higher order effects of B	$n - 3$
Interaction A × B	$(n - 1)^2$
Linear × linear (A_lB_l)	1
Higher order interactions	$(n - 1)^2 - 1$
T × S	$(n^2 - 1)\ (s - 1)$
T × R within sites	$(n^2 - 1)\ (k - 1)$
T × R × S	(n^2)— $(k - 1)\ (s - 1)$

Suppose we are interested in the joint effect of nitrogen (N) and phosphorus (P) fertilizers on the yield of wheat. We already know that wheat responds to both on many soils but not on others. It is also known that the yield level and the presence or absence of response may depend upon soil nitrogen supply, n; soil phosphorus supply, p; soil pH, a; subsoil phosphorus supply, q; initial soil moisture, w; precipitation after seeding, r; and mean seasonal temperature, t. The yield of the untreated control plots, Y_0, at many locations could then be given by

(29)

$$Y_0 = f\,(n, n^2, p, p^2, a, q, w, w^2, r, r^2, t, t^2, np, ap, pq, nw, nt, wt, rt, \ldots).$$

Of a large number of factor effects possible, we have written only 19. Some of these may be proven to be of little or no use in predicting wheat yields and others may be known or discovered later. One of the latter, for example, might be an index for a variety and another might be the seeding rate. Observations of the untreated yields at a minimum of 20 sites would be necessary to fit an equation to this functional relationship without provision for deviations from regression. An additional 10 to 15 sites would have to be sampled to provide for an estimate of error (deviations from regression) for the coefficients of a regression equation with these terms in it.

The response, ΔY_s, of wheat to nitrogen and phosphorus at a given site may be shown to be given by

$$(30) \qquad \Delta Y_s = f\,(N, N^2, P, P^2, NP, N^2P, NP^2, \ldots)\,.$$

But total yield at a site, Y_s, will depend upon Y_c and ultimately upon the effect of the factors which determine Y_c upon the coefficients of the variables in equation 30 when written as terms in a regression equation.

We have considered the terms in equation 29 as though all of these terms are characteristic site effects. As a matter of fact, many of these terms may be determined for each plot and probably should be. These include such terms as n, p, and a. If this is done, these become plot characteristics just as the rates of fertilizer applied to each plot except that they are uncontrolled. This has the practical effect of increasing, vastly, the number of observations on the soil variables and transferring the measurement of their effect from the among site variation to the within site variation. This should also have the desirable effect of providing better estimates of the interaction of soil and fertilizer treatment because both are measured on each plot. It is probably not feasible to measure the rest of the variates in equation 29 on each plot and, therefore, a value for each site or replication would be necessary.

It is evident that with a complete soil test for each plot, the number of variables in a within site yield equation would be increased considerably because it would include not only the fertilizer treatments and the initial soil analyses but the interactions of these two classes of effects. The within site yield equation would then become:

(31)

$$Y_s = f\,(N,\ N^2,\ P,\ P^2,\ NP,\ NP^2,\ N^2P;\ n,\ p,\ a,\ n^2,\ P^2,\ np,\ pa;$$
$$nN^3nN^2,\ nNP,\ pP,\ pP^2,\ npP,\ aP,\ aP^2,\ aNP,\ \ldots)\,.\,.$$

A regression of this size would require 30 to 40 field plots per site to provide for a number of degrees of freedom for deviations from regression within each site.

If the treatment or input on each plot is considered to be made up of both fertilizer applied and the soil analysis values, there can no longer be replication in the true sense of the word. Hence, it seems that there is little advantage or disadvantage to replicating or not replicating a set of fertilizer treatment combinations at each site. If many more than three variates are studied simultaneously, even a simple replication contains an unwieldy number of plots. Consider only a 4^4 factorial with 256 plots. The important thing is that there be the required number of plots (exceeding the number of expected variables in equation 31) at each site and that there are a minimum of four levels of each fertilizer applied. A number of the author's students have used a 24 plot design replicated twice in studies involving N, P and K fertilization of maize and forage grasses. The design is a modified central composite design of the $2(2^z)+2z+1$ type providing five levels of each element where z is the number of variables (BOX and WILSON, 1951; BOX, 1954; BOX and HUNTER, 1954, 1957). The levels are equally spaced and one plot in the design is untreated. The 24th plot is a second untreated control in each replication which is added for convenience in field layout (DESSELLE, 1967).

Having a replicated design permits an examination of the error mean square, that is, the replications by treatments interaction within each site. When this is compared with the mean square for deviations from regression, one can judge how adequately the chosen regression fits the data. If the mean square for deviations from regression is significant, the investigator should examine the soils and other factors of the environment in the experiment for a possible significant factor not being considered. In the few cases where the mean square for deviations from regression has been examined in relation to the replications by treatment error term, it has been found not to be significantly different (PESEK, 1956). This gives some confidence in the use of the quadratic equation for fitting the data.

The central composite or the modification of this design is favored by the author for experiments to be used in quadratic regression analyses because the estimates of the coefficients of the terms representing fertilizer inputs are estimated with more nearly the same degree of variance than is done using factorial experiments. Data secured from full factorial experiments estimate the second order and interaction terms with far more precision than the others. The author feels it is more desirable to increase the number of observations in such a way that all coefficients are estimated with about the same degree of confidence rather than estimating some coefficients so much more precisely than others.

Every investigator who has fitted multiple regression equations to experimental data has been faced with the decision of what to do with coefficients which are not significant at some level of probability. LAIRD and CADY (1969) are among the recent ones to have published on this question. This author takes a rather liberal position on keeping variables. In view of the fact that a variable must be logical even to be considered, there must be a good reason for deleting it if it does not explain a significant part of the variation. Therefore, the author is inclined always to keep variables which are significant at the 70% level. Under some conditions, any probability level of 50% would be acceptable for the term of highest order for a particular variate. For example, the second order is the highest order for the simple curvilinear effect of a particular variate.

Lower order terms for variates with significant higher order terms must remain in the equation. If the coefficient of the second order term of a variate is significant, then, the first order term must be retained even though the chances are slight that it is different from 0. For the same reason, simpler terms of variates occurring in significant interactions must also be retained because the significance of the interaction itself establishes the existence of an effect of all variates involved in the interaction.

Change of variate intensity with time

Upon incorpation of soluble phosphorus fertilizer in soil, a number of chemical, physical and biological changes take place almost immediately. Even before the crop absorbs the phosphorus from the fertilizer, the biological availability has changed. Therefore, the rate of fertilizer applied is no more than an index of the available quantity from that source. This change in availability will be different for different soils and this is one reason why we have significant interactions of soil properties with the effectiveness of a unit of phosphorus fertilizer. In the case of nitrogen fertilizer, there are certain biological changes which might take place to influence significantly the amount available, although the effects are not the same as with phosphorus. Because a large proportion of the nitrogen applied in fertilizer may be recovered by the plant, there is clearly a lesser quantity available, due to crop removal, by the middle of the season than there was at the beginning. Again, the rate applied is simply an index. TURRENT (1968) has dealt in depth with some of these concepts.

A different but related factor is related to the development of the crop. Initially, the root zone embraces the surface horizon of the soil in which the fertilizer is placed and the total amount applied is soon within reach of most of the root system. As the root system exploits the moisture in the subsoil under natural rainfall conditions, a significant part of the active root system is no longer in a position to exploit the fertilized zone. If the surface horizon dries below the wilting point, the fertilizer may have very little or no real availability to the crop. HANWAY et al. (1962) and other investigators have considered this problem and have arrived at the simple approach suggested in equation 29. Even though TURRENT included the vertical distributional factor, he was not able to test his proposals adequately because of the lack of satisfactory data. In reality, the situation must be more complex than suggested in equation 29, but we have not tested more sophisticated procedures.

Another major factor in crop production which is certain of change during the growing season in the field is the climatological factor or factors. These changes are unpredictable, on a seasonal basis, although the general behavior of climate is known. Again, equation 29 suggests a very simple curvilinear effect of the two major components of climate, rainfall and temperature. While adequate for purposes of illustration, the real effects must be much more complex – we actually know they are.

Recognizing that a given level of moisture availability might have different effects depending upon the stage of growth, climatologists and soil physicists have developed a concept of a stress day or a non-stress day. In general terms, a stress day is a day when the conditions of atmospheric demand for moisture, water availability in the soil, and stage of crop development are such that adequate moisture for meeting evapotranspiration demands cannot be extracted from the soil by the crop and the plants begin to wilt. Several variables go into the determination of a stress day and stress days do describe the reaction of plants to climate quite well (DENMEAD and SHAW, 1962).

Because one day of stress might have a different effect depending upon its time of occurrence relative to the crop, all stress days would not have the same coefficient. To accommodate this, various investigators have divided the growing period of a crop into two or more periods and the regressions are developed with numbers of stress days during specified periods. For example, the detrimental effect of a stress day during the time of blooming of maize is many times greater than that of a stress day soon after emergence (DALE, 1964; PUENTE, 1969).

FISHER (1924) recognized the distributional nature of precipitation and temperature and developed his concept of the regression integral to deal with this problem. This concept has not been used as much in the past as it should have because of major computational difficulties of fitting equations of fourth and fifth order to climatological data and the general lack of appreciation of agronomists of handling these and other distributional properties in this way in relation to crop yields.

One might visualize that the effect of some weather factors such as temperature, t, might be the accumulation of the effects of different levels of t multiplied by an effect coefficient, b. This equation may be written as

$$(32) \qquad Y_t = b_0 + b_1 t_1 + b_2 t_2 + \ldots + b_i t_i \,.$$

If there were 100 days in the growing season, then, there would be 100 of these terms meaning that there would have to be over 100 experiments measuring the effect of t for an equation of this size to be used.

In reality, FISHER visualized that the effect coefficient for successive days, like 1, 2, and 3, would vary very little from each other and likewise that the effect coefficient for days 80, 81, and 83 also would vary very little but that there might be a major difference between the mean effect coefficient for the first set of days as compared to the second. Agronomists have recognized this hy dividing the growing season into two or more parts.

FISHER further reasoned that the effect coefficient would vary very little from one day to the next; however, he visualized that this effect coefficient would vary rather uniformly and smoothly throughout the whole growing season. He reasoned that if one expressed the climatological factor, t, as an orthogonal function of time, T, the coefficients of T could be used as independent variables in the multiple regression relating yield to t. In other words, he visualized writing:

$$(33) \qquad t = a_0 + a\mathrm{T} + a_2\mathrm{T}^2 + a_2\mathrm{T}^2 + a_3\mathrm{T}^3 \ldots$$

We can then rewrite equation 32 as:

$$(34) \qquad Y = b_0 a_0 + b_1 a_1 + b_2 a_2 + \ldots + b_i a_i \,.$$

In using this procedure, some students working with the author found that orthogonal equations in T of the fifth order gave very adequate descriptions of the seasonal variation in t expressed in terms of the mean daily temperature. Because of the discontinuity of precipitation periods, this did not work as well so the procedure was modified to express accumulated precipitation as a function of time. This still was not completely satisfactory so SHAH (1965), TURRENT (1968), and PUENTE (1969) expressed the absolute amount of available soil moisture in the root zone in the growing period as a function of time and related yield and responses to fertilizer to orthogonal coefficients for available soil moisture expressed as the fifth order function of time.

To date, the author is not aware of any study which made an exhaustive evaluation of the relative effectiveness of the two general procedures for handling climatic factors. Besides the possibility of using the regression integral to help study climatological effects on crop growth, the regression integral presents some intriguing possibilities for studying the effect of any factor known to vary in time or in space; for example, the subsoil distribution of nutrients.

Our interest in the effect of climate and its variation upon response to fertilizers stems from the fact that decisions with regard to fertilizer use must be made with the best information available. Because climatological factors markedly influence the response to fertilizers, optimum rates are affected. A given experiment or set of experiments has the limitation that the data represents certain fixed points with regard to the intensity of climatological factors as well as soil factors previously discussed. Unfortunately, we cannot evaluate the climatological factors ahead of time as we can test soil. The variation in climate from year to year, therefore, becomes a critical factor in giving advice on fertilizer use.

SELECTING THE FERTILIZER RATE ACTUALLY USED

The use of fertilizers in crop production is an economic activity which depends upon the knowledge of a biological response. Because of this, no choice of fertilizer rate is *a priori* the correct rate or the incorrect rate provided the amount is within the rational economic limits for the specified crop, soil, climate and price conditions prevailing. The following two sections deal with the establishment of these limits.

The upper limit of fertilizer use

The optimum fertilizer rate, by definition, specifies that the last small increment applied gives a return just large enough to pay for the cost of that increment - it returns no profit. In reality, thus high a rate should never be used because the individual would be no worse off than if he simply did not invest this last increment of resource at all. In fact, by not investing it, he would avoid the uncertainty of losing the investment entirely to some unexpected natural event. A second, and more important reason for not using the optimum rate as defined, is that, in reality, most decision-makers have alternative opportunities to invest and secure some specified return on the types of resources needed for applying fertilizer. For example, the resources may be invested in animal feed with some given rate of return expected. They might also be invested in crop protection activities or even in the fertilization of another crop. A sum might also be invested in various securities which are expected to yield a given relative revenue.

Under conditions where there are adequate resources to purchase all the fertilizer needed and there is an alternative investment opportunity for money, the rate of fertilizer applied would be that rate for which the marginal unit applied gives a return equal to the return on the investment if it were invested in the best alternative. Assume that the best alternative would yield 10% on the investment, the optimum fertilizer rate would be given by rewriting equation 5 as:

$$(35) \qquad dy/dx = 1.1\, C_x/C_y \,.$$

To use more than this amount of fertilizer would lead to a reduction in the revenue to the individual or organization producing the crop.

Frequently, the resources for buying fertilizer are limited to such an extent that not all fields of crops can be fertilized even up to the level provided for in equation 35. The problem then becomes one of how to allocate the investment in fertilizer among various crops and fields to maximize the net return. This goal is achieved when the marginal returns from fertilizer use to all crops or all fields are the same. If the fertilizer response equation for three fields or three crops are given as $f(y_1)$, $f(y_2)$ and $f(y_3)$ and the costs of fertilizer and crops are appropriately designated, the maximum revenue will occur when the following holds:

$$(36) \qquad dy_1/dx_1 = dy_2/dx_2 = dy_3/dx_3 \,,$$

and the total of x_1, x_2 and x_3 multiplied by the prices does not exceed the limited resources. These equal marginal returns must, of course, be greater than the returns in alternative investments.

Another reason why a decision-maker might not use the optimum rate of fertilizer or even some high rational rate, is that he might discount future returns because of uncertainty to a greater degree than the return on a "safe" investment. This discounting characteristic varies among individuals for many reasons, but enters into decision-making whether or not it is recognized by the individual.

Usually discounting is expressed as a percentage just as in the case of interest. Some discounting is made on an economic basis such as the yield of revenue from alternative investments presented in equation 35. Therefore, part of any discounting has a firm basis, but the rest is an individual reaction to uncertainty. Suppose that the total discounting rate (including return on alternative investments) for an individual is 20%. Under these conditions, the rate of fertilizer which this individual should use would be given by

$$d_y/d_x = 1.2\, C_x/C_y \,. \tag{37}$$

PESEK et al. (1960) have presented examples of how discounting affects fertilizer use in the presence and absence of residual fertilizer effects and given one or more cropping seasons. If compounding of returns is considered, and the period of investment in crop growth exceeds the length of one compounding period, then the standard compounding formula must be used to determine the coefficient of the inverse price ratio in equations 35 and 37.

Long-term investments in soil fertility practices, such as liming acid soils, must be considered in light of a real or an individual discounting rate. Such practices as drainage and terracing must also be amortized over a period of time and discounting considerations help determine the maximum intensity of these practices to be followed.

Lower limit of fertilizer use

Given the diminishing returns response curve, the initial increment of fertilizer applied produces the greatest return. The maximum return per unit of fertilizer also is at this level and, if resources for fertilizer use are extremely limited and there is no fixed cost of fertilizer application, the smallest practical application of fertilizer would be the first one. (The optimum fertilizer rate and the rate for fertilizer discussed previously, maximize the return on a unit area basis). The *minimum rate* of fertilizer is defined as the rate which gives the greatest return per unit of fertilizer and application cost.

In reality, however, there is always a cost associated with the application of fertilizer whether a small quantity is applied or whether a large quantity is applied. This is called the fixed cost of fertilizer application and is indicated as line BD in Figure 1. Looking at Figure 1, it is evident that at least x_1 amount of fertilizer must be applied before the fixed cost and the cost of the initial increments are recovered. The profit at x_1 is 0 and less than 0 at rates below that.

Figure 5 (PESEK and HEADY, 1958) is a companion figure to Figure 1 and is a graph of the ratio of the difference between the response curve OCA and the total fertilizer cost line BDC. Note that the relative return rises to a maximum and then declines reaching 0 again at the point where a variable fertilizer cost line crosses the response curve.

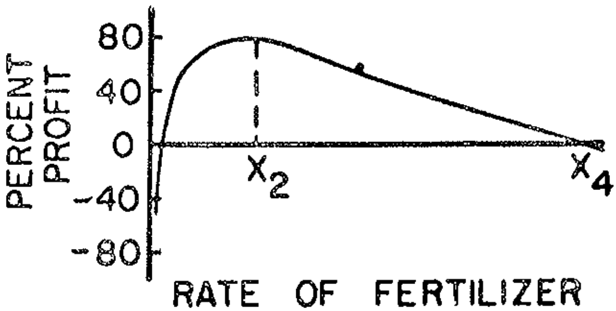

FIG. 5 — Graphical derivation of the *minimum fertilizer* rate, x_2, based on Figure 1. The curve is the ratio of the difference between the response curve and the total fertilizer cost line to the latter. (After PESEK and HEADY, 1958)

If the fertilizer response curve is written:

$$\Delta y = b_1 x + b_{11} x^2 \quad (38)$$

and the variable fertilizer cost line is:

$$C = m + rx \quad (39)$$

where m is fixed cost of fertilizer application per unit area and r is the cost of the fertilizer in units of response.

The quantity to maximize is the difference between these two equations divided by the latter. This maximum is reached at the level of x given in the following equation [1]:

$$x = \frac{\sqrt{-mb_{11} \pm (mb_{11})^2 - mrb_1 b_{11}}}{rb_{11}} \quad (40)$$

The previous calculation is the minimum rate of fertilizer used based on the assumption that a crop may be produced profitably without any fertilizer. In many cases, some fertilizer is required to produce a crop profitably. In this case, the total yield curve and the total cost of production line including the variable fertilizer cost must be considered and the quantity to be maximized is the difference between the yield curve

$$y = b_0 + b_1 x + b_{11} x^2 \quad (41)$$

and the total cost line

$$n = p + rx \quad (42)$$

where b_0 is the yield without fertilizer and p is the sum of the total cost of production and of fertilizer application per unit area.

The quantity of fertilizer which should be the minimum rate applied is given by the solution for x in the following equation [1]:

$$(43) \qquad x = \frac{pb_{11} \pm \sqrt{(pb_{11})^2 - rb_{11}\,(pb_1 - rb_0)}}{rb_{11}} .$$

The interpretation of the value for x in equation 40 is that all similar units of area should receive this minimum amount of fertilizer if there is enough fertilizer available. If there is not enough fertilizer to cover all units at this level, fertilizer should be applied at this level as far as it will reach and the other units should be left unfertilized. In the case of equation 43, x is interpreted as the rate to apply to all similar units, but if there is not enough to treat all units at this level, these excess units should be left out of production. Any other action leads to a reduction in revenue.

Game theory models for decision-making

The two previous sections in this part dealt with the establishment of a rational economic range within which the choices of fertilizer rates must be made. This range is conditioned by the expected (or average) response, the expected price structure, availability of resources for fertilizer purchase and alternative uses for capital which might be expended on fertilizer. We considered the solutions as if the yield functions were known and that they accurately predicted the expected outcome; or that the average of all functions over time is known and the producer will operate long enough to

(1) The author acknowledges simplification of the originally published equation by Prof. Malavolta, Piracicaba, Brasil.

realize this average. Hence, we viewed matters in a *risk* setting.

But we know that the actual functions are not the same each year, depending upon weather, pests, timeliness of operations, etc., none of which are fully known at the beginning of production. Even though the results may be viewed from the point of view of *risk* over a period of years, each year's outcome is uncertain. Therefore, we must consider decision-making under *uncertainty*. Decision-making under uncertainty is quite different from decision-making under *risk*. The behavior of an individual regarding *uncertainty* is probably affected by age, tenure, family situation, equity and psychological traits.

Walker et al. (1960, 1964) and Christensen (1968) applied game theory models to fertilizer and other crop producing decisions. There are at least four models which were explored in these studies, Laplace, Wald, Savage and Hurwicz.

The Laplace model is a special case of a simple risk model. In it, it is assumed that each previously observed outcome has an equal chance of occurring in the next season, or that the average condition will occur. The alternative chosen is the one which is expected to give the highest return. Because the "best" is always expected, the Laplace solution is an optimistic one and provides no protection against the occurrence of low returns because of the alternative chosen.

Just as the former model is optimistic, the Wald model leads to conservative action. It is set up as a game against nature with states of nature and alternatives making up the choice matrix. The decision-maker playing against nature assumes that nature "tries to do its worst" and, therefore, always selects an alternative which maximizes returns under the worst which nature presents. The fallacy is that nature, unlike a living opponent, does not take conscious action.

A Savage minimum regret model is less conservative than the Wald. Its operation starts with the Wald "states -

alternatives" choice matrix and a new regret matrix is generated by subtracting the highest outcome alternative within each "state" from each other alternative. This new matrix is one of *ex post* opportunity losses. The strategy is to minimize the opportunity loss for a given season or crop.

The HURWICZ criterion depends upon the assignment of an optimism-pessimism index a to an operator. This index lies between 0, optimistic, and 1, pessimistic; under the latter, the strategy in a given game is the same as the WALD solution gives. If m is the minimum and M is the maximum outcome under one alternative over all "states", and $1 - a$ is the individual's belief that M will occur, then $am + (1 - a)M$ is the a index for that alternative. The alternative with the highest a is the preferred one.

Even more favorable outcomes may be determined by using more than one alternative, e.g., part of the crop may be fertilized at one level and another part at a higher or lower level. Availability of rapid computational methods and linear-programming procedures makes the use of game theory possible in planning, especially at a regional or national level. It is assumed here that regional or national goals in crop production can accommodate individual preferences within the total plan. On an individual choice-making level, game theory can be used to help understand the behavior of producers and thus point out new approaches and research needed as well as helping them make more consistent choices with a fuller knowledge of why they make them as they do. The possibilities have hardly been touched.

SUMMARY

Developments in data reduction and analysis during the last twenty-five years have made it feasible to apply multiple regression analysis procedures to the results of multivariate

experiments on a scale not previously possible. Not only can more sets of observations be analyzed quickly, but the number of variables possible in the regressions has expanded tremendously. For the first time, then, it has been possible to consider the analysis of multivariate fertilizer experiments including several rates of N, P and K and other fertilizer nutrients, and the interactions of these nutrients with each other and with measured uncontrolled variables associated with the sites or seasons of a series of experiments.

These multiple regression equations relating yield to the various controlled and uncontrolled factors of production were the key to the application of economic principles for specifying the optimum range of fertilizer applications given the initial conditions determined by experience or prior measurement. This range is bounded by the *minimum* rate of fertilizer to apply, if any is used, and the *optimum rate* and represents the rational choices open to producers in all categories of capital, land and personal restrictions. The concepts developed may be applied to individual fields, firms, or regions for the purpose of optimizing the investment in fertilizer.

The second-degree polynomial has been employed as the basic equation for representing the concepts and procedures because it has linear parameters, is algebraically simple and most statistical or biometric calculations are easily applied. Other equations, intuitively, would seem preferable but they lack the simplicity of the polynomial which also may be expanded in degree to approximate the results of the other equations as closely as one wishes.

Before the advent of rapid computation methods, the size and complexity of experiments and their pooling was limited. Now, the physical limitations of the sites, their number, and experimental operations and measurements pose the most serious problems. The author favors some fractional factorial experimental designs with intensive sampling of each experimental unit for the generation of data to calculate the crop yield equations. Specifically the fractional factorial combinations in a modified central composite design based on five or more rates of each element studied is proposed. These data are to be collected at the maximum number of sites but with a minimum of units at each.

The initial conditions of the soil are measured by previously and independently calibrated chemical or biological analyses. Soil nutrients so determined are permitted to express their direct effect upon yield and also to affect the response to applied fertilizer nutrients through interaction terms in the yield regression equation. The matter of high intercorrelation of soil variables within a restricted number of sites has not been dealt with adequately, nor has the problem of the selection of terms to remain in the working equations. This results in the practical restriction of the equations to use in making recommendations only within a universe of similar soil and climatological conditions. The problems of an increasing rooting volume during the season and the decrease in availability of some fertilizer elements have been considered but no practical solution provided.

Uncontrolled variables associated with weather have been incorporated into the regression equations mostly through interaction terms involving both soil and fertilizer variables. The manner of reduction of weather observations has been either through a polynomial expression of temperature and precipitation or available moisture as a function of time or as an expression of moisture stress in numbers of days of stress and based on moisture supply and atmospheric conditions. The latter seems to have been most effective.

While not perfect, the procedures for conducting the experiments needed to estimate economic levels of fertilizers are available. In the hands of a competent agronomist working alone or with others trained in biometrics, computer programming, soil chemistry, etc., and supplied with material and labor resources, these methods can be applied anywhere. The results generated can be used to help in better allocation of scarce crop production resources at individual, local or national levels. The benefits, and problems, associated with more efficient food and fiber production by introduction of fertilizer and other technology are widely known. They can be turned to the advantage of mankind now. In the meantime, there is need for more research on fertilizer use for application to future needs.

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DISCUSSION

Chairman: M. Y. Coïc

Colwell

I would like to raise two points I think are important, one much more so than the other. Taking the smaller point first, this concerns your statement on page 18 of your paper concerning your preference of the natural scale rather than the square root scale for the quadratic response model. The great attraction of the quadratic model is that it leads to simple calculations for optimal fertilizer rates etc., and I think that we agree that the quadratic model on either scale is far from perfect. The square root model gives a lower and more realistic curvature in the vicinity of the optimum and this is its advantage over the natural scale model, as you indicate. The isocline map for the square root model converges to the origin whereas that for the natural scale does not and this you regard as a sufficient reason for preferring the natural scale. Now of course we would like to know the true form of the response surface to judge the validity of this preference and it is difficult to decide this point experimentally because the differences in this respect are usually small relative to experimental error. I suggest that your preference is on farely logical grounds and I wish to present a similar logical argument supporting the square root model.

Consider the response to a compound fertilizer containing several nutrients in a fixed ratio. Because the ratio of nutrients in such a fertilizer is fixed, the response to various rates is in a vertical phase intersecting the response surface of the origin. To this extent the response resembles much more closely response to simultaneous optimal rates of the individual nutrients, with the square-root scale. Although the isocline map is curved, the curvature is low so that the response to compound fertilizers resembles that to simultaneous optimal applications much more with the square-root model than the natural scale model.

Now my second point, which I regard as much more important, concerns the analysis of variance of Table 2. This is a dangerous analysis and is statistically incorrect. The objection concerns a mixing of two different variances in the residual sum of squares i.e. heteroselasticity. The nature of the error can be illustrated in simple terms by different substitutions for s (number of sites) and for R (number of replicates). For example consider the case of 101 sites and 11 replicates, compared with 11 sites and 101 replicates. According to the analysis these very different sets of data would have the same residual degrees of freedom i.e. (n^r-1) $(10+100+1000)$, and this is obviously not correct. In fact with 11 sites there is a total of 10 d.f. for between site comparisons and for 101 sites there are 100 d.f. The effect of this error is to make tests of significance on between site variables seem much more significant than they really are. This error has misled many people into claiming significant trends by fitting multiple regressions, when in fact the data do not indicate statistical significance. One way of analysing this sort of data is based on separating orthogonal trends from the data of each field experiment as described for example in some of my pubblications, cited at the end of my paper.

PESEK

Professor COLWELL has raised two important points which have not gone without consideration. We shall start with the first one. The experimental design which has been suggested in the paper does not employ mixed fertilizers but uses pure fertilizers, blending them according to the requirements of the treatments, and therefore the design does indeed include treatments along the edges of factor space. I do have observations with two, three and four factors and there is some significance of meaning to the straight isoclines. I cannot accept that it is more difficult to get very low yields than it is to get a very high yield. This is my basic objection to the root scale transformation. The comment on errors being different is true and this is recognized. You will note that I emphasised the greatest number of sites and the minimum number of treatments within sites. This will tend to give you more weight to the site effect error term so that it will dilute the precision within a site if errors are pooled inadvertently. Nevertheless, there are several lines of error terms in the regression analysis of variance and whenever experiments are pooled the first thing one does is to examine the different sources of error and one does not pool errors for testing the whole regression until after it is determined that the error terms themselves do not vary from each other. If they do not vary from each other, then they may be pooled according to published statistical texts, but if they do vary from each other, one has to use the appropriate error term for the appropriate regression coefficients; in other words, the site coefficients would be tested by the error term which is generated by the site effects.

HERNANDO

The real difficulty is how to solve the problem of agricultural research so as to be in line with industrial research. Last century many wellknown chemists like Liebig, Boussingault, Lavoisier etc. worked on agricultural problems; in this century the best researchers in chemistry are working in industrial and not in agricultural chemistry. I spoke to some of them and they told me not to be interested in agriculture which is good for humanity but does not offer the possibility to repeat an experiment when one would want to do it because of the many uncontrollable factors. That is why they prefer to work in industries where it is possible to repeat exactly the same experiment. Prof. PESEK presented a method to arrive at this system in agriculture so that we have now the possibility to get many chemists to work in our field who until now remained outside.

Now I try to ask you a question: One of the factors you use is the temperature and you say that you use an average day temperature. My suggestion is, would it not be better to use the lowest and the highest day temperature since they are more in relation to the growth factor. Maybe you will answer that this would be more complicated. But today we have the computers, and I believe that it is very important to have extreme temperatures in the equation.

PESEK

The answer to your temperature problem is that the only limitation is how many times you can repeat the experiment. If you can repeat the experiment enough times you could do this — the degrees of freedom are the crux of the matter. This is completely within the scope of the computer programme; is completely within the scope of the concept, and as a matter of fact, one of my graduate students from Peru actually used maximum temperatures during the day instead of average temperatures to study the effects of fertilization on rice.

HERNANDO

You are taking everyday temperatures in one of these experiments. I think it will be better if you do not have the possibility or degree of freedom to take the minimum and maximum everyday temperature maybe possibly every three or four days or maybe every week, because I think the lower temperature during the day and the highest are more important for growth than the mean one.

PESEK

Yes, we do take daily temperature but we reduce the daily time which Fisher proposed originally; simply a 3rd, 4th or 5th temperature from all observations of temperature to a function of degree polynomial of time which gives a very close fit of the temperature distribution and magnitude during a season. The temperature figures, as such do not go into the regression but the coefficients of these terms that describe this model. We have to reverse the process to get the optima back out, so we use perhaps 3,4, or 5 terms to describe the temperature for the whole season. This is the same of the moisture supply.

BLANCHET

Je voudrais faire une réflexion simplement sur ces problèmes et sur un aspect un peu délicat qui me paraît soulevé. Au début de son rapport, Dr. FRIED dit que quand on demande aux gens pourquoi ils mettent des engrais, ils répondent: pour augmenter les rendements. Or, c'est pour nourrir les plantes, d'abord, que l'on met des engrais. Je pense que le problème des éléments retenus par le sol, c'est-à-dire des engrais phosphatés et potassiques, peut-être même un peu des engrais azotés, pose dans ces calculs économiques un problème assez particulier et délicat. Souvent, tout ce qui est apporté par l'engrais n'est pas absorbé par la culture au cours de l'année d'apport, mais ce qui n'est pas absorbé reste, en général, dans le sol sous une forme assez valablement assimilable. C'est donc un capital qui est investi dans le sol, et je me demande si on a bien le droit, pour ces engrais phosphatés ou potassiques, de traiter le résultat sur la seule année de l'apport. Même la réaction de l'année suivante n'est pas forcément très valable à considérer seule, et à mon sens, la quantité non absorbée est à considérer comme une partie de la fumure de fond, donc comme une valorisation du sol qui peut être mesuré pas des techniques appropriées. En sols pauvres, je crois qu'elle constitue une création de fertilité, à proprement parler; en sols riches, elle peut éventuellement éviter l'apport d'engrais l'année suivante. Je serais heureux d'avoir le point de vue des agronomes économistes sur ce sujet.

I should like to make simply a reflection on these problems and on a somewhat delicate aspect which appears to me to be raised. At the beginning of his paper Dr. FRIED says that when one asks people why they put fertilizers they answer: to increase the yields. Well first it is to nourish the plants, that one gives fertilizers. I think that the problem of elements retained by the soil, that is to say phosphatic and potassic fertilizers, maybe even some nitrogen fertilizers, puts in these economical calculations a very particular and delicate problem. Often all that is supplied by the fertilizer will not be absorbed by the plant in the same year, but what is not absorbed remains generally in the soil under a quite validly assimilable form. Therefore, it is a capital that has been invested in the soil, and I ask myself if I have really the right, for these phophatic and potassic fertilizers, to treat the result just on the supply of the year. Even the reaction of the following year is forcibly very valid to consider singly, and according to me, the non-absorbed quantity must be considered as a part of the basic manure, thus as a valorization of the soil which may be measured by the appropriate techniques. In poor soils I believe, this constitutes a creation of fertility, properly speaking; in rich soils it may eventually avoid the supply of fertilizers in the following year. I should be glad to know the viewpoint of the agronomists-economists on this subject.

PESEK

This is a very good question and I use as an example this problem of an investment in the spenditure for calcium carbonate in the corn belt. This is an input probably which will not return a profit the first year, so our procedure has been to accumulate the response over the expected or a reasonable lifetime of the calcium carbonate application; we used 10 years. We added the value functions of all the crops grown during those 10 years and performed the analysis accordingly. Now the thing that one has to remember is that money costs money, and a return of 10 dollars ten years from now is not worth 10 dollars today. Therefore, we introduced the discounting equation to evaluate the accumulated discounted value of the returns over the life of the treatment with lime. Two colleagues and I published a paper in the Transactions of the International Soil Science Congress of 1960 dealing with discounting. It dealt with the question of what effect residual fertilizer carryover has on the economic optimum. The answer is that if the discounting rate of the future is not too high, the optimum is higher if you consider additional years of return for the same application. However, if a farmer knows he is on his land only one year, he has no future in that land, so he has to have a planning life of only one year. This is a very good point and I think it can be handled satisfactorily.

THE DERIVATION OF FERTILIZER RECOMMENDATIONS FOR CROPS IN A NON-UNIFORM ENVIRONMENT

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I. Introduction

The amounts of fertilizer required for the most economic production of crops in a region commonly varies in a largely unpredictable manner, throughout the region and from year to year. As a consequence potential profits are lost either because insufficient fertilizer is applied to obtain potential yields or because too much is applied, wasting money and possibly also depressing yields. The variability in fertilizer requirements is caused by factors such as differences of seasonal weather conditions, cultivation methods, varying infestations by weeds and pests, disease, and types of soil and levels of available nutrients in the soils. The usual sequence of research into the needs for fertilizers in such a region is firstly to carry out a series of field experiments with fertilizers, to obtain a general indication of fertilizer needs, and then to seek methods for estimating the specific fertilizer requirements of the crops to be grown in the individual fields of the region. This sequence of work seems to have proven very satisfactory in the more prosperous agricultural regions of the world, such as parts of Europe and North America, although the success of the work may have been judged more on the basis of the general prosperity rather than by a critical appraisal of the actual results of the research. For poorer agricultural regions where the needs for accurate estimations of fertilizer requirements is now of much greater importance, corresponding programs are being attempted. There are however severe practical difficulties to be overcome. Funds for research are usually very limited, large areas have to be covered with few trained research workers and there may be problems associated with primitive forms of agriculture. The work needed is both expensive and time consuming. It is important therefore to carefully assess the results of such programs during their course and to modify the programs on the basis of local experience. Methods for assessing data from such programs are considered in this paper.

II. Example data

The methods to be discussed are conveniently described and illustrated with a set of data from fertilizer experiments. For this purpose data have been taken from a series of experiments designed to show the effects of nitrogen and phosphorus fertilizer on wheat, in a region of southern New South Wales, Australia, and these data will be referred to as example data.

The example data are the yields of wheat grain from 46 fertilizer experiments in each of which the treatments were factorial combinations of 0, 20, 50, 100 kg N and 0, 10, 20, 50 kg P, applied as fertilizer at seeding, with 3 replicates for each experiment i.e. $4 \times 4 \times 3 = 48$ plots for each experiment. The experiments were carried out to represent a large region (300 by 500 km) over the 3 year period 1968-1970, and they consequently represent a variety of seasonal weather conditions and different types of soil. The data could be partitioned into less variable groups, but for the purposes of this paper they are considered as a whole.

Previous work in the region represented by the example data has shown that phosphorus is by far the most important nutrient affecting wheat production and that nitrogen is the only other deficiency likely to be important at least for the immediate future. Soil tests for P fertilizer requirements have not proved popular with farmers because wheat production based on soil test recommendations has not generally proven noticeably better than that for fertilizer applied on the basis of local experience. Nitrogen deficiencies also occur but nitrogen fertilizers decrease yields about as often as they increase them (e.g. COLWELL, 1963*a*; COLWELL and ESDAILE, 1968; DANN, 1969). At present there is no satisfactory method for distinguishing between soils which will give negative or positive responses to nitrogen fertilizers.

III. FERTILIZER REQUIREMENTS FOR INDIVIDUAL SITES

Fertilizer experiments are usually carried out to estimate fertilizer requirements for optimal crop production, at particular sites in a region. Simple exploratory experiments, with only 2 or 3 treatment levels for each fertilizer, may be carried out at first to identify nutrient deficiencies but thereafter the experiments are required to provide a basis for estimating yield response functions from which fertilizer requirements can be calculated. Empirical polynomial models provide a convenient means for representing experimental data as response functions, and regression methods may be used both to estimate the models and for significance testing on the effects of fertilizers on yield (e.g. COLWELL and STACKHOUSE, 1970). Standard statistical procedures are available for estimating the reliability of quantities that may be calculated from such surfaces (e.g. FULLER, 1962).

A convenient model for the example data is the quadratic, on the square root scale,

$$(1) \qquad Y = b_0 + b_1 N^{\frac{1}{2}} + b_2 P^{\frac{1}{2}} + b_3 (NP)^{\frac{1}{2}} + b_4 N + b_5 P \ldots$$

where Y = yield and N, P = rates of application of nitrogen and phosphorus as fertilizer. The square root scale is usually preferable to the natural scale for a quadratic model because it gives a more realistic response form with low curvature in the vicinity of maximum yield. It also serves to concentrate more information on the response to fertilizer into the orthogonal linear trend for the purposes of analysis of variance of factorial data and for soil test calibrations (COLWELL, 1967*b*, *c*).

The rates at which fertilizer should be applied to crops are calculated from response functions by a variety of procedures, some of which can lead to quite uneconomic applications of fertilizer. Appropriate mathematical procedures based on the law of diminishing returns have been known at least since the pioneering days of MITSCHERLICH (1909) but have not been always used possibly because the calculations can be cumbersome, without computer facilities, and also possibly because many scientists lack the mathematical background to appreciate the procedures. It is now 16 years since BAUM, HEADY and BLACKMORE (1956) felt the need to comment that "until recently relatively few agricultural economists had enough training in mathematics and statistical techniques to use this type of analysis", referring to appropriate procedures for calculating fertilizer requirements and unfortunately the comment is today pertinent of many agricultural scientists. Apart from these considerations there are still difficulties which prevent the use of mathematical procedures based on the law of diminishing returns, namely the occurrence of non-ideal yield functions not of the diminishing form. Different procedures are required for these forms and this use of different procedures can cause confusion. Accordingly the calculation procedures are briefly reviewed as a basis for the discussions.

1. *Simple fertilizer requirement*

Given a functional relationship, $Y = f(F)$, defining crop yield, Y, as a function of rate of application of fertilizer, F, the relationship between profit and money invested in fertilizer can be derived by,

$$\pi = V.Y - I - Q \ldots \qquad (2)$$

where π = profit, V = value of a unit of yield, I = investment in fertilizer and Q = fixed costs. Investment I is calculated by I = C.F. where C = cost of a unit of fertilizer. The yield response function, ΔY can be derived from the yield function Y, by,

$$\Delta Y = Y - Y_0$$

where Y_0 = yield for nil fertilizer and the corresponding function of profit from the use of fertilizer is,

$$\Delta\pi = V.\Delta Y - I .$$

The functions of fertilizer rate, Y, ΔY, π and $\Delta\pi$ are thus all closely related. The rate of return on some differential investment is simply the slope $\frac{d\pi}{dI}$, which is identical with $\frac{d\Delta\pi}{dI}$. In the simple and commonest situation when (1) the functions Y, ΔY, π or $\Delta\pi$ are of a diminishing form, (2) fixed costs associated with the use of fertilizers are negligible and (3) crop production with nil fertilizer still gives a profit, the rate of return $\frac{d\pi}{dI}$ or $\frac{d\Delta\pi}{dI}$ decreases with increase in I and fertilizer requirement is defined simply in terms of a minimal marginal rate of return, R. Thus because of the diminishing form, the fertilizer requirement can be defined as that amount of fertilizer which satisfies the equation,

(3) $$\frac{d\pi}{dI} = R \text{ or } \frac{d\Delta\pi}{dI} = R \quad \ldots$$

where R is determined from a consideration of the alternative investments available to the farmer. For maximum profit, $R = 0$ and since in practice farmers always have some alternative investment likely to yield a return, fertilizer should not, under usual circumstances, be applied for maximum profit. For an optimal investment the marginal rate of return will thus usually be greater than zero i.e. $R > 0$.

Since profit and investment are functions of fertilizer rate, $\pi = V.Y - I - Q$ and $I = C.F$, then it follows that $\frac{d\pi}{dI} = \frac{V}{C} \cdot \frac{dY}{dF} - 1$, so that fertilizer rate can be calculated more directly by solving the equation,

(4) $$\frac{dY}{dF} = \frac{C}{V}(R+1) \text{ or } \frac{d\Delta Y}{dF} = \frac{C}{V}(R+1) \quad \ldots$$

For the simple yield function,

$$Y = b_0 + b_1 F^{\frac{1}{2}} + b_2 F$$

fertilizer requirement is thus calculated by solving $\frac{dY}{dF} = \frac{b_1}{2F^{\frac{1}{2}}} + b_2 = \frac{C}{V}(R+1)$, so that,

(5) $$F = \left[\frac{b_1}{2\left\{\frac{C}{V}(R+1) - b_2\right\}}\right]^2 \quad \ldots$$

2. *Simultaneous fertilizer requirements*

The above procedure can be extended to calculate the optimal requirement for several fertilizers, applied simultaneously. Thus with the general yield function $Y = f(F_1, F_2 \ldots F_m)$ in which yield is expressed as a function of the application rates of *m* fertilizers, the optimal application rate of $F_1, F_2 \ldots F_m$ will satisfy the simultaneous equations,

$$\frac{\partial \pi}{\partial I_1} = \frac{\partial \pi}{\partial I_2} = \ldots \frac{\partial \pi}{\partial I_m} = R$$

or the equivalent set,

$$\frac{\partial Y}{\partial F_j} = \frac{C_j}{V}(R+1), \quad j = 1, 2 \ldots m \ldots \tag{6}$$

where C_j is the cost of the fertilizer F_j.

Thus for the quadratic model (1) the optimal application rate of N and P is the solution of the equations,

$$\begin{aligned} \frac{\partial Y}{\partial N} &= \frac{b_1 + b_3 P^{\frac{1}{2}}}{2N^{\frac{1}{2}}} + b_4 = \frac{C_n}{V}(R+1) \\ \frac{\partial Y}{\partial P} &= \frac{b_2 + b_3 N^{\frac{1}{2}}}{2P^{\frac{1}{2}}} + b_5 = \frac{C_p}{V}(R+1) \end{aligned} \tag{7}$$

An example of these calculations is given below for equation (8).

3. *Non - ideal response forms*

The calculations described above are simple in concept and can, in theory, be applied to any yield response function, and may involve any number of fertilizers. The calculations depend however on the response being of a diminishing return form and on the solution not being an extrapolation beyond the range of any of the data. Non-ideal response forms which do not meet these conditions are not uncommon due to inadequacies in experimental data which seem to be unavoidable amongst series of fertilizer experiments carried out under field conditions, despite the skill and care of experimenters. In retrospect many of the faults seem easily remedied. Inappropriate treatment levels may have been chosen to define the yield response function in the vicinity of optimum fertilizer requirements, experiment sites may prove non-uniform and so on. To repeat these experiments usually involves a delay of at least a year so that the experimenter feels obliged to interpret them as best he can. Similar but less obvious errors may affect other experiments in a series so that to reject experiments can introduce bias to any estimate of regional fertilizer requirements, simply because they do not conform to the ideal form. The types of complication that can arise from non-ideal forms with multi-fertilizer experiments, particularly those of a central composite type design, have been described elsewhere (COLWELL and STACKHOUSE, 1970). Only the simpler complications of the type depicted in Fig. 1 for a single fertilizer are considered here.

For responses of the form of curves 1, 2 and 3, (Fig. 1), the application of equation 3 to calculate optimal fertilizer requirement is meaningless. The fertilizer requirement is, however, obviously nil. Responses of form 1 or 2 occur when fertilizer depresses yield. This may be a result of toxic effects due to high levels of the nutrient in the soil, or indirect physiological effects such as an exhaustion of soil moisture reserves by stimulation of early vegetative growth by the fertilizer preventing full maturing of the crop. Nitrogen fertilizer may stimulate vegetative growth of wheat, for instance and yet depress grain yields (e.g. COLWELL, 1963; DANN, 1969). The response form 3 may be obtained when the fertilizer has had

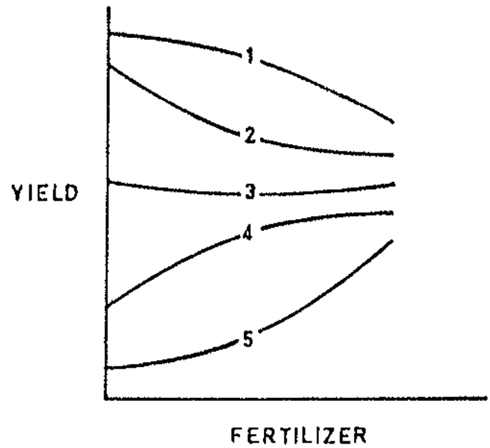

FIG. 1 — Non-ideal forms of yield function.

practically no effect on yield, the anomalous curvature being attributable to experimental error.

The application of equation (3) to a response of the form of curve 5 in also meaningless, and for curve 4, the calculated requirement will be an extrapolation and therefore possibly misleading. These forms occur when there is a very large response to the fertilizer and when treatment levels have not extended to a sufficiently high level to indicate the maximum response. The anomalous curvature of curve 5 could be experimental error associated with a large almost straight line response, or perhaps represent the beginning of a sigmoidal response form. In either case the only safe estimate is that fertilizer requirement is greater than the highest treatment level.

The occurrence of any of the non-ideal forms of response in Fig. 1 for a fertilizer in multi-fertilizer experiments, invalidates the direct calculation of all the simultaneous fertilizer requirements by equations (6). When the requirement of one fertilizer is clearly nil, (curves 1, 2 or 3), then a value of zero may be substituted for this fertilizer in the yield function and the requirements of the remaining fertilizers then calculated. When an extrapolation error is to be avoided (curves 4 or 5) the highest treatment level can similarly be substituted and the remaining requirements calculated. If there are positive interactions associated with the fertilizer giving the large response, these estimates will also be underestimates of the true requirements. In these cases the fact that optimal fertilizer requirement cannot be calculated, and that the true requirement is somewhat greater than the safe values actually calculated can be indicated by a sign $>$, signifying greater than.

Other difficulties can arise in the calculation of fertilizer requirements such as the occurrence of fixed costs directly associated with the use of a fertilizer, as discussed by PESEK and HEADY (1958), the need to allow for the residual value of fertilizers or uncertainty on the value (V) of the crop, as when fertilizer is applied to pasture.

4. *The use of relative yields for estimating fertilizer requirements*

A major source of error and confusion in the estimation of fertilizer requirements from experiment data, is the use of relative quantities for the calculations in place of actual yield figures. Such relative quautities are percentage yield sufficiency, $\%Y_s = \{ Y/Y_{max} \} \times 100$, percentage yield deficit, $\%Y_d = \{ (Y_{max} - Y)/Y_{max} \} \times 100$ where Y is actual yield and Y_{max} is the maximum yield attainable with the particular fertilizer for the local environmental conditions (e.g. BRAY 1944, 1948). It is hardly original to comment that a farmer derives his income from actual yields so that the cost of fertilizers must be justified by yield increases rather than by relative increases (e.g. BONDORFF, 1952). The reason usually given for the use of these relative quantities is that they correlate better with soil test values being less affected by the variations in level of yield from site to site caused by variations in environmental conditions. Unfortunately the relative quantities cannot be used to calculate fertilizer requirements on an economic basis unless the maximum yield is known so that avoiding the complication of variations in yield in this way does not help and it is misleading in this respect to cite higher correlations to justify their use. The need for maximum yield for calculations based on relative quantities is shown by the relationships, corresponding to equation (3),

$$\frac{d\ (\%Y_s)}{dF} = \frac{100}{Y_{max}} \cdot \frac{C}{V}(R+1) \text{ and } \frac{d\ (\%Y_d)}{dF} = \frac{-100}{Y_{max}} \cdot \frac{C}{V}(R+1)$$

Suspect estimates of Y_{max} are sometimes disguised by names such as target yields or goal yields, for the estimation of fertilizer requirements, the implication being that these yields can be attained simply by applying sufficient fertilizer. There are of course other factors limiting maximum yields so this practice can easily result in wastage of fertilizer.

There is also a statistical objection to transforming data to relative values. Dividing site yields by the maximum yield effectively weights error deviations inversely as the maximum yields and this can result in an undesirable bias in regressions involving data from several sites.

5. *Fertilizer requirements from the example data*

Fertilizer requirements have been calculated for the sites represented by the example data with appropriate allowances for non-ideal forms as discussed above. For these calculations local values $V = \$0.037$ per kg wheat, $C_n = \$0.21$ per kg N and $C_p = \$0.32$ per kg P were substituted in equations (5) or (7), with the minimal rate of return chosen as $R = .25$.

The possible calculations are illustrated in more detail in Table 1 for the average response function,

(8)

$$Y = 1576. + 20.3N^{\frac{1}{2}} + 219.P^{\frac{1}{2}} + 1.51(NP)^{\frac{1}{2}} - 2.12N - 16.3P \ldots$$

to be described later. Simultaneous fertilizer requirements for values of R ranging from 0.00 to 2.00 are shown together

TABLE 1 — *Requirements of nitrogen and phosphorus fertilizers as kg N and kg P per hectare for a range of marginal rates of return R. Y = yield response to the applications of N and P; I_n, I_p = investments in N and P fertilizer as \$ per hectare; $\Delta\pi$ = profit from fertilizer as \$ per hectare; G_n = gain from the use of N fertilizer together with P fertilizer.*

R	N	P	ΔY	I_n	I_p	$\Delta\pi$	P	Y_p	I_p	$_p$	$G_n = \Delta\pi - \Delta\pi_p$
0.00	2.9	19.6	688	0.6	6.3	18.6	19.1	644	6.1	17.7	0.9
0.25	2.1	16.5	653	0.4	5.3	18.4	16.2	615	5.2	17.6	0.8
0.50	1.5	14.2	620	0.3	4.5	18.1	13.9	588	4.4	17.3	0.8
1.00	0.9	10.7	562	0.2	3.4	17.2	10.6	538	3.4	16.5	0.7
2.00	0.4	6.7	472	0.1	2.1	15.2	6.7	456	2.1	14.7	0.5

with corresponding calculated values for yield response (ΔY), and profit from fertilizer ($\Delta\pi$) after allowing for the investments in fertilizer (I_n and I_p). The importance of calculating requirements for a value of R greater than zero is shown by the small decreases in profits, $\Delta\pi$, for relatively much larger decreases in the investments, with increase in R. The nitrogen fertilizer requirement is small and the value of using it in conjunction with the phosphorus fertilizer can be calculated by substituting $N=0$ in (7) and then calculating the phosphorus requirement for a single fertilizer by (5). The requirement of P alone is less than with N, (compare left and right sides of Table 1) due to the positive interaction effect and profits ($\Delta\pi_p$) are less. The gain due to using nitrogen fertilizer is the difference $G_n = \Delta\pi - \Delta\pi_p$, and as expected, is small for this yield function.

Corresponding calculations were carried out for all the experiments where possible and the requirements of N and P, profits and gains from the N values are listed in Table 2, for $R=.25$.

TABLE 2 — *Fertilizer requirements (kg N and kg P per hectare), profits from fertilizer ($ per hectare) and gain from N fertilizer, for marginal rate of return $R=.25$.*

Site	N	P	$\Delta\pi$	G_n	Site	N	P	$\Delta\pi$	G_n	Site	N	P	$\Delta\pi$	G_n
1	0	11	10.6	0.0	17	0	21	20.0	0.0	33	0	21	28.6	0.0
2	10	26	32.9	4.3	18	0	21	24.1	0.0	34	5	21	26.9	2.3
3	0	8	7.7	0.0	19	0	5	2.7	0.0	35	5	11	16.4	1.7
4	0	7	3.7	0.0	20	2	14	11.1	0.5	36	0	12	13.0	0.0
5	0	7	5.5	0.0	21	4	26	19.8	1.3	37	0	6	5.5	0.0
6	2	10	9.2	1.2	22	13	26	33.4	4.6	38	0	5	3.4	0.0
7	0	9	6.6	0.0	23	9	24	20.6	3.1	39	19	22	17.0	4.6
8	0	16	24.2	0.0	24	0	5	3.7	0.0	40	7	25	30.5	4.1
9	0	15	17.3	0.0	25	6	19	23.6	3.0	41	21	12	15.9	6.4
10	0	7	9.2	0.0	26	0	15	10.3	0.0	42	14	16	30.2	8.7
11	0	17	28.2	0.0	27	>45	>50	>35.0	>17.8	43	19	17	31.1	10.5
12	0	12	8.7	0.0	28	11	33	18.5	6.2	44	2	26	47.8	1.1
13	0	11	10.9	0.0	29	>16	>50	>48.1	> 4.0	45	2	5	6.2	0.6
14	7	19	40.5	3.4	30	15	22	37.1	7.5	46	12	6	11.7	5.3
15	0	34	44.8	0.0	31	2	19	37.1	0.4	Average				
16	35	27	24.4	11.4	32	0	28	40.9	0.0		6.2	17.8	20.8	2.5

Most of the sites showed either a non-significant effect due to nitrogen or a negative response, and for these the value $N=0$ was substituted and the requirement of P alone calculated by (5). For sites 27 and 29, the calculated requirement exceeded the highest treatment level ($P=50$) and to avoid extrapolated estimates, the N requirement was also estimated by (5) after substituting $P=50$ in (8). The P requirement is shown as >50 and the N requirements >45 and >16 in these instances to indicate that the true requirements can be estimated only by extrapolation. The fertilizer requirements for the 46 experiments range from 0 to >45 kg N and from 5 to >50 kg P, indicating wide ranges of requirements for this particular region. Series of experiments often give such a range of requirements thus leading to the problem, considered next, of what fertilizer rates should be used in the region in the absence of any specific indication of the requirements of individual fields.

IV. Regional fertilizer recommendations

A series of fertilizer experiments commonly give a diverse set of fertilizer requirements such as that in Table 2. Some sites obviously require heavy applications of fertilizer, others little or nil, and at some sites fertilizer will depress yield indicating what might be called a negative fertilizer requirement. In the absence of any means for indicating fertilizer requirements of individual fields, as with nitrogen in the region of the example data, fertilizer rates have to be estimated from a consideration of such a range of possible effects. Such general estimates are termed regional fertilizer recommendations.

1. *Recommendations based on frequencies of profits*

The yield functions estimated by a series of fertilizer experiments in a region, can be regarded as samples from an infinite population of yield functions characteristic of the variable environment of the region. Given an adequate sampling, probabilistic statements about responses in the region become possible and a regional fertilizer recommendation can be chosen on this basis. This is illustrated with the example data.

The responses of wheat to nitrogen and phosphorus fertilizers for the 46 experiments of the example data has been represented by model (1). Treating these functions as a sample of the functions that are characteristic of the region, the sample can be represented by the 46 equations,

$$(9)\quad Y_i = b_{0i} + b_{1i}N^{\frac{1}{2}} + b_{2i}P^{\frac{1}{2}} + b_{3i}(NP)^{\frac{1}{2}} + b_{4i}N + b_{5i}P, i = 1, 2 \ldots 46$$

The profit functions can similarly be represented by,

$$(10)\quad \Delta\pi_i = V\ (b_{1i}N^{\frac{1}{2}} + b_{2i}P^{\frac{1}{2}} + b_{3i}(NP)^{\frac{1}{2}} + b_{4i}N + b_{5i}P) - C_n.N - C_p.P$$

and the probabilities of profits for any particular recommendation of N and P can be estimated from the frequencies of the $\Delta\pi$ values indicated by the sample. Substitution of combinations of the rates N = 0, 5, 10, 20 and P = 0, 5, 10, 20, 40 in the profit function (10) for site 1 of the data gave the profits and losses in Table 3. Doing this for each of the 46 functions

TABLE 3 — *Profits as \$ per hectare from various combinations of N and P fertilizer, at site* 1.

	P kg/ha				
N kg/ha	0	5	10	20	40
0	0	10.0	11.6	11.5	6.4
5	− 1.49	8.2	9.7	9.4	4.1
10	− 2.86	6.7	8.2	7.8	2.4
20	− 5.57	3.8	5.2	4.8	− 0.8

gave a range of similar profits and losses, summarised as frequencies in Table 4. For this table profits have been counted for the frequency classes $ - 19.9 to - 10.0, $ - 9.9 to 0.0, $0.1 to 10.0, ... $40.1 to $50.0 and relative frequencies or probability estimates for these classes of profits for any of the fertilizer combinations, can be obtained by dividing the frequencies by 46. The class bounds can be varied according to the detail required.

Frequencies, as given in Table 4, summarise the expected consequences of particular regional fertilizer recommendations, if they were adopted for all sites at which the crop is to be grown in future years. Obviously very conservative fertilizer recommendations will lead to few profits of consequence but will also ensure no serious losses. On the other hand, liberal recommendations will result in substantial profits for a proportion of the sites as well as substantial losses for another proportion. The best recommendation for the region as a whole should be between these extremes.

The frequencies also serve to indicate abnormal sites and may point to ways for partitioning the data into more uniform groups each with its own fertilizer requirements.

It should be noted that the frequencies within the classes in Table 4, indicate that the continuous frequency distributions for the profits for each combination of fertilizers are skew positive. The use of a classification such as Table 4 avoids the need to assume any particular frequency distribution or to transform the data so that the profits can be represented by a normal frequency distribution, for the purposes of probabilistic statements about the general effects of various fertilizer rates.

2. *Average profits*

The average profit for a region resulting from a particular

TABLE 4 — *Frequencies of profits from various applications of N and P fertilizers, for 46 sites.*

N (kg/ha)	Profit class ($/ha)	P (kg/ha) 0	5	10	20	40
0	− 19.9 to − 10	0	0	0	0	1
	− 9.9 to 0	46	0	0	1	4
	0.1 to 10	0	19	12	10	16
	10.1 to 20	0	18	19	17	11
	20.1 to 30	0	8	11	10	8
	30.1 to 40	0	1	4	6	3
	40.1 to 50	0	0	0	2	3
5	− 19.9 to − 10	0	0	0	0	0
	− 9.9 to 0	28	0	0	1	7
	0.1 to 10	18	17	15	16	14
	10.1 to 20	0	15	14	10	7
	20.1 to 30	0	12	12	10	9
	30.1 to 40	0	2	4	6	6
	40.1 to 50	0	0	1	3	3
10	− 19.9 to − 10	0	0	0	0	0
	− 9.9 to 0	31	0	0	3	8
	0.1 to 10	15	19	17	14	13
	10.1 to 20	0	16	13	9	7
	20.1 to 30	0	9	11	11	9
	30.1 to 40	0	2	5	6	6
	40.1 to 50	0	0	0	3	3
20	− 19.9 to − 10	2	0	0	0	3
	− 9.9 to 0	33	4	3	6	10
	0.1 to 10	11	16	15	13	7
	10.1 to 20	0	16	12	9	8
	20.1 to 30	0	9	11	8	11
	30.1 to 40	0	1	5	9	4
	40.1 to 50	0	0	0	1	3

TABLE 5 — *Average profits as $ per hectare, from various combinations of N and P fertilizer.*

N kg/ha	P kg/ha 0	5	10	15	20	30	40
0	0	13.5	16.3	17.5	17.7	16.6	14.2
3	0.4	14.1	17.1	18.3	18.6	17.6	15.2
5	0.2	14.0	17.0	18.2	18.5	17.5	15.2
10	-0.5	13.4	16.4	17.7	18.0	17.0	14.8
15	-1.4	12.5	15.6	16.9	17.2	16.4	14.1
20	-2.4	11.6	14.7	16.0	16.4	15.5	13.4

combination of fertilizer rates can be estimated from (10) by $\frac{1}{n} \sum_{i=1}^{n} \pi_i$ where n is the number of experiments. Average profits for combinations of a range of application rates of N and P are given in Table 5, and these should be viewed in conjunction with the frequency distributions in Table 4. Highest average profit of $18.6 per hectare is indicated for N = 3 and P = 20 and this combination is indicated as satisfactory for the region by the frequencies in Table 4. Frequency tables for other sets of data, particularly for more variable regions, may indicate however that some fertilizer application other than that giving maximum profit may be desirable. Profits from other fertilizer combinations in the vicinity of the maximum are not much different because of the typical low curvature of the profit response function in the vicinity of the maximum and obviously high precision is not warranted in choice of a regional fertilizer recommendation. Thus if the fertilizer recommendation for the highest profit was likely to result in substantial losses for a proportion of occasions as indicated by the frequency distribution, then it might be desirable to choose lower fertilizer rates as a regional recommendation.

Strictly the sample of functions (10) should be weighted inversely to the number of experiments per season, and according to the portions of regions represented, for the calculations of averages and frequencies. If for instance most of the experiments were carried out in a particular year, the unweighted sample would tend to represent the seasonal conditions of that year.

An important advantage of the choice of a regional recommendation from frequencies of profits and estimates of regional averages resulting from alternative substitutions, is that fertilizer treatment levels and experimental designs can vary without invalidating the calculations, if extrapolations are avoided. A series of experiments assembled from the work of different people over many years is likely to cover a variety of treatments and designs.

3. *Optimal regional fertilizer recommendations*

The principles described for the calculation of optimal fertilizer requirement can also be applied for the choice of a regional fertilizer recommendation. Thus the mean profit for a region from application of fertilizers at the rates F_j, $j = 1, 2 \dots m$, is estimated by,

$$\bar{\pi} = \frac{1}{n} \sum_{i=1}^{n} V.Y_i - C_1F_1 - C_2F_2 - \dots C_mF_m$$

and the optimal fertilizer recommendation can be calculated by solution of the equations $\frac{\partial \bar{\pi}}{\partial I_1}, = \frac{\partial \bar{\pi}}{\partial I_2} = \dots \frac{\partial \bar{\pi}}{\partial I_m} = R$ or $\frac{\partial \bar{Y}}{\partial F_j} = \frac{C_j}{V} (R+1)$, $j = 1, 2 \dots m$, as described for equation (6). The calculation depends essentially on the estimation of a mean yield function $\overline{Y}$. This is simple if and only if the treatment levels and experimental design has been constant for each member of the series. The mean yield function can be estimated then from the mean of the yields over the different experiments for each treatment, or in the case of polynomials by averaging the coefficients. The mean response function for the series of functions (10) can thus be estimated by,

$$(11) \quad \overline{Y} = \frac{1}{n} \sum_{i=1}^{n} (b_{0i} + b_{1i}N^{\frac{1}{2}} + b_{2i}P^{\frac{1}{2}} + b_{3i}(NP)^{\frac{1}{2}} + b_{4i}N + b_{5i}P) \text{ or}$$

$$\overline{Y} = \overline{b}_0 + \overline{b}_1 N^{\frac{1}{2}} + \overline{b}_2 P^{\frac{1}{2}} + \overline{b}_3 (NP)^{\frac{1}{2}} + \overline{b}_4 N + \overline{b}_5 P \quad . \; . \; .$$

The mean function for the example data, equation (9), was calculated by this procedure, and so the optimal regional fertilizer recommendation can be chosen from the recommendations in Table 1. It may be noted that the maximum profit for $R=0$ is for $N=2.9$ and $P=19.6$, corresponding to the estimate from Table 5. As before, the profit frequency distribution for a recommendation should be considered in choosing a recommendation by this procedure, and again weighting according to representation of the region and seasons may improve the estimate of the average yield function for these calculations.

4. *Average of fertilizer requirements*

A regional fertilizer recommendation is often estimated simply by averaging the fertilizer requirements indicated by experiments in a region. Often, as with the example data such an estimate is not very different from that obtained by the above procedures. Apart from the difficulties of calculating averages when some of the individual estimates indicate extrapolation values, as in Table 2, it can be shown that mathematically the average of individual fertilizer requirements is different from the fertilizer requirements calculated from an average yield function, and so could give a misleading estimate. For the simple response model, for example,

$$Y_i = a_{0i} + a_{1i} F^{\frac{1}{2}} + a_{2i} F$$

the fertilizer requirement for each site is,

$$F_i = \left[\frac{a_{1i}}{2C/V (R+1) - a_{2i}} \right]^2 ,$$

by (5) and the average $\frac{1}{n} \sum_{i=1}^{n} F_i$ is different from the fertilizer requirement from the average of the yield functions (11),

$$F = \left[\frac{\bar{a}_1}{2C/V (R+1) - \bar{a}_2} \right]^2 .$$

V. THE VALUE OF SOIL TESTING

Any regional fertilizer recommendation, as derived above will, if followed, be optimal for only a small proportion of the crops produced in a region, that is for the relatively few instances when response to the fertilizers is as described by the mean yield function of the region. There is an obvious need to vary fertilizer rates between individual fields within the region, according to their particular fertility levels, and the way of doing this is often seen to be by soil testing. If the nutrient levels in fields can be measured by simple chemical soil tests then fertilizer applications can be varied above or below the general regional recommendation by amounts according to the soil test level. The appropriate variations for particular soil test levels can be derived from soil test calibration equations that have been derived from regional regression estimates. A soil test calibration based on regressions of the parameters of yield functions on soil test values provides such a means of varying a regional fertilizer recommendation (COLWELL, 1967*b*, *c*, 1968, 1970*b*; COLWELL and ESDAILE, 1968). The value of soil testing to a region can then be gauged from the increase in profits resulting from the variation about the regional fertilizer recommendation made on the basis of the soil test. Such a valuation is likely, however, to be an overestimation since in practice a regional fertilizer recommendation will be varied on the basis of local knowledge about cropping history and past performance of individual fields, presumably giving better estimate of local requirements. The valuation will also be favoured if the increase in profits likely to result from using soil test estimates is calculated from the same data as was used to derive the test calibration. A critical economic appraisal of soil testing would require a set of experiments, carried out within a region over a number of years, designed to estimate the increase in profit that would result from fertilizer applied according to a soil test recommendation, over the profit that would be obtained from fertilizer applied on some alternative basis, such as a regional recommendation modified according to local experience and land-use history. Clearly the better the soil test calibration and the worse the alternative estimates, the more valuable a soil testing service would be. This type of appraisal seems never to have been carried out. Research resources are usually devoted to developing and improving soil test procedures rather than to assessing the value of existing services.

The likely value of soil testing to a region can also be gauged from the data provided by a series of fertilizer experiments, even before a soil test has been developed or calibrated, by comparing the profits estimated for the optimal application of fertilizer at each experiment site with those which would be obtained by following a regional recommendation. Thus for the example data, the estimated average profit from the optimal application of fertilizer at each site for a marginal rate of return $R = .25$ is \$20.78 (Table 2) whereas the estimated average profit from the application of fertilizer for the regional mean function is \$18.43 (Table 1). Thus in this example, the maximum scope for improvement in regional profit by soil testing is only of the order \$2.35 per hectare cropped, even though there is an obvious wide diversity of fertilizer requirements above and below the regional recommendation of $N=2.1$ and $P=16.5$ (Tables 1 and 2). The explanation for this estimated small gain from the precise application of fertilizer at its optimal rate lies in the typical low curvature of the yield or profit surface in the vicinity of optimum profit. Even quite wide variations in fertilizer application rates have relatively small effects on profits, as illustrated by the calculated profits for the mean yield function (Table 1) and for site 1 (Table 3). The largest gain in profit from fertilizers is from the first crude estimates of their requirements, as by the estimation of regional fertilizer requirements, and later refinements to more precise estimates do not in general add much. For this particular region there seems little prospect of estimating nitrogen fertilizer requirements by soil testing, at least for the present, and phosphorus test correlations have been far from perfect. Add to this the known variations in crop response due to unpredictable effects of weather, weeds and disease which also affect fertilizer requirements and it seems obvious that soil testing will be of little value for this particular region considered as a whole. Rather than establish a testing service it would seem better to simply use the regional recommendation, varying it a little according to local knowledge about individual fields and districts.

Soil testing can have other, less obvious benefits, for example by bringing farmers into contact with local agricultural extension workers and by encouraging local experimentation with fertilizers. Such benefits may explain some of the relatively high agricultural prosperity in countries where admittedly rough and imperfect soil testing services have functioned for many years. The development of automatic methods for analysing soils, and of computer methods for furnishing soil test recommendations to farmers may mean ultimately that the cost of soil testing will become negligible, so that any gain from testing is worthwhile.

VI. Conclusions

The work needed to improve agricultural production in a region by the use of fertilizers usually seems obvious enough. Fertilizer experiments have to be carried out to find out local fertilizer requirements and then methods have to be devised to estimate the requirements of the individual crops to be grown in the region in the future. Commonly it is assumed that the need is simply to carry out a large number of fertilizer experiments and then to establish a soil testing service similar to those operating in North America and Europe. Fertilizer experiments are costly, however, if they are carried out properly and are reasonably comprehensive, and the objective should therefore be to obtain the information they can provide about a region with a minimum number of experiments. Also, given good general estimates of fertilizer requirements for a region, the economic gains from more precise estimates based on soil testing may hardly warrant the cost of the testing service. These considerations are particularly pertinent to development programs for the poorer regions of the world where research resources are very limited both with respect to funds and research personnel.

From these considerations it is suggested that research programs on fertilizer requirements should be regarded as sequential sampling projects. With this view-point the fertilizer experiments are carried out to provide samples of the response functions that are typical of a region, and as in normal sampling, the experiments will be located to represent the region with all its diversity of growing conditions from site to site and from year to year. From the beginning the samples should be studied for the information they provide on the variability of the region so that the infinite population being sampled can be partitioned into less variable groups, as on the basis of cropping history, soil type, geographic location and so on. The sampling can then be repeated within these groups. The needs for more specific estimation of fertilizer requirements can be conveniently examined by frequency tables, such as Table 4, and by comparisons of profits from the application of fertilizers according to specific and general estimate of fertilizer requirements. As shown by the example data, given a good estimate of regional fertilizer requirements, the gain from more specific estimates may be small, and this gain is likely to be reduced quite considerably if sites are classified on the basis of cropping history, soil type, location, etc. This can be shown for the example data which represents a very large region and a wide range of growing conditions. Soil testing should only be contemplated after a study of the fertilizer requirements of a region in this manner.

Note: *The discussion of this paper, for matter of time, was postponed. It was included in the Joint Discussion of the papers*: PESEK, COLWELL *and* FRIED.

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THE EFFECT OF CULTURAL PRACTICES ON EFFICIENCY OF FERTILIZER USE DETERMINED BY DIRECT MEASURE IN FIELD EXPERIMENTS USING ISOTOPICALLY LABELLED FERTILIZERS

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The question of why fertilizers are added to soils invariably receives the response "to increase yields". Yet, this answer tends to put a mental block on the real primary reason for adding fertilizer, and this is to feed the plant. It is only as a result of this feeding process that the plant may respond by giving a higher yield, or a higher protein content, etc.

Once the mental block is surmounted it is easy to get on with the real problem of how cultural practices affect the efficiency of fertilizer use because, by fertilizer use, we are talking about the uptake of a nutrient by the plant. Fortunately, there is a quantitative way of directly measuring the uptake of a fertilizer nutrient by the plant and this is by use of labelled fertilizers. The use of this tool in research of direct value to practical agriculture depends on an ability to determine actual fertilizer utilization in field experiments.

International research programmes coordinated by the Joint FAO/IAEA Division, Vienna, have involved over a hundred field experiments primarily in developing countries, where the effect of placement, time of application, fertilizer source, nutrient interactions, and other cultural practices on fertilizer efficiency was measured directly and quantitatively. The experiments were primarily with the major food grains rice, maize and wheat. Some of the results are presented and the implications discussed.

Rice - Phosphorus

Table 1 compiles the results of nine identical experiments located as far away from each other as Hungary and the Philippines. When phosphate in the form of superphosphate

TABLE 1 — *Effect of placement on the percentage of P in rice plants that was derived from labelled superphosphate (60 day harvest).*

Location	Treatments						
	Surface	Hoeing	Hill 10[a]	Hill 20	Row 10[b]	Row 20	LSD 5%
Philippines (Los Baños)	17	17	6	4	4	3	2
Thailand (Bangkhen)	68	68	50	34	51	36	9
Thailand (Surin)	37	40	22	15	26	23	2
Burma (Gyogon)	11	17	6	4	4	3	2
Burma (Mandalay)	25	25	6	6	6	4	3
Pakistan (Tandojam) (80 days)	48	50	5	4	4	4	5
Dacca	19	25	22	17	12	7	8
Egypt (Sakha)	64	60	37	38	38	37	10
Hungary (Szarvas)	3	3	2	1	1	1	1

[a] Placement at 10-cm depth in the planting hill.

[b] Placement at 10-cm depth between the rice rows.

is applied on the surface or worked into the surface, the plant takes it up more effectively than when it is applied at any other location. In one location placement in the planting hole at the time of transplanting was as effective, but not more effective. The results are clear and conclusive. Since this placement happens to be the easiest to apply, there are no complications as far as putting these results into practice are concerned.

Table 2 gives the results of ten identical field experiments concerned with the efficiency of utilization of superphosphate as affected by time of application. The superphosphate was applied at three different times as follows: (1) at transplant-

TABLE 2 — *Percentage of the phosphorus in rice plants derived from superphosphate treatment in kg P_2O_5/ha at the three different times of application*[a]. *Harvested three weeks after last superphosphate treatment.*

Location	60-0-0[a]	0-60-0	0-0-60	30-30-0	30-0-30	0-30-30	20-20-20
Burma (M)	31	30	22	33	28	30	28
Burma (G)	7.2	7.8	5.7	6.6	7.7	7.5	8.5
Hungary	12	7.6	7.1	11.6	9.3	9.9	10.3
Korea	19	22	19	23	24	23	23
Pakistan (T)	46	48	41	45	46	43	49
Pakistan (K)	44	46	39	41	45	49	46
Dacca	66	63	48	64	63	64	60
Philippines	10	10	9	11	11	11	10
Thailand	82	74	64	82	84	81	85
Egypt	39	27	33	34	35	33	35

[a] 60-0-0: 60 kg P_2O_5/ha at planting, 0 kg P_2O_5/ha at two weeks before primordial initiation and 0 kg P_2O_5/ha halfway between planting and two weeks before primordial initiation.

ing, (2) halfway between transplanting and two weeks before primordial initiation, and (3) two weeks before primordial initiation. The latter two treatments were made directly into the water in the flooded rice field. Split applications at two different times and one at all three times were also made. Again, the consistency was quite remarkable. It was indeed clear from the results of the analysis of the final harvest made three weeks after the last fertilizer application, that the applications of soluble phosphate fertilizers were effective even when applied directly in the water as late as two weeks before primordial initiation.

Rice - Nitrogen

The effectiveness of five different placements of nitrogen fertilizer for rice was investigated by measurement of N derived from the fertilizer in field experiments in the four countries shown in Table 3. The results indicate that nitrogen applied on the surface in the form of $(NH_4)_2SO_4$ may result in marked losses of the applied nitrogen. The magnitude of these losses

TABLE 3 — *Effect of depth of placement of* $(^{15}NH_4)_2SO_4$ *on the percentage of nitrogen in the rice grain that was derived from the fertilizer.*

Location	Treatments				
	Surface broadcast	Surface rows	5-cm depth in rows	10-cm depth in rows	15-cm depth in rows
Philippines	7.1	8.3	18.5	19.3	21.6
Rep. of China (Taipei)	20.4	19.3	25.2	26.8	31.2
Thailand	11.8	11.2	32.4	37.0	38.1
Madagascar	11.5	9.1	20.4	29.9	26.5

may be quite high. In another experiment at the 16 locations shown in Table 4, similar losses from surface-applied N were found at many but not all locations.

The effect of time of nitrogen application was then investigated with the results as shown in Table 5. The results were as remarkable as they were unexpected. Even though the rice plants were harvested three weeks after the last nitrogen application, the nitrogen applied in the standing water two weeks before primordial initiation was taken up in as large, and usually in larger, quantities than the nitrogen applied on the surface at the time of transplanting.

An extensive comparison was made of the efficiency of

TABLE 4 — *Effect of placement of $(^{15}NH_4)_2SO_4$ at 5 cm depth on the percent nitrogen in rice grain derived from the fertilizer.*

Location	Surface	Depth	pH H_2O
Burma	12.3	20.0	4.9
Ceylon	12.3	18.6	7.3
Rep. of China (Taipei)	16.7	22.7	5.5
Hungary	34.7	40.7	7.6
India I	27.6	35.3	.—
India II	25.3	31.3	.—
Italy	13.0	15.0	5.5
Korea	3.3	4.9	5.0
Madagascar	15.3	18.3	4.8
Pakistan	25.7	28.0	8.1
Dacca	10.0	17.0	5.3
Philippines	17.7	23.3	6.1
Thailand	23.0	23.3	4.7
Egypt I	23.7	23.0	8.2
Egypt II	27.3	28.7	7.9

TABLE 5 — *Effect of time of application on the percentage of nitrogen in rice that was derived from $(^{15}NH_4)_2SO_4$. (Harvested three weeks after last application of N).*

Location	Percentage of N derived from fertilizer (mean of six replications)						
	60-0-0[a]	0-60-0	0-0-60	30-30-0	30-0-30	0-30-30	20-20-20
Burma (Cyogon)	20	35	40	28	34	41	33
Burma (Mandalay)	16	29	37	25	30	29	24
Ceylon (Gannoruwa Peradeniya)	14	21	27	19	23	24	25
Ceylon (Maha Illuppallama)	32	28	35	32	32	32	29
Pakistan (Tandojam)	12	28	34	19	29	32	29
Dacca I	9	23	37	14	26	27	24
Dacca II	26	31	34	26	38	41	39
Hungary (Szarvas)	18	17	25	13	16	19	16
Korea (Suwon)	33	41	40	36	35	33	37
Madagascar (Tananarive)	18	24	37	18	30	31	25
Philippines (Los Banos)	10	22	30	14	20	24	20
Rep. of China (Taichung)	32	18	30	24	32	31	26
Rep. of China (Taipei)	16	24	37	22	29	31	22
Thailand (Bangkhen)	16	28	37	21	26	33	28
Thailand (Rangsit)	27	44	46	33	43	40	33
Egypt (Sakha)	26	23	31	21	32	29	28

[a] 60-0-0: 60 kg N/ha at transplanting, 0 kg N/ha halfway between transplanting and two weeks before primordial initiation, and 0 kg N/ha two weeks before primordial initiation.

various nitrogen sources for rice. The results are given in Table 6 for 15 locations. Nitrate fertilizer applied at transplanting was almost worthless. When applied two weeks before primordial initiation directly into the irrigation water, $NaNO_3$ was between 15 and 73 percent as effective in supplying N to the plant as $(NH_4)_2SO_4$ with an average of 43 percent. Urea and $(NH_4)_2SO_4$ were equivalent sources of nitrogen. Am-

TABLE 6 — *Field experiments on the effect of various N sources applied at different times on the percentage of N in the grain derived from the fertilizer.*

Location	$(NH_4)_2SO_4$ T	$(NH_4)_2SO_4$ P-2	Urea T	Urea P-2	NH_4NO_3 T	NH_4NO_3 P-2	$NaNO_3$ T	$NaNO_3$ P-2	LSD p=0.05
	Application Time*								
Burma	19	23	16	21	10	21	4	15	5
Ceylon	17	19	19	22	9	14	4	10	3
Rep. of China (Taichung)	19	30	20	23	14	26	3	13	8
Rep. of China (Taipei)	14	30	13	26	9	23	3	10	4
Egypt	13	14	12	18	5	11	1	14	3
Hungary	12	10	6	8	7	5	1	3	4
India (Cuttack)	34	37	33	36	20	30	14	25	4
India (Hyderabad)	19	23	21	24	12	16	2	7	4
Italy	15	18	17	17	10	14	1	5	3
Korea	19	20	19	25	10	16	1	3	7
Madagascar	6	20	8	19	3	13	1	7	4
Pakistan	29	15	19	24	14	17	1	9	5
Dacca	15	24	13	26	10	20	2	12	3
Philippines	11	20	19	19	13	15	2	8	3
Thailand	40	44	41	39	27	31	6	32	9

* Application Time: T = 5 cm depth at time of transplanting, P-2 = in water two weeks before primordial initiation.

monium nitrate of course reflected the poor performance of the nitrate ion as a source of nitrogen for rice.

Rice – Nitrogen/Phosphorus Interaction

Table 7 records the results of sixteen identical field experiments in various parts of the world, devised to study the

TABLE 7 — *The effect of mixing of $(^{15}NH_4)_2SO_4$ and ^{32}P superphosphate on the uptake of fertilizer nitrogen and phosphorus by rice (60 day harvest)**.

Location	% P derived from the fertilizer		% N derived from the fertilizer	
	separated	mixed	separated	mixed
Burma	4.4	5.0	23	28
Ceylon	38	50	32	36
Rep. of China	5.8	6.5	27	27
Hungary	7.5	13.5	48	52
India I	10	17	44	47
India II	44	60	46	36
Italy	22	36	15	20
Korea I	7.8	7.2	50	49
Korea II	9.8	11.5	26	22
Madagascar	67	75	40	37
Pakistan	40	40	33	36
Dacca	56	53	20	22
Philippines	8	15	31	28
Thailand	72	82	28	30
Egypt I	18	34	25	25
Egypt II	20	27	33	33

* applied in rows at 5 cm depth.

interaction between nitrogen and phosphorus placement on the uptake of fertilizer phosphorus and nitrogen. When phosphorus was applied in rows 5 cm. below the surface together with the nitrogen many locations gave increases in utilization of the phosphorus as compared to separation of the nitrogen and phosphorus. However, uptake of nitrogen from the fertilizer was unaffected.

In another experiment in 15 locations the effect of time of nitrogen application on the utilization of applied superphosphate was determined. The results are presented in Table 8. They show clearly that time of nitrogen application had no effect on the utilization of superphosphate applied on the surface at the time of transplanting.

TABLE 8 — *Effect of time of nitrogen application on the percentage of phosphorus in the plants that was derived from the superphosphate applied at transplanting (sampled three weeks after last nitrogen application).*

Location	Percentage of P derived from fertilizer (mean of 6 replications)		
	60-0-0[a]	0-60-0	0-0-60
Burma (Gyogon)	26	23	22
Burma (Mandalay)	38	36	37
Ceylon (Gannoruwa Peradeniya)	20	21	30
Ceylon (Maha Illuppallama)	40	46	34
Pakistan (Tandojam)	55	62	59
Dacca	64	66	61
Hungary (Szarvas)	9	8	7
Korea (Suwon)	12	13	14
Madagascar (Tananarive)	37	31	34
Philippines (Los Banos)	25	35	29
Rep. of China (Taichung)	13	13	15
Rep. of China (Taipei)	7	9	7
Thailand (Bangkhen)	65	75	66
Thailand (Rangsit)	40	47	46
Egypt (Sakha)	79	78	80

[a] 60-0-0: 60 kg N/ha at transplanting, 0 kg N/ha halfway between transplanting and two weeks before primordial initiation, and 0 kg N/ha two weeks before primordial initiation.

Maize - Nitrogen

A quantitative evaluation was made of the uptake of nitrogen from $(^{15}NH_4)_2SO_4$ as affected by placement and time of application. The results are given in Table 9. The experiments in Colombia, Peru and Egypt were irrigated, while those in Argentina and Brazil were not. In addition, it was a very dry season in Argentina. The results reflect these differences. Where moisture was adequate, side-dressed nitrogen was as effective and, where irrigated, more effective in supplying N to the plant than banded nitrogen. While the N taken up in the treatment halfway in time between 50 cm. high and tasseling is undoubtedly as effective in increasing yield as earlier applied nitrogen, the last two treatments, and particularly the last treatment, would be less effective in increasing grain yield but correspondingly more effective in

TABLE 9 — *Effect of placement and time of application of* $(^{15}NH_4)_2SO_4$ *on the percent nitrogen in the grain derived from the fertilizer***.

Location	Plow-down	Banded	Side-dressed*			
			50 cm	½ bet	T	T + 10
Argentina	20	23	16	16	10	4
Brazil	27	28	34	39	33	24
Colombia	19	25	38	50	45	34
Peru	24	38	46	43	46	32
Egypt	20	18	36	42	46	37

* refers to stage of growth: 50 cm = 50 cm high; ½ bet = halfway in time between 50 cm high and tasseling; T = at tasseling; and T + 10 = 10 days after tasseling.

** 15 kg P/ha applied in band.

increasing the nitrogen content of the grain. Of course, in practice side-dressing at 50 cm. height is convenient and does essentially no damage to the crop. A comparison of three fertilizer materials was made at the two different placements, BANDED (banded at a point 5 cm. to the side and 5 cm. below the seed at seeding time) and SD (side-dressed at 50 cm. height). Since isotope applications permit comparisons of identical fertilizer treatments except for the label, and in agricultural practice, high nitrogen treatments are often split between banding and side-dressing, split applications of 80 kg/ha N banded at time of seeding and 80 kg/ha N side-dressed at 50 cm. height, was the treatment. The results are given in Table 10.

Comparison of banding and side-dressing gives the same picture as Table 6, that is, where moisture is adequate parti-

TABLE 10 — *The percent nitrogen in maize grain derived from each time of application of a split application of three different nitrogen sources*.*

	Nitrogen Source								
	$(^{15}NH_4)_2SO_4$			$^{15}NH_4{}^{15}NO_3$			^{15}Urea		
Location	Banded	SD**	Total	Banded	SD**	Total	Banded	SD**	Total
Argentina	13	5	18	17	5	22	22	6	28
Colombia	14	47	61	18	42	60	14	42	56
Mexico	24	9	33	19	19	38	20	7	27
Peru	22	35	57	40	61	101	42	60	102
Brazil	13	17	30	14	18	32	14	17	31
Ghana	19	9	28	13	10	23	23	7	30
Romania	13	21	34	10	25	35	15	23	38
Egypt	16	43	59	15	28	43	17	38	55

* Superphosphate - 40 kg P/ha mixed with the N fertilizer in the band.

** Side-dressed at plant height of 50 cm.

cularly under irrigation (Colombia, Peru and Egypt), side-dressing is more effective than banding. When depending on natural rainfall, the adequacy of timing of the natural rainfall affects the relative utilization of banded *versus* side-dressed nitrogen. No essential difference in the three nitrogen sources is indicated by the data. The low value for $(HN_4)_2SO_4$ in Peru is not understandable but suggests a consistent error by a factor of 2.

Maize - Nitrogen/Phosphorus Interaction

The extent of a nitrogen/phosphorus interaction on the uptake of both phosphorus and nitrogen resulting from mixing $(NH_4)_2SO_4$ and superphosphate was determined quantitatively in experiments in eight locations. The results are presented in Table II. The results clearly demonstrate that whereas

TABLE II - *Effect of mixed* VS. *Separate placement of* $(NH_4)_2SO_4$ *and superphosphate on the percent phosphorus and nitrogen in maize derived from the fertilizer (plants sampled when 50 cm high).*

Location	% P dff		% N dff	
	separated	mixed	separated	mixed
Ghana	40	38	30	24
Brazil	31	45	37	43
Colombia	18	30	65	72
Romania	15	21	57	58
Peru	12	33	47	44
Argentina	11	38	24	29
Mexico	2.1	7.7	50	51
Egypt	0.9	2.2	14	14

$(NH_4)_2SO_4$, when mixed with the superphosphate, normally increases the uptake of phosphorus, the presence of superphosphate does not increase the uptake of nitrogen from $(NH_4)_2SO_4$.

Discussion

Tables 1-11 are presented to illustrate the kind of questions that can be answered quantitatively by using isotopically labelled fertilizers to measure directly the actual uptake of the fertilizer nutrient by the plant in the field. All the experiments described also had yield plots, and analyses were made for the actual content of the nutrient element in the plant. The additional information obtained by using labelled fertilizers gives a parameter which can be used to make quantitative economic decisions which could only be guesswork otherwise.

A particularly good illustration is given by the results obtained in a recent group of experiments as a part of an international coordinated research programme on wheat fertility. The results are shown in Table 12. The results show

TABLE 12 — *Percent utilization of N from $^{15}NH_4$ $^{15}NO_3$ applied to irrigated wheat**.

Location	Rate of Application - kg/ha 20	60	120
India	38	35	36
Turkey	24	34	37
Egypt	72	68	60
Pakistan	29	28	31

* Data supplied by research contractors in respective countries.

very clearly that the percent utilization of nitrogen from the fertilizer is essentially independent of the rate of application of NH_4NO_3. This quantitative result with all its economic implications was certainly unexpected.

A tremendous additional advantage of isotope-labelled experiments to measure fertilizer use is that for the first time fertilizer experiments can be performed where the desired information is obtainable with no variation of treatment. For instance, suppose we wished to compare the efficiency of broadcast treatments of three different materials, $(NH_4)_2SO_4$, $NaNO_3$ and NH_4NO_3. We could set up an experiment with three treatments as follows:

Treatment No.	Rate of Application - kg N/ha $(NH_4)_2SO_4$	NH_4NO_3	$NaNO_3$
1	50*	50	50
2	50	*50	50
3	50	50	*50

In each treatment, each of the three materials are separately broadcast on the surface. The three treatments are identical. The only difference is the position of the label (referred to above as *). Thus, a comparison can be made of the intrinsic ability of the fertilizer source to supply the nutrient in question under identical conditions. We could even compare the NH_4 and the NO_3 sources under the identical situation of using in one treatment *NH_4NO_3 and in the other treatment NH_4*NO_3, i.e., the same material but labelled on a different nitrogen atom. These comparisons can be made not only for materials but for placement, times of application and all kinds of interactions. The power of this kind of experiment to answer specific questions unequivocably in field experiments has hardly been utilized.

It would be erroneous to leave the impression that this information alone will solve all fertilizer problems. All the data given has been only a part of the data from experiments which included measurements of yield responses and nutrient analyses of all samples. The use of labelled fertilizers provides a method for obtaining the necessary quantitative data on fertilizer use efficiency which, when combined with other agronomic data, gives us the capability of making much more rational decisions concerning fertilizer use, both from an economic and a scientific standpoint. This is valid whether one is making a recommendation to farmers or deciding in which area to concentrate research. Why not use it more?

Note: Much of the data in the tables has been taken from the following two publications:

Fertilizer Management Practices for Maize: Results of Experiments with Isotopes. IAEA, Vienna, 1970.

Rice Fertilization. IAEA, Vienna, 1970.

DISCUSSION

Chairman: M. Y. Coïc

Welte

It was an interesting paper, Dr. Fried, because you have brought forward a very important problem. But I cannot agree that this exists only for the developing countries. It is of enormous importance also for the highly developed countries. The efficiency of a given amount of fertilizer as a function of placement, timing, splitting etc. is just a real problem in the European countries. May I give some example? For instance, it is usual in German agriculture to fertilize sugar beet by spreading fertilizer on the soil surface because it is easily done with modern equipment. Nitrogen, phosphorus and potassium is spread as NPK fertilizer at once; that means more than 1000 kg fertilizer material per hectare. Now the sugar beet in the stage of germination is very sensitive against this high salt concentration. By this, very often damages occur on our sugar beet fields due to wrong application procedures.

Another problem I wish to point out here is the importance of the high yield level in the developing countries in relation to the growth curve. During the growing season the amount of ions which must be taken up by the plant are much higher than in areas with low production. Especially during the shooting stage the amount of fertilizer per day comes into consideration, for instance for a high corn yield about 4 to 5 kgs K_2O per hectare and day must be available. Therefore splitting is more effective instead of applying the whole amount of fertilizer at once. We have measured — what we call the daily flow rate of nutrients (ion-flux) and often found that nitrogeu applied just before seeding is insufficient when the wheat plant has reached this stage of development.

And now a third remark. There are some mixed fertilizers which give results quite contradictory to your findings, especially PK fertilizers based on basic slack, which is coated by KCl. The effect of this granulated fertilizer is not a very good one if we apply it too late. We have to apply it during autumn or winter time because tbe roots have many physiological difficulties in going through this coat of potassium cloride in order to get phosphorus. That is a handicap, which causes a decrease in P uptake.

HERNANDO

I would like to add something to Prof. WELTE's remarks. With some special analysis it is very easy to find several types of the phosphate present in different soil kinds. But in order to get useful results, one must work on soil types.

Another point: I was related with labelled phosphate from 1950 to 1951. At that time I was working with Prof. SCOTT-RUSSELL at the Oxford University. We made some experiments with clay fixation, but since then I have always had the idea — and in this connection I want to ask you — what is actually true of the results we get from the absorption of labelled phosphate by the plant when we apply labelled fertilizer? I think iu the same way as the plant gets the phosphate from the soil, and on the other hand, the phosphate from the fertilizer. I daresay there will be some exchange in the soil between the phosphate contained in the fertilizer and the soil phosphate, and since the phosphate in the fertilizer is P-labelled, I suppose the plant will then take some time to absorb the total phosphate-labelled present in the soil after the first exchange. I would like to know your opinion about this, that is whether this is important or not.

FRIED

I am glad to give my opinion on that last subject because it has been a subject which at one time at least seemed to bother a lot of people. I think it is a fictitious kind of subject in many ways. Remember that we not only measure the uptake of the fertilizer phosphorus — and there is no question about this, what you are measuring is the uptake of the fertilizer phosphorus, every radioactive ion that you find there represents the uptake of fertilizer phosphorus. We also, of course, in these experiments — in any field experiments this is only an additional piece of information; we are also measuring the uptake of the soil phosphorus. I could have given results in terms of whether these factors happen to affect the uptake of soil phosphorus and I could have given you a quantitative answer to that question. I can do it for N15, for nitrogen, whether the amount of soil nitrogen is affected by the fertilizer application. Because we have that data and we cannot — in making a recommendation — take in isolation only the uptake of the fertilizer, but we are usually taking into account all the other factors but we never know the answer to that question of the uptake of the fertilizer, and this is a direct answer to that question. I do want to call your attention to the last paragraph in my paper which starts off with: « It would be erroneous to leave the impression that this information alone will solve all fertilizer problems. All the data given has been only a part of the data from experiments which included measurements of yield responses and nutrient analyses of all samples. The use of labelled fertilizers provides a method for obtaining the necessary quantitative data on fertilizer use efficiency which, when combined with other agronomic data, gives us the capability of making much more rational decisions concerning fertilizer use both from an economic and a scientific standpoint. »

PRIMAVESI

I have a question referring to your very interesting paper. In which state, on what soil type, and in what years have you made the experiments in Brazil referring to Tables 9, 10 and 11?

FRIED

Referring to Tables 9, 10 and 11, I did not do the experiments, the cooperator did them in Pericicaba. You know more about the soils there than I do. All of these locations are defined in the normal way that you would for a fertility field trial. I do not have the data in my head, but much of it would be in this publication on rice fertilisation and this one on maize fertilization, giving the location and the collaborators that actually did the experiments.

LATKOVICS

Professor FRIED illustrated, on the basis of a large number of data, the kind of questions that can be answered quantitatively by using isotopically labelled fertilizers.

In our Institute we have used this method too. In the following, I would like to present our results.

1. *Utilization of N fertilizers on pastures*

On the irrigated pasture of the solonetz soil, microplot trials were carried out to study the effect of the different nitrogen fertilizers labelled with ^{15}N.

Our data show that at the first cutting 32,4-39 percent, at the second cutting 14-16,5 percent, and at the third cutting 8,9-11,7 percent of the total N taken up by the plant derived from the fertilizer applied. It could further be established that the utilization of the different nitrogen sources was 17-19% and 1,9-3%, respectively. The N fertilizers added were utilized to an extent of 27,5-31,2 percent.

The utilization of the applied N-fertilizers was essentially independent of the kind of fertilizer sources, under the given conditions.

2. *Efficiency of nitrogen top-dressing.*

Micro-plot trials were also carried out to study the efficiency of top-dressing with labelled urea and ammonium nitrate on slightly acid brown forest soil with moderate humus content, available N and K contents and poor in available P. Fertilizers containing 50 kg N/ha were applied to Besostaja I intensive winter wheat in April.

The results show that after N top-dressing, the yields and the amounts of N taken up by the whole crop have increased.

The data indicated that 13,6-14,4 percent in the grains, 9,5-10,0% in the straw and 8,7-9,7% in the chaff of the total N taken up by the plant derived from the labelled fertilizers. 154,2 and 141,1 mg nitrogen taken up by the whole crops was from the labelled fertilizers and the degree to which fertilizer nitrogen was utilized amounted to 32,4-35,5 percent. Our data also show that there were no reliable differences between the effects of urea and ammonium nitrate.

3. *N uptake as affected by the time of N top-dressing.*

On brown forest soil, bifactorial micro-plot experiments were carried out to study the nitrogen uptake by winter wheat from N fertilizers added at different times.

The utilization of N amounted to 24,8-33,8 percent at the time of earing and to 29,9-36,0 percent at harvesting. Variance analyses have shown that the effect of N top-dressing was neither influenced by the time of application nor by the stage of plant development.

Our data illustrate that by using the isotope indication method, we can get further information concerning the N fertilization of pastures, and top-dressing, both from an economic and scientific aspect.

BLANCHET

I was also very interested in the report of Dr. FRIED and I would ask him if the proportion of P derived from fertilizer in his experiments is a function of the importance of the soil reserve, that is, the value of the pool of adsorbed P in the soils, because I observed in the field a variation from 5 percent to 80 percent for the proportion derived from the placed fertilizers in soils of decreasing value of adsorbed P.

FRIED

The proportion of phosphorus in the plant derived from the fertilizer is an inverse function of the supply of phosphorus in the soil. Since you are dealing with a limit of 100 percent utilization, in order to reflect the actual quantity available in the soil you would have to go through the appropriate mathematical transformation. We have developed the concept of an A-value based on the assumption that the plant will take up the phosphorus from multiple sources in direct proportion to the amounts available so that you can actually quantitatively calculate the level of phosphorus in the soil in relative terms from this type of data. Yes it does absolutely reflect the level of phosphorus in the soil.

THERON

I just want to ask Dr. FRIED something about Table 12 of his paper. There the amounts absorbed are very much the same percentages; are the yields in the same proportion as those applications?

FRIED

No, not at all. Each one gave a different response curve, if you want to call it that, but the relative efficiency was the same at different rates of nitrogen application. That is, the actual utilisation — the proportion of the nitrogen fertilizer that was actually used — was the same and was independent of the type of yield response obtained.

THERON

Does that mean then that the higher the yields made would be using less nitrogen in total?

FRIED

The higher yields may be using less nitrogen? Not because when you put on 60 kgs per ha as compared to 20 kgs/ha you are putting on three times as much; your percent nitrogen in your plant may go up if your yield curve is curvilinear. If your yield curve is curvilinear and your percent utilization is constant, then it would mean that your percent nitrogen in your final product actually went up. But obviously this is not at the point where the nitrogen can no longer be taken up by the plant; in other words it is not saturated with nitrogen.

RUSSELL

Dr. FRIED's paper gives the opportunity of making a complaint: United Nations agencies, FAO and the International Atomic Energy

Agency, and sometimes UNESCO, are responsible for a very large number of field experiments. Most of the result of these are quite inaccessible and unknown to the mayority of research workers, unless they have the good fortune to attend a meeting like this. I would suggest to United Nations Agencies that they should consider if there is not some better way of making known the main results they are finding, then by producing pamphlets like the two I saw Dr. FRIED produce. How is the ordinary person expected to know what the International Atomic Energy Agency and sometimes FAO are doing. I think it is a point which does need looking into. Now for a very minor point. Dr. FRIED showed us that the uptake of phosphorus by paddy rice was independent of its time of application. He therefore made the statement that if the fertilizer arrived on the farm late, it was still worth putting on because the uptake was the same as for an early application. Were the yields the same, whether the phosphate uptake is early or late? In the old days we were told that phosphates were needed early on in the growth of the crop and that a late application would not compensate for a lack early on. We do not want people to think that late application is as efficient as early, from the point of view of yield, if this is not the case.

FRIED

I appreciate that and we have all the yields listed here in this pamphlet that nobody knows about. But I was very careful to say that the sampling of the phosphorus took place one week after primordial initiation. We do know a lot about the rice plant and rice yields. And fertilizer that is taken up before primordial initiation is very likely, the only word I can use here without doing the experiment, to go into the yield component. That is the reason why we sampled one week after primordial initiation phosphorus and nitrogen of the last application which was there for three weeks only. The two experiments were the same, except that one was with phosphate and the other with nitrogen. I carefully pointed that out with maize also, that is in making the application only when the maize was 50 cm high, the nitrogen taken up would certainly go into the yield component. So I can only say that the indications are very strong, even for phosphorus. For the second time of application — made half way between two weeks before the primordial initiation and the time of transplanting — I do not think that anybody would have any question in their mind that if the phosphorus taken up was going into the yield component. In the case of nitrogen for rice, i.e. before the short straw varieties had developed, there was a tendency and certainly a strong recommendation in the U. S. to apply nitrogen late, namely at a time when you would not get the lodging but have it gone into the grain yield and not into the straw.

JOINT DISCUSSION

of papers: PESEK, COLWELL and FRIED

Chairman: M. Y. COÏC

WALSH

I was very interested in these three papers. We must take note of them in our final decisions about experimental techniques and experimental methods. The sort of sophistication we have heard here conflicted very much with what we heard from Mr. HAUSER in FAO's reports the other day which brought us back to the sort of approach in our country fifty years ago. I am still very doubtful about FAO's « average » approach. I doubt if it will yield really meaningful data for the future. We might ask if this is the right sort of data for their data bank. I do, however, fully recognise the difficulties of FAO. I wish to put one or two questions to Dr. COLWELL. He has taken very great care in replication. What sort of survey work does he carry out on an experimental site beforehaud. For instance, do the people laying down the experiments define the sort of soils and variations. I feel that before we close this meeting we will have to know something more about nutrient cycles and nutrient cycling because this is important in terms of the problems we may have to face, e.g. those raised by Prof. FITTS about the environment. To what extent, for instance, can isotopes be used to examine systems of nutrient use or nutrient partitioning in nutrient cycles, either for tillage crops, or more especially for pastoral system — the latter involving grazing, feeding in houses, the use of nutrients bought in feeds. If this could be done and if isotopes could have a meaningful use in this respect, it would be very valuable. It should never be overlooked that it is from developed countries such as those in Europe that new methodology, meaningful in terms of underdeveloped countries, can be developed. In this context FAO in my experience has paid less than sufficient attention to European affairs. They will have an appropriate dividend one day. They felt that they shouldn't for instance be interested in research in Europe. I have a strong conviction that we in developed countries have a total commitment, to produce methodology, which can be used in more underdeveloped countries.

COLWELL

The question was, do we do survey work in selecting sites, with an auger, and so on. Yes, we certainly do. These experiments which I showed you are a part of what we call our national soil fertility project. Our pedology section is interested to demonstrate the importance of soil classification and do our site selecting. I can assure you that a lot of differences that we see in soils do not show in crop growth, and alternatively we get a lot of differences in crops which we cannot see by looking at the soil.

HERNANDO

I wish to present two question: The first one to Prof. COLWELL. I read your paper and followed your very interesting explanation here. I try to put a point in relation to what you said about the use of soil tests in Australia. I have never had the chance to go there, but I have spoken many times with people from your country, and I know that there are some areas with similar climatic conditions as we have in central areas in Spain. I know that farmers are working in these areas for 100 years and sometimes even less; your farmers, however have more knowledge than farmers in my country. I believe the difference in time working in the field may possibly be overcome with a better technique. I suggest to use a method we developed in Spain in 1952, that is to check the soil test with the knowledge of the farmer and to develop a few field trials. We go to a village, talk to the most experienced farmers about the different soil types in the areas in relation to the yields. They, of course, talk to us of the results of a over hundred year's experience acquired by several farmers' generations. That means that the effect of climate, diseases etc. are completely avoided, and with these details on the soil tests we found a very good correlation when we tried to know the low level, the medium and the high level for an element, especially for phosphorus and potash in this region. We do not go any more into nitrogen for the problem everyone knows. These methods are working on like that in a few field trials only in order to know what amount to apply in a normal year, i.e. with mean climatic conditions. In this way we reduce the number of trials quite a lot.

My second question is to Dr. FRIED in relation to table 7. He showed us that in mixing phosphate with ammonia sulphate you can always get the main effect, namely the activation of the ammonia sulphate; but maybe this is another type of effect.

In my experience we made field trials with a different plant, i.e. with sugar beet. The important thing, however, is that you can comment on your result in relation to the other one I tried to show you. Our results show that experimental design with ammonia sulphate plus superphosphate, sodium nitrate plus superphosphate and the same amount at the same rate of nitrogen applied at the same time in the season, we always get in a three years' period of experiments a high level in the content of phosphate in the plant when we use sodium nitrate instead of using ammonium sulphate. I do not mean that these results are in their conditions different from those you gave. The only thing

I would like to ask you is an explanation for these results, especially when I tell you that we made the experiments on calcareous soils, alluvial calcareous loamy soils with about 20-40% of calcium carbonate near Madrid in Alcalá.

COLWELL

Replying to the first question before Dr. FRIED to his question. We select our sites in a very similar manner to what you do. We have been asking farmers to indicate to us what they thought was a good soil and what they thought was a bad soil. And we then go through the site selection which I was telling Dr. WALSH about, getting it to represent particular soil groups, uniformly. Just a point: the point I tried to bring out in this paper was that in assessing the value of a soil test, it is not sufficient to look at the correlation. We are trying to make an estimate of the economic value of a test to farmers in a region. This is a step further. Certainly, unless we have got a significant correlation, there is not much point in going further, but having got a correlation I think, the next question we are obliged to answer is, how much is this going to mean in actual dollars per hectare to a farmer.

HAUSER

I had a few remarks on the two previous presentations, but I had no chance to say anything. Now I must apologize that I did not understand what Prof. WALSH exactly said about the FAO work. What my experience is here from that meeting, and if I may talk openly here because we are in the Vatican City, is that everybody is inclined to judge according to his own experience which is normal, but it is not a guarantee that this experience also applies to other conditions. It was clear that we have a very difficult stand in FAO to convince people of the high developed countries, scientists, that our methods are well founded and that we have reason why we do it. We had, as I said also, very little help from these Institutes, not because they are all bad and not all the people want to do so, but because our experiences are different from theirs.

Referring to Prof. WALSH, we have very many times tried to group our thousands if experiments according to soil types, according to soil series, according to soil phases, but there was very little success; and now we are making the first multifactorial analysis for the soil testing calibration, and we find that the soil is so influential. There is a contradiction and that contradiction was not explained here in the meeting. I think we will have to find another patent solution to this. That is not a complaint. If we make these small trials, in two years we can say to the countries what fertilizers should be applied, and if we work five years we can tell them how much water to give, when to put in the seeds, when to put the fertilizer, on an average basis. I agree on an average basis but it is not the best that we can do. Now if we go and try to make more use of the soil testing we come into the trouble which is rightly brought up by Dr. COLWELL, but also by Dr. VAN DER PAAUW. Does it pay? We have no answer to that and the Governments determine which projects they want in their countries. The countries request help from us in this or that matter. The countries are also requesting our help for soil testing in order to know what fertilizer they should apply. This is very difficult because even in high developed countries it took a very long time to solve these problems. But we have to deal with these difficulties. Now I will no longer delay on this subject which we can discuss in private talks. I would like, however, to say a few other things: in regard to Prof. PESEK's presentation and Dr. COLWELL's reply. He said that it is important for this type of trial to have many spots covered in a certain area and only a few replications or a few plots on each site. This is right for a certain kind of trial and we do this also. We try to sample the fields of an area statistically as much as possible. Therefore, we must include many sites though this is not good for everything. We can do it wonderfully for determining with high probability which are the proper fertilizer treatments for the farmer on an economical basis. But if we go for instance for the comparison of fertilizer materials, it is not so. If we want to know whether urea or ammonium nitrate is more effective on a certain crop in the first year and the difference is, let us say, only 5%, we cannot determine this difference with dispersed experiments, because they are not sufficiently precise. But if with more exact experiments we find a fertilizer which is 5% more effective and this fertilizer is used in the whole country, the gain will be considerably. This we have to find out in more precise experiments. We have to make more replications on the spot and select only a few good sites; then we can determine these small differences in the effect. So there is no standing rule for this type or that type, no standing rule for many locations with few plots or few locations with many plots; this depends on what is the purpose of the experiment.

Another remark I have concerns the simple composite designs which were brought up here: let us take the 3 by 3 or 4 by 4 factorial. We in FAO are against these designs, not because they are a priori bad. Maybe they are statistically right, but because of certain curves, let us say a nitrogen curve on zero phosphorus, or a phosphorus curve on zero nitrogen, the general picture is disturbed, and therefore we try in our designs to leave these unbalanced treatments out. When you remember what one of the gentlemen said, I do not remember who it was, the surfaces we saw and which were so irregular — well, this irregularity was in the zero nitrogen or the zero phosphorus regions. Higher up on the return curve things are very normal until one comes to the maximum yield, then it becomes again variable and uncertain. Therefore, we are not a priori for the complete factorial designs.

With regard to yield functions, referring to Prof. PESEK, we had the same experience though much more pronounced in our figures. We used also the quadratic and not the root surface, and the reason is that the root surface cannot be interpreted if not very many points are observed in a curve. We have tried that with hundreds of trials, and if the fertilizer rates are not very well chosen, the maximum is always very far out of the observation points. Therefore, we cannot use the root surface, we must use the quadratic surface, and this can also be proved by quite interesting data material in FAO.

FRIED

Dr. HERNANDO had asked a question but I think that's going to involve a pretty involved discussion as to why he got the results he got and I think it would be better really if we discussed it together. I would like to make one remark on Dr. WALSH's question. If you want to know what is happening with the fertilizer, whether it is a pollution question, an efficiency of fertilizer use, whether it is pesticide; putting a label on the pollutant, if you want to put it that way, is an ideal way of course to study it and we do have some projects with pesticides with that kind of purpose in mind. We don't have any with fertilizer; It is not because we don't realise the potential problem which may be involved, but as you said, we are spending your money: and unfortunately most countries are very niggardly about their money: they don't give the international organizations as much in total as they would give to one university. Adding all the countries together they don't give as much as they would to one large university in their own country. So we just have to take the resources we have and apply them to the problems that at the moment seem the most serious, particularly in the developing world.

BUSSLER

Dr. FRIED you said you believe strongly in field experiments, but concerning your figure 1, Professor MARSCHNER in Berlin came with a laboratory experiment to the same results as you have in the field experiment. This is only an additional remark that in a laboratory we can have the same results as in the field.

FRIED

The final proof is always in the field, if possible.

PRIMAVESI

You said very well in your Summary: « Response to fertilizers is commonly effected by the more or less unpredictable effects of local and seasonal conditions; soil, weather, weeds, etc. ». And in your Introduction: « For poorer agricultural regions where the needs for accurate estimations of fertilizer requirements is now of much greater importance... », and in your paragraph 5 about the Value of Soil Testing: « ...Clearly the better the soil test calibration and the worse the alternative estimates, the more valuable a soil testing service would be »...

I think it is indispensable, at least for the tropic and subtropic zones, to study besides the soil type and the chemical properties of soil, also the physical and biological properties to understand the biodynamic interaction possibilities and to obtain a larger basis for the recommendations of fertilizer application which in this way will be more exact.

FITTS

I would just like to comment briefly on Dr. COLWELL's statement relative to soil analysis. I certainly agree with him that we should always evaluate everything that we are doing to see whether it is worthwhile or not. Also I would agree that a large amount of soil analysis around the world has been made purely for a psychological purpose to sell fertilizer or for something else, and I would agree that has very little real value. But I would also like to call your attention to the table which I showed you last Monday on data from about 100 field trials conducted in Peru over an eight year period. I do not have the data with me so I will have to comment on it from memory. These were good experiments on potatoes in the Sierra region of Peru. Now when we separated the data into two classes, below the critical level and above it, for the fields below the critical level the return was greater than 0.25 dollars for every dollar invested for fertilizer, and those above it lost 10 cents for every dollar invested. It happened that several thousand soil samples had been analysed from farmers fields in that area, and it came out almost a 50% for split, those below and those above the critical level. If I were a farmer living in that area I would certainly want to know if my soil was below the critical level or above it, whether I would get 190 dollars profit or lose 12 dollars, I believe that is profitable information, but you have to have the research correlation program in order to be able to do it.

PESEK

I wanted to make a comment on Professor COLWELL's idea of the soil test, during the rest period he convinced me that his soil test was much better than the ones with which I am familiar and instead of assuming that the soil test is worth only $ 2 plus, as he indicated, I am willing to accept it is worth only $ 1 per hectare. I asked him how large the region was and it appears that this region is at least 500,000 hectares in size, if one dollar per hectare is assessed for each of these, this is half a million dollars, and this really means something for one year. It is multiplied each year. The further problem here is that by not making a precise recommendation in areas which do not require much fertilizer as the average, the fertilizer user there is deprived of the use of this capital which is invested in fertilizer but which might have been invested in some profitable enterprise. Hence, not only is he deprived of a profitable enterprise he loses money on investment in the fertilizer. Can any region or individual accept such losses needlessly.

DAVIDESCU

Je désire faire quelques remarques en lisant les problèmes traités dans les rapports de M. PESEK et M. COLWELL.

L'emploi d'équation algébrique suppose l'acceptation de certaines hypothèse concernant la relation entre le rendement optimum et la modification des facteurs d'engrais. Certaines équations sont plus élastiques tandis que d'autres ne le sont pas. Ce qui veut dire en même temps qu'il existe une corrélation plus grande ou plus petite. La dose d'engrais économique optimum est généralement établie en disant revenue maximum et les frais de production pour la récolte à obtenir. Comme nous allons voir, on peut employer des équations qui expriment cette relation par une surface et un volume, mais je veux dire qu'à cause de nombreux facteurs contribuant à l'obtention de la récolte, il est difficile d'établir en fonction de production valables équations pour toutes les conditions. Pour calculer l'interaction des eugrais employés, ainsi que pour corriger la dose en fonction de divers facteurs du milieu — humidité du sol, climat, système d'agriculture, précipitation — a été proposée une série d'équations qui apparemment paraissait compliquée. Nous avons en même temps envisagé l'approfondissement de cette recherche permettant l'élaboration de quelques fonctions mathématiques capables d'offrir aux agriculteurs des recommendations sur le dosage économique des engrais, recommendations qui prendront en considération tous les facteurs influençant les conditions, par des facteurs techniques et économiques concomitants. En Roumanie, basé sur l'analyse des données climatiques et des récoltes de plusieurs années, on a établi une certaine corrélation entre la précipitation en automne et en hiver et la deuxième dose d'azote. Pour cela on aura voulu une situation par l'aide de laquelle dans la pratique on peut calculer la deuxième dose d'azote en fonction de la quantité de la précipitation dans la période du septembre au février: équations sur des types qui on été ici écrites sur le tableau.

Bien sûre, c'est une contribution modeste à cette question-là, qui est très complexe. En ce qui concerne mon travail, si vous êtes d'accord on peut discuter demain. Maintenant nous sommes contre le chronomètre.

I would like to make some remarks on the problems dealt with in the papers of Mr. PESEK and Mr. COLWELL. The use of algebraic equations implies the acceptance of certain hypotheses concerning the relation between the optimum yield and the modification of fertilizer factors. Certain equations are more elastic whereas others are not. This means at the same time that there is a larger or a smaller correlation. The optimum economic fertilizer dosage is generally established by the maxium income and the production expenses for the yield to obtain. As we are going to see, there can be used equations which express this relation for a surface and a volume, but I want to say that on account of the numerous factors contributing to the obtaining of the yield, it is difficult to establish in respect to the production valid equations for all of the conditions. In order to calculate the interaction of fertilizers used, and to correct the dosage in respect to the different environmental factors — humidity of the soil, climate, agricultural system, precipitation — there has been proposed a series of equations which apparently seemed complicated. We have at the same time envisaged the deepening of this research permitting the elaboration of some mathematical functions capable of giving to the farmers certain recommandations as to the economical dosage of the fertilizers, recommendations which take into consideration all of the factors which influence the conditions by concomitant technical and economical factors. In Rumania, on the basis of the analysis of climatic data and of the yields of several years, there has been established a certain correlation between the precipitation in autumn and in winter and the second nitrogen dosage. In order to do this one wanted a situation with the aid of which one could in practice calculate the second nitrogen dosage in respect to the quantity of the precipitation during the period from September to February: equation of the types which have been described here in the table.

Certainly this is a modest contribution to the question there which is very complicated. As concerns my work, if you agree, it may be discussed tomorrow. We are now short of time.

THE FATE OF ORGANIC MANURES IN SOIL AS TRACED BY MEANS OF RADIOCARBON

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I. INTRODUCTION

It is generally agreed that organic matter plays an important role in soil productivity [47], in the temperate zones as well as in tropical and arid regions [51] and in the humid subtropics [48], acting as a necessary factor in support of mineral fertilizers. It is well known that the beneficial effect of soil organic matter is mainly due to the « *indirect action* » (the favourable influence on physico-chemical properties of the soil), but in the last two decades also the « *direct action* » (the stimulation of physiological processes in the plant) has received increasing attention as a result of the research work of Blanchet [4], Chaminade [9], Christeva [10], Flaig [16], Hernando [24], Saalbach [52] and many other investigators. However, it should be well understood that soil organic matter is *of minor importance as a source of plant nutrients* when mineral fertilizers are available in sufficient quantities. The maintenance of an adequate level of soil organic matter together with an appropriate application of mineral fertilizers is therefore considered as an important factor controlling the increase of yields and the improvement of the quality of crops. Thus it is appropriate, on the occasion of a Study Week on the Use of Fertilizers, to discuss some recent knowledge of the role of traditional and modern forms of manures in maintaining the level of organic matter in soil.

The opinion has been frequently advanced that the quantity of crop residues, left in the soil after harvest, is large enough to compensate for the loss of organic matter by mineralization. According to this opinion no addition of organic manures should be necessary in order to maintain an adequate level of humus in the soil. It is possible to test the validity of this assumption by using an equation derived by WELTE [67]. He calculated that under the conditions of Central Europe the crop residues of a rotation with 60% grain crops amounting annually to about 1,8 t/ha would balance losses only in soils with a humus content below 2,5% and with an annual rate of mineralization below 2%. Since in many soils of this area the humus contents and sometimes even the rates of mineralization exceed these limits, and since moreover there is a clear tendency towards pure grain farming leaving in the field not more than 1,4 t/ha annually [37], the addition of organic manures is most advisable. The assumption that higher quantities of crop residues could be obtained by applying higher rates of mineral fertilizers, is not fully justified, because an increase of yields is not reflected by a proportional increase of crop residues. KÖHNLEIN and VETTER [37], testing 10 crops species, showed that e.g. a 98% increase of clover yield was followed only by a 22% increase of residues, a 64% increase of maize yield was accompanied by a 19% increase of residues, but a 39% increase of wheat yield did not result in any increase of crop residues at all. With regard to these findings, calculations whether carried out with WELTE's formula or based on tracer experiments (cf. chapter III. 3) lead to the conclusion — valid at least for Central Europe — that *any conservation of organic matter in soil merely through the enhancement of yields by increased mineral fertilizing is a quite risky venture.* The application of organic manures is therefore an indispensable precautionary measure.

For many centuries *rotted (decomposed) farmyard manure* has been the traditional organic fertilizer in Europe. If made correctly, it is the final product of a mixture of animal faeces and straw litter, moistened with animal urine, carefully pressed to layers and tightly stacked up for rotting in compact piles, covered with a roof. But with increasing industrialization the lack of farm workers, as caused by the rural exodus, became a limiting factor for animal husbandry in wheat-growing areas, whereas grain farming, thanks to the increasing mechanization, was not impeded by the lack of farm hands. This situation as well as difficulties in marketing surplus animal products have tempted farmers to reduce or even to abandon livestock husbandry in these areas and to rely mainly or entirely on crop farming; this development led to a serious *shortage of rotted (decomposed) farmyard manure* or, as in some areas of Central Europe, to its complete disappearance from the farm.

Where animal husbandry is still practised as a profitable source of additional income, there is a tendency to replace the laborious procedure of piling up the fresh manure for rotting by the easier procedure of simply flushing it out of the stable with water or recirculated animal urine (« Jauche ») into closed containers where it is kept under anaerobic conditions until further use. This procedure known in German-speaking countries as « Schwemmentmistung » (manure removal by flushing), saves two thirds of the labour costs and one half of the losses of organic matter and nitrogen normally occuring with traditional rotting [64]! The product obtained thereby, a mixture of animal faeces, urine and reduced quantities of litter with various amounts of water, is an *unrotted (undecomposed) liquid* or *semi-liquid manure* (« *Schwemmist* ») with the favourable C/N-ratio of 15:1, whereas C/N of ordinary (rotted) farmyard manure is 25:1. A further step towards a labour-saving removal of manures is the litter-free stabling of animals: special housing systems make it possible to omit the spreading of straw and to obtain an undecomposed semi-liquid manure, known in German-speaking alpine regions as « *Gülle* » (a mixture of animal faeces and urine with various amounts of water). Litter-free stabling which has been practised for a long time by grassland farmers for lack of straw, is more and more adopted by grain farmers in order to interrupt the labour-consuming « straw chain » along which the straw is conveyed from the field after combine harvesting, spread as litter into the stable, hence removed as manure to be piled up on the dung heap, and finally returned to the field in the form of rotted farmyard manure.

The decrease of livestock farms in cereal-growing areas as well as the expansion of litter-free housing of animals have created the *problem of straw removal.* Since there is no demand for straw, it remains on the field after combine harvesting; burning it seems to be a suitable way to dispose of it and this has been practised for a long time. Though one should shrink back from destroying energy-rich materials, burning of straw might be tolerated if the level of soil organic matter is restored otherwise; but if the supply of farmyard manure is limited or impossible, burning means really a waste of the farmer's energy-rich capital. Hence it is an obvious solution to return the untreated straw immediately to the soil instead of moving it along the laborious « straw chain » by converting it into decomposed farmyard manure. *Straw manuring* by ploughing in the undecomposed straw has been widely practised indeed for years and even for a few decades, after various difficulties associated with it, such as nitrogen immobilization, spread of cereal diseases and inhibition of seed germination, had been overcome successfully by suitable measures. It has, however, not yet been possible to reconcile the pros and cons, as demonstrated by extensive discussions in the literature concerned [1, 5, 17, 38, 34, 13].

For higher efficiency straw manuring can be combined with the application of liquefied litter-free animal manure (a procedure known as « kombinierte Güllerei ») or with *green manuring* which is widely practised as a method of restoring soil organic matter, however restricted to areas of sufficient rainfall and favourable temperatures in periods between main crops.

It is a characteristic of all the substitutes for rotted farmyard manure, such as liquid and semi-liquid stable manure (with and without litter), straw manure and green manure, that they have not undergone any rotting procedure and therefore contain large amounts of readily decomposable substances. Hence it has been a matter of discussion for a long time whether the prolonged application of these materials would lead to a similar stability of soil organic matter as it would be obtained by the application of traditional farmyard manure.

The success of two impressive meetings convened jointly by FAO and IAEA [18, 25] proved that investigations of this problem have been greatly stimulated by the advent of *isotopic tracers*. Indeed, the use of organic manures uniformly labelled with radiocarbon (^{14}C) has considerable advantages compared with conventional experiments with unlabelled manures.

In the present paper a review of selected data will be given as obtained by several investigators from laboratory, pot and field experiments with ^{14}C-labelled manures on cropped and uncropped soils dealing with the outlined problem. Particular emphasis will be placed on discussing the experiments carried out under field conditions at the Rothamsted Experimental Station, England [27, 28, 29, 30, 31, 32, 33], at the University of Bonn, Germany [53, 54, 55, 20, 56, 57, 58, 59] and at the Federal Experiment Station for Agricultural Chemistry in Vienna, Austria [68, 50, 43, 44, 69, 45, 46, 49].

The following aspects will be dealt with in turn:

1) the decomposition of manures in soil

2) the transformation of manures into humic substances

3) the conservation and accumulation of manure carbon in the field.

Yet it is beyond the scope of this paper to discuss problems of rural economy, fertilizer placement, crop production, phytotoxicity and phytopathology associated with the increasing application of undecomposed organic manures.

II. PRINCIPLES OF EXPERIMENTAL METHODS

1. *General Considerations.*

In following the decomposition and transformation of organic manures in soil by conventional methods differences between the carbon contents of manured and unmanured plots and of fractions of organic matter isolated therefrom are taken as a measure of the manure-derived carbon present in the soil. Disregarding here the effect of newly added manure on the decomposition of organic matter already present in the soil — a complication to be dealt with later — the major difficulty of this method is the detection of statistically significant differences between the carbon contents of different plots as long as manures are applied at the usual rates of practical farming. When a soil containing e.g. 20 mg C/g is fertilized at a rate corresponding to 2000 kg C/ha, the soil gains 0,66 mg C/g, but this amount falls after some months to about 0,22 mg C/g ($\sim$ 1% of the soil C) due to mineralization. The detection of such small carbon differences by conventional analytical methods is almost impossible, since the smallest detectable difference (at a 95% level of significance) is about 0,5 mg C per gram of soil. In conventional field experiments these difficulties are overcome by either

a) increasing the rates of manure up to the tenfold of what is usual in farming whereby significant carbon differences can be detected, of course at quite unusual soil-fertilizer ratios, or

b) repeating the application of usual rates of manure through decades as long as the sum of the annual increments becomes easily detectable, e.g. in the famous « Ewiger Roggenbau » (continuous rye cultivation) at Halle (Germany) where 2000 kg of farmyard manure per ha had to be applied annually in order to result in a carbon increment of 4,2 mg per gram of soil after 70 years [63].

2. *The Preparation of ^{14}C-Labelled Manures.*

The introduction of organic manures uniformly labelled with radiocarbon (^{14}C) has made it possible to overcome the difficulties of the differential method. Thus we are now able to make statistically significant statements on mineralization and transformation processes already after a single manure rate not higher than applied in practical farming. Furthermore we can detect accelerations of the decomposition of the original soil organic matter under the influence of newly added manures; this effect however occurs only in a few cases to any appreciable extent.

The *technical difficulties of labelling organic manures* uniformly with ^{14}C are remarkable. The essential step is the labelling of plants which have to serve either immediately as green or straw manures or are fed to animals in order to yield labelled excreta for the preparation of farmyard manure. Labelling of plants can be done only by exposing them to an atmosphere enriched with $^{14}CO_2$ under conditions favourable for photosynthesis. Any labelling of adult plants in closed transparent containers, under plastic tents etc. cannot be extended for more than a few hours because of unfavourable environmental conditions; plants treated by this short-time procedure are therefore not labelled uniformly all over their organic substance: primary products of photosynthesis and of metabolism, such as monosaccharides, amino acids etc. show the highest label whereas polymeric reserve substances (proteins, polysaccharides etc.) become only slightly labelled and skeleton substances, such as lignin, remain almost free of label.

The use of such non-uniformly labelled plants for studies on the transformation of organic manures results in an underestimation of the primarily interesting decomposition process of high polymers because of the very low specific activity of these substances; this leads to a misinterpretation of the processes actually occurring in soil [29, 54]. Research work done with non-uniformly labelled manures will therefore not be regarded in this paper.

Uniform labelling of plants with ^{14}C is feasible only by growing them from germination until harvest in an atmosphere containing $^{14}CO_2$ of constant specific activity. This is achieved in hermetically sealed *growth-chambers* providing an optimal environment for the plants by controlled temperature, humidity, light, and nutrient supply; the chambers have to be fitted with a device for the automatically controlled supply of $^{14}CO_2$ to the plants. Until quite recently gastight growth-chambers for this particular purpose were not manufactured commercially, but had to be built by the interested scientists, as was done in several institutes of the United States, Great Britain, Germany, and Denmark. A brief description of the older growth-chambers was given by ZELLER et al. [68] who adapted some well-established principles of these chambers in designing and constructing the growth-chamber of the Federal Experiment Station for Agricultural Chemistry in Vienna. This chamber (Fig. 1) was operated by OBERLÄNDER and ROTH [43] through 7 years who grew there 13 crops of green or mature maize or wheat resp. with a total dry weight of about 20 kg (Table 1). All the crops were uniformly labelled with ^{14}C, one of them additionally with ^{15}N [12]. The homogenious distribution of the label throughout the plant material and in the manures prepared therefrom was ascertained by proximate analysis (Table 2).

Recently a factory-built, most elaborate growth-chamber was set up at the Institute of Agricultural Chemistry, University of Bonn (Germany), and is being successfully operated by SAUERBECK and JOHNEN [59] (Fig. 2).

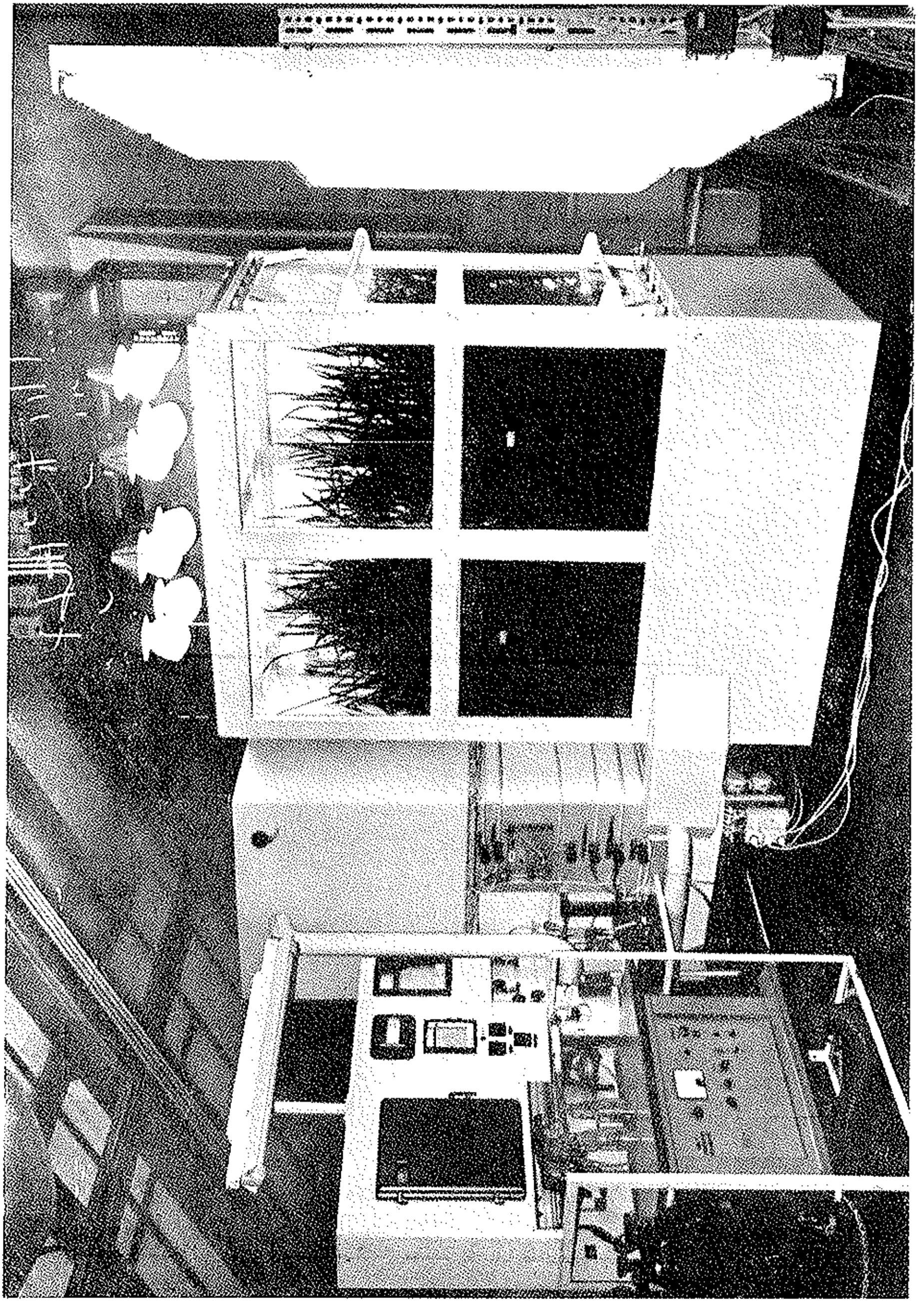


FIG. — *Growth chamber for raising uniformly ^{14}C-labelled plants to maturity.*
Designed and built at the Federal Experiment Station for Agricultural Chemistry in Vienna, Austria, in 1963 by ZELLER et al. [68], operated by OBERLÄNDER and ROTH [43].

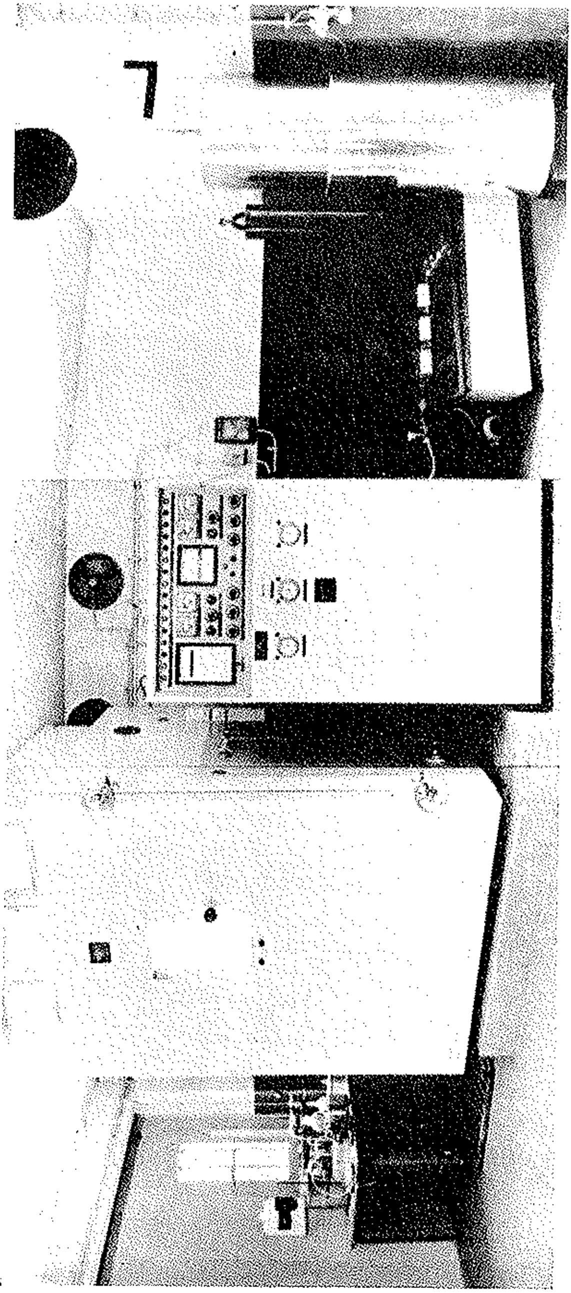


FIG. 2 — *Small phytotron for raising uniformly* ^{14}*C-labelled plants to maturity.*
Factory-built and set up at the Institute of Agricultural Chemistry, University of Bonn, Fed. Rep. of Germany, in 1970.
From SAUERBECK and JOHNEN [59].
By courtesy of Prof. D. SAUERBECK, University of Bonn, Fed. Rep. of Germany.

The *production of labelled farmyard manure* involves almost deterrent difficulties of all kinds besides of being a rather expensive undertaking. Large growth-chambers of the described special type are required in order to produce sufficient quantities of labelled animal fodder, and some problems of radiation safety may arise in handling such large quantities of radioactive materials. The assistance of veterinarians is indispensable to ensure proper feeding of the animals on the

TABLE I — *Production of ^{14}C-labelled plants in a growth-chamber.*

Batch	Plant species	Age of plants (days)	Dry weight of total plants harvested (g)	Specific activity of total plants (μC ^{14}C/g C)
A (1)	Maize, green	80	99	108
B (1)	» »	53	473	110
C (1)	Spring wheat, green	35	209	92
D (1)	» » »	28	154	99
E (1)	» » mature	100	875	171
F (1)	» » »	169	3673	233
G (1)	Maize, green	48	992	98
H (1)	» »	59	1723	278
I (1)	Spring, wheat, green	35	483	203
J (1)	» » »	38	373	126
K (2)	» » mature	169	2300	183
L (2)	» » »	218	4720	31
M (3)	» » »	189	4321	124 (4)

(1) Data from OBERLÄNDER and ROTH [43].
(2) Unpublished data of ROTH.
(3) Data from DANNEBERG and ROTH [12].
(4) Labelled additionally with 14,88 atom per cent ^{15}N.

TABLE 2 — *Homogeneous distribution of the label in various fractions of manures as revealed by proximate analysis* [50].

Fraction	Label				
	Carbon (μC ^{14}C/g C)			Nitrogen (atom p. cent ^{15}N)	
	Green manure (3,6)	Straw manure (4,7)	Farmyard manure (7)	Straw manure (5,8)	
Whole manure	110±7	221±16	32±1	125±2	14,9±0,1
Soluble in hot ethanol-benzene (1:2)	105	212	35	116	15,3
Soluble in hot ethanol-benzene	114	205	34	118	14,9
Soluble in cold 17 % KOH	108 (2)	(1)	(1)	(1)	(1)
Insoluble in cold 17 % KOH	116	(1)	(1)	(1)	(1)
Soluble in hot 2 % HCl	(1)	230	29	121	14,4
Hydrolyzed by cold 72 % H_2SO_4	116 (2)	217	24	126	14,3 (2)
Unhydrolyzed residue	115	227	32	125	14,3

(1) Not determined.
(2) Calculated by difference.
(3) Prepared from maize B (Table 1).
(4) Prepared by mixing unequal parts of wheat E and wheat F (Table 1).
(5) Prepared from wheat M (Table 1).
(6) Data from ROTH et al. [50].
(7) Data from ZELLER et al. [69].
(8) Data from DANNEBERG and ROTH [12].

prepared fodder in order to label the intestinal contents as uniformly as possible. Problems of veterinary hygiene and of radiation protection are involved in collecting the animal excreta separately through many days into harnessed containers. Since also mixing of the excreta with labelled litter and storage of the manure during the rotting process require some control as to a safe removal of gaseous fermentation products, the whole preparation of labelled farmyard manure is necessarily confined to specially equipped stables.

SAUERBECK was the first who prepared uniformly labelled manure-like model substances by feeding a rat with labelled plant materials [55]. ZELLER et al. [69] fed a cow under the supervision of veterinarians with almost 6 kg of uniformly labelled dry maize and wheat plants and collected faeces and urine separately under controlled conditions. By mixing proper quantities of the excrements with uniformly labelled straw litter of the same specific radioactivity they obtained 68 kg of a product which had a moisture content of 82% and a C/N ratio of 16 after a three months period of rotting. This final product resembled in all respects a rotted farmyard manure; it was uniformly labelled as shown by proximate analysis (Table 2).

3. *Characterictic Features of Experiments with ^{14}C-Labelled Manures.*

Due to the limited availability of labelled manures the turnover of these substances in soil was mainly investigated by *model experiments* in the laboratory (Lit. in [54, 32, 33]. For this purpose soil-manure mixtures are incubated in glass vessels at constant temperature. A CO_2-free air stream of constant humidity is pumped through the vessel; the total carbon dioxide $(CO_2)_{SM}$ developed in the mixture by microbial activity and consisting of the labelled $(CO_2)_M$ from the manure and the unlabelled $(CO_2)_S$ from the [illegible] is flushed into an absorption solution. By chemical and radiometric analyses of the solution the specific activity $*A_{SM}$ of the total carbon dioxide $(CO_2)_{SM}$ is obtained. When the carbon dioxides derived from the two sources are mixed, the specific activity $*A_M$ of the manure is reduced to $*A_{SM}$ inversely to the ratio of manure carbon dioxide to total carbon dioxide:

$$(1) \qquad \frac{*A_M}{*A_{SM}} = \frac{(CO_2)_{SM}}{(CO_2)_M}$$

Hence one obtains the amount of $(CO_2)_M$ evolved from the manure:

$$(2) \qquad (CO_2)_M = \frac{*A_{SM}}{*A_M} \cdot (CO_2)_{SM}$$

and the amount of $(CO_2)_S$ evolved from the soil:

$$(3) \qquad (CO_2)_S = (CO_2)_{SM} \cdot \left(1 - \frac{*A_{SM}}{*A_M}\right)$$

This approach provides information on the rate of decomposition of the manure and on any effect that newly added material might have on the organic matter already present in the soil. If, however, information is sought on transformations within the manure remaining in the soil, total and radioactive carbon have to be determined in the soil-manure mixture, and equations (2) and (3) can be adjusted by replacing CO_2-values by the respective C-values so as to obtain

$$(4) \qquad C_M = \frac{*A_{SM}}{*A_M} \cdot C_{SM}$$

and

$$C_S = C_{SM} \cdot \left(1 - \frac{*A_{SM}}{*A_M}\right) \quad (5)$$

Numerous *methods of carbon determination* by wet or dry combustion are in use. One of them which is based on dry combustion and on conductivity measurements in the CO_2-absorbing solution, as described by KOCH and MALISSA [36], has proved particularly efficient for large series of soil and humus analysis [14, 15]; it was adapted in the present author's laboratory for the subsequent determination of radiocarbon either by end-window or by liquid scintillation counting.

Some *shortcomings of the methods used to fractionate soil organic matter*, are revealed as soon as the humification of labelled manures in soil is followed. Many extraction procedures have been devised to separate humified soil substances from non-humified constituents of manures, but none of these extractants is selective enough to bring about a sharp separation. Detectable quantities of labelled non-humified constituents of the manure which may partly behave, in this respect, like humic substances, are therefore co-extracted with the material already humified. Thus it is not surprising that « humic fractions » can be isolated even from the pure unrotted plant material which is used to prepare the green manure, and it is a quite common feature of this type of experiments that immediately after mixing a labelled manure with soil, i.e. at a time when humification could not yet have taken place, considerable amounts of the radioactive label are detected in the humic fractions (Figs. 9 and 10). Moreover, SAUERBECK and FÜHR [57] as well as OBERLÄNDER and ROTH [45] found that the pattern of distribution of the labelled carbon among the fractions is different whether the manure had been fractionated alone or mixed with soil (Table 3). Less labelled « non-humic substances » and more labelled « humic substances » were extracted from the labelled manure in presence of soil than from the manure alone, presumably because in the soil-manure mixture some labelled low-molecular compounds were adsorbed to the soil humic colloids. Thus the appearance of labelled carbon in a humic fraction does not necessarily provide evidence of humification of the added manure.

This drawback of any fractionation of labelled soil-manures mixtures is no argument against the use of labelled manures, it only endorses the conjectures of earlier authors [62] that the fractionation procedures in humus chemistry do not yield chemically homogeneous fractions, but mixtures of dif-

TABLE 3 — *Percent distribution of labelled carbon in the fractions obtained by treating labelled fresh green manure with « humus extractants ».*

Fraction	Green manure derived from			
	Rape shoots (1)		Maize shoots (2)	
	Alone	Mixed with soil	Alone	Mixed with soil
Non-humic substances	15,6	12,5	21,1	14,4
« Humic » and « fulvic » acids	26,9	33,1	2,1	5,2
Insoluble residue	57,5	54,4	73,4	78,6
Losses			3,4	1,8

(1) Data from SAUERBECK and FÜHR [57]; successive extraction with hot 1,34-n N_3PO_4 and hot 0,5-n NaOH.

(2) Data from OBERLÄNDER and ROTH [45]; successive extraction with hot ethanol-water and cold 0,1-m $Na_4P_2O_7$.

ferent chemical compounds having in common only the same behaviour towards a particular extractant. Much effort has been devoted to describe and to overcome these difficulties ([32, 57, 26], but this author is inclined to share JENKINSON's opinion [33] that a completely effective separation may not be possible at all.

It can, however, be assumed that the labelled unstable impurities of the humic fractions are decomposed with time to such a degree that the label of the humic fraction becomes an increasingly reliable indicator of the humification of the manure as actually occurring in soil.

Incubation experiments in closed systems under laboratory conditions have a high degree of precision, since the influences of the environment can be kept fairly constant. But observations made by BIRCH [2, 3] on intermittent enhancement of the decomposition of soil organic matter by alternate dry and wet conditions have taught us to be cautions when interpreting results obtained under constant environment. SAUERBECK [53] attained an appreciable degree of « outdoor conditions » in his laboratory experiments by alternately drying and rewetting the soil in the vessels. Nevertheless, any valid conclusions for practical agriculture can be drawn only from *experiments under field conditions*. The limited availability of labelled manures suggests primarily the execution of *outdoor pot experiments*. Pioneering work in this respect was done by JENKINSON [30, 31, 32] who added labelled ray-grass to the soil and kept the mixture uncropped in special pots embedded in the ground for several years. Similar outdoor pot experiments with straw manure, cropped and uncropped, were initiated by FÜHR and SAUERBICK [20] and are being continued by SAUERBECK and FÜHR [58] in order to study the influence of different crop rotations.

More information, however, of the processes actually occurring in the field is derived from *field trials under the conditions of practical farming*. It is easily understood that the modest quantities available of labelled manures strongly limit the plot size in this type of experiments leading to serious inconveniences, such as a pronounced edge effect, a settling of the top soil due to the repeated sampling from the limited area, the impossibility to use tillage-equipment of common size etc. In spite of these limitations a small-scale field experiment with ^{14}C-labelled manures has been initiated by ZELLER et al. [69] and is being carried out by OBERLÄNDER and ROTH [46]; recently it was enlarged by a plot with double-labelled (^{14}C, ^{15}N) straw manure [12]. Considerable difficulties had to be mastered in this experiment, such as the handling of large quantities of radiocarbon in order to produce enough labelled manure (straw and farmyard manure) for 6 treatments in quadruplicate (plot size 1,5 m^2), problems of the homogeneity of soil samples due to the limited possibility to replicate sampling on the small plots, as well as difficulties of the radiometric detection of ^{14}C with regard to the remarkable dilution of the labelled material in the soil, still increasing with time.

III. RESULTS OBTAINED UNDER FIELD CONDITIONS.

1. *The Decomposition of Manures in Soil.*

a) *Rate and extent of decomposition.*

The opinion is upheld among agronomists that green manure as well as unrotted straw decompose rapidly and completely in the soil. This view is based on conventional field experiments subject to the mentioned shortcomings.

The advent of isotopes and the production of plant material uniformly labelled with ^{14}C have made it possible to follow the decomposition of manures in the field for many years with satisfactory precision. Several investigators [30, 56, 33, 58, 45, 46] described the decomposition unanimously as a process with a high initial velocity slowing down after about one year to a significantly lower rate (Fig. 3 and 4). It was shown that about 30% of the carbon of the added green or straw manure remained in the soil after one year, about 25% after 2 years and still 18% after 5 years [33], irrespective of

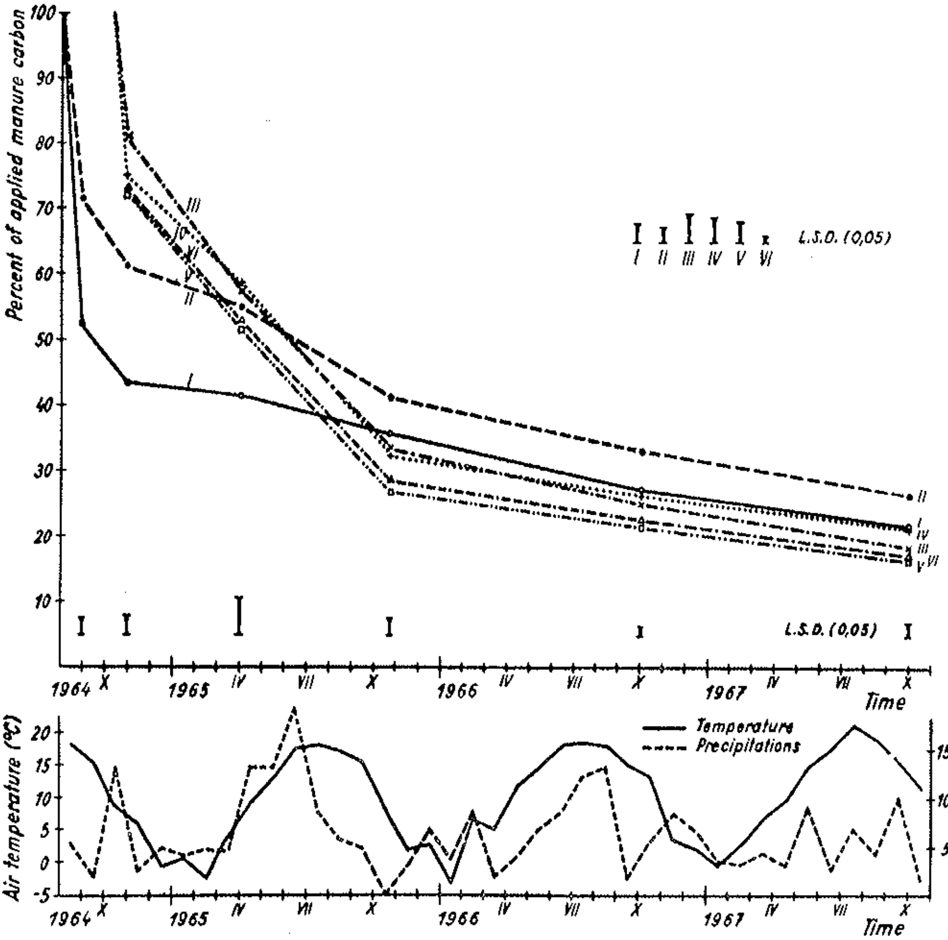


FIG. 3 — *Decomposition of ^{14}C-labelled green manure in soil under field conditions (bare fallow).*
(Labelled carbon present in the soil as percentage of labelled carbon added).

I	fresh green manure, brown earth.
II, III	air-dried green manure, brown earth.
IV	air-dried green manure, black earth.
V	air-dried green manure, brown earth, fivefold amount of manure added.
VI = III	+ 600 kg N/ha.

L.S.D.'s between treatments shown as bars above time axis.
L.S.D.'s between sampling shown as bars in right upper corner.

From OBERLÄNDER and ROTH [45]

the climatic conditions. These obervations were made in areas with moderate temperature fluctuations and with precipitations distributed equally, as in the Southeast of England and in the Northwest of Germany, as well as in an area with marked temperature fluctuations and with prolonged periods of drought, as in the Northeast of Austria. In this area straw decomposition was found to proceed somewhat slower in the first year (Fig. 4). All these results are rather surprising and they are quite contrary to the above-mentioned widespread view in agronomy.

b) *Behaviour of rotted and unrotted materials.*

It is of particular interest for those grain farming areas where animal husbandry is still practised, that the application of fresh litter-free animal manure saves a considerable input of labour as compared with the application of rotted farmyard manure. However, the opinion is widely upheld that it is more desirable to use fully rotted materials which already contain a considerable quantity of stable humic substances formed during the rotting procedure. The advocates of this opinion do not take notice of the inevitable losses of organic matter by mineralization on the dung-pile. The question is therefore raised whether it is not wiser to give up the laborious preparation of dung-piles, apply the fresh manure to the field and thus transfer the whole microbial decompostion process into the soil. A positive answer must be based on the proof that fresh as well as rotted manure behave similarly as far as their transformation in soil is concerned. SAUERBECK [55] furnished proof of this fact in laboratory experiments with labelled fresh and rotted rat manure. Besides of confirming the fact that fresh manure loses 20-30% of the carbon during the rotting procedure, he showed that after a three months' incubation with soil equal amounts of carbon remained there from fresh as well as from rotted material, in two different treatments, and only 5% carbon more of the rotted manure

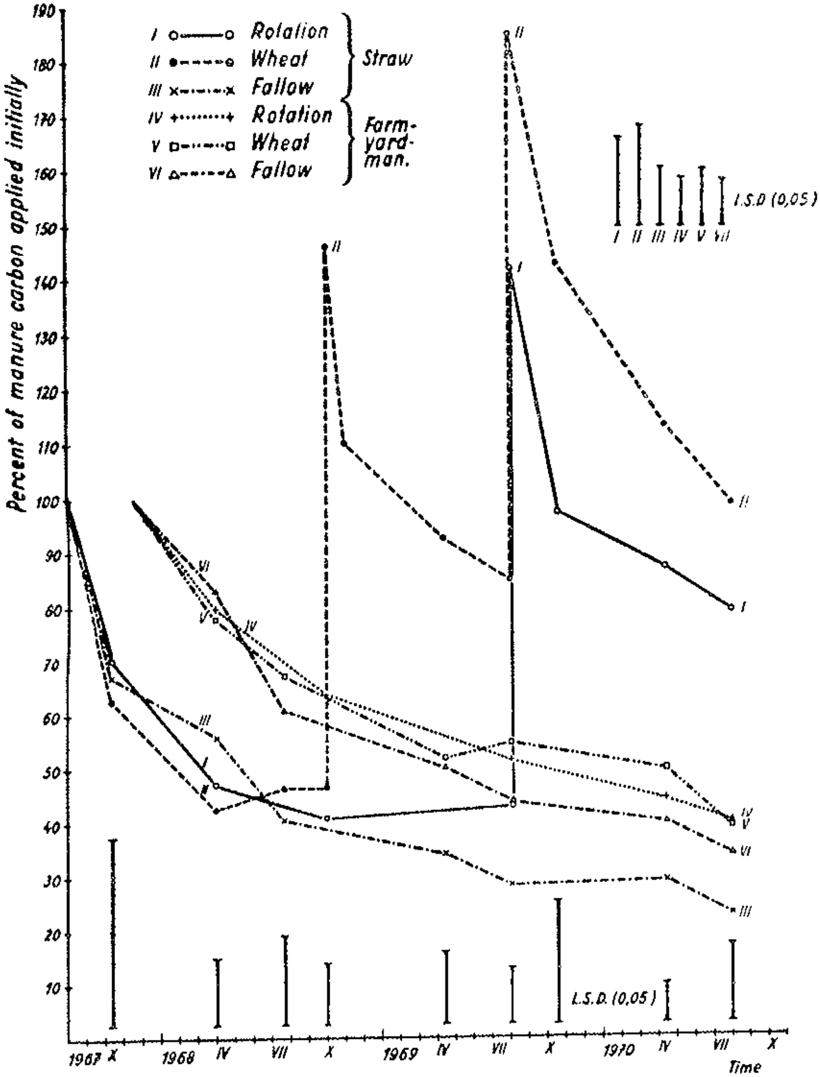


FIG. 4 — *Decomposition of straw and farmyard manure, both labelled with ^{14}C, in a small-scale field experiment.*
(Labelled carbon present in the soil as percentage of labelled carbon added initially).
Straw added to wheat plots annually, to rotational plots twice in 3 years, to fallow plots initially; farmyard manure added only initially.
L.S.D.'s given as in Fig. 3.

From OBERLÄNDER and ROTH [46]

in a third treatment. Thus the large losses of dry matter during rotting were not balanced by any appreciable increase in residual carbon derived from the rotted material, and there is no evidence from this experiment that rotted manure should be considered superior to an unrotted product.

With regard to the findings so far mentioned the presumed superiority of rotted farmyard manure to unrotted plant manure becomes rather doubtful. It was shown by OBERLÄNDER and ROTH [46] in a small-sized field experiment with uniformly ^{14}C-labelled farmyard manure corresponding to a rate of 5000 kg dry matter per ha that the carbon percentage remaining from this material in the soil after about 3 years under bare fallow was only somewhat higher than from ^{14}C-labelled unrotted straw applied at the same rate and supplemented with 35 kg N/ha in addition to basic NPK rates.

But it should be noticed that the straw decomposes initially, up to one year, faster than the farmyard manure so as to reach the level of stabilized constituents earlier (cf. chapter III.3 and Fig. 16). This means that the decay of readily decomposable constituents which takes place on the dung-pile in farmyard manure and leads to appreciable nitrogen losses, is transferred into the soil in the case of straw.

In a further experiment the decomposition of straw supplemented with mineral N as above was compared, on the basis of equal amounts of total carbon applied, with the decomposition of straw supplemented with liquefied animal excreta. Straw and animal excreta were uniformly labelled with ^{14}C; they had the same C/N ratio ($\sim$ 10) including organic and mineral N-sources. Preliminary results show that in both treatments about 42% of the total labelled manure carbon applied remained in the soil after two years. Hence, a lack of animal manure as an additive to straw, if compensated by mineral N, does not seem to be of any disadvantage for the retention of straw carbon in soil.

c) *Influence of application techniques on decomposition.*

In the first years of work with ^{14}C-labelled green manures it had been observed that large *quantities of plant material* decompose more slowly in the soil than small amounts would do [7, 21]. This observation was confirmed by SAUERBECK [56] in a series of model experiments under constant environmental conditions, but not when the soils were subjected to alternate wetting and drying. However, in all other investigations as listed in JENKINSON's review [33] no influence of the rate of manure applied was reported on the velocity of decomposition, particularly not in the trials carried out under field conditions [30, 45]; (cf. curves III and V in Fig. 3).

It has been recommended for a long time to let the cut plants wilt and decompose in the field until *incipient drying*, before ploughing them in as green manure. Fresh plants when ploughed in immediately, may give rise to a flush of ammonia harmful to seed germination. Initiating an overground plant decomposition to avoid the harmful effect seems to be reasonable if sowing the next crop cannot be deferred sufficiently. But a slow predrying on the surface has been also advocated as a means of increasing the resistance of the material against microbial attack in the soil. OBERLÄNDER and ROTH [45] tried to verify this assumption. They found indeed a slower decomposition of the green manure in soil when the material had been gently predried for some days (cf. curves I and II in Fig. 3), but during the pretreatment the plants had lost 35% of their carbon. A calculation of the balance of carbon saved during decomposition in soil and carbon lost during predrying leads to the conclusion that only rapid drying might result in a net carbon saving.

There are but few results available concerning the *influence of nitrogen* on the decomposition of labelled manures. In SAUERBECK's laboratory experiments, carried out under alternate wet and dry conditions, the influence of N (added as NH_4NO_3) was almost zero in a soil rich in N (0,36%), but it was appreciable when soil N was low (0,05%). The added nitrogen enhanced the decomposition of straw much more during the first few weeks than later [56]. Similar results were obtained by OBERLÄNDER and ROTH [45] with labelled green manure under field conditions when 600 kg N/ha were added (cf. curves III and VI in Fig. 3).

d) *Influence of soil factors.*

This influence on the decomposition of green manures is astonishingly small. Neither soil organic matter content nor soil pH, unless below 5, play any role in this respect; strongly acid soils retard the decomposition as shown by JENKINSON [27] with labelled green manure from raygrass. But there is some influence of the mechanical composition (grain size distribution) of the soil, in as much as an increasing clay content retards the decomposition of the added material, but not proportionally. JENKINSON believes that this effect is partly due to greater leaching losses from the sandy soils, partly due to the clay which might be shielding the added organic matter from mineralization [27]. OBERLÄNDER and ROTH, working with labelled green manure on two soils, not too different in chemical composition and distribution of grain sizes, did not find either any differences in carbon retention (cf. curves III and IV in Fig. 3).

e) *Influence of cropping.*

There are now some data available from cropped long-term experiments with labelled manures carried out in England, Germany and Austria in order to study the influence of vegetation on the decomposition process. JENKINSON [27] found that 39% carbon of a green manure remained in the soil after one year under grass, but only 28% under bare fallow. A similar observation was made by SAUERBECK and FÜHR [58] in their studies on the transformation of labelled straw under a rotation of root crops, a rotation of grain crops and under a bare fallow. The material decomposed within the first year faster under root crops and under bare fallow than under grain crops, but the difference disappeared after two years and does not seem to be of importance when lasting effects are considered.

OBERLÄNDER and ROTH [46] were not able to confirm the mentioned results; they did not detect any significant difference within the first year between the influence of a rotation (sugar beet — winter wheat — spring barley), continuous spring wheat and bare fallow on the decomposition of labelled straw (repeated applications of labelled straw to the rotational and to the continuous wheat plot did not allow further comparison with the single rate initially applied to the fallow plot). They did, however, follow through three years the influence of cultivation practices on the decomposition of labelled farmyard manure, but the difference between treatments was zero (cf. curves IV - VI in Fig. 4).

JENKINSON as well as SAUERBECK and FÜHR offered rather different explanations for the initial enhancement of decomposition under fallow. But since the effect does not last, the present author believes that the influence of crops on the mineralization process should not be overemphasized.

f) *The « priming action ».*

When ^{14}C-labelled plants first became available, a biological effect which may be caused by the application of readily decomposable manures has received much more attention than it would deserve with respect to farming practices: The « priming action » (effet excitateur, Zündwirkung). Already some decades ago LÖHNIS [39] had suspected that readily decomposable manures when added to the soil, might stimulate the decomposition of « native » organic matter already present in the soil. Although this effect can be measured conventionally in a rather troublesome way [42], an unequivocal demonstration became only possible after isotopic techniques were introduced [8]. On the basis of these experiments the opinion was advanced that the application of readily decomposable manures could do more harm than benefit, as it might deprive the soil of its reserves of stabilized organic matter.

Measuring a priming action in the soil would involve the determination of a very small difference between the amounts of native unlabelled carbon, remaining in a manured and in an unmanured soil, after the initial effect of the added manure has ceased. Since this difference is of the same magnitude as the analytical error of soil carbon determinations, a detection of priming actions in labelled field experiments is not feasible [44]. All our knowledge is therefore derived from determinations of the CO_2 evolved from manured soils incubated in the laboratory. Fig. 5 demonstrates how $(CO_2)_S$, evolved from an unmanured soil, is increased by the addition of readily decomposable manures so as to reach the amount of $(CO_2)'_S$. The difference $\Delta(CO_2)_S$ is the increment caused by priming action. $(CO_2)_M$, developed from the manure, is overestimated in conventional experiments with unlabelled materials: hence, the advantage of isotopic techniques becomes quite evident.

It remains to be examined whether the priming action plays any significant role in practical farming. The reviewers of the problem [29, 53, 33] agree in stating that only the effects found by the first workers using isotopic techniques some 20 years ago were large, but in none of the numerous recent investigations any effects were reported to be of such an alarming magnitude as in the earlier work. It may be left undecided whether this is due to a gradual improvement of techniques. JENKINSON [29] demonstrated that a number of apparent priming effects could be traced to experimental errors, such as the use of non-uniformly labelled manures, the exchange of $^{14}CO_2$ with soil carbonate and alterations of the soil microflora induced by the fresh organic matter. These sources of error being excluded, the origin of priming action

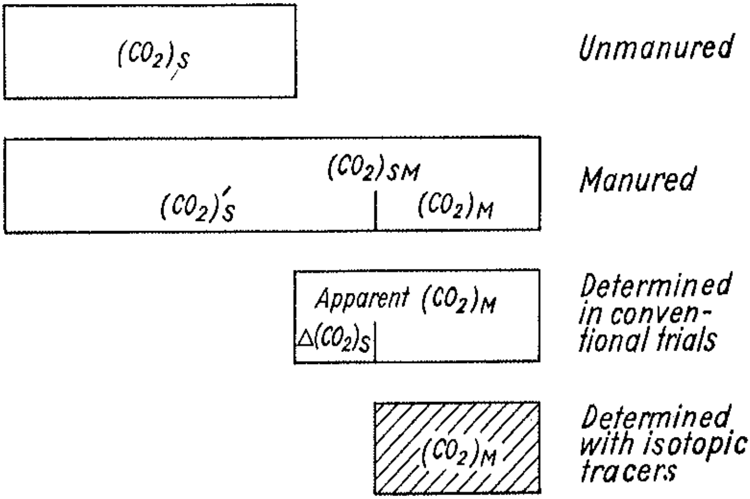


FIG. 5 — *Scheme of « priming action ».*

(CO_2)	from unmanured soil.
$(CO_2)'_S$	from « native » soil organic matter after the addition of fresh manure.
$(CO_2)_M$	from manure.
$(CO_2)_{SM}$	from the whole soil-manure mixture.
$\triangle\ (CO_2)_S$	from « native » soil organic matter in excess of $(CO_2)_S$ as a result of « priming action ».

may be seen in triggering the germination of microbial spores, leading to a higher respiration of the vegetative cells formed. Since microbial enzymes are then produced in abundance, the probability increases for a native stable humic substance to be split by an enzyme, and, as it is possible that some fresh products of plant decomposition may render the native soil organic matter more decomposable [40], the increased number of enzymatic reactions may lead to a measurable degradation of humic substances [35].

SAUERBECK evaluated the data reported on priming action in the literature since 1946 [54] and he found that in each of the experiments examined — with a single exception — the amount of native soil carbon mineralized by priming action was balanced or overcompensated for by the amount of manure carbon remaining finally in the soil in a stable form. He showed in his laboratory experiments [53], simulating field conditions by alternate drying and wetting, that the priming action was appreciably enhanced for a short time after each rewetting. But even under these conditions the amount of soil carbon mineralized under the influence of the added manure was never greater than the amount of manure carbon retained in the soil in stable form. He concluded that just a slight increase of the usual rates of manure could easily prevent unexpected disturbances of the carbon balance. It seems to the present author that the priming action is an inexhaustible source of discussions on the academic level, but it is certainly no argument against an increased application of undecomposed manures in the field.

2. *The Transformation of Manures into Humic Substances.*

Any appraisal of the role of manures in restoring soil organic matter cannot be confined to investigating whether and to what extent manure carbon remains in the soil, but it must proceed to investigating the process by which the manures are transformed into stable humic substances. It is well known that the high-molecular humified constituents of soil organic matter (as described by the German term « Dauerhumus ») are the source of the « indirect action » of humus, i.e. its influence on the physical and chemical properties of the soil. Since this is the main factor responsible for the beneficial effect of organic matter on soil productivity, it is legitimate to judge the value of a manure mainly by the extent to which it can be converted into humic substances in soil.

Results obtained, in this respect, with labelled manures should be cautiously interpreted for reasons described in detail in chapter II. 3. It was shown by numerous investigations with labelled materials that no complete separation is possible between humified and non-humified constituents, since any fractionation of soil organic matter means setting arbitrary chemical boundaries [32, 57, 26]. The main difficulty is some coextraction of high-molecular constituents of the manure, particularly of lignin, together with the humic acid fraction; this effect is rather insignificant with materials of low lignin content, such as green manures, but it becomes appreciable with straw or farmyard manure. It should, however, be borne in mind that these shortcomings become less significant when the coextracted unstable impurities are decomposed.

Several investigators have studied in laboratory experiments the distribution of the label in various fractions of soil organic matter as decomposition of added labelled material proceeds [33]. So have done SIMONART and MAYAUDON [65] and MAYAUDON and BATISTIC [41] who separated classes of constituents from labelled plants and added them to the soil in order to study the biochemistry of their humification. But the number of results available from experiments under field conditions is limited.

The *fraction of non-humic constituents* of manures follows the general decomposition pattern of the whole material. An example is given in Fig. 6 for the ethanol-water soluble fraction isolated from a soil which had been manured with labelled green maize under field conditions [45], (cf. Fig. 3). Similar results had been obtained previously in laboratory experiments in respect to acid soluble non-humic substances [57].

The *fraction insoluble in « humus extractants »* is called humines and is supposed to consist of rather inert humic acid-clay complexes. The label of the fraction should be zero immediately after the addition of labelled green materials and should increase with time. The reverse was the case in the experiments presented in Fig. 7. These curves do not reflect the formation of humine-clay complexes, but rather the de-

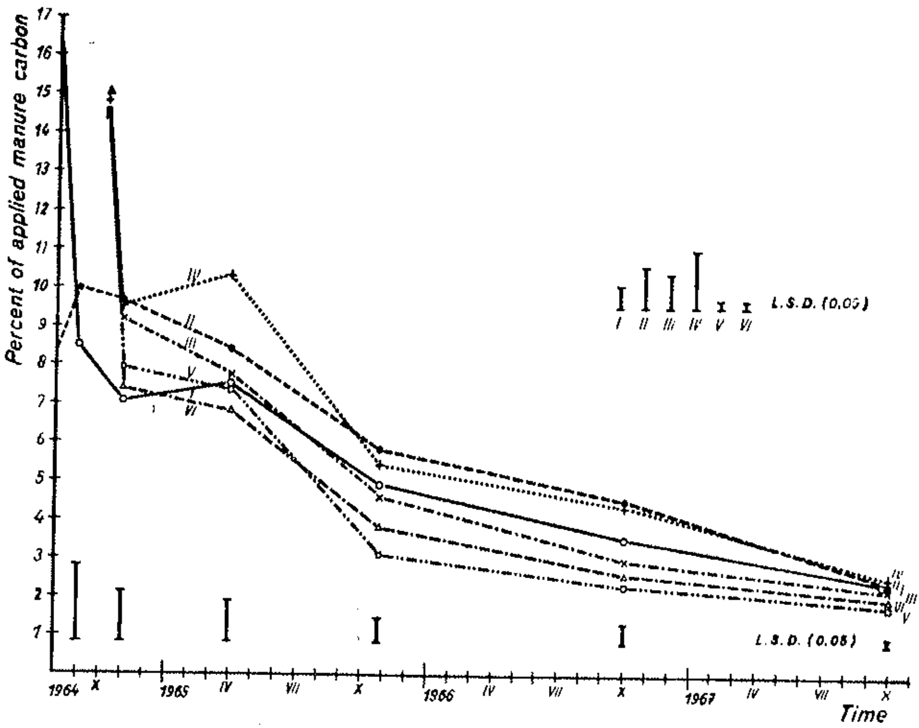


FIG. 6 — *Decomposition of the labelled non-humic fraction (soluble in ethanol and water) of two soils manured with ¹⁴C-labelled green maize.* (Labelled carbon of fraction as percentage of labelled manure carbon added). For details see Fig. 3.

From OBERLÄNDER and ROTH [45]

composition of contaminating constituents of the manure, presumably of cellulose [45].

Different pictures have been given by different authors of the emergence of the label in *humic and fulvic acid fractions* extracted from soil from time to time. SAUERBECK and FÜHR found a marked steady decrease of the label in both fractions whether derived from green mannre [57] or straw [58]. A

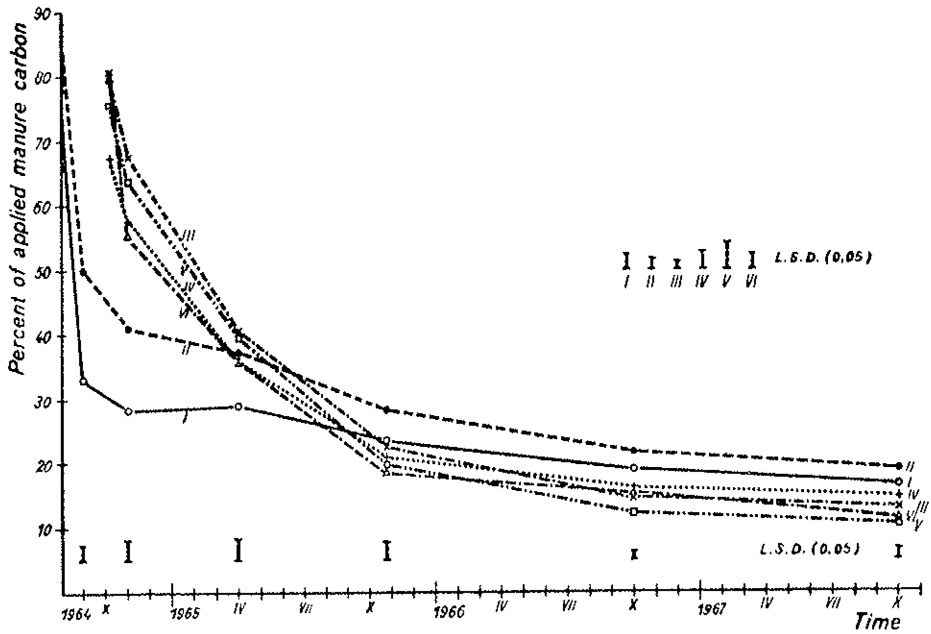


Fig. 7 — *Decomposition of the labelled insoluble residue (non-extractable by sodium pyrophosphate) of two soils manured with ^{14}C-labelled green maize.*
(Labelled carbon of fraction as percentage of labelled manure carbon added). For details see Fig. 3.

From Oberländer and Roth [45]

decrease during the initial period indicates the decomposition of coextracted non-humic matter; in later stages, of course, a decrease may be an indication of a decomposition of the less stable parts of the humic substances formed from the manure. The high initial label may have resulted, too, from the use of hot sodium hydroxide solution as an extractant which is known to give rise to highmolecular artefacts on the expense of coextracted non-humic compounds.

The choice of a milder, though less exhaustive extractant

— sodium pyrophosphate — seems to have enabled OBERLÄNDER and ROTH [45] to follow the formation of humic acids from green manure already in the initial period (Fig. 8). The authors described the process as being initially rather fast: after one month an appreciable amount of labelled humic acids had formed, few months later the labelled fraction reached the maximum and began to decrease at a steady, very slow rate. Some authors demonstrated even shorter initial phases: only 10 days were required for the saturation of the humic acid fraction with ^{15}N in a compost [11]; in soil the maximum labelling of humic acids with ^{14}C and ^{15}N was reached even after 42 hrs. [19]. These results of tracer experiments indicating a rather fast formation of humic substances are surprising, and they are contrary to traditional views in agricultural chemistry.

Differently from the picture given of humic acids the initial formation of fulvic acids was overlapped by the decomposition of coextracted contaminants (Fig. 8). More of the predried than of the fresh green manure was converted into humic and fulvic acids after incorporation into the soil (cf. curves I and II in Fig. 8), but this was only an apparent gain, since appreciable losses of organic matter had occurred during predrying.

In the mentioned small-scale field experiment (cf. Fig. 4), initiated by ZELLER et al. [69] and carried out by OBERLÄNDER and ROTH [46], the transformation of labelled straw and farmyard manure into humic substances was followed through 3 years (Figs. 9 and 10). In this case it was not feasible to trace the initial formation of humic acids because of the high lignin content of the applied materials; coextracted lignin was mainly the cause of the appearance of 2-3% of the applied straw carbon in the « humic acid » fraction immediately after application (cf. curves I-III in Fig. 9). This percentage decreased slowly through 3 years on the fallow plot, and it cannot be decided at which rate and to what extent the lignin was gradually converted to humic acids. The stepwise increase

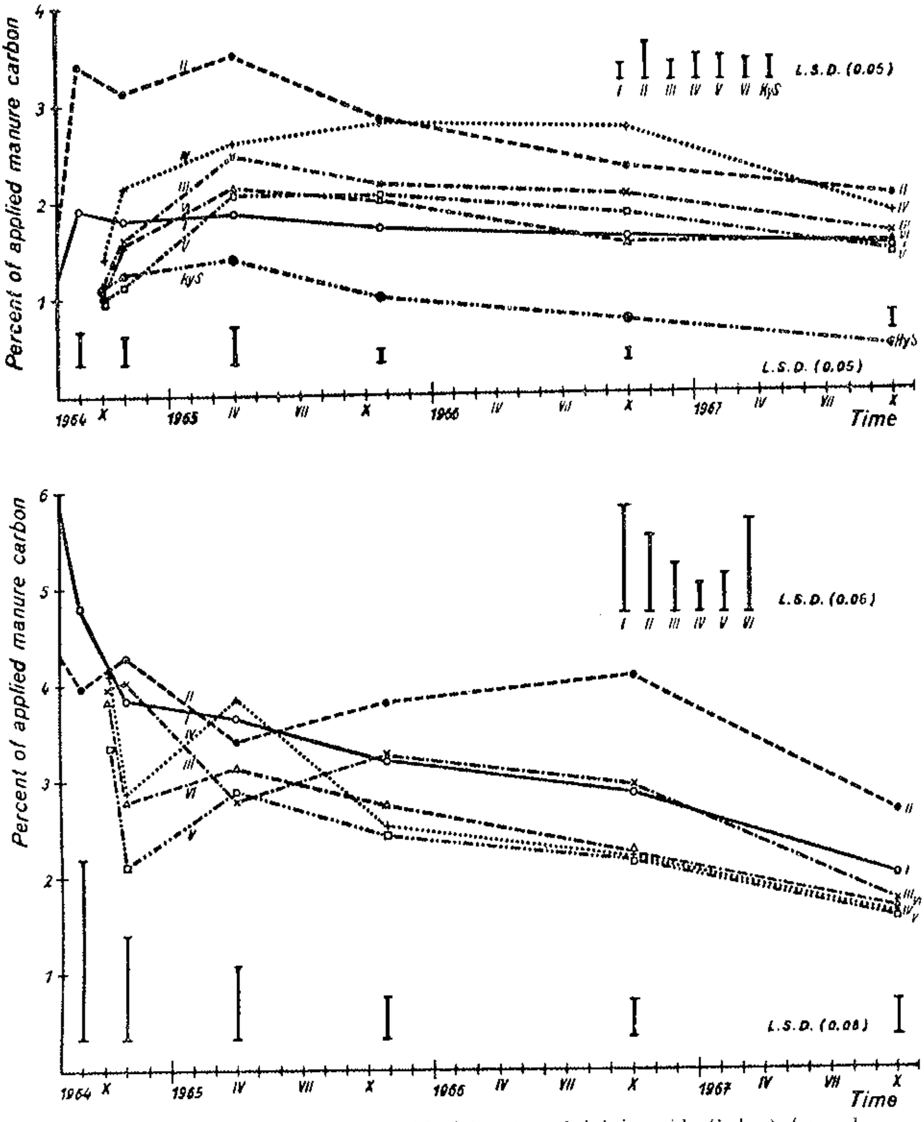


FIG. 8 — *The fate of humic acids (above) and fulvic acids (below) formed from ^{14}C-labelled green manure in soil.*
(Data plotted as in Fig. 7).
HyS = Hymatomelanic acids.
For details see Fig. 3.

From OBERLÄNDER and ROTH [45]

of this fraction after repeated application of straw is shown by curves I and II.

A good deal of the 3-4% of added manure carbon, present already initially in the humic acid fraction from the plots with labelled farmyard manure, may be humic adds formed during rotting on the dung-pile. The stability of this fraction was almost perfect through 3 years (Fig. 9) irrespective of cultivation. Fulvic acids whether derived from straw or farmyard manure, showed the same slow decrease with time in later years, irrespective of cultivation practices (Fig. 10).

Additional information can be obtained by presenting the data as distribution of fractions in percent of the manure carbon remaining in the soil at sampling time (termed « Jeweilsverteilung » by OBERLÄNDER and ROTH). A shifting of the distribution pattern of labelled fractions with time can be observed; by comparing it with the distribution of corresponding unlabelled soil fractions, the assimilation of the manure-derived organic matter to the native soil organic matter can be followed.

This way of presenting data was used by several authors [58, 45, 46]. In Fig. 11 a set of curves is given for one treatment of the mentioned experiment with green manure (cf. Fig. 3). Also in the other treatments the percentage of the labelled non-humic fraction remained above the level of the respective soil fraction; no « assimilation » had been attained after 3 years. The labelled humic acids, on the contrary, gradually reached the respective soil level (except on a black earth with a very high humic acid content), and the fulvic acids approached it. This finding, suggesting the *enrichment of humic acids* in the residue of green manure — in addition to the absolute increase of the fraction — is again contrary to widespread opinions in farming.

An appreciable enrichment of humic fractions takes place in the residue of straw and farmyard manure [46]. Fig. 12 demonstrates the shift of distribution under bare fallow, showing a relative increase of humic fractions and a relative de-

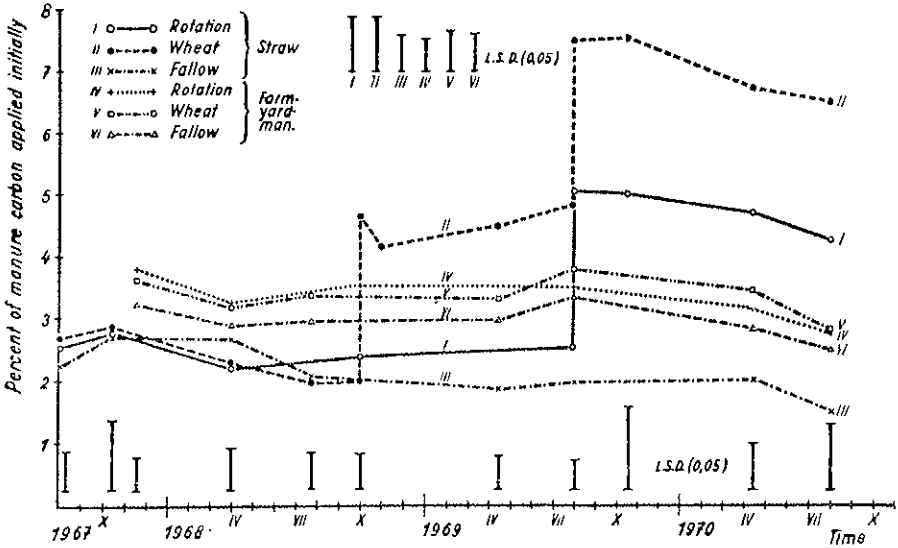


FIG. 9 — *The fate of humic acids formed from ^{14}C-labelled manures in soil.* (Labelled carbon of humic acids as percentage of labelled manure carbon added initially).
For details see Fig. 4.

From OBERLÄNDER and ROTH [46]

crease of non-humic and non-extractable fractions. However, the distribution does not become completely similar to the pattern of native soil fractions even after 3 years. In Fig. 13 the enrichment of the same humic fractions is demonstrated with cropped soils; the percentages of the native soil fractions (16% humic acids and 19% fulvic acids) are not reached either. The interpretation is somewhat intricate due to disturbances of the distribution pattern caused in a different way by repeated applications of labelled straw (shown as marked indentations in curves I and II), but a comparison of Figs. 12 and 13 reveals no clear influence of cropping. No conclusions can be drawn from the distribution patterns, very

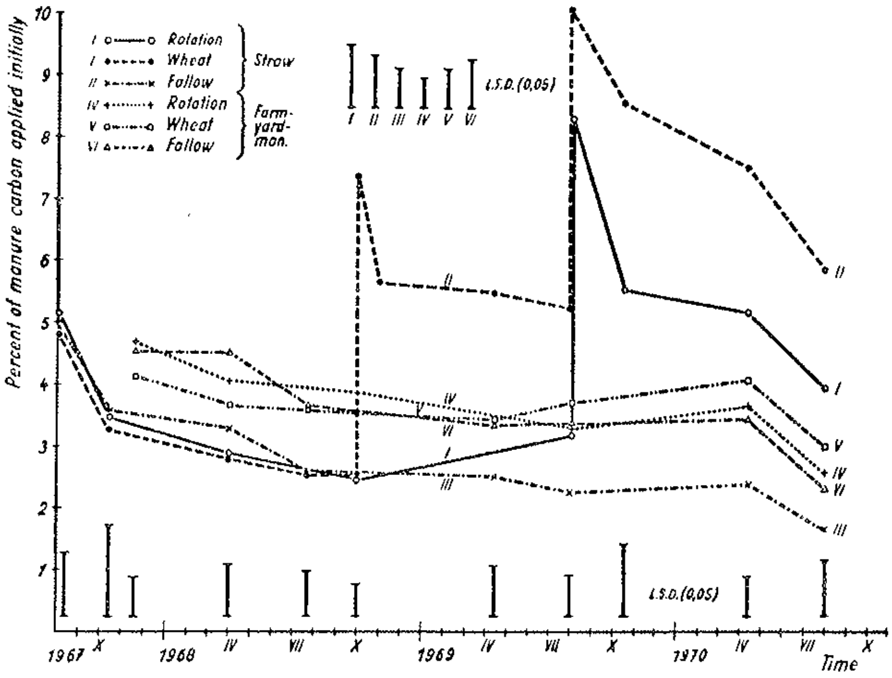


FIG. 10 — *The fate of fulvic acids formed from* ^{14}C*-labelled manures in soil.* (Labelled carbon of fulvic acids as percentage of labelled manure carbon added initially).
For details see Fig. 4.

From OBERLÄNDER and ROTH [46]

similar in the residues of both materials as to any superiority of farmyard manure to unrotted straw.

For further interpretation of their data OBERLÄNDER and ROTH plotted the *humification indices* which are the ratios of humic acid carbon to fulvic acid carbon (C_H/C_F), versus time [45, 46]. When labelled green manure was added to a brown earth (native $C_H/C_F = 0{,}5$) and to a black earth (native $C_H/C_F = 1{,}0$), the index of the labelled material ($^{14}C_H/^{14}C_F$) increased within a few months from $\sim 0{,}3$ to the level of the respective soil, soon exceeding this value and following the

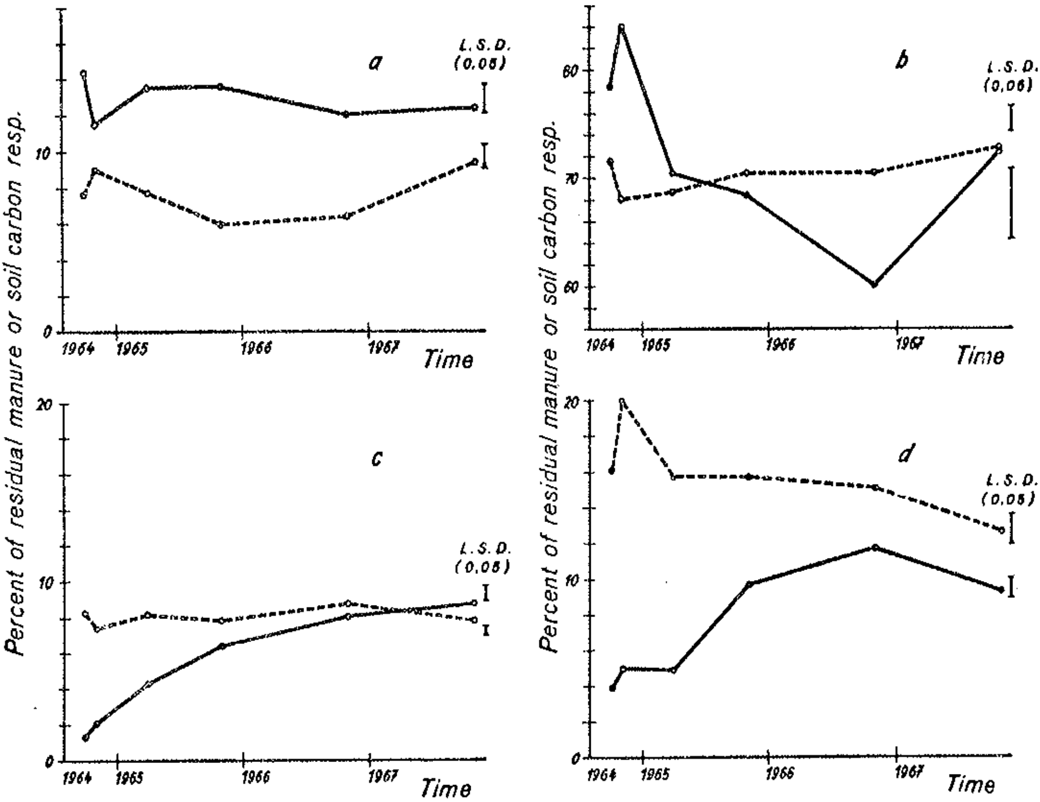


FIG. 11 — *Shift of labelled fractions of a soil manured with* ^{14}C*-labelled green maize, compared with unlabelled native soil fractions.*

(Labelled or unlabelled carbon of fractions as percentages of labelled or unlabelled carbon present in the soil at sampling time).

——————— labelled fraction (treatment III, Fig. 3).

- - - - - - - - - unlabelled fraction (brown earth).

a = soluble non-humic substances.

b = non-extractable residue.

c = humic acids.

d = fulvic acids.

$a + b + c + d \pm \triangle = 100$.

L.S.D.'s between samplings shown as bars at right end of curves.

For more details see Fig. 3.

From OBERLÄNDER and ROTH [45]

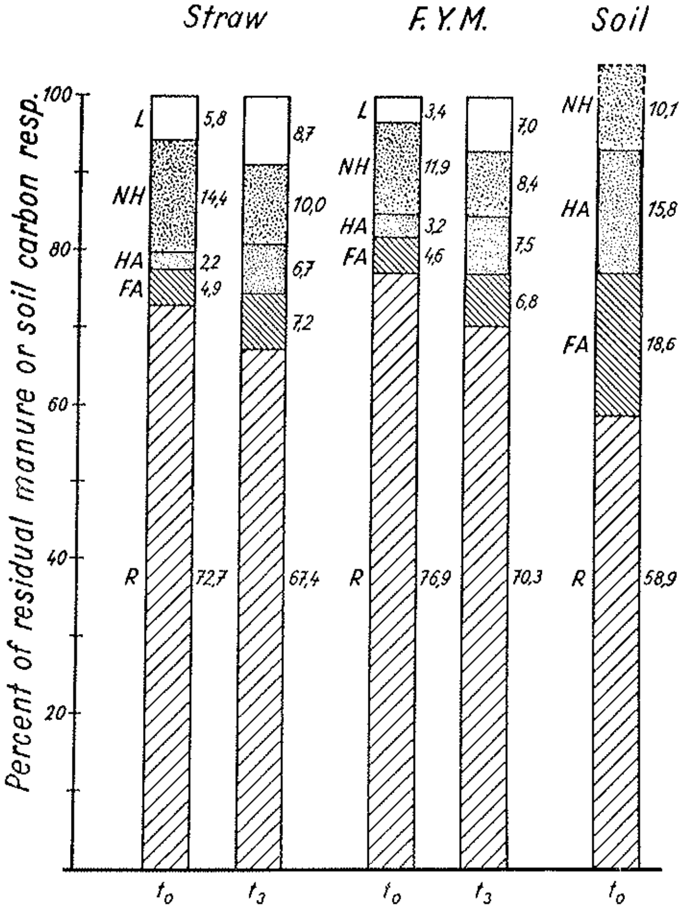
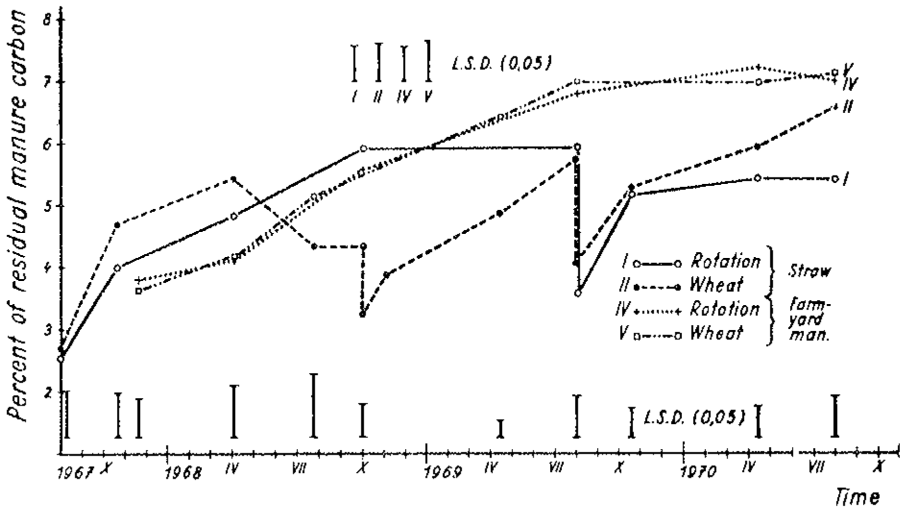


FIG. 12 — *Distribution of labelled fractions separated from a soil immediately after application of ^{14}C-labelled manures (t_0) and after three years under bare fallow (t_3), as compared with the distribution of unlabelled (native) soil fractions.*

(Labelled or unlabelled carbon of fractions as percentages of labelled or unlabelled carbon present in the soil at sampling time) (cf. Fig. 13).

L = losses during fractionation.
NH = soluble non-humic substances.
R = non-extractable residue.
HA = humic acids.
FA = fulvic acids.

From OBERLÄNDER and ROTH [46]



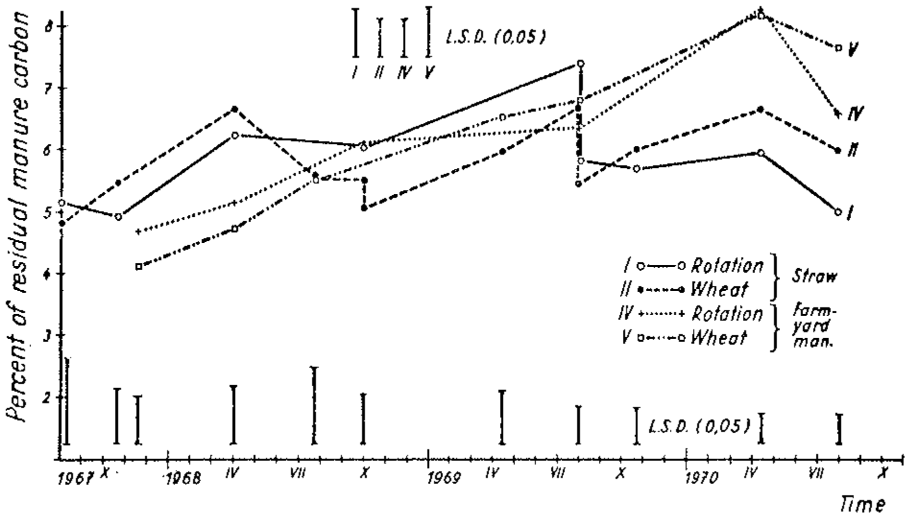


FIG. 13 — *Enrichment of humic acids (above) and fulvic acids (below) in the residues of* ^{14}C*-labelled manures in cropped soils.*
(Labelled carbon of fractions as percentages of labelled carbon present in the soil at sampling time) (cf. Fig. 12).
For details see Fig. 4.

From OBERLÄNDER and ROTH [46]

gently rising plateau of a saturation curve (Fig. 14). The maxima reached (0,7-0,9 in the brown earth, 1,1 in the black earth) showed a clear dependence on soil type: the black earth provided an environment obiously more favourable to humification, but both soils integrated the green manure satisfactorily into their process of humification.

By plotting their results of straw humification in black earth (native $C_H/C_F = 0,85$) in the same way, the mentioned authors [46] obtained a picture similar to green manuring, with indices rising finally to 1,1 (Fig. 15). The low initial values found with green and straw manures and reappearing after each new dose of straw (cf. curves I and II) are due to the high initial contamination of the fulvic acid fraction with readily decomposable constituents. Since rotted farmyard manure does not contain much of these contaminants, but appreciable amounts of humic acids formed during rotting, it showed humification indices similar to those of the soil, already initially, in comparable trials (Fig. 15). The maximal indices, however, did not exceed the straw values reported; rotted and unrotted materials evidently follow the same process of humification.

3) *The Conservation and Accumulation of Manure Carbon in the Field.*

For a long time agronomists have been interested to know whether and to what extent manuring, when repeated annually, can influence the organic matter content of soil. A deeper insight into this relationship should enable farmers to adjust rates of manuring as may be required to maintain a certain humus level. Maintaining this level means keeping in balance the supply of manures and crop residues with losses of the added materials and of native soil organic matter. In order to predict the supply necessary to maintain an equilibrium, knowledge is required of the velocity of decomposition of the whole organic matter contained in soil.

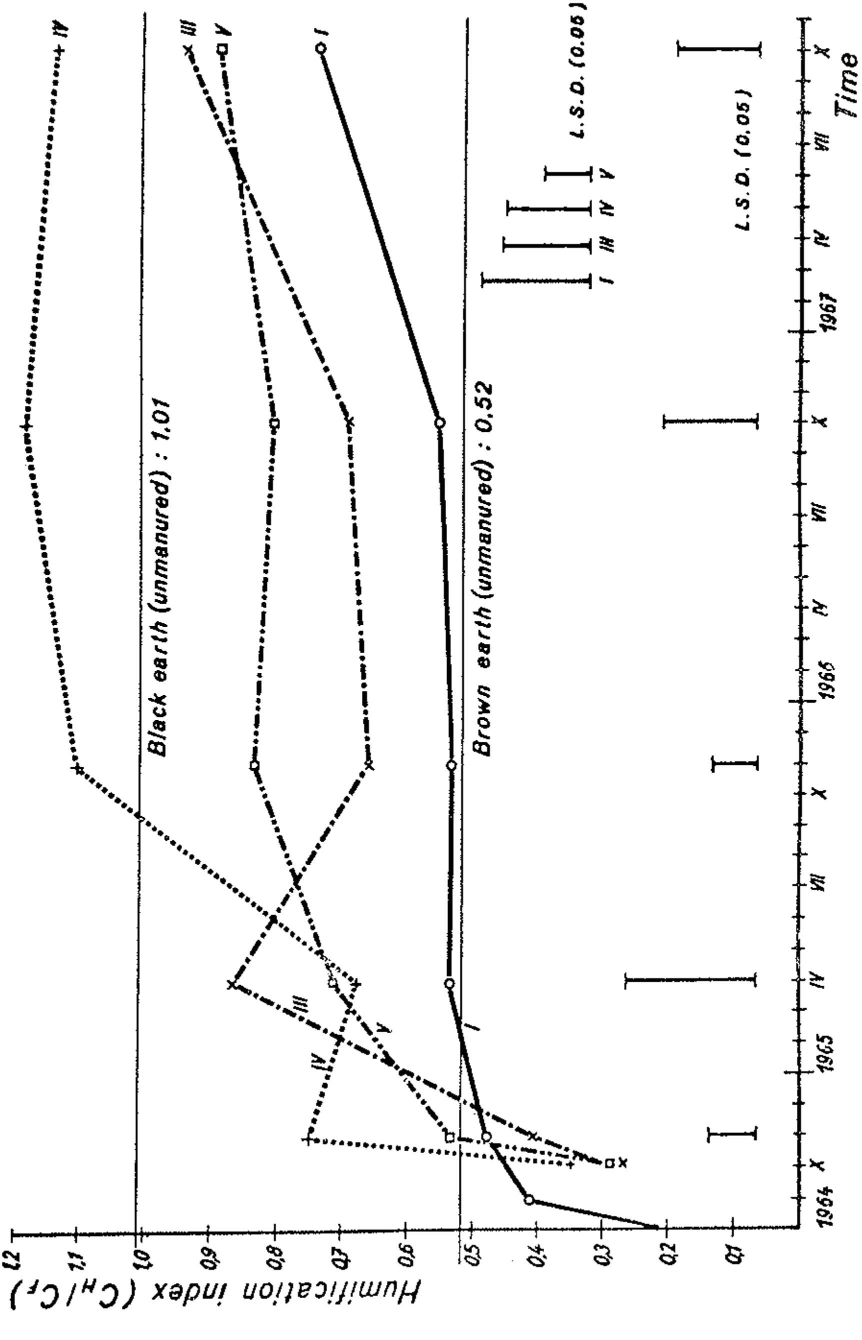
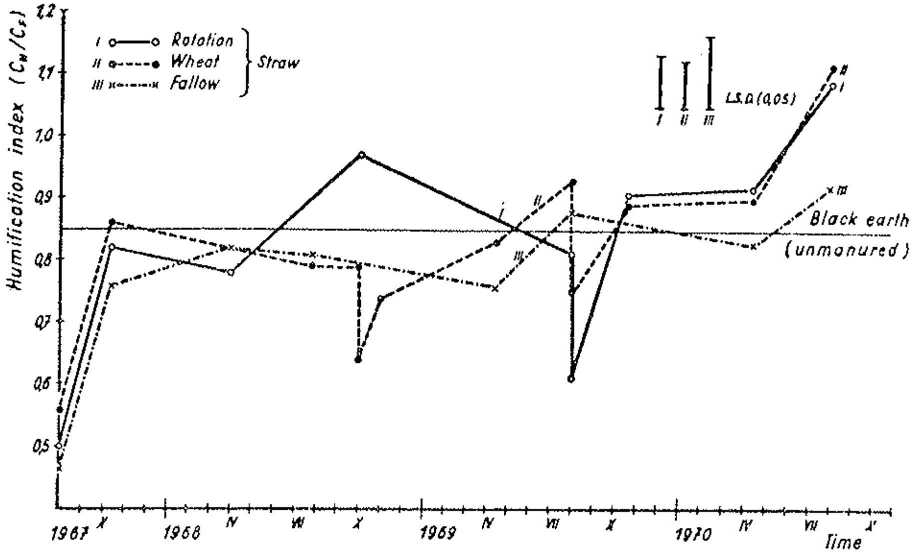


FIG. 14 — *Progress of humification of green manure in soil.* For details see Fig. 3 and text.
FROM OBERLÄNDER and ROTH [45]



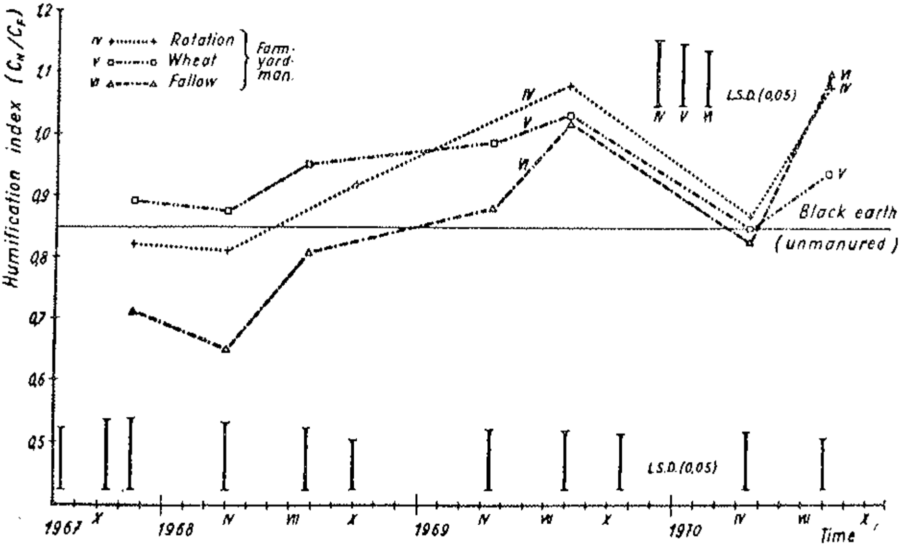


FIG. 15 — *Progress of humification of straw (above) and farmyard manure (below) in soil.*
For details see Fig. 4 and text.

From OBERLÄNDER and ROTH [46]

A number of differential equations as reviewed by JENKINSON [28] and by BROADBENT [6] have been developed to describe *changes in the level of organic matter in soil* (taking into consideration the annual supply of organic materials and the continuous process of mineralization. Some of these equations suffer from the simplifying assumption that all fractions of organic matter present in soil, whether native humified matter or added materials, decompose at the same rate. Under this assumption the overall process is determined by the rate constant r which can be calculated from carbon analyses (or in the absence of carbon data from nitrogen analyses) carried out through decades in the soils of permanent field experiments, such as initiated at Rothamsted, England [66] and at Halle, Germany [63] in the 19th century. An annual decomposition rate of 2,5% was calculated for the former location [28] and rates of 1-5% for the latter [67].

However, the whole decomposition process must be obviously split at least into two parts, the fast mineralization of the added materials and the slow mineralization of the humified soil matter. This implies a splitting of r, the overall rate constant, into r_M and r_S, the rate constants of the partial processes. HÉNIN et al. [22, 23] have recognized this and modified their original terms by setting up a two equation model. They calculated r_M values of 0,3-0,7 and r_S values of 0,01-0,02. But even two rate constants do not seem to describe adequately the whole process; presumably each organic fraction is decomposed at its own rate. A detailed kinetic analysis, taking into consideration several fractions, should therefore display a whole spectrum of rate constants leading to rather sophisticated mathematic models.

It should be borne in mind that the values of r, as given above, were obtained from conventional field experiments with unlabelled materials and are subject to the well known difficulties encountered with soil carbon determinations. Taking soil nitrogen as a measure of soil organic matter is somewhat arbitrary anyhow. Schemes of the interplay between annual manuring and changes of the humus level in soil when based on rate constants describing the actual process inadequately, are therefore necessarily imperfect.

The production of ^{14}C-labelled materials in quantities sufficient for small-sized field experiments has made it possible to tackle problems of turnover of soil organic matter more efficiently. JENKINSON [28], a pioneer in this field, outlined possible experimental approaches. He also examined whether published analytical data from long-term field experiments would follow the path predicted by the general form of differential equations describing changes of organic matter in soil. In absence of carbon data he used figures for soil nitrogen from an experiment under continuous barley carried out at Rothamsted for the last 120 years. The earlier analytical data used fitted well into the theoretical curve, calculated for the increase of soil nitrogen (initially 0,103% N) under the influence of annual supply of farmyard manure. The theoretical curve approaches asymptotically to the predicted equilibrium level (0,311% N) and has reached at present (after 120 years) 97% of this value which cannot be exceeded under the current manuring practice. Admitting soil nitrogen to be taken as an approximate measure of soil organic matter, this example shows that the measured accumulation follows quite satisfactorily the predicted saturation curve; pictures of this process, sometimes encountered in literature, showing a linear increase, are obviously misleading. The fact that doubling of nitrogen, in the given example, took 25 years and trebling 120 years, is a proof of how difficult it is to restore soil organic matter when it has been lost.

Recently SAUERBECK and FÜHR [58] published a hypothetic diagram predicting the carbon content of a soil under the assumption of an annual supply of 2 t/ha straw carbon. The diagram was based on data taken from an experiment on the decomposition of a single dose of labelled straw in soil, observed through 4 years. The authors calculated that the highest possible accumulation of straw carbon in soil, under the assumed annual rate of supply, would amount to 6,5 t/ha. 95% of it would be reached after 25 years. The turnover time τ_r of the slowly decomposable (« humified ») straw fraction at annual supply was found to be 6-7 years (i.e. by definition the time required for the mineralization of an amount of the fraction equal to the amount contained in soil). Assuming an annual mineralization rate of the native soil carbon of 1 or 2% alternatively, the authors were compelled to the surprising conclusion that the assumed annual supply of organic matter would not suffice for maintaining the original level of native soil carbon (0,87% C) through more than 27 or 12 years respectively.

ROTH and OBERLÄNDER [49] made an attempt to give a *kinetic interpretation* of their data from previous experiments [45, 46] including a plot with annual supply of labelled straw. They succeeded in demonstrating a good agreement of the actual increase of labelled carbon present in the soil in stabilized (« humified ») form, measured through 4 years, with a hypothetic curve calculated from straw decomposition data. Both curves followed the path of the theoretical curve corresponding to an equation of HÉNIN et al. [23]. In order to obtain basic data for their calculation, ROTH and OBERLÄNDER plotted their decomposition curves of green, straw and farmyard manures in semilogarithmic form (Fig. 16) as suggested by JENKINSON [28]. The parts of the curves describing later stages of the process proceeding at a lower rate of decomposition, were converted to straight lines, whereas the curvilinearity still inherent in the initial part indicates that at least one more process, presumably the mineralization of the rapidly decomposable constituents, is initially superimposed on the slow process. After one year, when the pool of rapidly decomposable constituents becomes gradually depleted, the decomposition of the less decomposable constituents dominates the whole process, following fairly well a straight line as given by

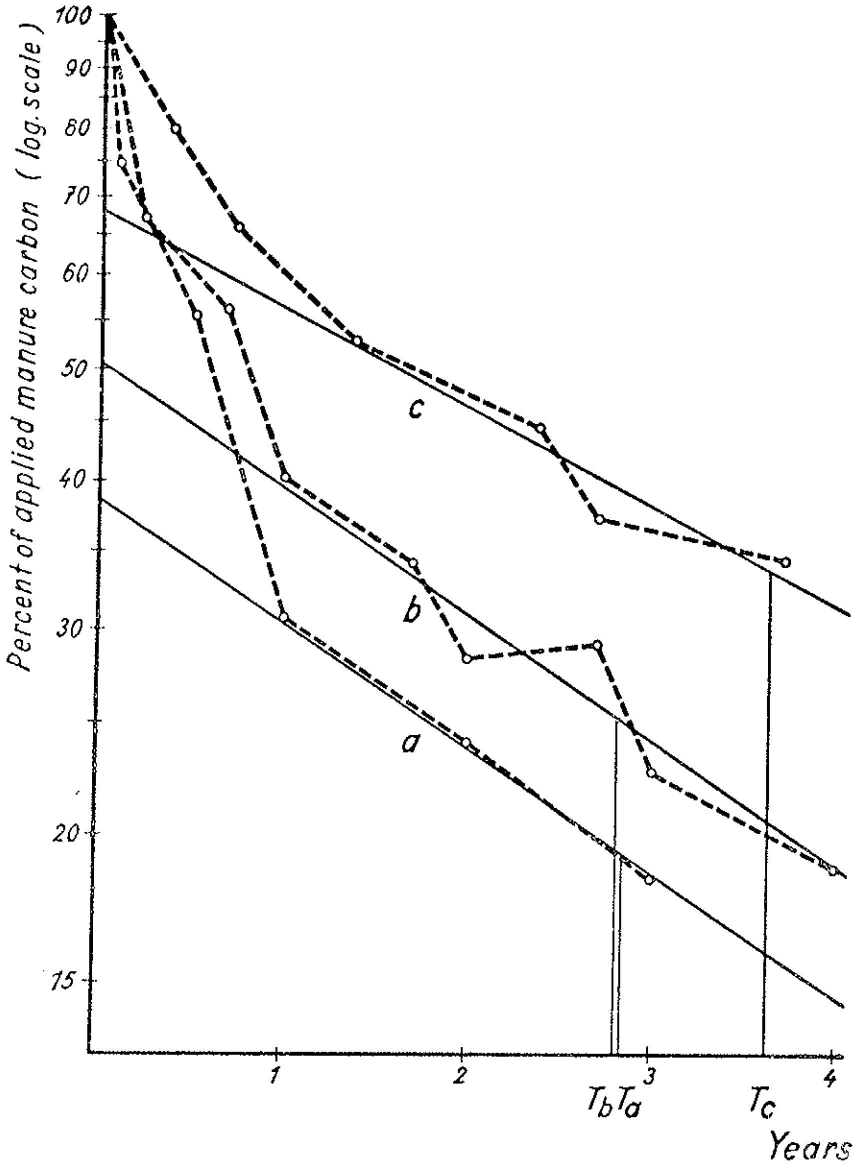


FIG. 16 — *Semilogarithmic diagram of the decomposition of* ^{14}*C-labelled manures in soil.*
a = green manure (mean of curves III-IV, Fig. 3).
b = straw manure (curve III, Fig. 4).
c = farmyard manure (mean of curves IV-VI, Fig. 4).
Sloping regression lines (*a*, *b*, *c*) calculated from straight part of curves (1-4 years) and extrapolated to ordinate axis.
T_a, T_b, T_c = half lives of the slowly decomposable (« stabilized ») residues of manures.

Adapted from ROTH and OBERLÄNDER [49]

(6) $$\ln x = \ln x_0 - \lambda t$$

the logarithmic form of

(7) $$x = x_0 e^{-\lambda t}$$

obtained by integrating the differential equation of a first order decay reaction

(8) $$\frac{dx}{dt} = -\lambda x$$

x = carbon of labelled slowly decomposable (« stabilized ») constituents present in the soil at time t

x_0 = carbon of labelled slowly decomposable constituents of the initial dose of manure (entering the soil at time t_0)

λ = rate constant of the decomposition of labelled slowly decomposable constituents

t = time

Two characteristic terms were calculated (Table 4): The half life T (the time elapsed when x has dropped to $x_0/2$) and the mean residence time τ (the time required for x to become x_0/e) which equals the reciprocal rate constant ($\tau = 1/\lambda$).

Using the data obtained from Fig. 16 the cited authors showed that the measured increase of the slowly decomposable fraction followed the path of the calculated summation curve (Fig. 17) as well as the path of the theoretical curve of accumulation (Fig. 18) corresponding as mentioned to the equation

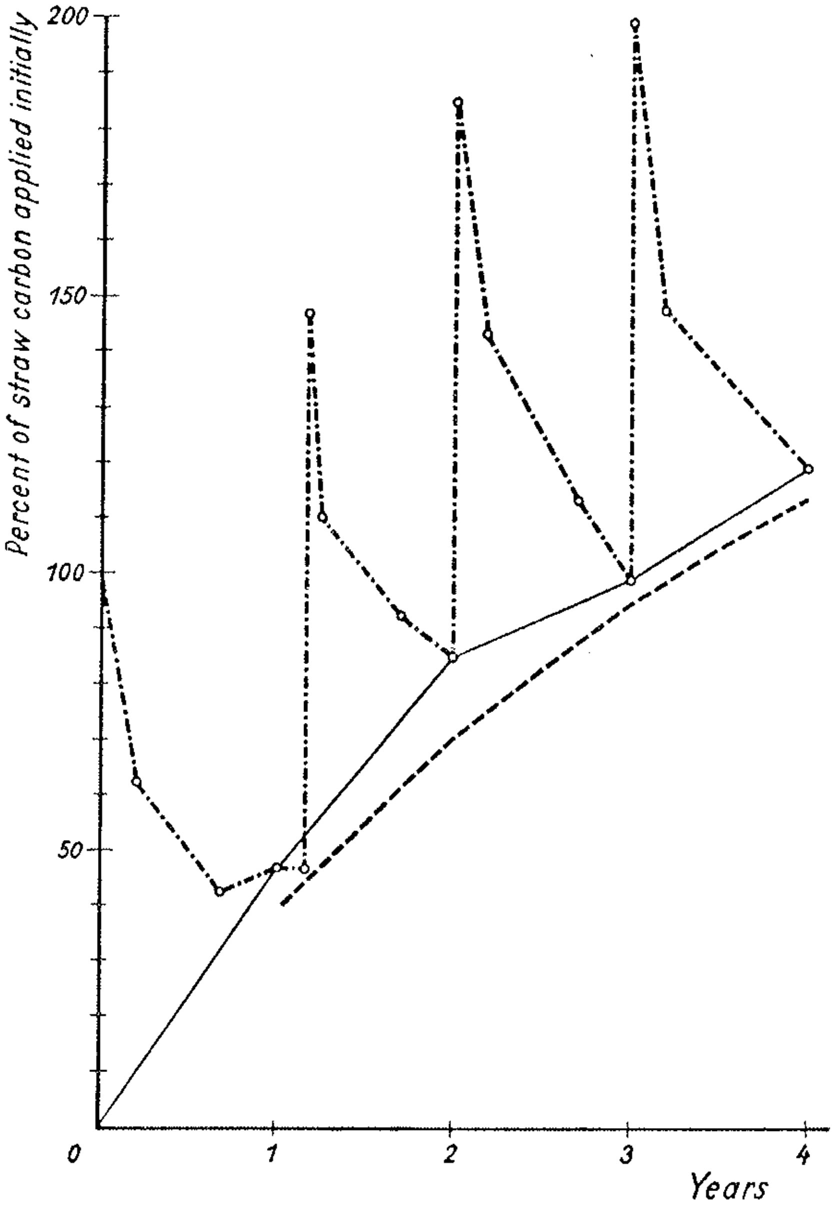


FIG. 17 — *Decomposition of ^{14}C-labelled straw applied annually and accumulation of the labelled slowly decomposable residues in soil under continuous wheat.*

-·-·-·-·- supply and decomposition of straw (curve II, Fig. 4).
o———o measured accumulation of labelled residues.
- - - - - - - - calculated accumulation of labelled residues (by summation of annual sections of curve III, Fig. 4).

Adapted from ROTH and OBERLÄNDER [49]

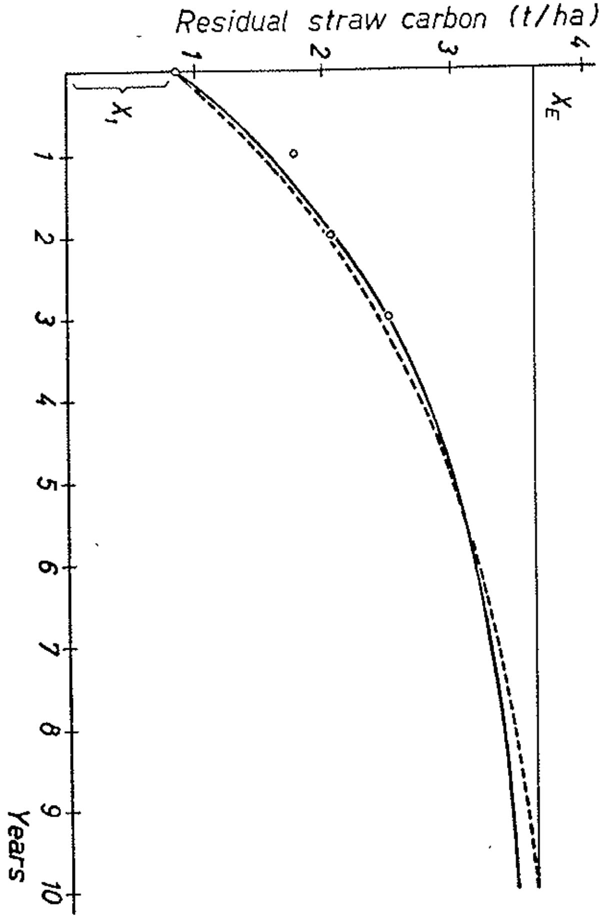


FIG. 18 — *Measured and calculated accumulation of labelled slowly decomposable residues in soil after annual supply of* [14]*C-labelled straw.* (cf. Fig. 17).

o o o o o o o measured accumulation.

- - - - - - - - - calculated curve of accumulation (cf. Fig. 17).

———————— theoretical curve of accumulation according to equation (9).

For x_1 and x_E see text.

Adapted from ROTH and OBERLÄNDER [49]

$$x_r = \frac{x_0}{r} + \left(x_1 - \frac{x_0}{r}\right) e^{-rt} \tag{9}$$

which is the integrated form of the differential equation

$$\frac{dx_r}{dt} = x_0 - rx, \tag{10}$$

x_r = carbon of labelled slowly decomposable (« stabilized ») constituents present in the soil at time t

x_0 = carbon of labelled slowly decomposable constituents of manure entering the soil annually (= ordinate interceptions in Fig. 16)

x_1 = residue of x_0 remaining in the soil one year after first addition (= ordinate interception in Fig. 18)

r = rate constant of the decomposition of labelled slowly decomposable constituents supplied annually

t = time

When supply and losses of the same fraction are in equilibrium, equation [10] becomes

$$\frac{dx_r}{dt} = 0 \tag{11}$$

whence

$$\frac{x_0}{r} = x_E \tag{12}$$

x_E = equilibrium concentration of labelled carbon of the « stabilized » fraction in soil (maximal attainable concentration under the given annual supply)

Equation (9) had been originally developed [23] to describe changes in the level of total carbon in soil, the native as well as the newly added components, assuming a mean rate constant of decomposition. ROTH and OBERLÄNDER used equation (9) to describe solely the accumulation of labelled straw carbon irrespective of soil carbon, in order to investigate this process separately. They also calculated analogous data for green and farmyard manure, assuming a model with a fictive annual supply.

Data summarized in Table 4 do not show fundamental differences between the three kinds of manure tested. The kinetic terms of green and straw manures are very similar, the farm yard manure being only somewhat more stable, but the supply of slowly decomposable constituents by the farmyard manure is much greater (68% of the total manure carbon) as compared with 39% in the case of green manure.

Further kinetic data listed in Table 4 are as surprising as the analogous values adduced by SAUERBECK and FÜHR [58]: turnover times τ_r (defined as above and calculated as $1/r$) of the « stabilized » fraction were found to be rather short (3-4 years) as compared with the figures calculated and quoted by JENKINSON [28] for unlabelled organic nitrogen (15-45 years). They are certainly not comparable with the age of soil organic matter which was found to range from many hundred to 2000 years as determined by radiocarbon dating [60, 61]. Facing these discrepancies several authors [58, 35] had recourse to the assumption of a labile pool of less stable humic substances undergoing a rapid turnover and being arranged around a core of old inert material.

The increase of the level of « humified » carbon in soil seems to be rather limited, even if derived from farmyard manure. Table 4 suggests that an annual supply of 5 t/ha dry matter would lead to a maximal accumulation of about 3-6 t/ha « humified » manure carbon (equilibrium concentration x_E) as compared with a content of native soil carbon of 36,7 t/ha. About 95% of x_E would be reached after 10 years of annual manuring (approximate equilibrium concentration x_{10}). It should be kept in mind that these data refer solely to the

TABLE 4 — *Kinetics of decomposition and accumulation of slowly decomposable residues of ^{14}C-labelled manures in soil* (cf. Figs. 3, 4, 16, 17 and 18).

Soil: 1,4% C (= 36,7 t/ha).
Initial (= annual) supply of manure (dry matter): 5 t/ha (= 2,1 t C/ha).

Kinetic term	Symbol	Green manure	Straw under bare fallow	Straw under continuous wheat	Farmyard manure
Rate constant (decomposition)	λ	0,24	0,25	—	0,19
Half life (years)	T	2,9	2,8	—	3,6
Mean residence time of initial dose (years)	τ	4,1	4,1	—	5,2
Supply of slowly decomposable constituents (% of total manure supplied)	x_0	39	51	51	68
Rate constant (decomposition under annual supply)	r	0,33 (1)	0,33 (1)	0,30	0,26 (1)
Turnover time (years)	τ_r	3,1 (1)	3,0 (1)	3,3	3,9 (1)
Equilibrium concentration of labelled carbon (t/ha)	x_E	2,5 (1)	3,3 (1)	3,6	5,7 (1)
Approximate equilibruim concentration of labelled carbon (t/ha)	x_{10}	2,4 (1)	3,2 (1)	3,5	5,3 (1)

Kinetic terms are explained in the text.

(1) Values based on a hypothetic curve of accumulation (dashed curve in Fig. 18) calculated from decomposition data, assuming a fictive annual supply as given above.

Data partially adapted from ROTH and OBERLÄNDER [49].

labelled « humified » manure-derived fraction, irrespective of soil carbon.

Any predictions that could be made from Table 4 in order to balance the accumulation of labelled carbon with the loss of native soil carbon, should be looked upon with some reserve, regarding the approximations necessarily involved in computing the data listed in the table. Assuming a 1% annual rate of soil carbon mineralization, the manure carbon accumulated under the given conditions would not suffice to maintain the original level of soil carbon for longer than for 7-15 years, according to kind of manure. This is a rather surprising conclusion if compared with the results of permanent field experiments; SAUERBECK and FÜHR [58] recently faced the same dilemmatic situation when making predictions on carbon equilibria in soil as outlined above. One could think of smaller rates of soil carbon mineralization; actually no losses of soil carbon within 4 years were detected in the reviewed experiments [45, 46], but it would be unreasonable to talk of a constant level. The author prefers to believe that the dilemma is due to inaccuracies necessarily inherent in extrapolating short-term experiments, even if they have been undertaken with labelled materials. This is one reason more to stress the importance of carrying on experiments of this type for some more years. In spite of these limitations the kinetic approach demonstrates that considerable quantities of organic materials are required to compensate for losses due to mineralization and how early careless management may lead to declining carbon levels in soil.

IV. CONCLUSIONS.

The use of organic manures uniformly labelled with ^{14}C or ^{15}N for research purpose has appreciably increased our knowledge of the role of manures in conserving and restoring soil organic matter.

For reasons explained earlier it is essential that manures used for this kind of research are *uniformly labelled* and that the homogeneous distribution of the label has been proved by proximate analysis. It is no question that the difficulty of preparing uniformly labelled materials was a deterrent to investigators until recently, but since growth-chambers required for this purpose have become available on the market (cf. e.g. Fig. 2), technical difficulties involved in the production of these materials have been reduced considerably.

Only a few small incubation experiments using *double-labelled* (${}^{14}C$, ${}^{15}N$) *materials* have been conducted in the laboratory, yet it is probably in the use of this kind of material that *a great future potential* lies. Research work of this type is in progress in Austria: some time ago more than 4000 g of double-labelled plant matter have been produced [12] and were recently applied to small-scale field plots in order to trace the paths of carbon and nitrogen during humification processes in soil.

As useful as labelled manures have proved when the turnover of the whole labelled matter is studied, as *difficult to interpret* are results obtained when the labelled matter is *fractionated by successive extraction* as discussed earlier. Any modifications of the commonly used methods of extraction, hydrolysis etc. aiming at a better separation of classes of constituents do not seem to be promising. More success might come from the application of gel chromatography or similar methods.

Undoubtedly, shortcomings encountered in fractionating labelled soil organic matter are more than balanced by the incontestable advantages of using labelled materials for an *easy and precise determination of small changes of the added organic matter* in presence of large quantities of native soil organic matter. Some results obtained in this way are conclusive enough as to urge upon agronomists the necessity of changing their traditional views of the fate of organic manure in soil.

One of these new findings obtained with labelled substances is the fact that *fresh or undecomposed materials*, such as green and straw manures or untreated (unrotted) animal manure, *do not decompose rapidly nor completely* in the soil within few weeks or months as commonly believed. Statements of nearly 100% mineralization of added organic materials within short periods, as found in the literature until quite recently, are erroneous and therefore misleading, because any mineralization will always be connected with some production of microbial tissue. Thus some of the manure-derived organic matter will enter successive microbial generations and will persist in the soil biomass for several years.

We know, however, — and this is again one of the results obtained exclusively by means of labelled materials — that some per cent of fresh and unrotted manures, apart from the constituents entering the biomass by frequent transformations, are *stabilized in the soil in « humified » form*. This was clearly shown for green manures (Fig. 8); in the case of straw the begin of the humification process cannot be defined exactly, but it was proved that the stable fraction, whether being still lignin or already « humified » matter, persists in the soil for several years.

The objections to an increased use of green manures raised in the early times of work with labelled materials, as described above under the heading « *priming action* », have been meanwhile convincingly invalidated, partly by reducing some of the older findings to *technical errors*, partly by calculating that a priming action *never causes net losses of organic matter* when the whole soil-manure system is considered.

The comparison of several kinds of undecomposed manures with conventionally rotted farmyard manure has not shown any essential differences between the distributions of fractions in the « humified » residues nor between the stabilities of these residues. Farmyard manure is only slightly more stable than the other manures. Of course, a greater percentage of slowly decomposable constituents enters the soil with farmyard manure; but it would be a paralogism to deduce a superiority of rotted farmyard manure from this fact, because during the rotting procedure, the preparations of which require a considerable input of labour, about one fourth of the dry matter is lost by the fast initial decomposition on the dung-pile. The use of unrotted manures, on the contrary, does not consume any labour to prepare rotting piles, and, moreover, some benefit for soil fertility may result from the products of the fast initial decomposition taking place in soil.

A final balancing of the input of labour and of the losses of dry matter on the one hand, with the quantity and quality of stabilized organic matter obtained from the various manures tested on the other hand, certainly leads to the *advice of giving up the preparation of rotted farmyard manure* in favour of using unrotted manures of various forms. This implies the *acknowledgement of untreated straw as a suitable form of manure,* as far as its convertibility into humic matter is concerned. Of course, straw manuring under excessively dry conditions will always be subject to some limitations.

In making *predictions on the conservation of humus reserves of soil* a kinetic approach can be useful. Attempts to calculate equilibria between annual supply and mineralization of organic matter, even if carried out using many approximations, have shown that soil management trying to restore organic matter by *merely relying on crop residues implies,* whenever soil carbon equilibria are approaching boundary conditions, *certain risks of humus losses* with the well-known *undesirable consequences for soil structure.* But as the increase of yields and the improvement of the quality of crops is founded, all over the world under all climates and agricultural systems, on the well-balanced, risk-free interplay between an adequate nutrient supply by mineral fertilizers and a favourable physico-chemical state of the soil due to its humus content, it is wise to make any possible efforts to maintain this favourable state, whenever necessary, by the supply of organic matter in appropriate form and in sufficient quantities.

V. Summary.

Problems of humus formation in soil associated with the substitution of undecomposed organic manures for traditional (rotted) farmyard manure are outlined.

Advantages of using ^{14}C-labelled materials in solving these problems are discussed. The preparation of uniformly labelled manures (including rotted farmyard manure) and some salient features of laboratory, pot and field experiments with these materials are briefly described. Shortcomings of the fractionation of labelled soil organic matter are mentioned.

Results obtained from experiments on decomposition, humification and accumulation of various kinds of ^{14}C-labelled manures in soil under field conditions are reviewed in detail, including influences of application techniques, soil factors and cropping systems. The « priming action » of fresh materials is briefly discussed. Conclusions as to the value of the tested manures for humus formation are drawn.

Kinetic studies of the turnover of labelled organic matter in soil are discussed. The risks involved in restoring soil organic matter merely by enhancing the growth of crops are mentioned. Additional supply of organic manures as a precautionary measure is recommended.

* * *

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DISCUSSION

Chairman: O. T. Rotini

Hernando

I was very pleased when listening to your paper since it gave me the answer to one of the most important problems in farming, that is the necessity on the part of the farmers to apply manure to the soil in order to stop the decrease in organic matter. We believe that this is always true. But the farmers complain that they have not enough animals on the farm to produce manure. In this case we suggest to apply compost, but even though this might not be the same, I am satisfied that we are in the right direction.

I should like to ask you about the experiment dealt with at the end of page 22. There you make a comparison between farmyard manures and straw manures. My question is: have you any plots with unrotted straw and without any additional nitrogen?

Oberländer

It would have taken too much time to tell that with straw manuring there are certainly some shortcomings if you do not have enough precipitations. And this is probably the case in parts of Spain. We also have it in parts of North Eastern Austria, an arid region, because in this area the transformation of straw would occur rather slowly, and we are usually recommending in these case to our farmers not to apply the straw automatically every year without checking if the straw from previous years has already decomposed. This is one point so that I would like to say: the success of straw manuring is just depending on humidity. But in humid areas it would work on farms.

Now to answer your question I must say that unfortunately we did not use a plot without nitrogen, because agronomists who have made experiments on straw manuring already for decades, say that you have a fixation, an immobilization of the nitrogen in your soil, and since the straw is low in nitrogen you must add nitrogen. But as our experiment was rather expensive, we could not reproduce it as you would reproduce another experiment; thus, in order to have the smallest risk, we added nitrogen and we did not use a plot without N.

HERNANDO

I mentioned in a previous discussion that in leaving the straw on the surface in areas with low rainfall, there is not enough moisture for the decomposition of the straw, in summertime, of course. In the autumn we mix the surface soil with the rotting straw, and then it is different. You say in your paper that with certain total rainfall there is enough water to grow plants. But I do not think that usually it is always like this. I remember areas with rainfalls of more than 1,500 mm where this water problem exists. Because there the rainfall lasts only for three to four months in the year, whereas for the rest of the year the temperature is very high without any rain. On the contrary in the Central Areas of Spain we have about 500 mm rain every year. These 500 mm tend to come at the right time, i.e. in autum, winter and spring. We often get 3,000 kg per hectare of winter wheat. People farming in this area do not use large amounts of fertilizer, and we could show them very clearly that, when there is water deficiency, they must apply higher amounts of fertilizer than usually to overcome the lack of rain. We can easily demonstrate this because with high rainfall we got very often lower yields; therefore it is not always a problem of water but of bad fertilization. Well, I was trying to explain also that during fall, winter and spring the straw has some effect on the soil, because with rainfall the parts covered with straw get more water and remain more humid afterwards than the uncovered parts.

OBERLÄNDER

I would like to say that in the field, usually right after the harvest, the straw is brought about 10 cms deep. We imitated this practice in our experiments; the straw was turned down with a rotor cultivator about 10 cms deep and was left at this depth one month or six weeks until autumn when it was ploughed down to 10 more cms. Actually we used no plough in this experiment, we did it by hand with a spade.

PRIMAVESI

First, I wish to congratulate Dr. OBERLÄNDER on his excellent paper. I agree perfectly with what is said on page 17 that « any valid conclusions for practical agriculture can be drawn only from *experiments under field conditions* ». This is also our experience and that of all teams we are in relation with in South America. We have been working in Brazil since 1949 with field trials under conditions of practical farming.

I also agree perfectly with what is said on page 28 about the high-molecular humified constituents of soil organic matter (Dauerhumus) and its influence on the physical and chemical properties of the soil. Unfortunately my experience indicate that this information is not well known in many places in Sonth America.

RUSSELL

Prof. OBERLÄNDER's work is very exciting and I would like to make one or two comments on what he has said and what he has not had time to say. The first point is: he gave us a curve on the board — actually figure 16 — showing the rate of decomposition of organic matter in the soil plotted on a fixed scale. That rate is surely not due to the decomposition of different components of the material added to the soil, but to the decomposition of the biomass or of the metabolic products of the soil microorganisms. So it is naturally constant for all the added materials because you are now on the decomposition of biomass or decomposition products.

The second point I would like to make that Prof. OBERLÄNDER had not time to discuss is that this work now allows us a much clearer understanding of the various components of humus and it shows us that the traditional method of humus analysis has no good theoretical foundation because it will not separate out the humic acid of the biomass, the humic acid of the soil organic matter and the humic acid of the metabolic products of biomass. This work has given us a completely new picture of the whole of humus chemistry. You are well aware of that naturally, but I would like to emphasize that this work has got much larger repercussions than merely what Prof. OBERLÄNDER had time to show us. I now come to a much more controversial thing. We have been at a high level of science: I now come to the sordid level of the farmer in the field. I do not know what experience you have in Austria, but with the field experience we have had in Great Britain on farms running over a period of 10 years, we were not able to show any benefits to the farmer of ploughing in straw compared with burning it. Burning has other advantages in that you get more control of plant disease by burning. Have you got any evidence from your country to show what benefit a farmer gets by this system of ploughing in straw.

I now come to a third point which I think I disagree with you on. I am not quite certain. For any system of farming you tend to have a given level of organic matter in the soil but that level of organic matter depends on the rate of addition of organic matter to the soil and the rate of decomposition of organic matter in the soil. And if you take a continuous cereal policy, growing cereals only, you will tend to get a certain level of organic matter, but you do not go down to zero of organic matter.

So if a continuous cereal growing policy is adopted, the soil organic matter content will stabilise at a definite level; it will not fall to zero. It is possible that there is a definite organic matter content below which soil conditions deteriorate sufficiently to affect the economics of soil management. There is also the well-known Broadbalk field at Rothamsted where most plots have received neither straw nor organic manure for over 130 years, and high yields of wheat are still obtained on these plots receiving high levels of fertiliser, and some yields are still well above our national average.

The field has however a naturally well-structured clay loam of redbrown colour containing an adequate level of active iron or aluminium hydroxides. I would expect some fine sandy and very fine sandy loams or loamy fine or very fine sands to have a structure more sensitive to organic matter level than the Rothamsted soil, though I don't think we yet know what it is, nor under what farming systems it would fall to too low a level.

OBERLÄNDER

To answer your first question Prof. RUSSELL, I mentioned just some details in my talk and I should like to make it clear now. If we find labelled carbon after five or ten years still in the soil, it does not mean that this is entirely undecomposed manure material, it may be carbon of micro-organisms which have been formed during this time and have been retransformed to the next, and again to the next generation. When talking of organic matter it is useless to talk of the original material and try to separate it from the newly formed material, because you actually don't have any boundary where you could say the material has already been transformed. And if you use labelled materials you even can't distinguish the newly formed substance from the one you have added.

Prof. RUSSELL's second remark was whether one can afford not to plough in the straw. This is really a point of controversy. I think I have mentioned it already several days ago in the discussion, we just don't know the critical level of organic matter for any soil, we don't know how much we can exhaust our soils, how far we can let drop the level and when we should stop, and this was also the conclusion of my presentation. It is a matter of risk, it may be, it may not be, and I am just concluding that if the labour which is spent on adding manures can be afforded and justified, when it doesn't mean additional trouble for the farmer, why should he not add manures?

HAUSER

The results which Dr. OBERLÄNDER reported are for us technically very reassuring because we had such problems of whether green manure would work or would not work, or whether straw should be added, or whether it is worse than farmyard manure and so on. In the dry zone where the soils are rich in calcium carbonate, rich in basis as found in the area from Lebanon up to Pakistan, in these soils the carbon content is tremendously low, very often under one percent, nearly always under two percent C. Still, these soils are by no means unfertile if they are deep enough. If they are deep enough they are the soils where the high yielding varieties from Mexico give their highest yields, up to 7-8 thousand kilos of grain per hectare. It is obvious that these soils are working on a different level of carbon. If a bush is taken off and the soil has two and a half percent carbon after cutting the bush, this content will drop to maybe one and a half percent during cultivation, but still this soil is very fertile. In the humid tropics you have completely different conditions, the carbon content is somewhat higher normally but seldom up to three percent (except in soils which are of organic origin), and there the addition of organic matter is much more effective than in the arid zones. In the humid tropics an addition of the right amount of organic matter, the yield may increase enormously. We measured mainly the money returns from these soils in the vulcanic areas of Java, and they went up many times especially on poor soils by the application of organic matter.

The conclusion from Dr. OBERLÄNDER's presentation would be that any organic material applied to the soil can be expected to have a suitable effect on the yield and is a security factor for the farmer. Especially in arid climate the organic matter remaining in the soil in humified form will probably increase the water holding capacity. This effect of organic matter was not mentioned by Dr. OBERLÄNDER, as it was probably not determined, but it is of great interest.

OBERLÄNDER

It should be understood that our experiments are entirely valid for central European conditions, climate, soils and management practices and, frankly speaking, I would not dare extrapolate anything from it to any other region, arid or sub-tropic or humid tropic, because the systems would certainly change in a rather surprising way. In mineral fertilising the situation is much easier, I think we can extrapolate, to a certain extent, what we find in Central Europe to other climatic zones and there would be much more probability that it would work out under very different conditions in other parts of the world, but to extrapolate organic matter experiments from Central Europe to somewhere else, I would not dare so. Therefore, I always wonder wby do international organisations pay so little attention to organic matter problems outside of the temperate zones.

HERNANDO

I would like to add some results of an experiment in relation to the critical level of organic matter. Yesterday, whilst speaking to Dr. COLWELL, I suggested he used the knowledge of farmers to know which will be the best method to correlate the yields in the area with the soil test, but when we make that, we need to talk with the farmers. My impression of the different areas we have studied in this way, is that farmers as an average always say that 50 years ago the problem of cultivating the soil with good tilth after rainfall was not so difficult as now. They find now that the fields retain the rain very badly, and also the condition for cultivation is much worse than it was 50 years ago. Our only explanation for that is that this soil has actually a lesser amount of organic matter, and therefore the good condition of the structure and possibility to work the soil properly with ploughing are reduced in many areas by less than 1% of organic matter when they need to work the soil. Sometimes it is too wet, and sometimes too dry and in this latter case they get too much erosion by the wind. Therefore, it may not be possible to say that there is a critical level of organic matter throughout the world. I rather think that with any climatic condition with the same soil type, there is certainly an amount of organic matter which is critical. For the Central Area of Spain with loam clay soil we found that it is between 1% to 1.2%.

WALSH

It is obvious that this question of organic matter disposal and its effect on the soil is very much a regional matter. You have quoted figures that apply to France, Great Britain and yourselves. I would content that this effect from organic matter is very much related to climatic conditions and to the regional situation in relation to soil. We found no significant effect from farmyard manure, other than from the nutrient it carried. There were no effects from the organic matter as such, for the simple reason that we have sufficient organic matter in our soils already. With us in actual fact, the disposal of farm residues and waste is now something of an embarrassment. Under modern intensive conditions of animal production, the disposal of waste from our farms or farmyards becomes quite a difficult problem, and I think we must consider this at this meeting. We must devise conditions that will ensure that from these very intensive animal production units, there is a way of disposing of the nutrients and the other material so as not to contaminate the invironment. Today we are collecting these materials as slurries. Under these intensive conditions the use of straw is limited because it is too costly to use straw and too difficult to distribute on pastures. We are now looking at this from the point of view of feeding the straw together with supplementation by way of urea, or converting, with the use of anhydrous ammonia, the straw into an animal foodstuff closing the cycle if you like and making the maximum use feed-wise of what we produce. We are, in effect, beginning a new cycle of production related to nutrient conservation and its conservation of the environment. This is a matter of the very greatest significance, not alone in the developed countries but in under-developed countries as well. I want to remind you here at this meeting that we have talked almost totally of the underdeveloped countries. We must also think, however, of the soil fertility problems in the developed countries, because if we do not we are not looking at the whole spectrum. It becomes equally important from a societal point of view that we look at the developed countries where agriculture is intensifying. We can learn from this because the underdeveloped countries of today will, we hope, be the developed countries of tomorrow.

CHEMICAL FERTILIZERS AND CROP QUALITY

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Today many specialists consider the quantitative increase of the crop quite as important as the improvement of its quality but in certain situations it is more important to realize in the first place an improvement of the quality of the crop.

The evaluation of the quality of an agricultural product intended for human food must be made conformably with a number of properties. It is not possible to do this according to one criterion only, although in certain cases such an evaluation is being applied.

Indeed the notion of "quality" must include three types of characteristics:

a) the quality, from the point of view of biological value, that is to say of the nutritional value, according to the content of elements with high biological value;

b) the quality from the organoleptic point of view: taste, smell, colour, consistency, etc.;

c) the hygienic quality including both the absence of residues of toxic chemical products and pathogenic bacteria, and the absence of certain natural products with toxic character or inhibitors of certain physiological processes.

We refer particularly to the effect of the nutritional conditions on the quality, both from the point of view of the content of elements with high biological value and of the imbalance which may arise because of an inharmonious relation among the nutrient ions of the solution of the soil or of the plants.

At present there are a few agricultural products whose commercial value is estimated according to the quality of certain biologically active chemical components (sugar beet, oil-bearing plants, fruit juices, etc.). More often the quality is estimated according to the exterior aspect and according to certain physical properties (hectoliter weight, weight of 1000 grains, volume, uniformity of the colour, brilliance, taste, etc.). Surely there exists a certain relation between the exterior aspect and the quality of specific components with an active biological role (vitamins, enzymes, sugars, proteins, etc.), but these physical properties could never express the quality. The quality of a plant product should never be judged only according to its exterior aspect and certain physical properties, but also according to its content of active biochemical elements, which assure the nutritional value of the product.

The nutritional deficiencies determined by the fertility state of a soil reflect themselves at first in the plant products and then in their consumers.

The health of an individual, of a nation, depends largely on the variety of the products they live on, on their biological quality which, of course, is closely connected with the soil where they grow and with its state of fertility.

The effect of fertilizers on the crop is being studied in many works, and we find it reflected also in the works presented at four regional colloquia organized by the Institut International du Potassium with the theme: "Le potassium et la qualité de la récolte", and in the works of four symposia organised by the Centre International pour la Coopération en Agriculture with the theme: "La composition de la matière végétale et la qualité de la récolte" (Paris, 1964), as well as in the works of the 3rd World Congress of Research in Agriculture (Rome, 1969) with the theme: "Modern agricultural technique and human health".

There is no doubt that a large number of factors acts on the crop and on its quality: edaphic, climatic, genetic, chemical, phytosanitary, economic factors (fig. 1). The researches have thrown into relief that an efficient and quick measure, which not only influences the quantity of the crop but also its quality, is constituted by the nutrient conditions. One may thus obtain, per unit of surface, with the same climate and soil conditions, more proteins, fatty substances, vitamins, essential aminoacids, etc. It is more difficult to check the modifications of the climate, of the humidity of the soil than the nutrient conditions. Numerous studies and researches have put in evidence the fact that the judicious utilization of the fertilizers can modify the metabolism of the plants in determining an increase in the content of proteins, fatty substances, sugar, starch and other substances.

Function of the conditions of culture (variety, climate, soil, agro-thechnique) may vary the quality of the crop within very large limits. For example, as concerns the environmental factors and the variety, the protein content varies between very large limits from 9 to 23%, the starch content from 52 to 75%, and the content of fatty substances from 2 to 5%. This means that from the same crop quantity per surface unit, one can obtain products with a higher nutrient value.

In Rumania the researches on the quality of the agricultural production have passed through several stages which characterize the evaluation criteria of the crop with regard to the technical possibilities of the respective period.

During the period 1900-1930, C. CÂRNU MUNTEANU, C. ROMAN, I. ENESCU, AL-ZAHARIA, C.C. DOBRESCU, in their researches have determined crop quality based on physical analyses, and in a certain measure, also by means of chemical analyses.

During the period 1930-1960, the control of crop quality, especially of the cereals and fodder plants, carried out by M. IONESCU, H. SLUSANSCHI, MAGDA IVĂNESCU et al. regards particularly the characterization from the technological point

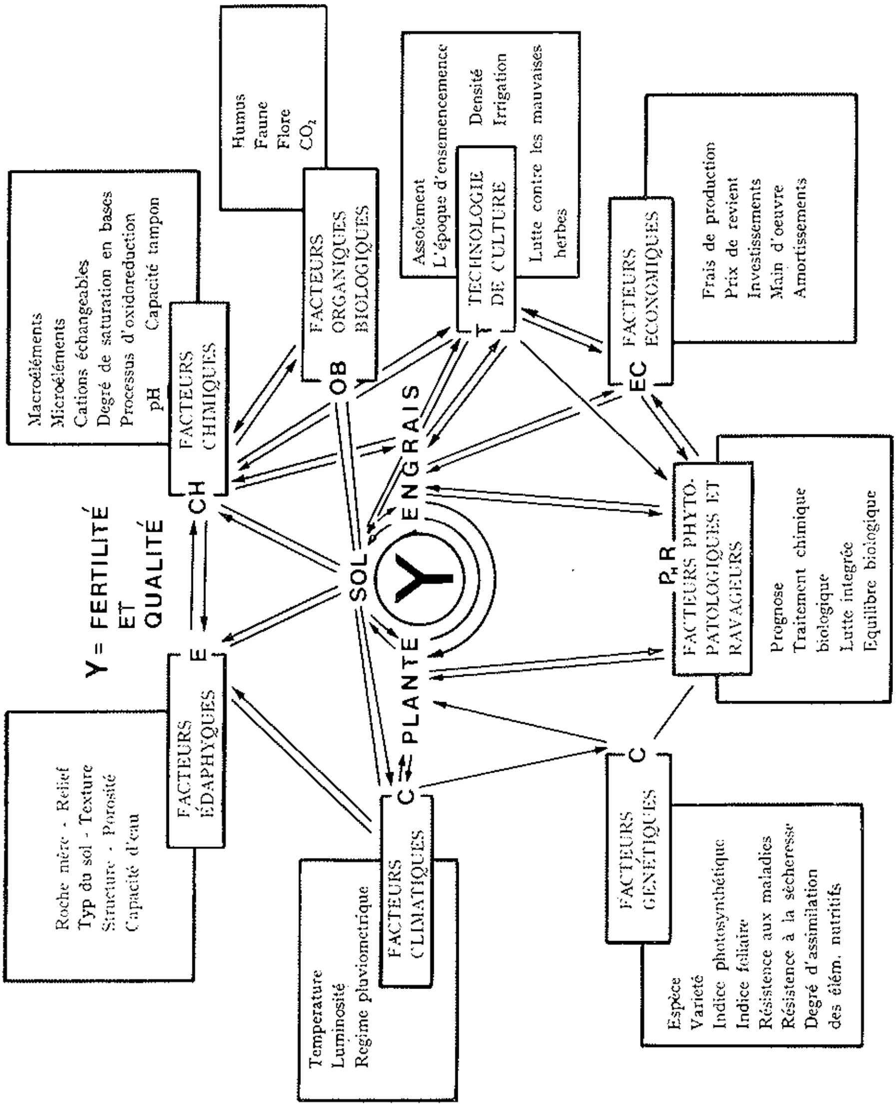

Fig. 1 — Schematic representation of the factors determining the fertility and quality of the crop.

of view, the quality of bread production and industrialization. Although chemical analyses are being approached to an ever larger extent, the problems of biochemical crop formation and of the content of biologically active substances are as yet not solved.

After 1960, simultaneously with the intensification and utilization of fertilizers in the Rumanian agriculture, there have been initiated also systematic researches in order to establish the modification of chemical composition under the influence of fertilizers or other vegetation factors, and the relation between the biochemical indices and mineral nutrition.

In this direction researches have been made on the influence of fertilizers on the crude protein content and protein fractions (albumin, globulin, prolamine), and on their composition of aminoacids, in wheat, maize, potatoes and fodder crops.

There exists a close relation between the mineral nutrition of the main biochemical indices of the plants. The researches made in Rumania by I. CSAPO [2] show under this point of view the following:

— the most important vegetation phases where the influence of the fertilizers reflects itself on wheat, are the phase of intensive growth and the phase of flowering;

— in the vegetative parts and in the grains, during the phase of intensive growth, there increases under the fertilizer influence the ratio of crude protein (Pb), soluble glucides (Gs), one ascertains a decreased ratio Gs/Gr [soluble glucides, directly decreasing glucides (Gr), diminish the total glucide content (Gt)]. These modifications contribute to a more accentuated synthesis of the constitutional matters and of the apparatus of synthesis.

One notices a positive, clearly significant correlation between the production of directly decreasing soluble glucides (Grs) and the production of crude protein (Pb).

— During the flowering phase, one observes under the influence of the nutrient conditions, a correlation between the production of soluble glucides (Gs) and that of brute protein (Pb), which can be improved by the ratio Pb/Gs when there exists a significant correlation also in Pb/Gs of the grains as well as in the production of the grains.

In fig. 2 we present schematically, after CSAPO I., the relations between the chief biochemical indices and the production of grains in wheat, under the influence of the nutrient factors.

In winter wheat the influence of fertilizer doses and of the ratio between them, on the basis of the coefficients of relation between the chief biochemical indices, have led to the conclusion that in wheat the phosphorus dose and the N/P ratio are the main factors which significantly influence the production and the content of crude protein (fig. 3).

During the intensive growth period P and NP nutrition has had a significant influence on the production of crude protein. During the flowering period more important for the nutrient conditions are the formation of soluble glucides and of crude protein.

The character of the dynamic exchanges under the influence of nutrient factors may show us the measures that have to be taken in view of the increase of protein production, by means of the combination of agrochemical tests of the soil with the character of biochemical transformations taking place in the plant. The unilateral doses of N or P, by provoking qualitative changes in the glucide and protein metabolism, prejudice the accumulation.

In a further series of researches carried out lately on wheat by D. ISFAN [12] with increased doses of nitrogen (40-80-120-180-220) on phosphorus basis, there has been put in evidence the positive influence of nitrogen fertilizers on the production of wheat and on the production of crude protein (table 1 and fig. 4). The development of the curve of the production shows that the higher doses (180 kg/ha N) do not procure any more economic gains of the production. As concerns protein, one states that its increase becomes slower at the dose of 80 kg/ha and higher at the doses of 100 to 120 kg/ha.

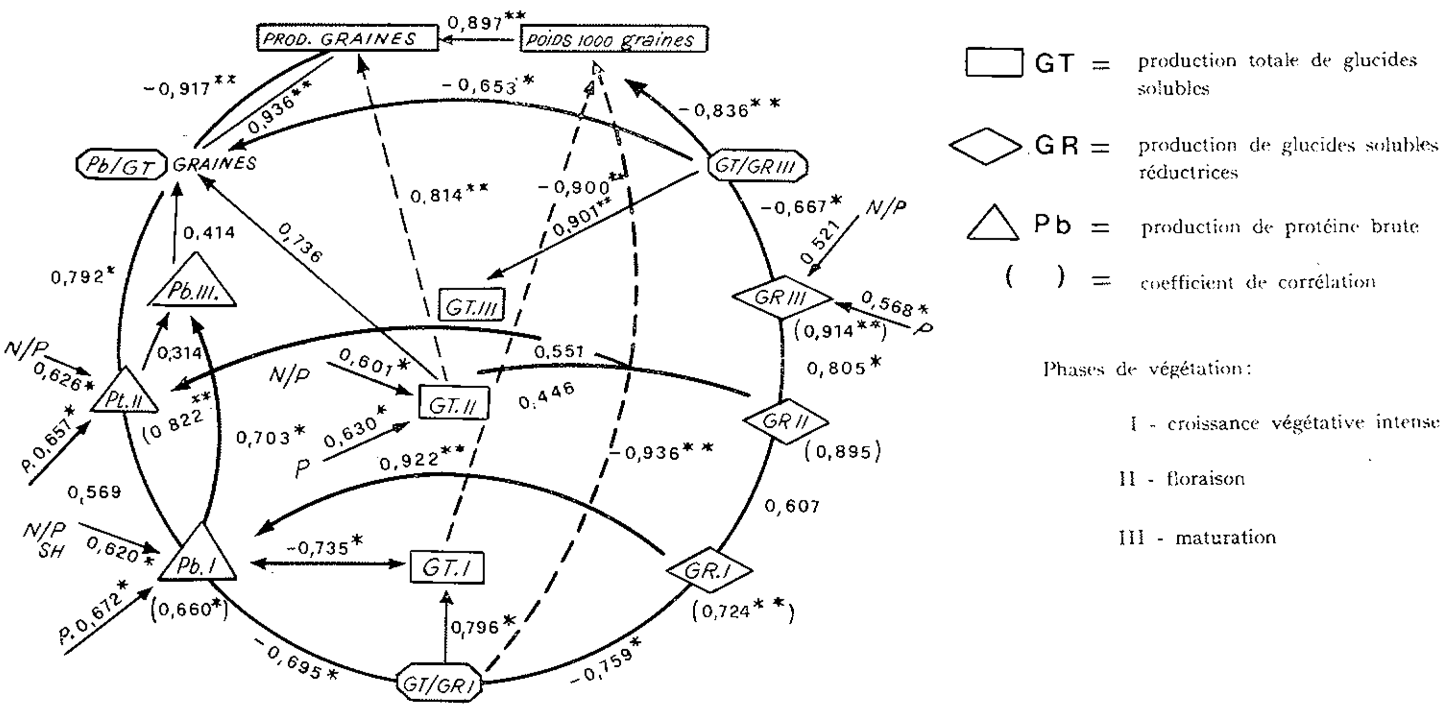

FIG. 2 — Schematic representation of the relations between the chief biochemical indices and the grain production in winter corn. (After I. CSAPO)

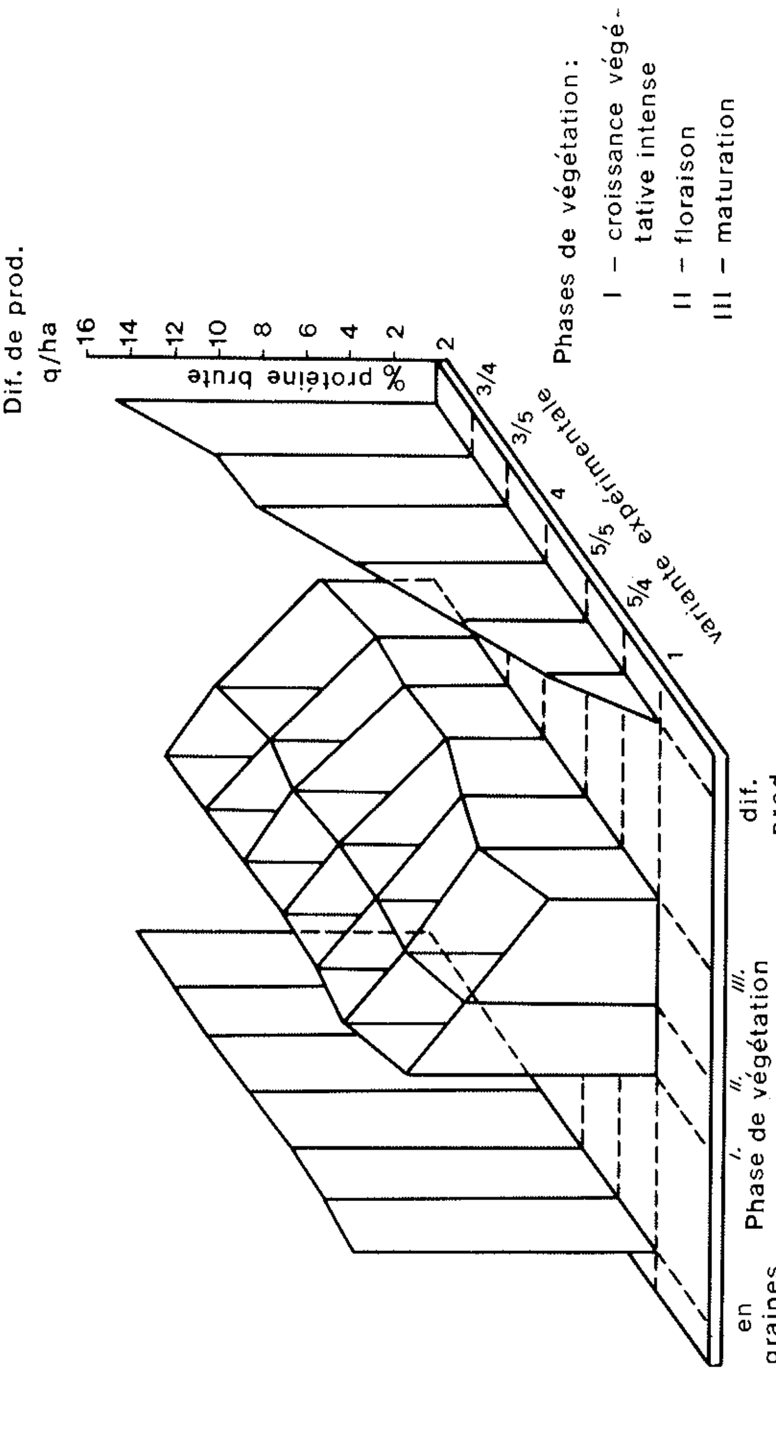

FIG. 3 — Dynamics of the content of brute protein in winter corn.

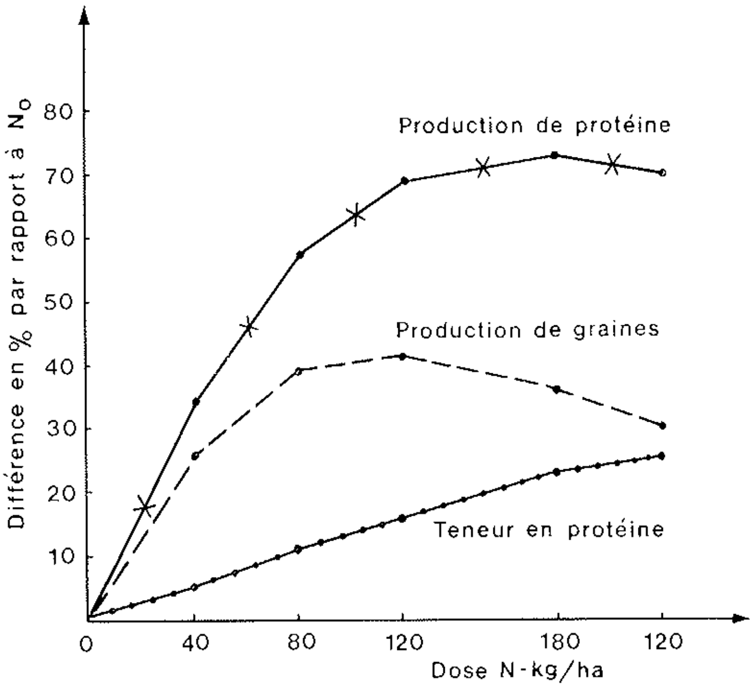

FIG. 4 — Increase in the percentage of crude protein, function of the increase in grain and protein production in proportion to N_0.

The nitrogen doses have favourably influenced also certain technological indices of the quality — note on the farinograph, PELSHENKE index, weight and volume of the bread which have simultaneously increased with the increase of the nitrogen doses.

As regards the physical indices (quantity of 1000 grains and hectoliter weight) there have been recorded higher values with decreased doses (40 kg/ha N), whereas with higher doses they descreased.

The results of other experiments with nitrogen fertilizers

TABLE I — *Adjusted values and regressions of the production and of the indices of quality with N doses applied at the basis of P (50 and 100 kg/ha P_2O_5) in wheat, after maize, according to* D. ISFAN.

Specifications	Year	N Doses kg/ha 0	40	80	120	180	220	Equation of regression N-dose of azote (kg/ha)
Yield in q/ha grains	1965	30,6	37,9	42,7	45,2	45,5	43,8	$30,6 + 0,217\ N - 0,00089\ N^2 + 0,0000007\ N^3$
	1966	12,6	21,0	26,7	30,0	31,3	30,1	$12,6 + 0,249\ N - 0,00097\ N^2 + 0,0000009\ N^3$
	1967	30,7	41,0	44,2	42,8	37,4	35,2	$30,7 + 0,367\ N - 0,00301\ N^2 + 0,0000065\ N^3$
	1968	26,0	28,3	28,6	27,7	26,0	25,6	$26,0 + 0,866\ N - 0,00084\ N^2 + 0,0000020\ N^3$
	1969	20,2	24,9	26,9	27,4	26,9	27,6	$20,2 + 0,161\ N - 0,00116\ N^2 + 0,0000026\ N^3$
	$\overline{x}$	24,2	30,7	33,8	34,6	33,4	32,4	$24,2 + 0,211\ N - 0,00132\ N^2 + 0,0000024\ N^3$
Crude Protein %	1965	10,48	11,32	12,24	13,18	14,46	15,11	$10,48 + 0,0192\ N + 0,000050\ N^2 - 0,00000019\ N^3$
	1966	14,89	14,54	14,66	15,08	15,92	16,40	$14,89 - 0,0157\ N + 0,000193\ N^2 - 0,00000041\ N^3$
	1967	11,10	11,66	12,76	13,98	15,14	14,87	$11,10 + 0,0041\ N + 0,000293\ N^2 - 0,00000106\ N^3$
	1968	11,60	13,11	14,55	15,76	16,85	16,88	$11,60 + 0,0376\ N + 0,000020\ N^2 - 0,00000037\ N^3$
	1969	13,55	14,34	14,85	15,06	15,15	15,31	$13,35 + 0,0321\ N - 0,000201\ N^2 - 0,00000043\ N^3$
	$\overline{x}$	12,28	13,00	13,85	14,63	15,52	15,71	$12,28 + 0,0155\ N + 0,000075\ N^2 - 0,00000034\ N^3$
Dry Gluten %	1965	6,95	7,65	8,39	9,12	10,10	10,60	$6,95 + 0,0164\ N + 0,000028\ N^2 - 0,00000012\ N^3$
	1966	10,40	10,20	10,27	10,56	11,24	11,75	$10,40 + 0,0091\ N + 0,000108\ N^2 - 0,00000018\ N^3$
	1967	7,11	7,76	8,95	10,26	11,56	11,37	$7,11 + 0,0060\ N + 0,000298\ N^2 - 0,00000108\ N^3$
	1968	7,77	8,66	9,82	10,93	11,80	11,39	$7,77 + 0,0162\ N + 0,000183\ N^2 - 0,00000083\ N^3$
	1969	8,10	9,10	9,51	9,58	9,52	9,71	$8,10 + 0,0339\ N - 0,000250\ N^2 - 0,00000083\ N^3$
	$\overline{x}$	7,94	8,67	9,44	10,16	10,89	10,98	$7,94 + 0,0166\ N + 0,000049\ N^2 - 0,00000028\ N^3$

on cereals have shown that nitrogen determines the increase of the glyadine content and the decrease of the glutenin content and at the same time the decrease of the content of certain amino acids, like lysine and arginine.

From researches carried out in Rumania it results that nitrogen fertilizers applied alone or with phosphatic fertilizers, have led to an average increase of the gluten quantity of 1 to 3%. In slightly provided soils, the gluten content in wheat fertilized with nitrogen (on PK basis), compared with the variant which received PK only, increased 1,5 times (fig. 5). Besides the quantitative gluten increase, also the relation between different protein fractions as well as between amino acids have changed.

Coïc, Fauconneau and Terroine show that the application of nitrogen fertilizers in a late stage of the wheat, can lead to a substantial increase in protein and to an increase in the zein content and to a decrease in the lysine content.

The results obtained with maize and published in our work [7] show that by applying nitrogen fertilizers, the crude protein may increase from 7,6% to 11,9% (100 kg/ha N) and the starch content from 72,2% (100 kg/ha N) to 74,9% (50 kg/ha N). In case of an insufficient supply of nitrogen, the protein content decreases greatly, even down to 50% as compared to the best variant (N_{100}). The decrease in starch content, in case of progressive nitrogen doses, explains itself by the fact that during the numerous metabolic stages of nitrogen, the plants consume a large quantity of energy obtained from the oxidation processes of the carbohydrates. Likewise, the intense biosynthesis of the nitrogen compounds contribute to the decrease of the content of carbohydrates of the plants.

The fertilizers change the crude protein content in proportion to the genetic potential of the variety, thus also the amount of the protein fractions (albumin, globulin, glutelin, prolamine), and the relations between them. The highest value of protein fractions was noticed since the utilization of

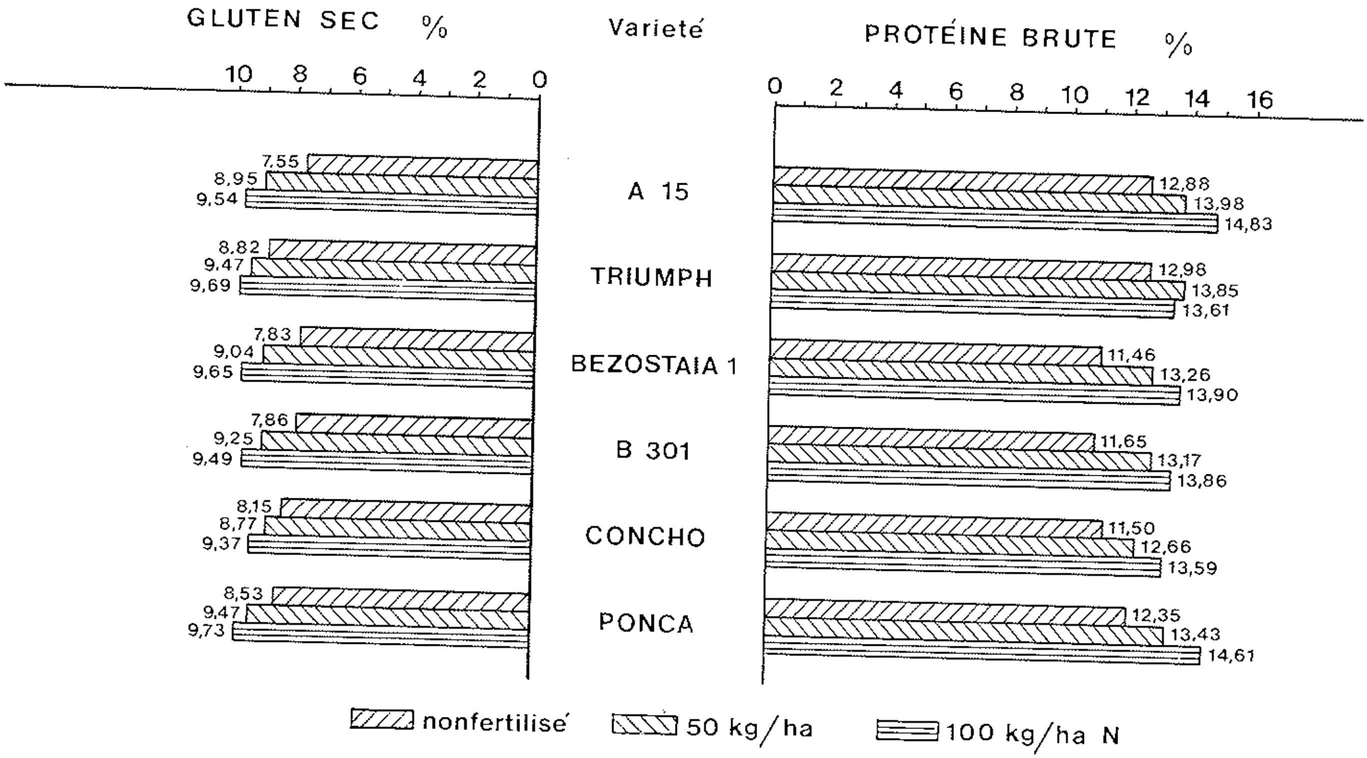

FIG. 5 — The influence of nitrogen fertilizing on crop quality.

compound NPK fertilizers, followed by NP. Albumin and prolamine have increased in all of the cases where chemical fertilizers were applied, whereas the globulin content increased only in the variant with NPK. In the same way the amino acid content of each protein fraction increased under the influence of fertilizers with NPK, and also the amount of amino acids. The deficiency of phosphorus and potassium diminishes the accumulation of starch and fatty substances.

The researches made by D. DAVIDESCU and L. REICHBUCH on *potato tubers* [13], likewise put in evidence the possibility of improving its quality with the use of fertilizers.

From the analysis of the data represented in table 2, it results that both the percentage of protein content in potato tubers, and the one calculated per hectare were influenced by modification of the nutrient regime through the application of fertilizers. The highest values were obtained where very high doses of chemical fertilizers had been used: $N_{180}P_{120}$-K_{120}, and in the variant where manure had previously been applied in the course of the rotation.

The researches made with *fodder maize* have shown that in parallel with progressive doses of nitrogen fertilizers increases also the nitrogen content in the plant. The protein nitrogen of a certain doses lessens the accumulation rhythm by increasing, in exchange, the content of the non-protein nitrogen.

Elevated nitrogen doses applied unilaterally lead to an imbalance in the assimilation of magnesium by the plants, and the accumulation of nitrates in the plants owing to the antagonistic phenomenon of the ions and the imbalance between photosynthesis and nitrogen (C/N) accumulation.

Animals, and especially milk cows and sheep, which are put to pasture early, on meadows heavily fertilized with nitrogen become sick of "grass tetany", known in Rumania under the popular name of "burnt grass". The fodder plants containing large quantities of nitric nitrogen have a toxic

TABLE 2 — *Protein*[x] *content of potato tubers and the total quantity per hectare.*

Variant	1965		1966		1967		1968		Average 1965-1968			
	N% x 6,25	Protein kg/ha	N% x 6,25	Protein kg/ha	N% x 6,25	Protein kg/ha	N% x 6,25	Protein kg/ha	Protein kg/ha	%	Diff.	Sign.
1. Non-fertilised	7,25	1660	6,87	1729	7,42	1730	7,58	1787	1726	100		
2. N_{100} P_{40}	7,92	2445	7,25	2825	7,29	2735	8,76	3622	2907	168	1181	xxx
3. N_{60} P_{40}	7,82	2055	7,56	2254	8,15	2261	8,04	2306	2219	129	493	x
4. N_{100} P_{80}	8,54	2549	7,81	2582	7,77	2363	8,33	2563	2514	146	788	xx
5. N_{180} P_{120} K_{120}	8,54	2685	7,43	3119	8,31	3069	8,58	4141	3253	188	1527	xxx
DL 5%											469	
DL 1%											649	
DL 0,1%											895	

effect because of the formation of metahemoglobin which prevents the normal oxygenation of blood.

Under the influence of phosphorus and potassium doses the nitrogen content of plants decreases. An increase of potassium doses reduces the assimilation of nitrogen, indicating an antagonism between nitrogen and potassium.

Fertilizers modify not only the chemical composition of the protein substances but also of phosphorus compounds (orthophosphates, phosphoric esters, phospholipids, ribonucleic acids, desoxyribonucleic acids, compounds of sulphurs, of oligoelements, sugars, vitamins, etc.).

The researches made by D. DINCĂ and H. CÎMPEANU on lucerne, spring vetch, sorghum, Sudan grass, fodder maize, show an increase in the content of carotene and xanthophyll with an equilibrated fertilization of these plants (table 3).

TABLE 3 — *Influence of fertilizers on the vitamin content (carotenoïdes) of fodder plants (according to* DINCĂ D. *and* CÎMPEANU H.).

Variant	mg/% dry matter Lucerne		Spring vetch		Sorghum		Sudan grass		Maize (leaves)	
	C	X	C	X	C	X	C	X	C	X
Non-fertilized	12,1	17,8	5,6	9,1	2,3	5,9	1,5	4,1	3,2	5,4
N_{50} P_{30}	13,2	18,7	6,1	9,8	2,6	6,3	1,7	5,1	4,1	9,2
N_{100} P_{65}	11,3	15,9	5,6	8,0	2,4	4,5	1,3	4,0	3,0	5,0
20 t manure + N_{50} P_{30}	13,8	19,4	6,5	10,4	2,9	6,8	1,9	5,6	4,7	12,5

C = carotene

X = xanthophyll

Among the fodder plants *lucerne* occupies an important place in Rumania. Thanks to its chemical composition, lucerne can in its green state, in the form of hay or lucerne meal, substitute a good part of other categories, used in cattle, pig and poultry feed. Since in superior agrotechnical conditions lucerne can yield up to 70-100 t/ha green matter, it is desiderable that this be also of high quality.

The researches carried out by C. COVRIG [3] during the period 1966-1970 on the effect of chemical fertilizers on lucerne, put in evidence the increase of protein content thanks to the judicious use of N and P fertilizers (table 4).

TABLE 4 — *Crude protein content of lucerne hay in proportion to the doses of nitrogenous and phosphatic fertilizers.*

	Crude Protein content							
	N_0		N_{50}		N_{100}		N_{150}	
	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
P_0	17,00	1666	17,37	1832	17,87	1826	18,06	1990
P_{50}	17,43	1960	17,62	2024	18,00	2243	18,18	1989
P_{100}	18,43	2223	18,93	2443	19,56	2452	19,68	2496
P_{150}	18,87	2213	19,62	2360	19,62	2416	17,93	2262

On *meadows* the judicious use of nitrogenous fertilizers increases production quantitatively and qualitatively. The experiments made by RODICA MARINESCU on three meadows in Carasova-Resita, Poiana-Brasow and Rarau-Suceava at a meadow rate and pasture rate with 8 levels of nitrogenous fertilization (0, 30, 60, 90, 120, 240, 360, 480 kg/ha N on the basis of 80 kg/ha P_2O_5 and 120 kg/ha K_2O), show an increase of the total nitrogen of the plants in proportion to the improvement of the total nitrogenous nutrient rate (fig. 6) in the plant, and important modifications between the relation in which the protein nitrogen finds itself in proportion to the soluble nitrogen and the comparative nitric nitrogen to the total nitrogen, and to the level of fertilization. Under the influence of nitrogen doses the composition of crude protein is modified, the production of proteinic nitrogen decreased and the production of non-proteinic alpha-aminic, amidic and nitric forms increased. Likewise when the plants accumulate nitric nitrogen, the total nitrogen decreases under the influence of elevated doses of nitrogen fertilizers which leads to a depreciation of the fodder quality.

It has been insisted on the influence of fertilizers on the quantity and the quality of protein since no product can replace this substance in human or animal food. The maximum accessible protein source and the less expensive is at present assured by cereals and leguminosae. According to the FAO-UNESCO data, of the total of 85 million tons of proteins yearly used in the human consumption, approximately one half derives from cereals. Hence particular attention must be given to the improvement of the crop, also from the qualitative point of view, both through the cultivation system and by the development of varieties with higher protein contents.

The different species of cultivated plants have certain limits concerning their content of proteins and of different amino acids. Researches have shown that in general the protein content can easily be increased in varieties cultivated on land of reduced fertility or not fertilized previously, and in plants deriving from seeds yielded from cultivated plants in conditions of deficiencies of nutrient elements. The protein content of cultivated plants in normal conditions may be influenced, within certain limits especially with regard to the relation between the different amino acids.

The results obtained in Mexico with wheat, in the Philippines with rice, in the north European countries with barley and in the United States with maize put in evidence that in order to increase the protein content, one must create new varieties by utilizing especially the method of mutations. The mutations obtained in maize are known with regard to the elevated amylase content, to the reduced zein content and to the proteins better equilibrated from the point of view of the lysine and tryptophane content realized by transfering the genes opaque 2 and floury 2.

In general the cereals are relatively better provided with sulphur-containing amino acids (methionine, cystine), poorer in lysine and sometimes in tryptophane. The protein is better equilibrated from the point of view of the relation between amino acids.

The increase in production of protein per hectare and the improvement of quality are likewise in close relation with the way of application of the fertilizers. The best results were not obtained by the unilateral application of one fertilizer or another, but by the combined use of fertilizers with NP or NPK. In the same way one obtains an increase in protein per hectare in irrigated wheat culture, resulting from an increase in total production, but often there has been observed a reduction in the protein per kilogram of the dry matter; this deficiency can be corrected by a better combination of fertilizer and irrigation.

Another aspect of the modification of crop quality under the influence of nutrient factors may be constituted by the application of fertilizers in inharmonious, imbalanced ratios which reflect on the quality of the products of economic value.

Elevated or excessive doses have a relative significance, since they must first be analysed with regard to the relation of the nutrient elements existing between them and then in proportion to the other nutrient elements in the soil.

From the quantitative point of view, the same fertilizer dose may be excessive if in inharmonious relations — leading to serious imbalances in the plant — and can be normal when it is in harmonious relations with the other nutrient elements inclusive oligoelements. These imbalances caused by the excess of certain nutrient elements, must therefore be understood in the sense of creating certain inharmonious nutritional conditions. The use of higher doses becomes sometimes necessary for increasing the production, but if this leads to *induced deficiencies,* one should not refuse to increase the doses but try to find their best means of utilization for the sake of correcting these deficiencies; for instance for the improvement of the qualitative indices in wheat. MASLOVA L.B. shows that the increase of nitrogen doses must be assured by a K/Ca ratio in favour of calcium and other bivalent cations. When the ratio monovalent cations/bivalent cations is in favour of the monovalents (K^+, Na^+) the process of desorption of the elements is stronger, the process of transformation goes down and that of the transport of phosphorus diminishes.

The effect of the insufficiency and excess of nitrogen.

The role of nitrogen in the improvement of crop quality is well known, and so is the effect of the deficiency of this element. Less known are the effects of an excess of nitrogen.

If there do not exist living compounds of the plant organisms without nitrogen which makes an integral part also of the enzymatic system intervening in the energetic and synthetic transformations, then it is explainable why a judicious nitrogen supply improves crop quality. Certain constituents have a more or less passive role (the proteins), others a regulating role of transport or support (the chloroplasts, the mitochondria). The molecules of chlorophyll have a very short life and renew themselves permanently which explains the permanent necessity of the element. In different parts of the plant the total nitrogen content varies on an average of 0,2 to 4,5% of the dry matter. In seeds the non-protidic nitrogen rarely surpasses 10% of the total nitrogen.

A good nitrogen provision of the plants favours the formation of vitamin B_6 (riboflavin), a protective factor against azoic-cancerogenic substances.

Increase of protein content under the influence of nitrogen fertilizers takes place within the limits of the genetic potential of the species and of the variety. That is why the excess of a certain optimum dose has no more an effect on the increase of the protein content and may provoke very serious imbalances and repercussions.

Abundant or excessive nitrogen nutrition and the insufficient supply with other elements (P, K, etc.) lead to the formation of an important quantity of nucleic acids which favour mitosis. At the same time the ratio C/N goes down leading to an imbalance. An excess of nitrogen necessitates a surplus of light in order to intensify photosynthesis and the formation of organic acids and carbohydrates.

Excess of nitrogen nutrition favours the appearance of certain diseases [10] which handicap the growth and the development. Thus, for example with wheat: excessive nitrogen doses favour the attack of *Fusarium graminearum* and *Erysiphae graminis* (table 5).

TABLE 5 — *Effect of nitrogen doses on the attack of* Fusarium graminearum *and* Erysiphae graminis *in certain varieties of wheat (after* I. DUMITRU).

Variety	Fusariose %					Oïdium (notes)				
	N_0	N_{40}	N_{80}	N_{120}	N_{160}	N_0	N_{40}	N_{80}	N_{120}	N_{160}
Dacia	1,5	2,5	3,0	4,5	6,5	2	3	4	6,5	7
Maldova	1,5	2,5	4,0	5,5	7,5	3	4	5,5	7	8
Excelsior	1,5	2,5	4,5	4,5	6,5	2,5	3,5	4,5	6,5	7,5
Favorit	1,5	2,5	3,0	4,5	6,5	2,0	3	4	6,5	7
Bezostaia	3,0	4,5	5,0	7,0	9,0	4,0	5	7	8	9

Excess of nitrogen diminishes extension of the root system, thus limiting the supply of other nutrient elements.

Excess of nitric nitrogen fertilizers (NO_3^-) leads to an *accumulation of nitric ions* in the plant. When there is no equilibrium between photosynthesis, that is between the formation of organic acids and the quantity of nitric ions, the latter remain uncombined and accumulate in the plant. This accumulation of nitric ions in fodder plants can provoke serious intoxications and even the death of the animal. The cause is the imbalance of the plant metabolism, owing also to other elements such as the insufficiency of magnesium which leads to an imbalance of the Ca/Mg ratio.

Another effect of the imbalance caused by an excess of nitrogen in plants is the *diminution of the assimilation of the copper* of the soil. This oligoelement influences likewise the increase of the crop and of its qualities. Forages with 8 ppm copper content (dry matter) reduce the copper content in the blood serum of the animals below 0,65 g/1, a limit considered normal by the Dutch researchers. This deficiency of copper reflects itself both in the health of the animals and in their productive capacity. Researches effected in Holland by ANDRÉ VOISIN [14] show that milk production or the gain in weight decrease in the same measure as the copper of the blood serum diminishes.

Insufficiency of copper in food constitutes also one of the complex causes of the sterility of the animals, conjointly with the deficiency of manganese and estrogenic substances.

Deficiency of copper in forages causes also in young growing animals, exclusively nourished on pasture ground, disorders in bone formation, in the depositing of calcium and phosphorus, which lead to rachitism, to osteomalacia and to bone fractures.

According to A. VOISIN the cause of "enzootic ataxy" of lambs is also the deficiency of copper in forages on which the ewes were fed during gestation.

According to Prof. GHENTA [11] excess of nitrogen in cabbage increases the content of the antithyroid factor. The milk of cows fed on these cabbages carries this factor into the human organism causing serious repercussions on the thyroid.

Effect of the insufficiency or the excess of phosphorus.

Since phosphorus is one of the main constituents of the compounds accumulating and transporting energy, it is distributed in all of the plant organs, but chiefly in the seeds and in the tissues in growth. Each process of cell division and seed formation is connected with the metabolism of phosphours.

Deficiency of phosphorus causes a series of physiological imbalances.

In certain plants, such as subterranean clover (*Trifolium subterraneum*), deficiency of phosphorus favours the excessive increase of isoflavone content, a product with very strong estrogenic action.

Excess of phosphorus, resulting from a large accumulation in the soil or from the application of too high doses not harmoniously equilibrated with the other elements, causes a reduction in the assimilation of zinc and *copper* by the plants as a result of the antagonistic effect of the ions. That is why simultaneously with the increase of the doses of fertilizers with phosphorus, one must control the quantity of zinc and of assimilable copper, both in the soil and in the plant tissues. On maize cultures in Rumania there has also been observed the deficiency of zinc as the result of unilateral or excessive doses of superphosphate given to the soil.

In leguminous plants excess of phosphorus reduces the quantity of nodosities.

Effect of insufficiency or excess of potassium.

Potassium is just as indispensable for the growth and development of the plants as nitrogen and phosphorus. It is found in all the tissues and organs of the plants except in the grains of chlorophyll. Potassium activates a number of enzymes or enzymatic systems such as those of phosphorus, of the respiratory metabolism, of the transfer of energy, of the transfer and accumulation of the carbohydrates, etc. Potassium influences the physical state of cell colloids and of the cellular membrane, contributing to the best functioning of the organism and to exchange of substances. It is a regulator of the water content.

Insufficiency of potassium in nutrition of the plant organism weakens the intensity of the processes of synthesis, of transfer and transport and depositing of substances. The insufficiency of potassium increases the hydrolytic activity which leads to an increase of the non-protidic nitrogen content. The deficiency of potassium disturbs the cell metabolism, the mechanical tissues of support develop weakly (diminishing their resistance to be beaten down). Insufficiency of potassium reduces the resistance of plants to certain cryptogamic diseases and other unfavourable factors of the environment.

Deficiency of potassium disturbs the synthesis of vitamin B_1 (thiamine) which plays a certain role in the metabolism of carbohydrates and in the synthesis of amino acids.

Excess of potassium in the nutrient environment as the result of the inharmonious application of fertilizers, causes *diminution of the assimilation* of *magnesium, calcium, sodium,* and *boron* by plants, and the deficiencies induced in these elements. Besides the negative effect on production, one observes also an influence on quality. The more reduced content of certain mineral elements with an active biological role, and of certain vitamins (B^1) is responsible for it.

This explains the fact of the more frequent sterility in animals fed on plants coming from grounds excessively fertilized with potassium, and of the disease known under the name of "grass tetany", for a more reduced content of magnesium and sodium in the plants.

Chapman shows that excess of potassium is considered to exert an unfavourable influence on the absorption of zinc and iron. In greenhouse conditions one observes very frequently the effect of excessive potassium doses, for the deficiencies induced by magnesium, as a result of the antagonistic K/mg effect.

Effect of deficiency or excess of calcium.

On soils with acid reaction, where calcium has been leached, the unfavourable conditions for plant nutrition are due to the excess of the ions of hydrogen H^{+}, of aluminium Al^{3+}, and of iron Fe^{3+}. On acid soils calcium diminishes the toxic effect of boron by reducing its solubility.

Excess of calcium in the nutritional environment diminishes the assimilation of certain nutrient elements by plants, such as manganese which passes from the bivalent form (easily assimilable) to the not easily assimilable tetravalent form.

Likewise diminishes the solubility of *phosphorus, boron, copper, iron* and *zinc* on soils with basic reaction, or where there have been made improvements with calcium. This leads to the appearance of induced deficiencies. Excess of calcium leads also to the increase of potassium quantities fixed in unchangeable form.

Effect of insufficiency or excess of magnesium.

Deficiency of magnesium may be an induced deficiency owing to elevated doses of potassium or owing to parent rock. It may also be caused by applying excessive doses of calcareous manure leading to modification of the Ca/Mg ratio.

Both a strongly acid reaction and a strongly basic reaction reduce the assimilation intensity of magnesium.

Excess of soluble salts, due to high fertilizer doses, favours the leaching of the soluble forms of magnesium causing implicitly an induced deficiency.

It has been ascertained that high doses of nitrogenous fertilizer lead to a reduction of the magnesium content of leaves.

The increased concentration of hydrogen ions in the nutritional solution, accentuates the symptoms of magnesium deficiency.

Deficiency or excess of manganese.

Calcium, as well as a basic reaction, diminishes the assimilation of manganese by the plants causing induced deficiencies because of the transformation of the bivalent manganese into tetravalent manganese. In this case the manganese deficiency can be corrected both by extraradicular nutrition with manganese sulfate or by fertilizer with elevated equivalent acidity (ammonium sulfate, ammonium chloride) which because of the local modification of the reaction, permits the assimilable manganese content to increase.

Excess of manganese in assimilable form is mainly noted in acid soils (pH $< 6{,}5$). Excess of manganese can cause induced iron deficiencies.

A much reduced manganese content of plants causes physiological imbalances, and likewise a decrease of the vitamin C content because of the diminution of its synthesis.

In animals fed on plant products with reduced manganese content, one observes disorders in the skeleton formation, bone deformations and increase of sterility.

Fertilizers and crop yields obtained in Rumania.

In Rumania agriculture, like all the other branches of the national economy, have experienced profound changes during the last two decades which have transformed the social-economic relations and the life of the peasants [9].

Thanks to her geographical position, favourable climate and soil quality, Rumania presents propitious conditions for the different cultures, specific for the temperate zone. The consumption of fertilizers per surface unit and per head of the inhabitants has increased (table 6) during the last decade (fig. 7).

The first experimental researches concerning chemical fertilizers in Rumania were effected in 1888 in Striharet, district of Olt.

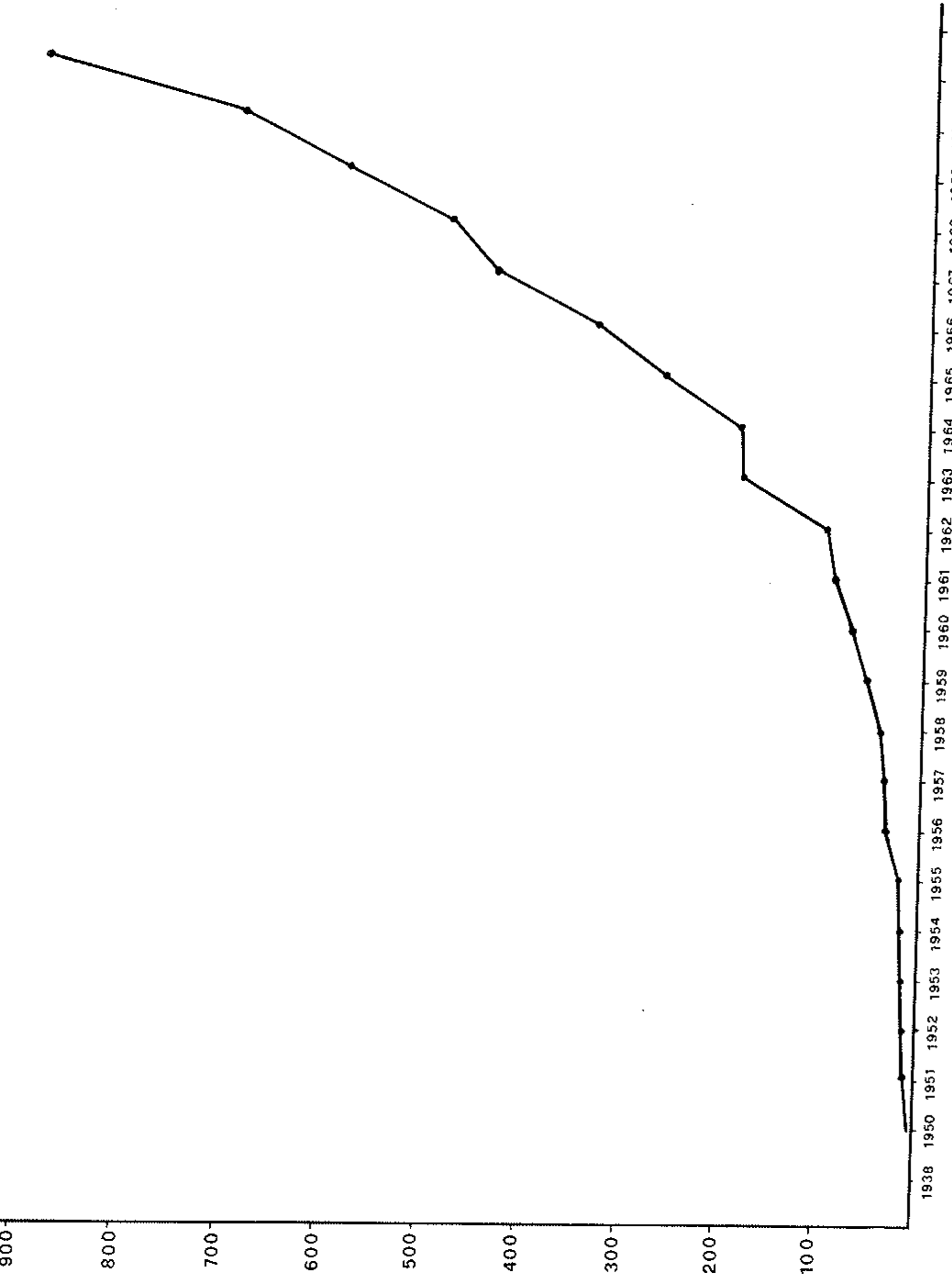

FIG. 7 — Total consumption of chemical fertilizers in Rumania (in 000 tons of fertilizer elements) 1938-1971.
Consumption of chemical fertilizers in Rumania (kg of fertilizer elements per inhabitant) 1938-1971.

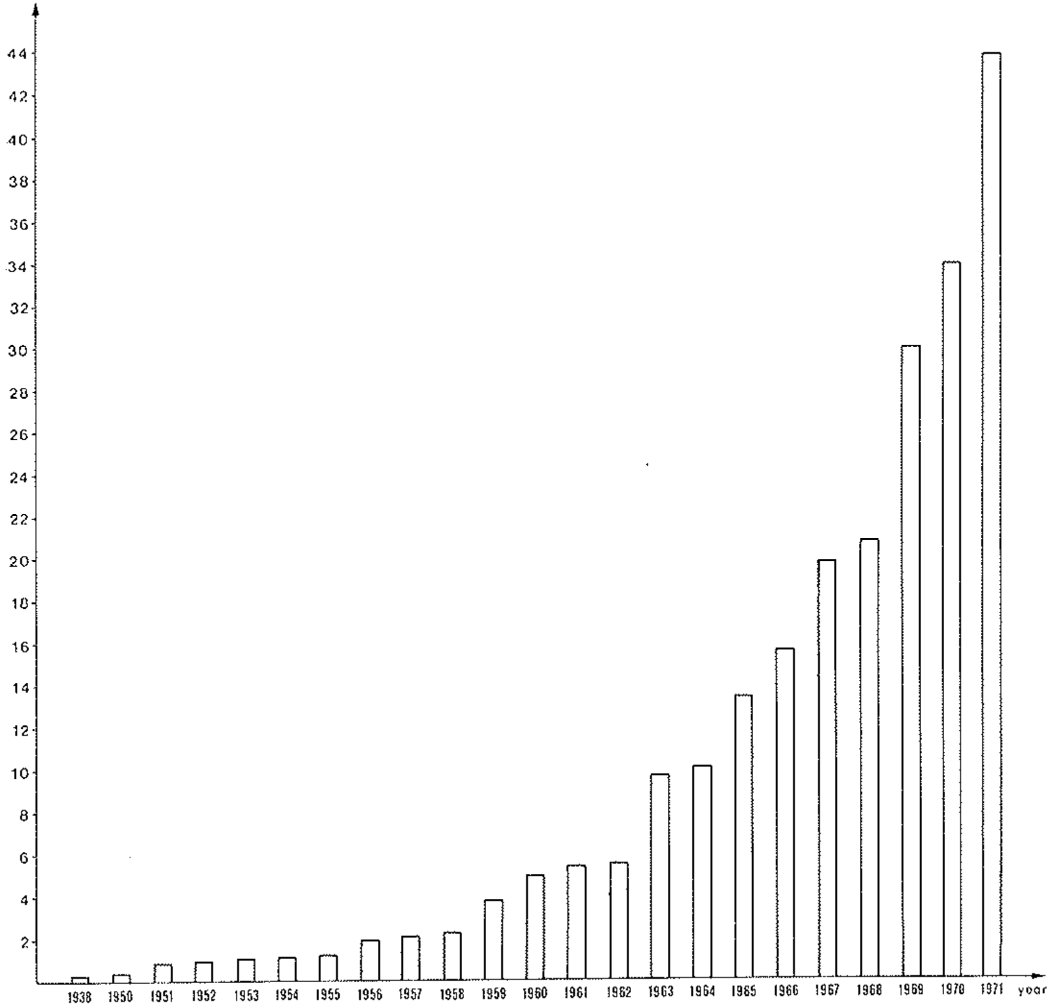

FIG. 8 — Consumption of chemical fertilizers in Rumania kg of fertilizer elements per inhabitant 1938-1971.

TABLE 6 — *Consumption of chemical fertilizers in Rumania 1938-1972.*

Year	Total thousand tons		kg/ha arable land		Per head of inhabitants	
	gross weight	Fertilizer element	gross weight	Fertilizer element	gross weight kg	Fertilizer elements kg
1938	11,1	2,5	0,820	0,200	0,712	0,173
1950	22,6	5,9	2,412	0,583	1,380	0,335
1955	87,6	21,9	9,090	2,210	5,056	1,230
1960	370,0	74,5	37,640	9,134	20,105	4,890
1965	1054,0	266,4	121,00	29,470	55,40	13,480
1971	3104,7	938,0	316,800	87,500	180,840	44,00
1975	—	1955-2155	—	195-215	—	95-100

TABLE 7 — *Average crop yield of the main cultures relative to fertilizers, to ecological conditions and to the agro-technique used.*

Plant	For 1 kg active fertilizer substance				Mean profit per hectare	
	N	P*	NP	NPK	%	kg
Autumn wheat	6-16	5-14	5-9	3,5-8,6	14-23	440-1370
Maïs (double hybrid)	5-20	2,4-9	4-11	2,5-6,4	10-40	235-1557
Sunflower	2-8	4-11	1,7-3,5	1,5-2,3	6-42	200-955
Sugar beet	10-22	25-77	38-68	32-68	8-45	2600-10000
Potatoes	6-50	—	42-65	20-81	36-85	3500-11000
Natural grassland (hay)	19-40	3,7-9	11-16	15-18	30-100	1600-3100

P = P_2O_5

TABLE 8 — *The efficacy of NP fertilizers on the production of maize, winter wheat and sugar beet, in irrigating conditions (1968).*

Steppe Zone

Nitrogen Doses	Maïs q/ha		Wheat q/ha		Sugar beet	
	P_0	P_{50}	P_0	P_{40}	P_0	P_{60}
N_0	77,5	77,7	35,9	37,0	56,4	56,2
N_{50}	86,9	90,1	43,7	45,2	67,7	70,3
N_{100}	91,5	94,4	45,4	49,8	71,9	73,0
N_{150}	95,6	96,1	47,2	51,7	74,9	75,2
N_{200}	96,9	98,9	48,7	52,2	73,7	78,4

Sylvo-steppe zone

N_0	67,1	68,0	30,2	30,2	37,2	42,3
N_{50}	82,2	81,6	38,8	39,4	46,9	53,9
N_{100}	86,5	88,4	40,4	44,0	51,8	58,2
N_{150}	91,9	91,4	44,2	46,3	54,9	61,9
N_{200}	93,7	94,5	44,2	45,8	56,6	64,9

Alluvial soil

N_0	68,3	70,1	33,4	33,8	61,1	63,1
N_{50}	85,3	88,3	40,7	43,1	70,8	75,0
N_{100}	95,1	97,4	43,7	45,7	75,8	81,6
N_{150}	95,6	100,4	43,5	45,9	79,2	86,9
N_{200}	95,4	102,8	42,0	45,0	80,0	86,3

A better organized and vaster system of experimentation with fertilizers on the different cultures in the main types of soil has been noticed after the organization of the Institute of Agronomic Research (1929) and after the development of the network of research thanks to the creation of new Institutes of Research (1957) and regional laboratories of agrochemistry (1959) for the periodical control of fertility.

The experimental results during this period obtained on account of the application of fertilizers, in the form of increased crop yields relative to the type of fertilizer, are represented in table 7.

In analyzing the factors which contribute to the increase of the wheat production, in Rumania one arrived at the conclusion that if the crop yield is equal to 100, then 38% is due to fertilizers, 34,5% to the cultivation of soil, 15% to first quality seed stock, and 12,5% to the rotation of cultures.

Measures taken during the last decade for increasing agricultural production include also the extension of irrigation. At the end of 1971 the irrigated surface being almost one million ha, it follows that at the end of the year 1975 it will reach approximately 2 million hectares.

Irrigation permits a better utilization of the other vegetation factors and a much more intense succession of agriculture cultivations (table 8). By using all these factors in the increase of production, it is anticipated that global agricultural production will increase during the 1975 period from 36 to 49% as compared with the average of the years 1968-1970.

Acknowledgment

I want to thank VELICIA DAVIDESCU for the collaboration in the development of this paper.

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DISCUSSION

Chairman: E. WELTE

PRIMAVESI

Je vous présente mes felicitations pour votre magnifique travail, spécialement sur ce qui est écrit à la 2ème page sur « les carences nutritives déterminées par l'état de fertilité d'un sol, se reflètent d'abord dans les produits végétaux et puis chez ceux que les consomment. » En effect, c'est un aspect très important et explique la raison pour laquelle les peuples dans terres épuisées, sans nutrients ou avec un grand déséquilibre des mêmes, n'ont pas de la vigueur, sont malades et miserables, tandis que les peuples qui vivent dans des terres fertiles sont fort, dynamiques et salubres. Dans les mêmes, nous avons étudiés cette expérience maintes fois confirmées, dans plusieures contrées de l'enorme pays qui est le Brésil, ce qui a été toujours confirmée.

Je crois que votre déclaration mérite spéciale évidence, car elle respecte à la santé et bonheur humaine. C'est justement pour ça que je suis d'accord en avoir une fertilization bien équilibrée de tous les nutrients qui manque au sol, soient macro- ou microéléments. On ne doit jamais oublier, que la fertilization se reflet, par la même raison citée par l'illustre Professeur, sur la santé humaine. Alors, une fertilization déséquilibrée pourra occasionner maladies humaines. Par contre une fertilisation orientée rendra forte la santé humaine et donnera vigueur au peuple. C'est pourquoi on doit éviter au maximum une fertilization unilaterale, désé-

[27] VI, 5 - *Davidescu* - p. 33

quilibrée avec les autres éléments nutritifs dans le sol, dans la plante, et par conséquence pour l'homme, qui se nourit des produits de provenance du sol.

I congratulate you on your magnificent work, especially on what is said on the second page: "the nutritional deficiencies, determined by the fertility state of a soil, reflect themselves first in plant products and then in those who consume them". Indeed this is a very important aspect and explains the reason why people in impoverished land, without nutrients and with great imbalance of these, have no strength, are sick and miserable, whereas people living in fertile land are strong, dynamic and healthy. We have made this experience on them which has many time been confirmed in several regions of the enormous country of Brazil.

I daresay that your declaration merits particular attention because it concerns human health and welfare. I agree perfectly on the point to have a well equilibrated fertilization of all the nutrients the soil is lacking of: both marco- und microelements. One should never forget that the fertilization reflects itself, for the reason mentioned by the eminent Professor, on the human health. An imbalanced fertilization may cause human diseases whereas an oriented fertilization renders the human health resistent and gives strength to the people. Therefore, an unilateral fertilization, unbalanced of all other nutrients should at the utmost be prevented in the plant and consequently in man who feeds on products deriving from the soil.

OBERLÄNDER

Prof. DAVIDESCU, in the second part of his paper has painstakingly listed the disease of animals which more or less are caused by excess or imbalanced fertilization of pastures. The literature in north-western countries of Europe is full of these observations. To my greatest astonishment I found that this point in the first draft of the introduction is touched upon only with three words « even potential pollution ». I think we have to put it like this, even potential pollution is possible, but we have to spend some words on what really can happen, particularly the words « animal diseases » I have not found yet in any of the statements, so I think this has to be brought in in some way. I realize it is not of such eminent interest for less developed countries, but as they are adopting our techniques, they will later be facing the same problems, so we should already warn them about what can happen.

BUSSLER

Do you think that it could be dangerous for men to get nutrients with a dis-equilibrium of anions and cations and organic substances which were made by these mineral deficiencies or toxicities?

DAVIDESCU

Bien sûr qu'un déséquilibre a des répercussions sur l'alimentation normale et aussi des répercussions sur la croissance normale de la plante, mais il est difficile d'obtenir l'équilibre quand on utilise des doses massives d'engrais; chez nous, quand nous n'avons pas d'engrais nous n'avons pas de problème de déséquilibre, mais depuis la dernière décennie quand les quantités des engrais ont augmentées, nous avons maintenant des problèmes de déséquilibre parce que les spécialistes utilisent des engrais sur les recommendations générales. Je crois que cette situation se trouve aussi dans d'autres pays qui utilisent de grandes doses d'engrais.

Certainly an imbalance will have repercussions on the normal alimentation and also on the normal plant growth, but this is difficult when one uses massive fertilizer doses.

In our country, when we have no fertilizers there is no problem of imbalance, but since the last decade when the fertilizer quantities have been increased, we have problems of imbalance, because the specialists use the fertilizers on general recommendations. I believe that this situation is found also in other countries where large fertilizer doses are used.

HERNANDO

I have some questions to ask you. I think the most important is in relation to Table 1. You write about the yield with different doses of nitrogen with two levels of phosphate, but I wonder where are the different yields with 50 and 100 kg/ha of phosphate, because there is only one yield for each dose of nitrogen and nothing in relation to phosphate.

DAVIDESCU

Evidement il est très difficile d'établir les conditions de nutrition plus adéquate, mais le résultat peut encore être interprété. Je suis d'accord avec votre observation.

Evidently it is very difficult to establish conditions of a more adeguate nutrition, but the result may still be interpreted. I agree with your observation.

COÏC

Je pense que les engrais ont surtout été utilisés justement pour remettre en bon équilibre la nutrition des plantes. L'emploi excessive des engrais, ou le mauvais emploi des engrais peuvent créer de nouveau déséquilibres mais au début il est bien évident que c'est pour créer un équilibre de bonne nutrition de la plante. Il ne faut pas confondre l'équilibre de la fertilisation avec l'équilibre de la nutrition, et le but est d'obtenir un bon équilibre de nutrition de la plante.

I think that fertilizers have especially been used to bring the plant nutrition again in a good equilibrium. The eccessive use of fertilizers or the bad use of fertilizers may again provoke an imbalance, but at the beginning it is quite evident that this is done for the sake of an equilibrium of a good plant nutrition. One must not confound the equilibrium of the fertilization with the equilibrium of the nutrition, and the aim is to obtain a good equilibrium of plant nutrition.

DAVIDESCU

Je suis d'accord avec la suggestion de M. Coïc.

I agree with Mr. Coïc's suggestion.

FRIED

I think you have clearly established, as other data had established, that we can change the quality of a product by fertilisation or if there are genetic means of changing it also. I think we are fundamentally then involved with the problem of whether the farmer is going to be paid for this quality factor, and while in dealing with commercial crops this is not uncommon, it is quite uncommon for the normal food grains, and I wonder what Professor DAVIDESCU sees in the future — of how, for example, a higher protein content of rice or any of the other food items might be implemented unless the farmer himself receives a higher return for a higher quality product.

GENERAL DISCUSSION

Chairman: E. WELTE

WELTE

First I would ask if there are some additional remarks in relation to the sessions we have had during the week and which should not go into the conclusions.

SAALBACH

I have some remarks to the paper of Dr. OBERLÄNDER. Dr. OBERLÄNDER has found that farmyard manure, straw and also green manure, have the same effect on some humus fractions and the humus content in the soil. We have tested the influence of organic matter on the efficiency of mineral nitrogen fertilisers in view of the yield in field experiments. We have taken for our experiments straw, farmyard manure and also green manure. Principally the three forms of organic fertilisers had the same effect on the efficiency of the mineral nitrogen fertilisers, if the different nitrogen: carbon ratio of the single forms of organic manure were respected. Organic fertilisation led to a better efficiency of the mineral nitrogen.

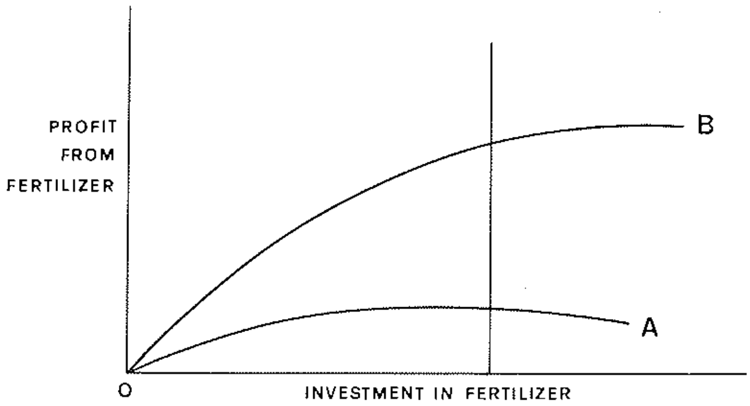
OBERLÄNDER

I would like to comment very briefly and rather generally on the statements of Dr. SAALBACH and Dr. WALSH before the break. You can find in literature many thousands of experiments that show an effect of organic manuring, but you also find many thousands of experiments that show no effect of organic manuring. So the situation is as dark as the substances involved. And in this case it is better not to risk anything and to apply organic manures — I just can't put it otherwise.

COLWELL

N.B. This comment is rather meaningless without the figure.

Mr. CHAIRMAN, I wish to raise a matter which I will call a matter of scientific ethics. This is my point. I am going to show you a salesman's way of selling the value of soil classification, or the value of soil testing. And a more ethical way of demonstrating the value of these things. Consider these plots of profit from fertilizer versus investment in fertilizer.



Let uns consider the case when A and B are different soils. A saleman would say there is an enormous difference in the profit from fertilizer for soil A compared with soil B, and therefore, soil classification is of immense value. Now I suggest, in all honesty, this is stretching things a bit because this assessment is based on the response over no fertilizer at all. We know very well that fertilizer is going to be put on, say at rate x. If we compare the differences between profits for investment x and the respective maxima, the difference in profit, indicating the value of soil classification is a very much smaller amount. So if we are trying to establish the value of soil classification we should make the comparison against the best alternative, i.e. x, not the worst, i.e. nil. Now this is for z soils. Curves A and B could very well be for two different soil test levels. Exactly the same line of reasoning should apply. And this is the point that I tried to bring out in my paper yesterday, and I think a lot of you were surprised at the very small difference I showed in favour of soil testing. Even given an ideal test that would forecast exactly the result of an experiment allowing for climatic effects and everything else than can effect the response. These differences can be very small if compared against the best alternative fertilizer recommendation. I know that someone remarked to me that my data must be for a very uniform region. Well, if you look at the data which I present in Table I, you will find that it is far from a uniform region.

FRIED

I would like to comment on this last point which has come up previously. If I had diabetes I would want to be treated for it, but if I looked at the community as a whole, as to whether we should treat everybody as a whole for diabetes I obviously would come to the conclusion that we shouldn't or maybe we should raise the level of insulin to a small amount for everybody and then those that have diabetes would not suffer as much and those that don't have diabetes wouldn't be bothered by it. I think that averaging out the whole community is a real problem that has nothing to do with ethics, it has to do I think with the individual farmer who, if he is the one that suffers, is the one that we are really looking at.

COLWELL

If I could just come back briefly on that. Obviously Dr. FRIED has not undertood what I said. If you want to talk about diabetes, we are comparing two different diabetics in this case. Both curves A and B are suffering from diabetes and the question is now what should we do. Just give a reasonable application of insulin or try to work out more accurately the exact amount of insulin that should be applied?

FRIED

I just want to say that I think the analogy is very good because if you gave a common amount of insulin some of those people would die and if I was one of those I would be mighty unhappy to say the least.

PESEK

To the individual involved the loss may be quite serious. As a scientist I cannot accept the idea of not offering to the farmer the best choice that is in my capability to give him to guide him in his fertilizer use program. Now it is his decision to use my services or ignore them, but I cannot rest peacefully if I know that I am not giving every individual farmer the best information available for his situation. And like I indicated yesterday even if a region loses 0.5 dollars per hectare on one million hectares, it is still half a million dollars.

COLWELL

That is right. It is a question of how much better is your recommendation than an alternative. And this is what I mean by ethics and salesmanship. The alternative is not nothing. The alternative is not the worst, the alternative is the best, and if necessary it is worth two dollars per hectare and that mounts up to a large amount of money and that is the way of it but it is not the gross response to the fertiliser.

WALSH

Chairman, I agree with Dr. PESEK on this matter, I just can't understand what Dr. COLWELL is getting at. I just can't understand the analogy whatsoever. I raised this matter initially about the value of soil classification and equally I am totally convinced that soil survey is a valuable tool. If you don't find in Australia that either soil classification or soil testing are of any value that is your business in the final analysis. As far as I am concerned we would never try to sell it the salesman way, you suggested. It would be a very foolish man, either scientist or salesman, that tried to sell this idea in what you would describe as the unethical fashion. I will tell you that such a salesman in our country would not do so for very long.

FITTS

I wonder if someone from the Committee, possibly Dr. FRIED, would like to give us a brief review related to what the Committee has been discussing in regard to the conclusions. Otherwise we shall be talking without knowing what has already been considered by the Committee.

I think it would be better if we could actually deal with the recommendations, otherwise I feel it will be too confusing. I would suggest that any discussion be in relation to the recommendations that have already been received and we could formerly start going through these at any time that the Chairman wishes to start the operation.

FRIED

Agrees to the above suggestion.

WELTE

First I would ask Dr. ARATEN if he wants to present additional recommendations.

ARATEN

In the first place it seems to me that we are interested in contributing to the solution of two problems.

1) The basic economic research together with technological research, should result in producing nutrients in the most efficient and economic form.

2) The fertilizer plans in underdeveloped countries should work at higher capacities than at present. At recent they are working at only about 50% capacity, and if the capacity will be increased, more and cheaper fertilizers will be produced. In order to reach this goal, I suggest adding two conclusions to Dr. FRIED's paper.

a) In addition to the joint team of medical, physiological and soil conditioning and research workers proposed on page 4 by Prof. FRIED, to form cooperative research between agronomists, physiologists, bacteriologists and chemists which will contribute to a better understanding of the basic processes taking place in soil, roots and plants.

b) To suggest an education programme for chief engineers and chief technicians in fertilizer plants able to run a fertilizer plant ably and efficiently. From experience I know that it is impossible to improve a situation in a plant if you try to re-educate the existing chief engineer and chief technician in a factory working for years at a 50% capacity. In such a Plant the technical management has to be changed, and an education programme for new people is therefore essential.

WALSH

It has been emphasized that if you want to get over a deficiency there are several ways of doing it besides putting nutrient into the soil. For instance in relation to trace elements « hazard » areas should be defined and treated each one according to what is required. I believe that is a very important point. The other one, I think we brought forward here and it is related to arguments put forward by Dr. FITTS following his paper, that fertilizer companies concerned with the manufacture of fertilizer should in their formulation work have an eye on the conservation aspect of fertilizer use, both from the point of view of the supply and renewal of resources on the one hand and on the effect of these fertilizers on the environment on the other. This seems to me to be an important point. I believe also that there is another aspect of the matter which needs to be incorporated in the report, i.e. the whole question of nutritional needs of people and the satisfaction of human wants. As people become more affluent, they look more and more for instance to animal products in the diet. Therefore concentration on animal farming and the development of animal products should be an important consideration for this meeting. This means the development of systems of animal production based on soil fertility, grassland and forage development which will be efficient in the context of developing economics.

Then, of course, we come to the other highly important point, i.e. the impact of farming on societal matters. This has been referred to in a general way, but I think it needs to be widened out a little. I will talk more about this when I come to the point. There is very little said here in this document about markets and the need for markets, how markets are developed and how the various systems of farming, both the developed and underdeveloped countries, must be geared to meet the needs of specific markets. I believe this is a cardinal point in the business of farming in the context of the subject matter of this week. We must look at soil fertility work against a background of overall integrated programs of rural area development. Anybody aware of development will know that this approach is receiving more and more attention. Also a question which has been raised marginally here is very important, i.e. of how technology can be best transferred and adopted. In that context, Mr. HAUSER's statement about the setting up of a World's Soil Data Bank is of utmost significance, and I believe that this should be emphasized in the report.

Also the other and final point I am going to talk about now is the question of how we can develop the right sort of package, of practices for the farmer, i.e. how effective packages can be synthesized from the different components from research and how these can be harmonized and quantified in relation to the specific needs of some farmer somewhere either in Brazil or Ireland. In other words, how can we develop the right sort of package? I believe the time has come when research people should be involved in the synthesis of systems of farming, either for cropping or for animal farming that can be converted into an appropriate package by the people advisers and others in the different areas concerned for use by farmers.

FRIED

Firstly I would like to say that I agree entirely with all of the points that Dr. WALSH has made, but I would also say that if I worked up until midnight and got up every morning at 5 a.m. for a whole week, I could never write the kind of book that he wants me to write. We can only touch on some general points. I am sorry, but I do not see any other way to do it. I respect the ideas, we will try to include within our general points but that is about all we can do in the way this thing was set up. I really don't know what else to say. So as we come to the individual points let us either try to emphasize them or re-emphasize them in relation to the relative importance. If we put everything in the manuscript it will be worthless. The only thing we can do is to highlight some of the things that have been brought up and some of the things that can have a major impact in the areas in which we are trying to work. I would be very happy to have a discussion on that because we all are involved with it. We have asked for suggestions and believe it or not, we have taken into account every suggestion that has been handed to us. They have all been discussed by the Committee — sometimes a whole page may have gone into two words in the report which emphasizes something which was not emphasized before. But that is how we are working the suggestions into the report, and I can only suggest that we continue to do that although there is no reason why a particular paragraph cannot be added on a point that has been completely left out. But if the point has not been completely left out let us try to modify the way it has been presented to give it its relative importance that the group feels it ought to have. I have taken advantage of this question to give the rest of you the general philosophy on what we have tried to do here and that is we are confined to making general statements on problems, needs and means of solving them, that the group here feels are important and that have been indicated in their presentations, in the discussions and even in discussions individually with the Committee. Some of you will recognise your ideas as you go through them. We have already made a substantial number of changes and there is a group of papers that should be distributed to everybody. As you all know the whole thing is divided into introduction, research and fertilizer requirements and farming utilization. I would like to give you some of the changes that have already been incorporated, not because these changes are final but because that gives you the ability to discuss whether they make any sense and because obviously they have taken into account some remarks that have been made and some suggestions that have been given to us.

If you have in front of you now the introduction with the eleven points you might wish to add or change the following. In paragraph III the first sentence should now read « in addition a great number of other cultural practices » that was just an editorial change — most of them are not editorial changes. On the following line after the words — necessary components of yield — there should be the words « ranging from physical structure ». In paragraph IV The Study Week of necessity has only concerned itself — should read « The Study Week could only concern itself ». Now for more substantial changes.

Item 2 on the first page of the Introduction — the suggested change is — « much can, should and must be done by Regional and International organization to help. » This remains the same — up to « help train local staffs to — « insert not only new information but already accumulated information and expertise » then follow on to « into the local system ». (We are trying to put in one of the points Dr. WALSH mentioned).

Item IV on the next page, the second line of item IV we have added a few items after the word « nutrient balance ». The items to be inserted are — soil structure, affects of time of planting and disease control measures.

In Item VIII the second sentence of Item VIII — most of this increase will not be feasible without — instead of « tremendous » we have used the words « very large » increases in « present level of fertilizer use.

Now substantial additions to items 10 and 11:

Item X — the word « pesticide » is suggested instead of the word « insecticide » — maybe you have other suggestions. — At the end of that sentence which ends in « pollution in the environment » we would like to suggest the inclusion of another sentence that says the following — « The efficient use of fertilizers, particularly at high use levels and recycling of man and animal waste will help minimise pollution and conserve scarce resources.

Item XI — the last three words of item XI is « need not decrease ». Would you please cross that out and add the following: « can definitely be maintained and even improved. Technologically this can be achieved. (A very positive statement now — we can discuss it later).

I must say that in relation to the discussion you will have had to read the whole paper in order to actually carry on this discussion because many of the items that you have suggested come not in the general Introduction but in the specific areas under Research and under Fertilizer Requirement or Farming Utilization, so if it was possible I would hope that the suggestions you make would be related to the particular part of the drafted conclusions where might be pertinent. We can always make shifts one way or the other.

Now I would like to open it for any further remarks before we go any further.

HAUSER

On reading that thing about scientists again here under para. 6, I think there is a mistake here which I did not recognize before. Para. 6 on page 3. The second sentence is « this may be a direct response to the added fertilizer or may be the elimination of some other limiting factor such as water or even genetic potential. » I don't think that this is right. Water cannot be replaced by fertilizer under any one condition.

FRIED

There must be something wrong with the drafting. I think that will have to be clarified. The point was that increasing yields may be associated with fertilizer use or elimination of some limiting factor. It was not meant to imply that the fertilizer use took care of the limiting factor. We will have to redraft the English there to make it clear.

PRIMAVESI

Para. 6. page 3. Says: « Increasing yields are invariably associated with increase of fertilizer use ». I think it is necessary to add « when soil conditions permit, availability of nutrients added for the plants », because then save nutrients from the soil, but if it cannot be used by plants, it is not all right. In para. 8, same page. « Most of this increase will not be feasible without having those increases in fertilizer use », I think it will be added in adequate soil conditions.

FRIED

Many of these things have been discussed by the group because they are quite clear and the statement made by Dr. PRIMAVESI is certainly valid. However, we are faced with this problem that you do not get a fertilizer response unless there is enough water, unless you have the right genetic material, unless you have the right soil structure, unless you have the right light intensity, unless you have the right associated culture practices; I mean there are 15 of them. Each time we talk about fertilizer use we can not add all 15. We are faced with this factor and I think we do want to bring out those things which are more important but I do not think that every time we talk about fertilizer use and response we can put in all of the conditions when you have the right variety, we just have to try.

We are faced with a problem, and when making our general assessment we, the committee, will get together and discuss each proposed point. We will try to reflect the study group, if it is all right with you.

WALSH

Mr. Chairman, I am very happy about what you have put in here and the addition is quite candid. I should like to make another point that I have raised to a very considerable extent. At the bottom of page 2, I think the change is quite simple. You talk here about « including kind, placement, methods of distribution ». It is only one word or so. You know on the land of eveness of distribution, I mention it as being important because it was mentioned at the FAO meeting also in Geneva as an important factor. The other one here I am inclined to your additions here on item number 10, the effective use of fertilizer at high use levels and recycling and so on, we have to minimize pollution. I was going to put that in a more positive way and that is, it would help conservation. In effect what I wanted to say was that you said we would have to minimize pollution. I do not like the word pollution, it would be more positive to say it would help towards conservation and conserve scarce resources. Yes, well that is the scarce resources part of it, the conservation of the environment and of scarce resources — something like that, we can think about it. Pollution is a dirty word, and we should leave it out of this report as much as we possibly can.

HERNANDO

But I do not know if someone talked about the point I wanted to raise. It is in relation with the 1st point: « food supply per capita need not decrease ». This should be made more positive.

FRIED

This has already been done. For script see introduction paper.

RUSSELL

Dr. PESEK and I have had the opportunity of discussing some of the things in this draft, some others were done first thing this morning, and Dr. BLANCHET has not seen them. We are dealing with this section headed Research under several sections: in relation to environment, relation to plants, relation to soil, relation to man and animals and so on. You have had the opportunity to read in relation to environment, and this section has not been altered. In the section « In relation to plants » what we have done is to remove from the existing draft those things which refer to human and animal health and to keep in those that are only referring to plants. (a) was in the original draft « the need for breeding varieties capable of responding to high level of fertilization. (b) was « on the nutrient requirements of different varieties of a given crop and different stages in its development ». (c) was « on the effect of fertilizer on the susceptibility of a crop to different pests and diseases ». (d) is a new one, « The possible effects of adding various substances on increasing response to fertilizer or the level of fertilizer at which responses remain economic ». There have been no changes in the section « In relation to soil ».

The section « In relation to the soil » has not been altered. The new section « In relation to human and animal health »: (a) is as in the old draft « The effect of fertilizers on crop quality including total protein, amino acid composition and other organic substances such as contributing to flavour and keeping quality, etc. ». The second also was in the original draft « The effect of fertilizer on inorganic constituencies of the harvested crop ». The third is also in the original draft although there is a word gone wrong, « The need for medical research on the effect of human health of crops having different mineral compositions ». And the fourth is a new « The need for monitoring the quality of fodders on the health of the animal ». The next section again is a new one. It is in relation to increasing the efficiency of fertilizer use: « Research for increasing the efficiency of fertilizer application and fertilizer uptake by plants including the proper placement of fertilizer, the splitting of dressings, the time of application, production of fertilizers in the most effective form for uptake ». The second one is Research on ways of improving the agronomy of crop production to enable the crop to make the most efficient use of added fertilizer. And the third one is the adaptation of fertilizer application policy to the cropping rotation, including the development of more intensive rotations based on a high level of fertilizer inputs.

Page 3 « In relation to reducing the drain on the natural sources of the world, research on the recycling of nutrients present in farm and human wastes back onto the land in a way that causes the minimum hazards to health and to the pollution of the water draining off the land, and the development of new processes for the development of fertilizer manufacture to make minimum demands, for example, of the saving sulphur in making sulphuric acid, making phosphoric acid and throwing away all the calcium sulphate. Finally « In relation to extension work » the sections are. Research on hindrances to the acceptance of research findings of efficient method of fertilizer application by the farmer; the necessity for developing genuine cooperation between the extension and research services to ensure that adequate research on increasing crop yields through the efficient use of fertilizers is carried out within a framework involving the minimum disturbances, the deep-seated social customs; and I have only just been given the wording, a proposed wording of the third, which will I think need some alteration. The draft wording is: to conduct in each country limited but sufficient studies on the extension learning process and the adoption process of farmers in accepting and using new ideas, methods and materials, to establish the extent to which these processes are similar to, or different from, the behaviour of the farmer as determined in more detailed studies elsewhere. An efficient extension service is possible only if its procedures maximise the rate of adoption which is possible only with effective knowledge of the system and processes ». Those are the headings that we are proposing for this section on research.

ARATEN

I would like to suggest that there should also be a team of agronomists, physiologists, pathologists and chemists to do basic research regarding processes taking place in soil, roots and plants, which are at present unknown.

RUSSELL

I have assumed that research would be carried out by inter-disciplinary research teams when that is appropriate, but we can put in the words inter-disciplinary to emphasize this point.

Would it be agreeable to you if we had a recommendation that more research in plant physiology and plant bio-chemistry, root uptake and so on is necessary and is essentially inter-disciplinary?

ARATEN

I think a joint team is very important.

WALSH

I think that Dr. RUSSELL's approach here is quite satisfactory. What you want is inter-disciplinary teamwork, but you don't need to go much beyond that in a statement. It is a general conclusion and Mr. RUSSELL, I think you can move that one in the context of the inter-disciplinary teamwork. It is a general recommendation isn't it?

RUSSELL

Yes I think it is the basic recommendaton that we need more work on fundamental plant physiology.

HERNANDO

I think I am in agreement with the idea of Professor ARATEN. It will be convenient to write these points in part II, i.e. the need for medical and clinical research on the effects of the crops with different mineral composition on human health; this cannot be left only to medical research workers. I know that it is very difficult to get, but there is a difference between doing it by one self or ask someone else to have it done. I think we must emphasize the need of interdisciplinary studies inducing medical, soil chemistry and plant physiology researchers.

RUSSELL

If we accept it I would like two recommendations. This medical one is for the medical people; what are the effects of these various things on health? If we want an analytical recommendation on more work on analytical methods of determining these things, we want it as a separate recommendation not muddled up with the medical one. I would not have thought that we need to make recommendations on more research on analytical methods because it is going on so actively throughout the world, but if you want one, we can put it in.

HERNANDO

I said that I know medical people and I have discussed the problems in practice with them. They are not convinced of the importance of this aspect. We may suggest to them to carry out the work, pointing out that not only the study of the normal plant composition is important but also to study the problems in this field of research jointly with soil chemistry or plant physiology experts in order to avoid confusing results.

PESEK

We have a statement which Professor ARATEN requests relating to fertilizer requirement for the general statement in our last paragraph of our opening statement part III. « A word needs to be said about cooperative efforts amongst disciplines, institutions and countries. Much knowledge is already available on tropical agriculture; this knowledge must be fully exploited, something which requires communications among individuals, disciplines and institutions. Joint planning of research should be encouraged, perhaps demanded, so that scarce scientific resources are used most efficiently ».

RUSSELL

Could I just refer to Dr. FRIED's introduction, I do not think that is a specific research recommendation. I think it is more one for the introduction, but I would like Dr. FRIED to comment on that.

FRIED

I thought I had mentioned something in the introduction concerning this but I would have to look back on it. We could have the suggestions written down then the Committee could consider them.

PESEK

What he is saying is that on Page 1A of Fertilizer requirements, the statement concerns disciplinary efforts with Prof. ARATEN, that is a word need to be said about cooperate efforts among disciplines, institutions and countries. Much knowledge is already available on practical agriculture and this must now be fully exploited. So I think that the point he is making is that there is a statement of this kind in anything you might want to insert — taking into account the statement that already exists.

SAALBACH

Page 3, point a: « Research on the recycling of nutrients ». There are in the wastes not only nutrients but also organic substances. For instance, in the wastes of farms with intensive dairying it may be that these organic substances have no good influence on the fertility of cows (oestrogenic substances). In my opinion we should write under (a) « not only nutrients » but also « organic substances » i.g.; oestrogenic substances.

RUSSELL

It is difficult to know how much detail to go into here. Details of slurry or *gülle* disposal have not been given. If a method of recycling farm wastes is used which allows toxic organic substances to accumulate in this soil, this would be an effective method and research would be needed to improve it.

WALSH

Commenting on Dr. RUSSELL's point: On page 1 in relation to the plant, the need for breeding varieties capable of responding to high levels of fertilization and high levels of fertilizer use. In relation to increasing the efficiency of fertilizer use you may be able to bring in the methods of distribution of fertilizer on the land On page 3 hindrances should in actual fact be real barriers.

RUSSELL

This is included in the section relating to human and animal health-section D — the need for monitoring the quality of fodder and health of the animal.

WALSH

It is more than that. I am talking about trace element situations relevant to both crop and animal production. It is a question of identifying « hazard » trace element areas as related to soil type as a basis for rationalizing the extension of information.

CAPÓ

On the first page of research, third paragraph, the second line, I would recommend a change. After the word « length », I suggest the elimination of the words « photosensitive varieties », so that the statement will read: « to the extent the climate, rainfall distribution, temperature and even day length determine plant growth and crop response to added fertilizers ». The suggestion is made because all the varieties are photosensitive. So my suggestion is to eliminate after length the three words that follow and insert after "determine" « plant growth and crop response ».

RUSSELL

The reason I put in photo-sensitive varieties is that we have a lot of varieties in Africa that are not photosensitive, which can be used over a wide range of latitude. That is why I put in those words.

CAPÓ

As far as I know, most of the crops in Puerto Rico are affected by daylight; sometimes corn is affected in yield depending on the time of the year to plant, 50 per cent, potatoes 300 per cent, even though the length of the day varies only two hours. You can get a very great influence of the length of day with most crops in Puerto Rico.

WELTE

That is the situation in your country. In other countries it is quite different, and we have to see the whole world.

CAPÓ

What I say is that practically all crops are photosensitive. If there were no light, there would be no plant growth.

RUSSELL

I would like to give the redraft that I have done of one or two sentences on the first page, headed research, in the first paragraph which begins « research involving fertilizer use of necessity » is involved with terminology. I would like to add the sentence « and must include fundamental studies of plant physiology and plant-soil relationship » which refers to the point that Dr. ARATEN has made. On the new page 2 which is headed « in relation to human and animal health continued » (d) is replaced by the following: « Survey of trace element contents of soils to identify soils in which plant and animals may suffer from their lack of excess. » Then (e) is a new one « effects of fertilizers on oestrogens and other organic substances in plants on animal health and production ». And at the bottom of the page, in relation to increasing efficiency of fertilizer use, (d) more attention be paid to the design of fertilizer distributors to ensure more uniform spreading of solid fertilizers than is possible at present.

FRIED

Chapter 3 as you will see has a rather large introduction, a large general introduction, and then essentially it deals with field trials, tissue analysis, and soil testing, so that you may want to confine your remarks into the appropriate section. As you recall, this section was part of the work of the sub-committee of Dr. WELTE and Dr. PESEK, and I think Dr. PESEK will be answering any of the questions, remarks, suggestions, etc.

PESEK

I really have no general remarks in particular except that the chapter is before you, and if you will look on the back page,

page 6, you will see the paragraph entitled « Soil Testing ». This paragraph must be transferred in its entirety to the page marked, « page 2 », which is the third sheet, and insert immediately under Roman, Numeral III « fertilizer requirement - continued ». The last paragraph on the last page, page 6, entitled « Soil testing » should be transferred in its entirety to become the first paragraph on page 2.

VAN DER PAAUW

I have no general remarks to make Mr. Chairman, but I want to say that I was very much pleased by the pages 2 and 3 concerning soil testing. We have in Holland a large experience in soil testing, and I think that this concept is very good. I only should like to propose an addition relating to nitrogen. In Holland, and also in other countries, Germany, England, France, there is a very promising development in the use of the correlation between the rainfall in winter and the amount of soluble nitrogen present in the rooted zone of the soil in early spring; on this basis there can be recommended the amount of nitrogen which has to be applied to cereals. The recommendation is much appreciated by the farmers; in Holland we are doing this already since 1959 sucessfully. There is another development, namely in so far as models have been made about the distribution of water and solved nitrogen, making use of the physical composition of the soil and the amount of precipitation, so that we are able to calculate the distribution of nitrogen in the upper soil by means of the computer. Therefore, I want to draw attention to this development, and I would be pleased if it might be possible to add something about the need of behavior studying the nitrogen in the soil and its relations to precipitation.

PESEK

I changed the middle of the paragraph somewhat, the paragraph on page 2 as it now stands; in the middle of the paragraph the sentence beginning: "because", I have changed this on the basis of a suggestion made because of the nature of the soil nitrogen cycle. Suitable recommendations can usually be made, based on information about the nitrogen cycle, and the point is that nitrogen is known to be needed. Perhaps the rainfall should be included by saying, « information about the N cycle, precipitation and the quantities of nitrogen known to be needed for a given yield of a given crop ». Will that take care of that point.

HAUSER

I would propose to take out the sentence, "no suitable tests for routine testing of soil nitrogen and visibility, are now available". Because the nitrogen test they are now using in the States is very promising and gives very good correlations with the yields, although it is not applied much, or not tried out yet. We should not include that sentence because it might be wrong already now.

PESEK

My response to that would be that I agree with you perhaps either we should take it out or we might say 'no tests for routine testing for nitrogen availability are now used' instead of "available". What about generally used? I'm willing to go along with the rest.

HERNANDO

I suggested on page 4 to put in the paragraph on tissue analysis « tissue analysis and sap analysis », because sap analysis is completely different from tissue analysis, and there might come up misunderstandings. It is not because we are working on that, but because I find such a large difference especially in determining clearly the needs of microelements.

PESEK

Our committee had your sap analysis and other sap analyses and all sorts of tissue analysis in mind when it started the first sentence, by saying: "use of tissue analysis of various types", now perhaps sap is not a tissue, even though it comes from tissue. Reaction one way or the other requires only two words.

WELTE

Dr. PESEK, I think that if we change the words, the problem will be solved.

FRIED

Particularly in the tree crops, many of these are actually plant analysis, plant samples and that what we think of in terms of plant tissue. Does that include all kinds of I wondered whether you might want to say plant analysis of various types which might be much more conclusive.

PESEK

I assumed we were speaking of plant tissue here but maybe we should remove all doubt and say the "use of plant tissue analyses".

Hauser

I have a small remark here. Would it not be good to clarify the matter in so far as to say that the tissue or plant analysis are mainly important for the perenial crops, and for annual crops more the soil test.

Colwell

Plant tissue and sap analysis. It seems to me that this chapter and some of the other chapters raise controversial issues, and no provision has been made for this in the draft. Actually, instead of making it look as though we have agreed on everything, we should summarize the points on which there seems to be some controversy. Now there is one here in particular on page 3 about the middle where we refer to determining the correct ratio of nutrients by the method of Homès. Now, without wishing to bring up this controversy again, I thought there was in fact quite a strong controversy on the use of this technique of Prof. Homès, and I suggest that this should be deleted.

Pesek

May I read what that paragraph now says. "The purpose of the initial field trials is to verify the correlation of the soil plant cultures, and calibration of the soil test, to separate the ranges of the chemical tests representing very low, low, medium, etc. categories, to indicate relative levels of nutrients, to determine the optimum rates of nutrients for yield and quality, to make regional fertilizer recommendations, and to secure some understanding of the influence of other soil and climatic and management factors on the response of the fertilizer, or to the fertilizer". So we have taken out one name and we have added a concept of regional recommendations, and we have distinguished between correlation and calibration of the soil test as well, so we have modified that considerably.

COLWELL

Might I suggest you also delete this « representing very low, low, medium categories » I don't think we need be as specific as that. In the same vein, the last sentence of the first paragraph of this same page where you say mathematical and graphical procedures to be used may be either the Mitscherlich, etc.

PESEK

I have no objection to taking out the words "representing very low, low, medium, etc. categories". It should be to identify the ranges of the soil or the chemical test.

We have not finished with that mathematical statement. I have rewritten it a little but did not take care of your objection. "Mathematical and graphical procedures to be used may be either the Mitscherlich curve or the nutrient yield A value, perhaps others".

COLWELL

Well, in fact this is the first time it has been mentioned at this meeting, I think. Mitscherlich is just one of several models, I think on the whole we would be better without it. And also another deletion I would suggest. It is the middle of page 4. There is a sentence there starting "the use of these procedures for NP or K". I suggest that that could also be left out, on the basis that it is really getting too specific. Then at the bottom of that page I find long-term experiments, where did they come from we did not talk about them at all.

PESEK

The long-term experiments belong in the field trials section. The committee thought that long-term experiments were important and so did several people who turned in notes on long-term experiments.

COLWELL

I don't recall that we mentioned agreement on the desiderability of long-term experiment and certainly I would wish to speak against them if this subject was to be debated. Ideas change so very dramatically over a few years. There are many examples of these experiments which have been very expensive to carry out. By the time many reach the stage where they might be interesting, because they have been going for such a long time they are demonstrating things which are no longer of interest.

BUSSLER

I would prefer to have the words as described by HOMÈS on page 3 to be inside the paper, because it was a very important method, and the method was known together with the name. I think it is the first progress after the method from Mitscherlich and so I think the words, as described by HOMÈS should not be distorted.

HAUSER

I have a remark on what is now the last paragraph on soil testing and which should be moved ahead. I cannot agree to that at all, because calibrated chemical and biological soil analysis procedures are not the first essentials of the fertilizer use programme and never were. 150 years ago when in the highly developed countries fertilizer use was introduced, field experiments came first and the calibration of soil tests took a long long time thereafter. In this regard also under the paragraph « Field Trials » the first sentence is absolutely wrong. The purpose of a field trial is primarily not the calibration of the soil testing. It is impossible to first calibrate soil tests in a practical fertilizer promotion programme in a country where that has not been done before. The field tests are the first thing to do. The calibration comes years and years later when already the farmers know what fertilizer to use and then the calibration and the soil tests are only an abbreviation of the field testing, not the other way round and therefore, I think we should change that sentence to the reverse.

WELTE

I think that is a very essential point. Dr. PESEK would you agree?

PESEK

In my view these things tend to go on simultanously and in a way it is difficult to write in a few words exactly the precise order in which one might do things. I keep in mind the comment I made this morning, we are looking for eventually developing the best scientific approach. There are other approaches which might be taken in the meantime which are presumably already going on to indicate the benefit of fertilizers. This does require quite a change in philosophy and makes me wonder whether I could rewrite it to meet these particular objections. I welcome anyone to rewrite the first paragraph if they want to. We may recast it somewhat but it is still a question whether it will come out right or not.

FRIED

I can only say as far as redrafting is concerned it is simple and I think probably more accurate to leave out that first sentence on soil testing and change the word needed to useful because you certainly cannot set it up as an absolute requirement, there has been a discussion as to whether it is even useful. So I think you could not say it was an absolute requirement. If you took out the first sentence entirely and changed the word needed to useful and the other essential to useful in avoiding pollution. I think you would get meet the objections. Take out the first sentence entirely, in the second sentence change the word needed to useful and then the next "essential in avoiding potential" put "useful in avoiding potential pollution".

FITTS

I think this is a question entirely of philosophy and involves which way are you going to approach getting the information. During the next few days the U.S.A. will launch another space ship to the moon. They do not send up 1000 rockets to find if one of them is going to get to the moon. This is the same philosophy in research disciplines. What is the procedure for research? Are you going to get all the information about the soil first plus any information you can get from potted plant studies and then use the field trials as a testing procedure to see if you are reaching the goal that you are after?

VAN DER PAAUW

In regard to Dr. BUSSLER's remark, Mr. Chairman, Dr. COLWELL did not say that the theory of Dr. HOMÈS is not important but his argument was that it is still controversial.

PESEK

Our sub-committee talked about this and we thought that in the interest of matters of treatment of all the participants that we should avoid identifying by name any one of them in this final report and this is why we choose to restate that in the way that it was restated which clearly identifies exactly what we mean and anyone familiar with the field will identify this procedure. That is in relation to ratio of nutrients to optimum yield and quality.

HAUSER

I would say that there are certainly two philosophies possible, but the one philosophy we have chosen is in any case effective. In a very short time, easily in two to five years we can tell the people what fertilizer to use, but that was never possible with the other philosophy, and therefore, I would suggest not to stress any philosophy as suggested by anybody, leave it open and maybe say both, but do not say that one is better than the other.

HOMÈS

Of course I completely agree to have my name kept out of the text but I would like to have the principles which I have presented mentioned in some way, I mean the importance of the ratio between the nutrients and the possibility to find a maximum yield from an optimum composition of the fertilizer. Those are facts about which I am quite prepared to see this meeting disagree. If the meeting does disagree it may be left out completely but anyway something should be said about basic research about the way to explore something which is as yet unknown. No question about my name, but I would appreciate some mention of the tendencies which I mentioned in the text. It is possible that there are serious controversies about the method but it is surprising that I did not hear any serious controversy during my presentation or after, so I think it has been considered worthwhile being present here, and in some way it should be mentioned without my name.

PESEK

I have here as one of the objectives of field trials the optimum ratios of nutrients for yield and quality.

WELTE

Are there further remarks especially on the point soil testing.

SAALBACH

Can we include the magnesium analysis in this chapter, then it is my opinion we have good methods for characterizing the magnesium level of arable soils.

PESEK

You would suggest adding magnesium here as well. That would be as « phosphorous potassium and magnesium and for pH requirement ».

WELTE

It could be done in connection with P and K mentioning also magnesium. Then I think we have all things together.

HAUSER

I have one small remark on « Field Trials ». The first sentence does not make very much sense. It reads « The purpose of the field trials is to verify the calibration of the soil testing and the soil-plant cultures ». I think we must include there that the purpose of the field trials is first of all to find the required fertilizers, quantities and kind. That is the purpose of these field trials, we cannot leave that out.

PESEK

Would you listen to the way I have this paragraph written « Purposes of the initial field trials is to verify the correlation of the soil-plant cultures and calibration of the soil tests to separate the ranges of the chemical tests, to indicate the relevant levels of nutrients, to determine the optimum ratios of nutrients for yield and quality, to make regional fertilizer recommendations and to secure some understanding of the influence of other soil and climatic and management factors on their response to fertilizer.

BRAMAO

These experiments should be located on selected benchmark soil types. I would like to know exactly what you mean by benchmark soil types?

PESEK

To me benchmark soil type is a soil type which is representative of a major group of soils in an area, and there may be several in a country or in a state. This was my meaning. I'm not sure how else to state it because this is what I mean.

BRAMAO

Would it be something like a major soil type?

PESEK

That will accomplish the same purpose.

WALSH

In the last paragraph referring to research. This statement on research should be transferred to the section dealt with by Professor RUSSELL, its primarily drafting matter. I was very pleased to see that Dr. PESEK had included in his field trials, some words about establishing soil capability values as one of the purposes of these trials.

COLWELL

What is the general feeling of the meeting. I think there are controversial issues in this chapter and it seems to me a lot of the writing just conveys some of the personal views of people here rather than general views.

VAN DER PAAUW

I want to add physical soil testing for the determination of soil structure. There are very interesting developments in this field.

WELTE

I think this has been forgotten indeed.

PESEK

I did not quite understand the suggestion.

WELTE

Physical methods for testing soil structure are particularly used in the Netherlands.

PESEK

I struggled with this and I ended up with « physico-chemical » to represent all this, but if it is preferred to have « calibrate chemical, biological or physical soil analyses », then I am willing to make the change.

WELTE

We are now discussing the proposal of Dr. VAN DER PAAUW in relation to soil testing. Dr. VAN DER PAAUW has suggested to put into the paper methods, especially physical methods, for the determination of soil properties.

FITTS

I would probably eliminate that first sentence and start with soil fertility and I believe we come back to the question of our study week. How we are getting over into soil properties. Is that part of our responsibility?

VAN DER PAAUW

Personally I said that the study of physical soil structure is also important in respect to its connection with the effectiveness of fertilizers.

HERNANDO

I think it is very easy to name physical, physico-chemical and chemical soil analysis biological soil analysis. Now with that we cover the three aspects, and we gather these three into one word.

PESEK

The only problem Prof. HERNANDO is some other men have suggested striking the first sentence completely. And starting with the second one. I had in mind to strike it out — perhaps I should not do it.

RUSSELL

We have agreed to remove the first sentence of soil testing and I think that if that sentence comes at the end rather than at the beginning as a part of soil testing, it would make sense. I agreed with the reason why it was at the beginning, but I think we could draft something like that at the end rather than at the beginning of the paragraph.

FRIED

Can I just suggest, since I have suggested removing the sentence, that when COLWELL and PESEK are working on this that I get involved with this particular part. I think that would represent all of the philosophies. We will try to put in the physical soil test in there in some way.

WELTE

Yes, I think that would be a good proposal, Dr. WALSH, do you agree?

WALSH

Chairman, I have this objection. I don't think that anywhere in the proceedings of the meeting we actually discussed the question of physical soil tests, and I am not for putting anything in this report that we have not discussed. I agree with Dr. PESEK on this one. We did not come here to this meeting to discuss physical soil tests. If it is in somebody's paper and has been agreed to, and if it is the general view, I am for it.

VAN DER PAAUW

Mr. Chairman, the only thing I have to say is that it was in my paper. It has not been discussed as it could have been discussed.

HERNANDO

Well, I agree with the proposal of the point brought up by Professor VAN DER PAAUW; we also discussed this point here in the general discussion, and therefore it could be included. Had we not discussed it, it could possibly not appear in the conclusions, since we are discussing this point, the results shall be printed.

WELTE

I think these difference are not so wide apart that the main commission should not be able to find the right solution. I would like to recommend that especially this chapter 3 should be written once more guided by Dr. PESEK, Dr. HAUSER and Dr. COLWELL during the break.

FRIED

This chapter is headed « Farmer Utilization ». Someone asked me what the farmers are going to be utilized for. You may even want to change the heading, but this was again handled by another sub-committee and particularly represented an attempt to put down some necessary items after we had gotten our research done, after we had found our fertilizer requirements and hopefully developed a reasonable sort of soil test, or tissue test, how do we then put it into use. The sub-committee consisted of Dr. BRAMAO and Dr. BORNEMISZA and I believe that Dr. BRAMAO is prepared to answer all questions and suggestions.

BRAMAO

I have already a suggestion here to change the title from « farmer utilisation » to « utilization by farmers ». Well I think that the consensus was that people with English mother tongue should decide rather than we. Anyway, there are very few modifications to the piece of paper that you have. I think that only in paragraph 2, number a. it should read « national agricultural institutions must obtain information leading to an understanding of the factors affecting the reputation and acceptance of new agricultural practices. This knowledge should be used by the extension services, to guarantee that the new information on improved agricultural production is carried to the farmers in a way acceptable to them. ». Those are the only modifications, Mr. Chairman, that I have to present to you.

WALSH

This is in fact a very important chapter. If this is not right the other parts are not meaningful. Dr. BRAMAO mentioned « to guarantee », well in drafting I would say « ensure ». On the second chapter here it says « there should be demonstrated on economically operated pilot farms and to the extent possible, on actual farmers' fields ». Where animal practices are concerned, you have to demonstrate on a whole farm system. In actual fact there is a matter here which should be included — I mentioned it earlier on today and I feel rather strongly about it: that there must be synthesis research to put the components together into viable systems. The right sort of package must be developed to be used by farmers under specific conditions. We must be concerned with the development of a package of practices. Quite a few people talked about this and rightly so, but I do not see anything about it here. Generally the other part of it is allright, but personally again, I would like to see something said about looking at the fertilizer use situation in the context of an integrated rural community development approach, because it is only in that way that in the final analysis the work at farm and farmer level can be really be made fruitfut in terms of the community and in terms of the country or state. I believe this is an approach that is lacking in our proposals here.

Finally I would like to repeat again that synthesis research should be the function of research stations and research workers and that it should occupy an important part in this whole pattern of things. It has not come through clearly enough in this document.

HAUSER

I would propose, in persuit of what Dr. WALSH said and what was right, I would say to write here: « Under local farm conditions », that is what really is meant and I would change the title from « farmer utilization » which is not very good English I think, to: « extension of knowledge to farmers ».

BRAMAO

It seems to me that « extension to the farmers » would be allright, but I would like to have the opinion of other people around the table.

RUSSELL

I would like to suggest that the title of this is « Problems of increasing fertilizer use on the farms ». I think that is what this section is about. « Farmer utilization » I am quite certain must go. The heading could contain the word « extension » as Dr. HAUSER suggests, but my own view is what this section is really about is the problems of increasing fertilizer use in farms. There are very minor points, a word has gone wrong in a) the second line « affected adaptation ». I think the word « adoption » is meant, not adaptation.

ARATEN

I second the proposal of Dr. RUSSELL who suggests the title « Problems of increasing fertilizer use on farms » also for the reason that I propose to include in this chapter a suggestion on an education programme for engineers and technicians in fertilizer factories. I know I am in a strong minority as a chemical engineer here, but still it is a fact that in underdeveloped countries most of the factories work about 50% of their capacity. This means that in the same factories work 80%, 90%, 100% more than other plants, and even as I heard from Professor EWELL, there is one factory in India with 100%. The reason that this is the case as I already mentioned is due to a lack of engineers and technicians who have enough education in this field. You must change the technical management in such a factory. You must give opportunities to gifted young people to work a year longer in a good fertilizer factory before going over to a factory in an underdeveloped country. We had such problem in Spain, and in Holland and in Israel and from great personal experience I can say that this is the way to do it. And fertilizer factories in underdeveloped countries plus the Governments have vested interests in this education. They will pay it, if you would agree that this is important and you would suggest an education programme for young gifted technicians and engineers and try to have them for a year or more in a fertilizer factory somewhere in Europe or America or Japan, I am convinced that the fertilizer factories in a few years' time would produce more and cheaper fertilizers.

HAUSER

I would withdraw my suggestion for the title mentioned before and would agree with the one proposed by Prof. RUSSELL.

BRAMAO

I would like to say that the title suggested by Prof. RUSSELL is very well with me: I think it expresses very well whatever we have in mind. Concerning, the suggestions put forward by Dr. WALSH, I myself think that these economically operated types of problems are very important, at least under the conditions of the topics I know. I think it is probably one of the ways of helping the farmers to go ahead and start producing: they have got to see something that is within their reach also, something that is operated by such funds. I would like to ask Dr. WALSH, could he draft a small paragraph containing general suggestions that he was putting forward.

WALSH

I believe the title as suggested by Professor RUSSELL might not be just the exact one either because we are not dealing in this chapter with the problems of applying fertilizer. We are dealing with the solution to these problems. A heading such as « extending the use of fertilizers to farmers », « developing farmer use of fertilizer » would express the position better. And I would agree too with what Prof. ARATEN has said here, for the reason that in improving the use of fertilizer, the people concerned with the input industries such as the fertilizer industries, and the people concerned with the output activities, such as marketing and merchandizing, can affect the economic optimum use of fertilizer on farms. Anybody who was again at the Geneva meeting would know of the document presented by one of our French colleagues there, a very fine document on the question of how fertilizer efficiency and economics at farm level is affected by systems of distribution.

FRIED

I would like to suggest modifying Dr. RUSSELL's suggested title by leaving out the words « Problems of » which would then mean « Increasing Fertilizer Use by Farmers », and have changed « on farms » to « by farmers ». It may be a fine distinction and if you don't like the change, but I really want to get it down to the farmer level because otherwise « on farms » becomes the same general story of the research and everything else. So that would be my suggestion on the title. I would like to say that I think Dr. ARATEN has made a good point, and that we should add a sentence. I had started drafting one but I didn't get finished.

WELTE

Can we agree with the proposed title now? Yes, we can, thank you. Coming back to the discussion remark of Dr. ARATEN, of course, it is a real problem. The only thing is, should we educate people working in the industry, or did I misunderstand you?

ARATEN

Increasing fertilizer use by farmers. They will increase it if fertilizers are cheap, these problems will solve themselves.

WELTE

That's right, but the capacity of the fertilizer industry is just another thing. I may also say, if the industry had not enlarged the capacity, there would be a better market.

FRIED

I do think that Dr. WALSH's point belongs in the research section. I mean that is my impression from the point you were making of developing package systems, synthesis is research, so I think you would have to get together with doctor RUSSELL maybe and work up something in there.

BORNEMISZA

I tried to put together a sentence on Dr. WALSH's recommendation. How would you like the following addition to paragraph (a) as the last sentence: « This information on fertilizer use should be incorporated with the other techniques necessary for progressive farm operation in a « package of improved practices ».

WELTE

Conclusions. The second draft.

I think we have already come to an agreement on Chapter 1 (Introduction) and also on Chapter 2 (Research). Therefore, we should now go along with Chapter 3 and 4. As Chapter 4 has already been discussed, a certain agreement has been reached. Increasing Fertilizer Use by Farmers is the new title, I think. We can also agree to the corrections. Dr. BRAMAO informed me that all the ideas and all the remarks will be considered. But Chapter 3 has to be changed completely, and I would ask Dr. FRIED to say something about this chapter.

FRIED

Chapter 3 is what we have been talking about, — Fertilizer Requirements, section 3.

WELTE

Section 3 has not been distributed because the sub-committee has just finished the work. Perhaps Dr. FRIED will be so kind as to say something about the new setup.

FRIED

Before going into Chapter 3, you have received Chapter 2, and there were some typographical and maybe slight editorial changes that I think Dr. RUSSELL would like to give to you. And then we will go on to Chapter 3.

RUSSELL

Would you all look at the new draft of Chapter 2 which is headed « 2 Research, second draft ». Now that it is typed altogether there are some alterations of wording I would like to make which have nothing to do with changing the sense of the recommendation, merely in improving the English. The first paragraph will read as follows: « Research involving fertilizer use. Of necessity it involves obtaining knowledge, not determining knowledge. Both basic and applied research which enable the prediction (change of word order), the prediction of the effect of fertilizer application of both the yield and quality of crops. Then, in the next sentence « draft soil climate » were omitted from the typescript. « Interdisciplinary approach » which must include fundamental studies of plant zoology and plant soil climate relationships. Have you all got that.

And then in the next line the total environment determines the limits to yield. That is the « s » has got in the wrong place. The next paragraph I suggest should read, and this is purely a rewording: « The effect of the various components of the climate, i.e. radiation, rainfall distribution, temperature and even day length on those varieties of crops to added fertilizer should be determined as accurately as possible ». It is a more re-wording of that paragraph. On page 2 in relation to the soil (b): second line, the world should be « ease of cultivation » and not east of cultivation. NPK fertilizers. Then the next sentence, this includes « each nutrient in the soil » I suggest « each plant nutrient in the soil » and you want no hyphen between plant and nutrient. (This includes a study of the constitution of the available fraction of each plant nutrient). In (f) first line, last word: including « determining the... » and not « determination ». Fourth line of (g):

The verb should be « allows » and not « allow »: that efficient use of fertilizers allows economic crop production.

On page 3, in relation to human and animal health (d), in the first line the word should be « contents » and not « controls ». And I suggest again a purely verbal alteration, the contents of soils to identify those of which animals may suffer from their lack or excess. (e) there is a spelling mistake « effects of fertilizer on the estrogen » (insert « r ») and other substances on animal health and the words « and production » have got left out.

On page 4 at the top (c), third line: « On the high level of » instead of « on the high load of ». (Insert « level » not « load »).

In the next paragraph (d) in the second line: the word is « distributors » not « distribution ».

In the next para called (a) I suggest in the second line towards the end: « ...on to the land in ways that cause » (« ways » in the plural).

On page 5 (c) you haven't seen this at all, but I read it out, a much longer version quickly. I reduced the draft Dr. PESEK gave me and I am not certain that I have got that correct, but the last line to read as follows: « and to establish the extent to which this process » (rub out all the rest) « differs among farmers in different regions of the world ». But I would like to ask Dr. PESEK if he agrees with that draft.

WALSH

Just one or two points in general at this stage. Under « Research » there is a drafting matter. We should state that « research including fertilizer use of necessity is *"concerned with"* rather than *"involved in"* ». On page 3, in relation to human and animal health under (d) change to « to identify soils in which animals may suffer from imbalance or excess ». (l) Effect of Fertilizers on the *estrogenic* (*not oestrogen*) and other organic substances. The next change I suggest is « research on the recycling of nutrients present in farm and human waste in a way that causes minimum hazard to health or pollution of water draining off the land ». Professor RUSSELL's statement that « the necessity for developing genuine co-operation on extension research service to ensure that adequate research on increasing crop yields with the efficient use of fertilizers is carried out », I feel this needs re-consideration.

In relation to n. 4, « My approach would be that the statement relating to the necessity to establish organizational methods or approaches to develop genuine cooperation » is not a research problem and hence should be placed elsewhere. (c) Under the statement « research on improving methods for the efficiency of extension methods including the learning process of farmers in accepting new ideas », I feel that it would be desirable to add « and the synthesis of efficient production systems ».

RUSSELL

But this is quite a different kind of research from the one that is put in here.

WALSH

You might think it is, but it is not.

RUSSELL

On page 4, I don't think it comes in here, at the top, b, c, d, e, it is in relation to increase the use of efficient fertilizer use. Some words about the « given to package systems for selling to the farmer », something like that.

WALSH

Professor RUSSELL, I believe that comes in; you see, I am looking at this in the context that it is a package job and I was referring to the designing of techniques to give the adviser a package to bring to the farmer. If he does not bring it to him, nobody else will. It is in the extension research context.

FITTS

Just one short comment on — the design to ensure mode of uniform spreading of solid fertilizers — I wonder if we might not take out « solid » and just say spreading of fertilizers because uniform is understood in all forms.

WELTE

No other comments. Then Chapter 2 is adopted. Now we come to Chapter 3. Dr. FRIED would you be so kind to explain the changes that were made.

FRIED

I just wanted to say that we have considered all of the remarks that were made here. Four of us worked during the break to try to implement the things that the group wished us to do. Dr. COLWELL, Dr. PESEK, Dr. HAUSER and myself and I shall now indicate to you the changes that were made. Under Soil Testing, which is on page 6, because that is really the first change because it is located in the wrong place, but it is located on page 6; we have taken out the whole first sentence.

WELTE

Only to give you some information. We are coming to an end in our Study Wook and have now to prepare the conclusions. The conclusion consists of four chapters: Chapter 1, Introduction, Chapter 2 dealing with research, Chapter 3 dealing with fertilizer requirements and Chapter 4 with soil testing. Now we are just speaking about Chapter 3.

FRIED

We were on page 6 of section 3. On page 6 under Soil Testing, we have left the first sentence out entirely. Going back to page 2, because that is what follows, still talking about Soil Testing, we have inserted in the first sentence on that page so that it reads as follows: « Soil testing procedures for phosphorus, potassium, magnesium, pH, calcium carbonate requirement and physical properties have been and should continue to be utilized as one of the factors to be considered in making fertilizer recommendations. Now if we go to the third sentence in that paragraph, starting off « No suitable tests... » it now reads: « No suitable tests for routine testing of soil nitrogen availability are generally available ». And we have struck out the rest of that sentence. And we have struck out the beginning of the next sentence, and started with the words: « Suitable recommendations » and I will read now what we ended up with: « Suitable recommendations usually can be based on the quantities of nitrogen known to be needed for a given yield of a given crop, taking into account the efficiency of uptake of applied fertilizer, losses of nitrogen that are likely to incur in the environment». You will recognize the addition of « in environment ». The last sentence in that paragraph starting with: « These data are derived from experiments, trials and experience ». We have put a period at the end of experience and taken out the rest of the sentence.

The next paragraph, there are individual words that have been changed and I will just read the words because they are only insertions of one word or another. « Correlation of the soil analysis results is first made by relatively inexpensive soil plant cultures, followed by more costly and time-consuming calibration in field trials with the crops actually to be grown. This must be done under local conditions with local soils. Soil in these cultures should include the complete range of possible soil physical, chemical and biological conditions determined above ».

The soil plant culture results must include a nutrient element yield and the yield of dry matter.

The next page — Under « Field trials ». « In addition to the determination of crop response to fertilizers the purposes of field trials are also to check the reliability of the results obtained in pot cultures and calibration of the soil test ». We have taken out of that sentence — « to separate the ranges of the chemical tests » and « to indicate relative levels of nutrient.

The following sentence which starts — « The degree of complexity is governed by the degree of original uncertainty of fertilizing needs and their prediction. Then if you go down to the penultimate sentence starting with — « Procedures for those in other types of studies » — that whole sentence comes out.

We have also taken out the last part « also diseases and insect attacks ». The last few words in parenthesis at the end of the page have been taken out.

In addition to adding sap analysis which you know of, we have changed the last paragraph on the page — starting with long-term experiments — and it now reads « Experiments should be established to measure changes due to fertilization. These experiments should be located on selected major representative cultivated soil types and include several fertilization and cropping systems, in addition to observations (the « usual » is taken out) and the crops, soils and climate, the soil should initially be characterized in great detail (Leave that « physically, chemically » of course). Also at the end of the page leave out the last part of the sentence « and studied carefully on a planned schedule. » Put a full stop after the word « followed ».

On page 5 — you have a sentence in the middle which says « and tissue analyses are needed to evaluate and plan a fertilization programme ». « While important everywhere this is of particular importance in many developing countries because there crops are an important source of foreign exchange. A tissue analysis Research programme with the most important of these crops should have a high priority where applicable for assessing the management programme for NP and K as well as for other essential mineral elements ». I think this could probably be shortened if you would let us edit it down a little.

I think those are all of the major changes that we have made. If we have missed anything important or we have to argue about something important let us do it now.

BRAMAO

Just one word — on page four where you say « in great deal » I would put adequate there and I will tell you why. Because there was a very important Institution in one developing country making 150 determinations in the soils but they did not know how to interpret them and this might be something that they consider to be exhaustive although they do not understand what they are doing.

WALSH

You talked about the cultivated soil types, I would leave out the word « cultivated » because what you say is equally important for all soils whether cultivated or uncultivated. Some grassland types are never culticated. I also think a link sentence in page 5 of your Introduction pointing out now you have examined these matters in detail in the following sections.

BUSSLER

We are speaking about words and better English in these papers — I think it is important enough, but I cannot understand really that the method of systematic variations has now disappeared completely. I think that also those who do not agree with this method cannot cross it out in this manner. No one of us has published a paper in which he writes his experience about this method that is not in accord with the papers of HOMÈS who works on this, and I think this must be inside the conclusions, maybe without the name of Professor HOMÈS, but effects of this method must be included. The second remark refers to page 5 — the last sentence in the first Abstract that is for the « assessing the management programme for NP and K as well as for the other essential minor elements ». I think NP and K could be eliminated — « assessing the management of » — it is enough to write essential elements.

FRIED

I do have to give a reply to the other one, because we have discussed this over and over since we recognised the problem. I do want to point out that we have talked about checking the reliability of the results and determining the optimum ratio of nutrients for yield and quality, to make reasonable fertilizer recommendations. I must say, I really feel after our discussion with the various Committees, Members before and now, that we have not anywhere here mentioned any particular method for doing a job; we have not mentioned the best phosphorus method; we have not mentioned the best type of yield trial method although we have had a paper on it by PESEK; we have had other papers on it by other people; we have left out any of that kind of detail. Why should we put in that kind of detail in this one particular case. I have spoken to a lot of people here about it now in two ways:

1) as to whether they agree with the method, and 2) whether they think that going down to a level that we have not gone down to in any other case. I have not put down that the best way to determine fertilizer efficiency is to use isotopes even though I am convinced about this, but I would not be surprised if someone here is not. I think that this is getting to a different level of detail and that is why we have kept the concepts in, but left the methods out. By concept I mean the concept, that the relative ratio of nutrients that are utilized, is important. I am only trying to reflect this. Is there anyone in the Committee I have worked with who thinks differently, please say so.

BUSSLER

I think that I overlooked that the words optimal ratio are inside, when these words « optimal ratio » are inside, then I agree completely. (They are not in the conclusions).

WELTE

Suggests to go on to discuss Chaper IV and asks Dr. BRAMAO to add his remarks.

BRAMAO

I think that Prof. FRIED did not yet include a sentence covering the idea that was suggested here.

FRIED

No, I think there is only one factor left in Section IV - I think you are all aware of the changes that have been made. No additional changes were made and that is the problem, because we did talk about education of workers on fertilizer plants in order to obtain maximum capacity of production from a given plant. There seems to be a difference of opinion in that I tried to draft various things and they always came out in a way that was difficult to get any kind of agreement on. Part of the reason for this is, I must say, not only the question of whether we should deal with a problem that is important to industry which works at a different level from the farmer, or on extension service type of operation, but also that various remarks were made that when you increase the capacity of the fertilizer plant what you usually do is increase the profit for the person who owns it and not make more fertilizer supplies available to the farmer. I thought that perhaps we should put something in that we should make more fertilizer supplies available to the farmer at low cost. Then I went back to this easy credit terms etc. and we may be able to insert something in there, but I think we will have difficulty in being specific about training for the fertilizer industry. That is my impression. I don't know how the rest of the group feel.

BRAMAO

I feel strongly that in many cases where I have experience the fact that the factory has been installed and is working at full capacity, does not usually mean that the consumer is going to get the product at a cheaper price. I have seen many cases in which the overheads of that industry become much heavier and the profit goes some other place, but certainly it is not reflected in the low cost of the product. I would suggest strongly that we put in a sentence stressing the urgent needs for the farmer to obtain the necessary fertilizers at low cost, even if it is with a subsidy from the government. What we are interested in really, is for the farmers to have the fertilizers at low cost so that they use fertilizers and increase production.

ARATEN

I believe we are interested in two things that the farmers should get more fertilizers and the undeveloped countries should import less from abroad which costs a lot of foreign exchange and that the farmer should get fertilizers at a low cost. From my experience as a chemical engineer in the chemical industry, I would say that if a factory is working at low capacity the prices of the product are going up, you have to import fertilizers required and spend foreign exchange.

BORNEMISZA

I think I have something that gets close to Prof. ARATEN's idea and even widening it slightly because from this excellent idea I thought that actually not only fertilizer technicians but other people supporting efficient agriculture might be in short supply — for example, low level market managers and so on, so I would suggest the following paragraph: « Technical personnel should also be prepared to support the farmers with the materials needed for increased production and its efficient marketing ».

WELTE

Can we agree to this additional remark to Chapter IV? Yes. Are there any additional remarks or proposals for cancellations?

WALSH

Do I take it that Dr. BORNEMISZA's original insertion is also in? Reply: yes.

FITTS

I have no remarks in general but I think a lot of editorial work is still needed on this, I think it should be gone over by somebody who will put it all together, particularly on the draft conclusions. Considerable improvement can be made in the way it is presented and I am sure somebody will have to do something to it to make it read more smoothly.

FRIED

I do not know myself what the final procedure is. I hope that we will be allowed by the group to make editorial changes as Dr. FITTS just mentioned, because there are a lot of them. I think you might ask a Committee of three. We can circulate it even through the mail if necessary, Dr. HERNANDO may be more familiar with how it was done in the past.

HERNANDO

Our idea is to publish this conclusions on the whole of the theme as soon as possible but that does not mean that there are no possibilities to make some changes in the final draft. We will try to look at it on the whole here but when we find something that is not clear we send it to the author. The general practice we used in the past was to send it to everyone by airmail asking to reply within three days after receiving the letter. If we do not receive an answer within 15 days, we assume that there is agreement with the conclusions and we immediately go ahead with publication. But as regards the papers we do not send any draft unless we have some troubles in understanding.

FITTS

I was just raising a question of procedure and I think that all of us should try to do this and I was wondering if the Committee would welcome any suggested changes so they can look at it because somebody is going to have to undertake the final writing of it. A Committee cannot do it and I was wondering whether Dr. FRIED is going to assume the whole responsibility or whether he would like to have some suggestions handed to him.

WELTE

I think it is possible Dr. FITTS. This opportunity will be given and you can contact Dr. FRIED and then make your proposals. I believe the essential point here is to come to an agreement in general on the important points of the conclusions.

HERNANDO

I should repeat that the general conclusions will be typed maybe before Sunday evening and will be distributed to all of you (at least to all who remain). You could take them along with you, read them over and send them back with the changes you would like to suggest. But the problem is if the change is in some way related with the method of presentation, this would be easy, but if you try to change something in the substance it would not be possible to change, otherwise we should all have to meet again to get another agreement. I think the best thing would be if everyone can read the whole because many people find errors easier than a single person does. I would also suggest that people who live out of Europe should give me their address in Europe before leaving for their home countries so that I can send them the general conclusions there.

HUNDRED YEARS OF INCREASING CROPS THANKS TO THE USE OF COMMERCIAL FERTILIZERS

A retrospective view at the year 1900 and an outlook on the year 2000

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I was indeed very unhappy that I was not able to arrive at the beginning of this Study Week. I did not feel well and as I am already in the eightieth year of my life, I have to obey Doctor's order and to be careful. I am now very glad that I finally was allowed to come here and to attend at least the last day of the Study Week. However, far from here, on the island of Madeira, I tried to take part in the Conference and was grateful to be given the opportunity to read the papers which had been presented to the Conference. I must confess that seldom in my life have I learnt so much. The papers which my colleagues have presented to this Conference are a real treasure of knowledge, especially those concerning the technological and managerial problems of application and production of fertilizers. I, as an economist, shall now concentrate myself on the economic side of the problem.

The most significant discoveries regarding the importance of plant nutrition with fertilizers of industrial and mineral origin were already made in the middle of the last century. Justus v. LIEBIG, in his book "The organic chemistry and its application in agricultural chemistry and physiology", and

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For this paper in German language see Appendix Nr. 8.

the studies of the famous English Research Station Rothamsted have demonstrated which nutrients we must give the plants in order to get permanently high yield. They have shown us also how we can produce these nutrients in mines and manufacturing plants in large quantities as fertilizers.

FIRST, however, more than half a century went by before these discoveries gained ground, even to an appreciable extent, in practical farming in the world.

At the beginning of our century the acreage provided with commercial fertilizers was less than 1 percent of the farmland in the world. The consumption of nitrogen had reached a quantity of about 300.000 t N. 240.000 t about were supplied in form of Chile saltpetre and 88.000 in form of ammonium sulfate as by-product of the coke industry. The consumption of phosphoric acid amounted to a total of about 900.000 t of P_2O_5, of which about one third fell to the United States, another third to Germany and the last third to the rest of Europe. The world consumption of potash lay in the range of 250.000 t of K_2O, of which 117.000 t fell to Germany, 30.000 t to the other European countries, and 80.000 t to the United States.

About the turn of the century the world supply of nitrogen was still prevailingly based on a natural product, namely Chile salpetre. Shortly before the turn of the century Sir WILLIAM CROOKES, in a meeting of the British Association for the Advancement of Sciences, had pointed out that the easily cultivable virgin lands of the world were running short, and that around the year 1930 humanity would be faced with a famine in view of the increasing population, unless we succeed in synthesizing the unlimited quantity of nitrogen present in the air with hydrogen into ammonia. At that time this synthesis had indeed been worked out in the laboratory, but methods for the industrial production had not yet been found. He emphasized that the development of such industrial possibilities would be by far the most important contribution to the solution of the world food problem. At the end of the first decade of our century, there had been opened up a modest industrial production of synthetic nitrogen by means of the flame-arc process, thanks to the inexpensive hydroelectricity in Norway. The decisive course, however, was then taken during the First World War and shortly afterwards with the explosive increase in nitrogen production according to the Haber-Bosh process.

Of the plant nutrient phosporic acid Justus v. LIEBIG had already shown that phosphoric acid, contained in bone meal in form of tricalcium phosphate, is little absorptive for the plants and that it can be made absorptive, by rendering it soluble with sulphuric acid. This was the beginning of the superphosphate industry though it remained a modest industry as long as only bone meal was known as the disintegrative raw material. The enormous step forward was made shortly before the turn of the century thanks to the discovery of rich deposits of rock phosphates in different parts of the world, especially in Florida and on the Isle of Nauru in the Pacific Ocean, but also in North African countries. These phosphates were likewise disintegrated with sulphuric acid and converted into superphosphate assimilable by plants. Another important source for the plant nutrient phosphoric acid became Thomas slag, a by-product of steel production.

The third important plant nurient, potash, just like THOMAS slag, became first known as a waste product. The development of potash mining began in Germany with deep mining for rock-salt in Stassfurt in 1843. Initially one was badly disappointed to find enormous strata of magnesium sulphate above the rock-salt which, at first were thrown on tbe waste heaps as potassium-magnesium salts. ADOLF FRANK acknowledged the value of these potassium-magnesium salts for the supply of the plant nutrient potash. In 1861 the first factory for potash fertilizer salts was founded in Stassfurt. At the beginning of the new century, however, the total production amounted only to a quarter of a million t of K_2O, and more than half of it was used in Germany.

The starting point of our consideration, the year 1900, we may therefore characterize as follows: The most important scientific knowledge about plant nutrition had already been acquired half a century ago. The manufacturing industry and mining industry were prepared to supply large quantities of the plant nutrients potash and phosphoric acid. The most important industrial development, namely the large production of synthetic nitrogen, had been successful in the laboratory, and the industrial use on a large scale was near at hand. Consequently the presupposition was given that the world consumption of plant nutrients of a total of scarcely 1,5 mill t pure nutrients at that time could be increased to 65 mill. t pure nutrients, i.e. the fortyfold, up to the present time.

As to the geographic distribution of the consumption of plant nutrients in those days, we may state that the modest consumption was completely concentrated on two territories, namely on parts of the agriculture in Western Europe, especially in the Netherlands, Belgium and Germany, and on the east coast of the United States. There a considerable part of plant nutrients was used for the cultivation of tobacco, the rest principally for potatoes, fruit and vegetables. In the year 1900 the Unites States' agriculture produced the major food, bread grain, forage, root crops and dairy products practically still without any appreciable use of plant nutrients. The only source of production was the natural soil fertility which was exhausted to a not inconsiderable extent.

The yields per hectare were accordingly low. For the year 1900 we may assume a yield per hectare of 10 cwt for almost all of the cereal varieties in the largest part of the world; and this not only in developing countries, where it is yet today for the most part on the same level, but also for the largest part of Europe and North America.

The development from 1900 up to the present time is chiefly characterized by the fact that the yields per hectare have increased fourfold in ever larger territories of the world.

This fourfold increase has been attained wherever the necessary quantities of plant nutrients were used. Of course, plant nutrients must be combined with highly efficient seeds and, where necessary, with irrigation and pest control products. The plant nutrients are not a miraculous drug to simply throw on the field in order to get a fourfold yield. If nevertheless we repeatedly indicate in our study statistical data on the use of commercial fertilizers in connection with the increase of yields per hectare, we do this because the consumption of plant nutrients is that factor which can easily be dealt with statistically.

About a quarter of a century later, in the year 1925, the consumption of plant nutrients was still very low. The consumption of nitrogen had increased to 1,2 mill t N, the consumption of phosphoric acid to 2,7 mill t, and the consumption of potash to 1,7 mill t of K_2O. These appeared to be impressive increases, but after than, they were by far overshadowed by the increases during the second and third quarters of the century.

Of the situation of the use of plant nutrients and the level of the yields per hectare in Europe around the year 1925, the diagrams 1 and 2 give so to say an instantaneous photograph. At that time the Author delivered an expert judgement to the World Economy Conference, held in Geneva in 1926 and 1927, containing an estimate [1] of the production reserves of the European agriculture in the light of the use of plant nutrients.

At first sight one notices the very close relation between the use of plant nutrients, here in form of nitrogen, and the yields per hectare, here wheat.

In the entire Europe there was only a very small district, where the yields per hectare were quite high with more than

(1) FRITZ BAADE, *Produktions- und Kaufkraftreserven in der Europäischen Landwirtschaft*, Berlin 1927.

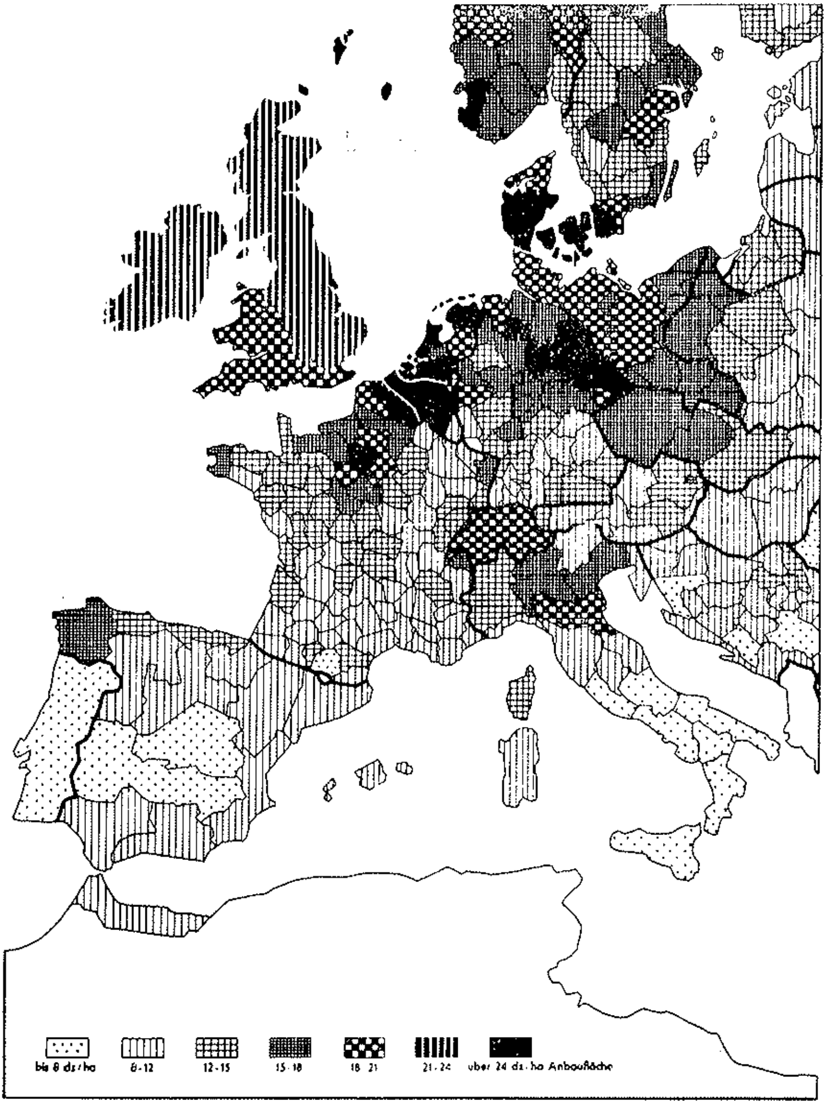


DIAGRAM 1 — Average yield of wheat in Europe 1922-24 (cwt on 1 ha acreage).

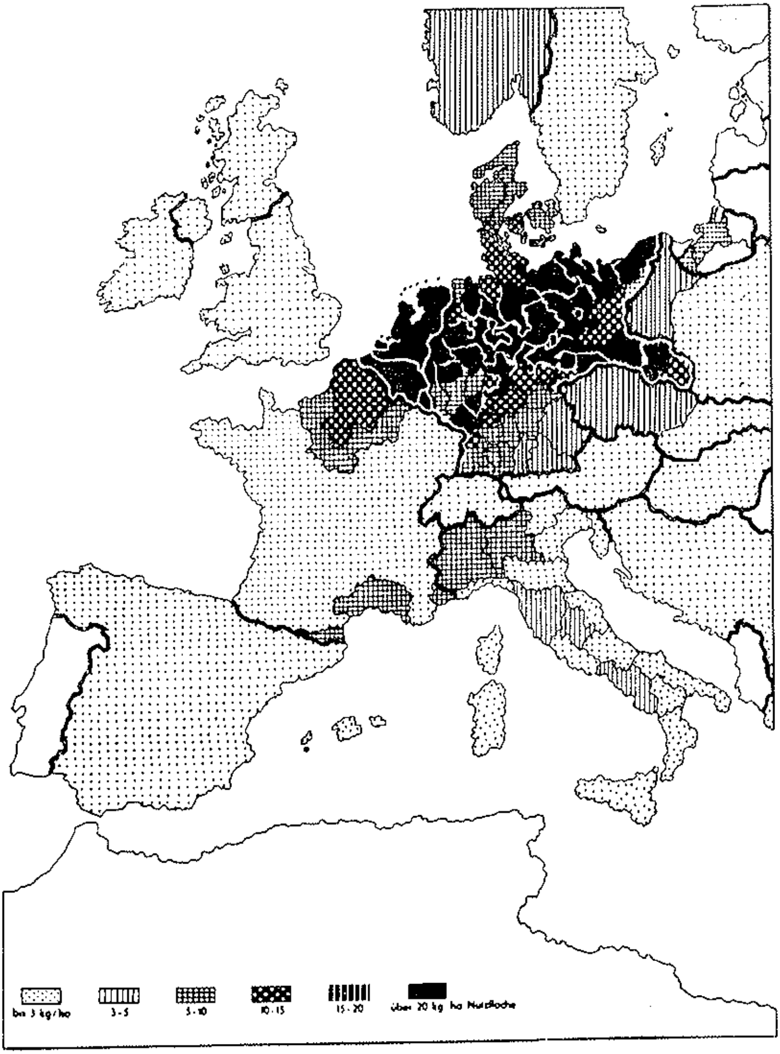


DIAGRAM 2 — *Consumption of commercial fertilizer in European agriculture* (kg pure nitrogen per ha farmland).

21 cwt per hectare, whereas they were low, in part alarmingly low, in other districts. A larger part of France, Italy and even South Germany had at that time wheat yields per hectare corresponding in size to the present hectare yields in the most underdeveloped countries, i.e. 10 to 12 cwt or even less than 10 cwt per hectare.

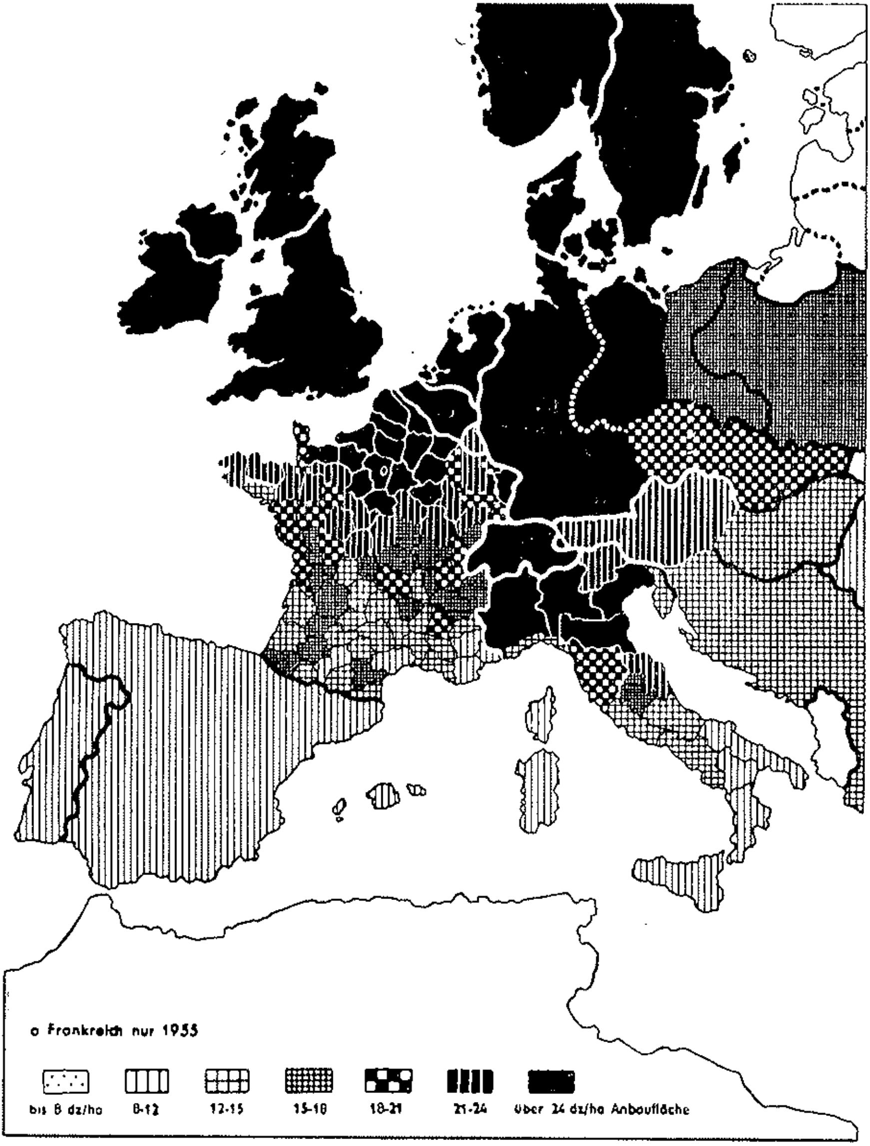
Diagram 2 shows that there was an appreciable consumption of commercial fertilizers, in this case of nitrogen, in those European territories where a high wheat yield was proof of a high standard of agricultural technique: in Belgium, the Netherlands, in a small part of North France and in East and Central Germany.

At thans time the Author ventured to draw keen conclusions from these diagrams. He has affirmed that the use of plant nutrients, f. i. of nitrogen, ought to and would be raised to 30 kg per hectare in the larger part of Europe, and that this improvement of plant nutrition would bring about a higher production in European agriculture, thus eliminating the dependency of Continental Europe at least of mass imports of grain from overseas. The prediction might have appeared very keen in 1925, but 25 years later it had proved to be generally right.

The diagrams 3 and 4 show that in 1955/56 the area with wheat yields of more than 24 cwt/ha in Europe had been greatly enlarged. Not only Great Britain and Ireland, the three Scandinavian countries, Belgium and the Netherlands belong now to this territory, but all Germany, that is both the Federal Republic and the DDR.

In Italy the territory of high yields has advanced to Central Italy, and in France the part with high yields has greatly extended.

In absolute parallelism with this has developed the use of plant nutrients during these thirty years. During the years 1922-24 there existed in Europe no region with a nitrogen use



Quelle: Auf Grund amtlicher Statistiken im Institut für Weltwirtschaft gezeichnet, Kiel 1958.

DIAGRAM 3

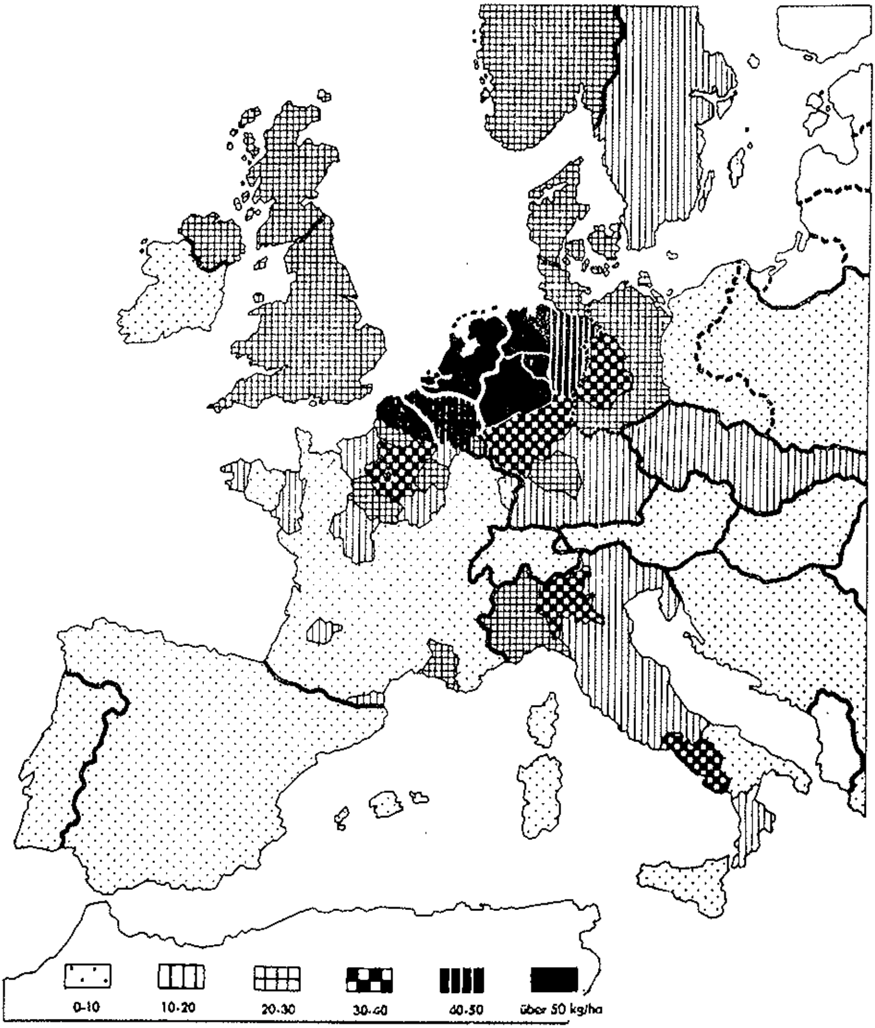


DIAGRAM 4

of more than 30 kg/ha (²). In the meantime, however, there has developed a large area with a nitrogen use of 30 to 40 kg, of 40 to 50 kg and over 50 kg per hectare.

And now the effect on the food supply in Europe: Already in the middle of the 1950s the additional requirements of wheat from overseas in Continental Europe, taking the territory as a whole, had practically ceased. The German Federal Republic though was still in need of imports. On the other hand Sweden and in particular France had a surplus in exports so that the area of Continental Western Europe had indeed become independent of wheat imports from overseas, as had been predicted in the expert judgement in 1927 for the World Economic Conference.

And now we advance once more for about one and a half decade and arrive at the end of the 1960s. In 1967, wheat yield per hectare had exceeded the 24 cwt limit not only in Scandinavia, Great Britain, in the Netherlands and in all Germany bul also in France except for very small areas in Central France and in the Provence. But there, too, had already been obtained yields of 21 to 24 cwt per hectare. Only in Spain, Portugal, Sardinia, Corsica and in South Italy including Sicily yields per hectare were less than 21 cwt. In East European countries, especially in Poland, Czechoslovakia, Hungary and Jugoslavia, yields had partly amounted to more than 24 cwt., otherwise they were from 21 to 24 cwt. Besides, diagram 5 does not even show the whole situation, because the yields obtained in the black marked areas are for the most part not only over 24 cwt/ha but over 32 cwt/ha.

To this corresponds the use of the plant nutrient nitrogen. The territories with a nitrogen use of more than 50 kg/ha have extended in Europe, above all where also the wheat yields per

(²) Diagram 4 had to be designed differently than diagram 2, because the consumption had so much increased. In diagram 2 all areas are black with a consumption of more than 20 kg/ha, in diagram 4 all areas with a consumption of more than 50 kg/ha farmland.

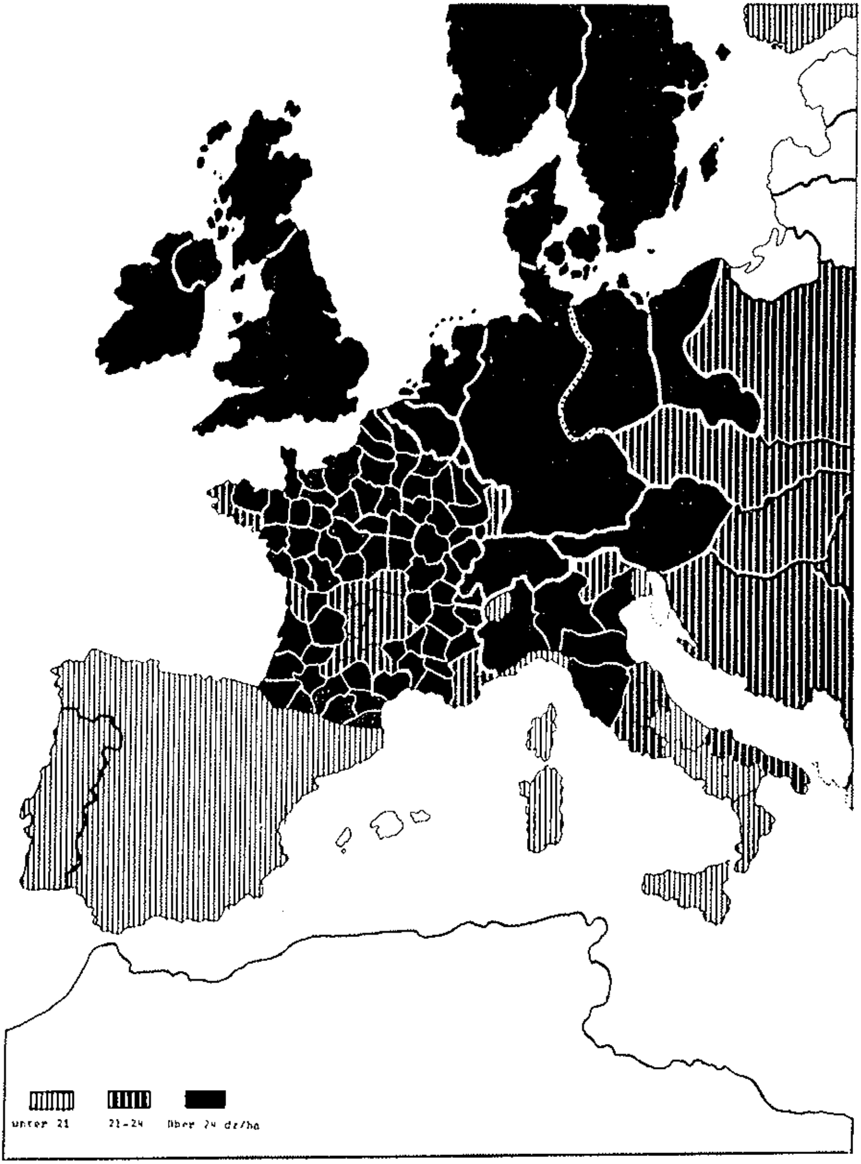


DIAGRAM 5

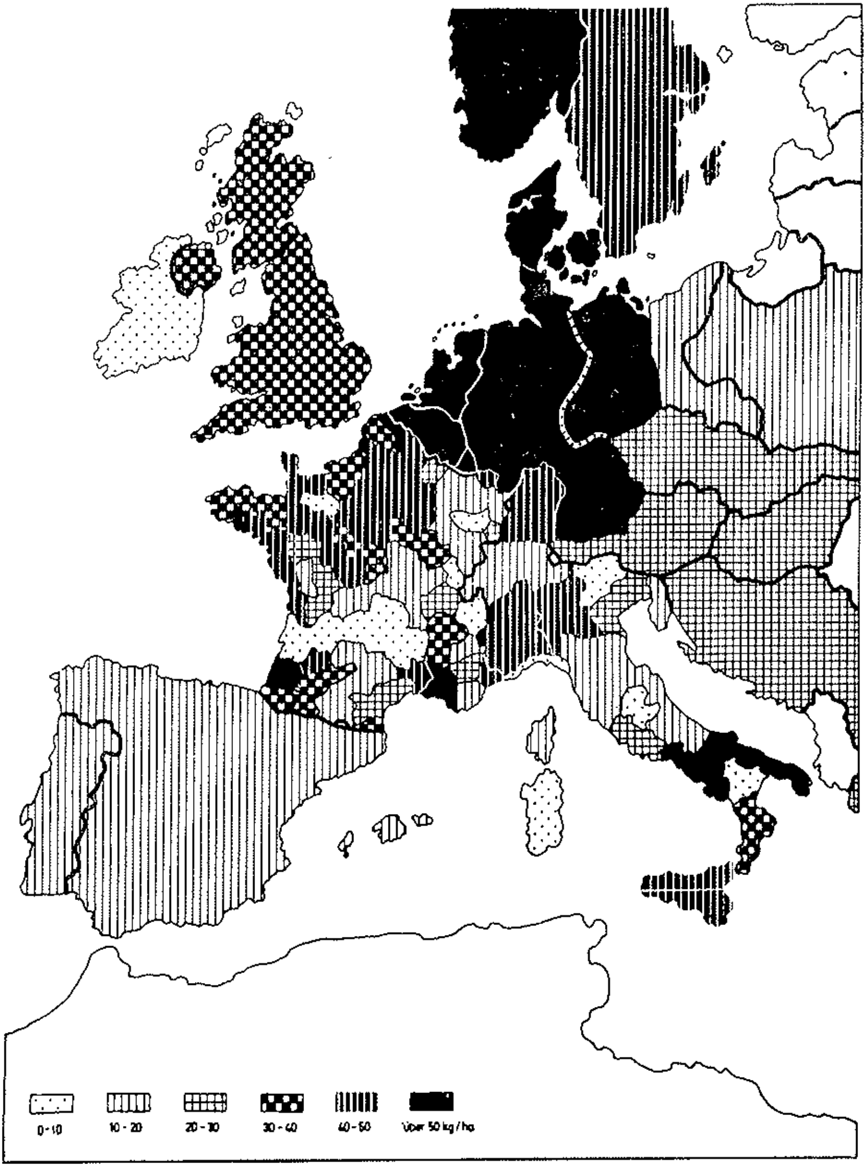


Diagram 6

hectare have been raised to more than 24 cwt. In one part of the black marked area in diagram 6 there is being used a quantity of nitrogen not only of more than 50 kg/ha but for the larger part of more than 100 cwt/ha.

The development of production has gone far beyond what was predicted with the presentation of the diagrams of 1922-24 at the World Economic Conference in Geneva about the production potential of European agriculture.

In vast European areas the yields per hectare not only of wheat, but of all grain varieties, have increased to threefold and even to fourfold of what they had been in 1925 in the largest part of France and in large parts of Germany and Italy. Also in East European countries there has been obtained a tripling of the yields per hectare, and this most evidently due to the widened use of plant nutrients. Here it should once more be pointed out that these high yields per hectare, of course, are not only the result of the plant nutrition use but of a whole "package of measures":

Use of very efficient seeds, good pest control and, at least in parts of Europe, a sufficient water supply through irrigation.

We will now cast a glance at the next decade of our century.

If we consider the grain economy as a whole, we can state that the present world situation corresponds largely with what it was in Europe about fifty years ago: Only in some parts of the world are there high yields per hectare of the extent of 30 cwt, and even 40 or 50 cwt, and these are territories with a high use of plant nutrients. In the larger part of the world grain economy, especially in the developing countries, things are still as was the case in large parts of Europe in the years 1922-24: low, in part alarmingly low yields per hectare. And this is clearly connected with a markedly underdeveloped situation of cultivation technique, characterized by a completely insufficient, or even quite lacking, use of plant nutrients. From this backwardness and the possibility to overcome it arises the hope that not only we must prevent a world famine but that we can also prevent it. We can produce sufficient food for all the peoples of the world, if the agricultural backwardness everywhere in the world — especially also in developing countries — will disappear.

Sufficient use of plant nutrients, namely of commercial fertilizers, will thereby play a determinant rôle. The use of plant nutrients must go hand in hand with the use of highly efficient seeds. Where the farmland does not get sufficient water for lack of rain, there irrigation must be added. Since in the warm climate of the developing countries with abundant distribution of plant nutrients weeds grow just as rankly as cultivated fruits, there must be combined intensive pest control. Therefore the following measures must be associated in one "package": plant nutrition, highly efficient seeds, sufficient water, better cultivation of the soil and pest control. This "package approach" is effective also for the simple reason that it will be hardly possible to stir up an illiterate peasant in an underdeveloped country by demonstrating a single yield increasing factor, as f.i. the use of fertilizers. If he is being told that with such fertilizers he can obtain a yield increase of 20 to 25 percent, he will hardly be prepared to spend money for such fertilizers, or even to make debts. If, however, in his own village he is shown a field that yields double, threefold or even fourfold of what he himself, his father and his grandfather had even seen or believed to be possible, he will start moving and ask for such seeds, for such fertilizers and such pest control products.

In development of the "package" politics the Rockefeller Foundation has particular credit for having cultivated the "miracle wheat" in Mexico. The recipe was really very simple: the hitherto existing wheat varieties have long straw, and if they are intensively fertilized especially with nitrogen, they fall over (lodge). In Mexico the collaborators of the Rockefeller Foundation have cultivated the so-called dwarf-straw wheat, i.e. a wheat with a very short but strong straw. This dwarf-straw wheat tolerates quantities of 100 kg and even 125 kg of pure nitrogen per hectare; and if, besides the abundant sunshine, is also provided with sufficient water, it yields from 40 to 50 cwt per hectare; there have been obtained even yields up to 80 cwt. With this contribution of the Rockefeller Foundation, i.e. the "miracle wheat", Mexico has succeeded to multiply not only the yields of particularly progressive farmers but the total average crops of the country, and this within such a short time as it had never been believed to be possible. Around the year 1950 the average yields of the country were still about 8 cwt/ha, but ten years later they had reached the twofold and after another five years even the threefold of the yields of 1950.

Tripling of the yields per hectare in a whole country within only fifteen years is something that had never happened in the entire history of agriculture. In Europe, for instance in the German Federal Republic, wheat yields have increased from 8 cwt to 16 cwt and finally to 24 cwt/ha, which is a tripling. But the fathers, grandfathers and great-grandfathers of the present farmers have needed 150 years to do this, whereas the Mexicans have realized it in fifteen years thanks to the Rockefeller Foundation. If it is possible to cultivate this wheat also in the big famine-threatened countries — and we shall see that this will have come true within an amazingly short time — then the Rockefeller Foundation has put a real "miraculous weapon" for the victory over the hunger in the world in the hands of all the peoples of the earth, both of those who are starving and of those who reflect about what they can do to abolish the hunger. Humanity is highly indebted to the ingenious wheat cultivator Borlaug who not only has cultivated the miracle wheat for the Rockefeller Foundation in Mexico but who also introduced it into large practical use by farmers. It was therefore an excellent idea to award the Nobel Peace Price to this man.

The Rockefeller Foundation has not only cultivated this wheat but has decidedly helped that the use of high-yielding seeds be combined with large quantities of fertilizers. In the fifteen years during which the wheat yields have tripled in Mexico, the use of fertilizers was raised by twentyfold. The same must happen in all those countries that are anxious to follow Mexico on the way to the Green Revolution.

Therefore, in economic sciences the relation between the use of plant nutrients and increase in food production constitutes for many years the central point of all considerations. For a long time the Author has estimated in books and articles that in developing countries the use of fertilizers must be increased by tenfold or even by twentyfold. As regards Turkish agriculture, he estimated in the expert judgement of the working team of the FAO (3) already in 1959 that the use of nitrogen must be raised by twentyfold, and indeed within only ten years, from 1959 to 1969, nitrogen use in Turkey increased by twentyfold.

The Committee of the 110 specialists, who submitted the expert judgement on "The World Food Problem" to the President of the United States, estimated that food production in the developing countries must be doubled by 1980, and therefore the use of plant nutrients of 6 mill t, consumed in the developing countries in 1967, must be raised to 67 mll. t, that is eleven times as much (4).

In those developing countries in which there have been at least initial results thanks to the "Green Revolution", there have been set up corresponding programs for the increase of the consumption and finally for the proper production of commercial fertilizers which meanwhile have been energetically put into effect.

In *India* — at least for wheat — in the territories of the

(3) Turkey. Country Report (Food and Agriculture Organization of the United Nations. Mediterranean Development Project.) Rome 1959.

(4) The World Food Problem. A report of the President's Science Advisory Committee, Vol. 1 and 2; Report of the Panel on the World Food Supply. Washington, D.C., The White House, May, 1967.

Punjab, particularly suitable for wheat cultivation, the area sown with high-yielding varieties imported from Mexico, has been enlarged to more than half of the wheat area. The use of nutrients in fertilizers ($N + P_2O_5 + K_2O$) increased from an average of 97,000 t in the years 1948-52 to 1,474,000 t in the year 1968/69. India set up a program to increase the use of nitrogen for the whole country to 2.5 mill t N in 1973/74. The consumption has remained until now, however, behind the planned expectations. But even if in the year 1973/74 there should only be attained a use of 2 mill t N, against the very low starting point of an average of 63,000 t in the year 1948/52, this would be an impressive increase by 35 times in little more than two decades.

In clear relation with the improvement of plant nutrition, Indian yields have likewise increased in an impressive way. At the beginning of the First Five Year Plan in 1950, the total crop of foodgrains amounted to 52 mill t approximately. By 1964 it had increased to 89 mill t. Then two consecutive catastrophical drought years caused a setback to 72 mill. t and 74 mill. t respectively in the years 1965 and 1966. With the return of normal rainfalls the total production of foodgrains increased to 100 mill. t in the year 1968 and to 106 mill. t in the year 1969/70. For 1971/72 one expects a crop of 113 mill. t, and in the successive years one of 120 mill. t. Since, despite the boring of then thousands of irrigation wells, the Indian crop depends still on the very variable monsoon rainfalls, setbacks are not excluded.

The general level of the Indian crops, however, has still increased by two and a half times, and the consumption of fertilizers has a decisive share in this. In view of the continuous increase of population, this development must proceed intensively. Even the nitrogen consumption of 1.4 mill. t N approx. in the year 1968/69 for an area of 144 mill, hectares, corresponds only to a use of 10 kg/ha. Since all of the Indian cultures — not only cereals but also sugar cane and cotton — are in urgent need of fertilizers, the next decades will require another increase in the consumption of fertilizers which must be doubled at first and then raised fourfold.

Things are similar in *Pakistan*. In West Pakistan, thanks to the combination of high-yielding seeds with abundant plant nutrition and the provision of irrigation water through tube wells, wheat production has increased to such an extent that the wheat deficit has been eliminated and a wheat surplus was obtained which, at least in part, may cover the food deficit in East Pakistan. Before the use of the Mexican varieties and the consumption of corresponding large quantities of fertilizers, wheat production amounted in West Pakistan to a yearly average of 4 mill. t. Then it increased within three years to 6 mill. t, that is one and a half times, and today it is about 7,5 mill. t. An increase to 8 mill. t, that is the double of the former yields, will be expected for the year 1971/72, provided somewhat normal weather conditions. The forecast that the wheat yields may be doubled in five years and tripled in ten years might be realized in the case of West Pakistan, however keen it appeared originally, though of course only if Pakistan increases the use of plant nutrition in the form of commercial fertilizers.

The use of nitrogen has already increased from the insignificant average quantity of 5,000 t of the years 1948/52 to the 25fold, namely 131,000 t N in the year 1968/69. In view of the area of 28 mill. ha, however, this means a consumption of 4,5 kg/ba only.

Of the Pakistan rice production the quantitatively less important production in West Pakistan has indeed greatly increased thanks to the use of efficient seeds and large quantities of fertilizers. The more important rice production in East Pakistan, however, bas up to now only shown an absolute insufficient increase. Since in Pakistan, beside rice, also sugar and cotton need urgently fertilizers, there must be obtained a particularly high increase in the use of fertilizers during the next decades. First a double increase and then fourfold as in India will hardly be sufficient.

These two populous countries give an idea to what extent the means of better plant nutrition must be employed in the developing countries to overcome hunger.

Hence arises the problem of the provision of raw material. As to the nitrogenous fertilizer, particularly important for yield increase, the factor nitrogen (N) will be taken from the unlimited supply of the atmospheric air. Nitrogenous fertilizer will be produced by preparing first ammonia through a synthesis; ammonia must have the formula NH_3, that is one part nitrogen requires three parts hydrogen. This hydrogen for the ammonia synthesis was in India as everywhere in the world at first prepared from coal. Since, however, all developed countries in the world have changed their procedure in nitrogen production from coal to that from natural gas or from material of the petroleum refineries (naphtha), the developing countries are going the same way. A particularly promising possibility for an abundant provision with the plant nutrient nitrogen results from the fact that in the oil countries of the Near East and North Africa the natural gas that escapes unused into the air, shall in increasing measure be used for the production of synthetic ammonia. It has been calculated that the natural gas that up to now escaped in the air in the Near East and North Africa, would be sufficient for the production of 40 mill. t ammonia, i.e. a quantity larger than the present world production of ammonia. The opening up of more and more crude oil reserves evidently brings about also the opening up of increasing quantities of natural gas. Thus a very large part of the enormously rising demand from Asiatic countries may be covered by utilizing the raw material now escaping in the air. Besides the adaptation of the nitrogen production from coal to natural gas consequently leads to a great reduction of the investment cost and to a most remarkable reduction of the total cost of production so that we may hope that the most important production means for the increase of food production, namely nitrogen fertilizer, may be made available just in

Asiatic and African developing countries in unlimited quantities and at low production costs.

Somewhat more difficult is the question of the phosphoric acid supply. To convert the water insoluble tricalcium phosphate of the rock phosphate into superphosphate, one needs sulphuric acid. If, however, the natural gases which up to now escaped in the air, will be desulphurized during their conversion to ammonia, and if the desulphurization process will also be extended to the largest possible part of fuel oil, then from this raw material source may be obtained the quantity of sulphuric acid for a multiply increasing world supply of phosphoric acid fertilizers. Natural deposits of rock phosphates have been discovered in large quantities during the last decades, especially in Jordan and Egypt. But India also has discovered rich deposits of raw phosphates so that a universal scarcity is not to be feared, even if the the world consumption of phosporic aicd fertilizers increases many times.

Particularly favourable are the possibilities of potash supply. In the course of our hundred year's consideration it may be pointed out that at the beginning of our century Germany held the world monopoly of the mining production of potash. With the cession of Alsace and the potash mines there to France, the world monopoly became a German-French one. Then already during the First World War and especially during the Second War, the United States started to exploit their rich deposits of potash salts, and during the last decade there have been discovered and exploited deposits of potash salts in Canada. These deposits secure a world agricultural supply with this plant nutrient even at low prices, if until the end of the century consumption should increase seven to eight times.

We may conclude our considerations with an estimate on the increase of the world consumption of commercial fertilizers up to the end of our century. In the year 1965 the International Mineral & Chemical Corporation published an article on "The

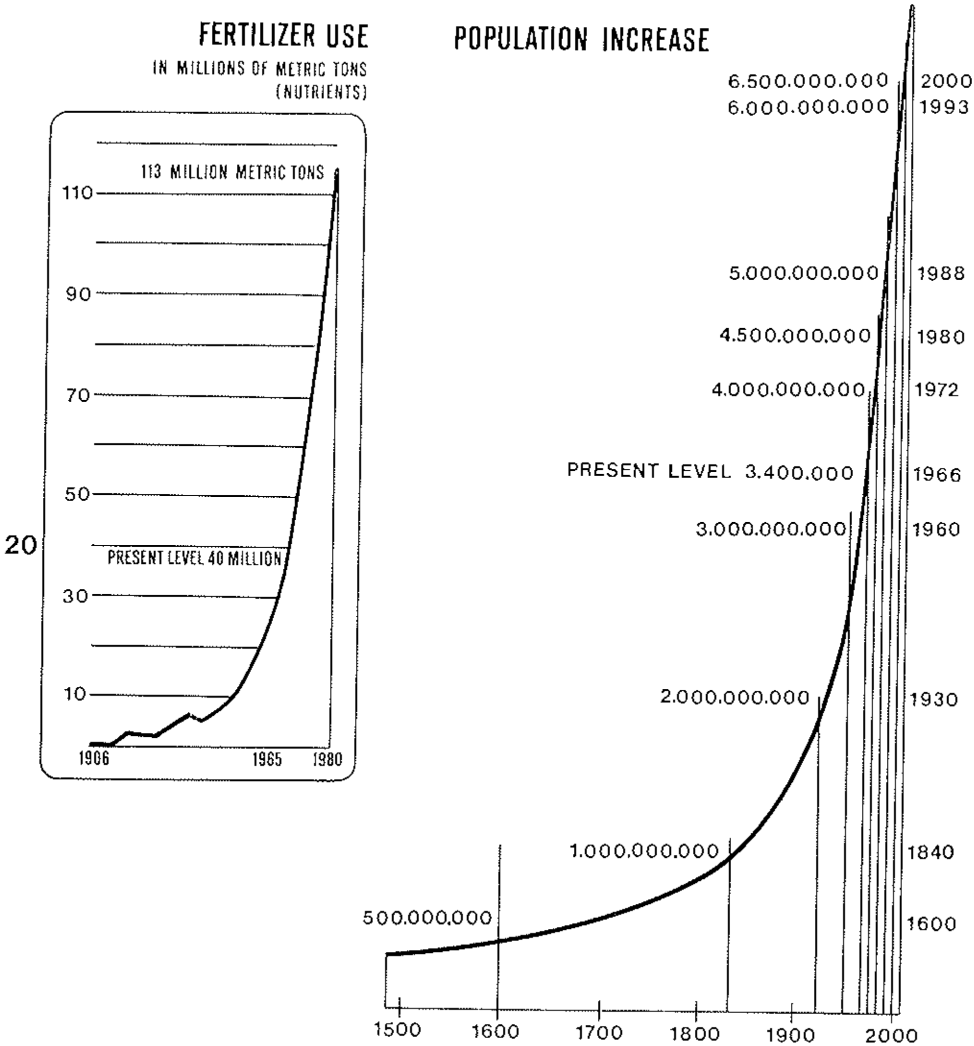


DIAGRAM 7

Chart above shows total world consumption of chemical fertilizers from 1906 to 1965, and projected to the year 1980.
World population climb from the Middle Ages through this century is shown in chart at right.
Use of chemical fertilizers has been increasing even faster than population, as world agriculture moves into a new era of much more intensive farming.

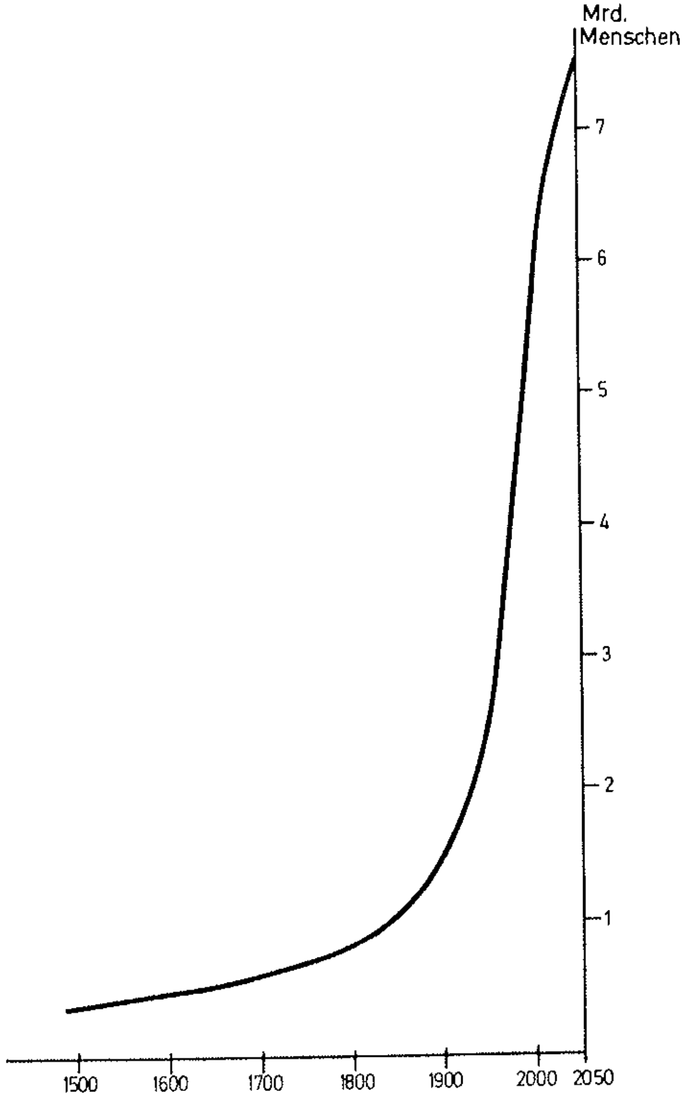


DIAGRAM 8

Quiet Revolution" (5). Here a diagram reflected the steeply ascending world population increase set against the steeply ascending consumption of plant nutrients. Anyone worried about the population explosion may be comforted by the fact that an explosive increase is also to be expected from the use of commercial fertilizers (Diagram 7).

Doubtlessly until the year 2000 or 2050 respectively both curves will present quite a different aspect than that of continuously ascending fountains. During the last decade, maybe even already during the last one and a half decade the curve of the world population increase will undergo a certain flattening, and this flattening will intensively continue during the first decades of the new century.

Absolutely groundless are the frequently expressed apprehensions that the inhabitants of the earth, up to the year 2300, might increase to such a number that there would not even be room for them to stand on the ground. In all of the countries in which owing to the reduction of mortality, especially also of the child mortality, the population had rapidly increased, because the birth rates remained high at first, the curve of the birth rates has largely adapted itself to the mortality curves, although only after decades. We may venture such a prediction especially for the reason that during the last decades there happened in many countries a decisive diminution in the growth rate of the population. The countries in the Mediterranean area have had an explosion of population not very long ago. Today the growth rates in Greece have decreased to 1.0 percent, in Spain to 1.2 percent and in Italy to 0.8 percent. In the East European countries the growth rates are approximately as follows: In the Soviet Union 0.9 percent only, in Poland 0.8

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(5) The Quiet Revolution. A call for action in world agriculture. With a review and projection of chemical fertilizers' role in helping a hungry world win the war on want. Publ. by IMC (International Mineral & Chemical Corporation), Skokie, Ill., 1965.

Quelle: Bis zum Jahre 2000: The Quiet Revolution, a.a.O., from the year 2000 to 2050: personal estimate.

percent, in Bulgaria 0.6 percent and Hungary even 0.4 percent, that is even less than in the German Federal Republic.

But things are similar also in Asiatic countries. In Japan the birth rate has diminished to such an extent that by the end of the century one should rather predict a decrease than an increase of the present number of the population, unless there be registered another increase in the birth rate. Also in some other Asiatic conntries, f.i. in South Korea and in Taiwan, we note today already a considerable reduction in the birth rate and in the growth of population. It is characteristic of these territories, which for some time have been under Japanese domination, that during this period they were able to achieve a valid diminution of illiteracy. Both are now witnessing a considerable increase in prosperity. In direct relation with increasing prosperity and elimination of illiteracy, birth rates have greatly decreased.

In those countries in which hunger and poverty are today still dominant, and where 80% men and 90% women of the villagers are illiterate, checking the population explosion will take longer. But there, too, increasing elimination of illiteracy may also be expected to decrease the birth rates by the last decade of our century.

While thus the curve of population increase will decline during the last decade of our century and above all during the first decades of the 21st century, in the curve of fertilizer consumption we may expect a remarkable inclination already for the decades before the year 2000. The use of commercial fertilizers which during the decade from 1959/60 to 1969/70 has more than doubled, i.e. from approx. 27,8 mill. t to 62,8 mill. t, can under no circumstances continue such a development during the next decades until the end of the century. This is obvious, because the continuation of these growth rates wonld lead to a consumption of 764,3 mill. t at the end of our century.

In diagram 9 it has been estimated that the fertilizer consumption during the decade 1970-1980 will increase at the

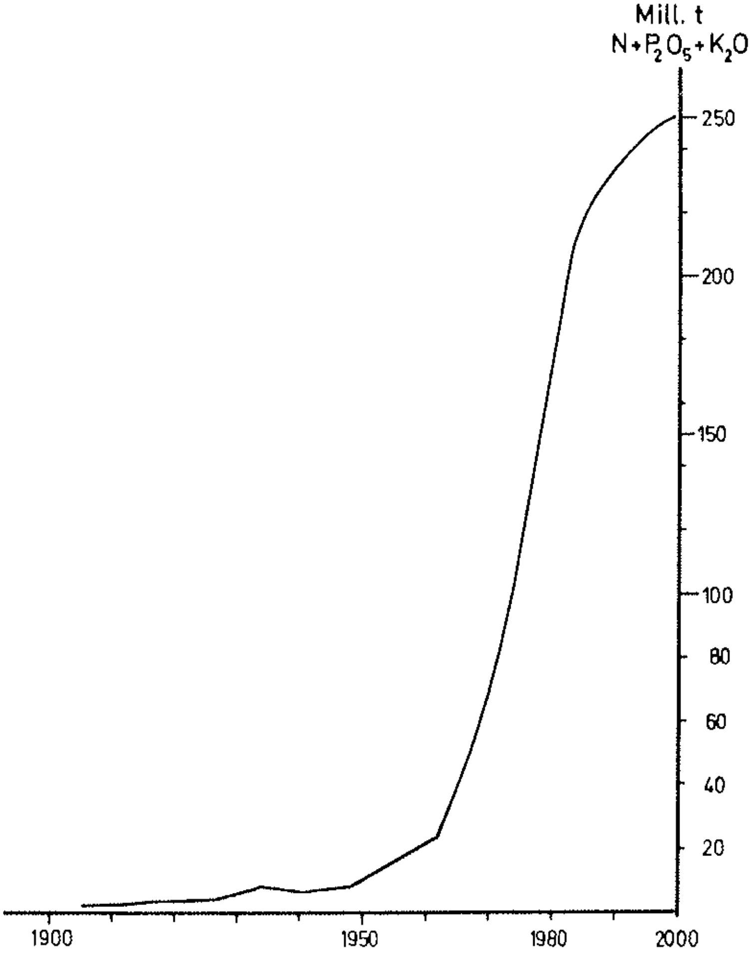

DIAGRAM 9

[28] - *Baade* - p. 26

same rate as in the decade from 1960 to 1970, i.e. to 145 mill. t; but that in the following two decades the increase will slow down in a way that around the year 2000 the fertilizer consumption will only be about 250 mill. t.

The curve will thus already until the year 2000 change from that of a steeply ascending fountain into an S curve. But even these reduced figures promise us a universal food surplus. If during the decade 1970-1980 the use of plant nutrients rises to 145 mill. t, the inhabitants of the earth, in the meantime increased to 4,5 milliards, will then avail of an essentially larger food reserve per head than today. And if up to the year 2000 the use of plant nutrients will rise to about 250 mill. t, then with an increase of the world population to 7 milliards, even the poorest countries in the world may permit themselves a food consumption that corresponds to the today's food consumption in Western Europe. The abundant plant nutrition by means of commercial fertilizers will thus also during the forthcoming decades decidedly contribute that the situation of the world food supply will change from a deficiency to a surplus.

This optimistic advance estimate is based also on the fact that by combination of very efficient seeds with large quantities of fertilizers, the cropping efficiency obtained with a weight unit of fertilizer, has greatly increased. We were used to calculate roughly that 1 kg nutrients in fertilizers would under average conditions effect an increase of 10 kg grain equivalent. Today, however, thanks to the highly efficient cultivated seeds, it may be calculated that with 1 kg additional use of nutrients, there will be obtained a production raise of 20 kg grain equivalent.

In order to feed by the end of the century a world population of presumably 7 milliards human beings, and this not scarcely as today, but sufficiently, there will be needed 3,5 mrd t approx. of grain equivalent. This includes already a considerable food improvement. Because, while we in Europe need about 0,5 t grain equivalent for a man's food, in India one calculates only with a consumption of 0,2 per head of the population. If therefore until the end of our century we calculate with a quantity of 0,5 grain equivalent for the total humanity, we have, as just mentioned "even for the poorest countries of the world calculated with a grain consumption that corresponds to the present food consumption in Western Europe". Now supposing that with a generally abundant manuring, and where necessary with irrigation, the new varieties would yield an average of 40 cwt/ha of wheat, rice, maize and millet — and this appears to be a modest aim — then of the arable area of the earth, which today comprises about 1,3 mrd ha, there would only be used one milliard hectares with such high yields in order to produce 4 mrd t grain equivalent, that is abundant food for 7 mrd human beings. The remaining land would then largely be available for other purposes, or, as it is already practiced in the United States and in Europe, withdrawn from the cultivation.

Our consideration on the development of the use of commercial fertilizers in our century shows that humanity has been offered a tool with which food production not only may be increased considerably but explosively. In the first three quarters of our century, this increase happened above all in wealthy industrial countries. This brought about that the industrial countries of the world — at first the United States, but now also Western Europe — have a food production that not only is sufficient for feeding their population, but that yields surpluses with which part of the deficits in developing countries can be covered. In the last quarter of our century we shall witness the same process on a world scale, that is to say, the at present hunger-threatened developing countries shall improve their production not so much by extending the area but chiefly by increasing the yields per hectare. The food deficit of the developing countries perhaps will already disappear in the 1970s, but certainly completely in the 1980s. Thereby the better and abundant plant nutrition, especially with the use of commercial fertilizers, will play one of the most important roles.

So much for the technical and material aspects of the problems. But after all we are dealing here not with a technical question but with a humanitarian question. The decisive question is how we can induce the farmers in the developing countries not only to use the necessary quantity of plant nutrients but to do this also in the right measure and intelligently — considering that these farmers up to now hardly use one of the most important discoveries in the history of mankind, namely the nutrition of plants with commercial fertilizers.

The consumption of plant nutrients in the world is concentrated in those territories where there lives a dense population, but a population that can read and write. Completely insufficient is the consumption of plant nutrients in those densely populated countries where most of the people are illiterate.

A good insight into the relations between educational level, plant nutrition and human food is obtained by making a comparison between the following figures.

In Japan rice yields amount to more than 50 cwt/ha. Japanese consumption of fertilizers is with 100 kg nitrogen per hectare equal to the maximum consumption in Europe, and illiteracy is practically eradicated in Japan.

In China rice yields reached until recent years about one half of the Japanese yields. There was a modest consumption of commercial fertilizers, but an intense increase in preparation. The fight against illiteracy had just begun.

In India, Indonesia and Burma rice yields are about a quarter of the Japanese ones. Until some 20 years ago the consumption of commercial fertilizers was virtually zero, and in the villages about 80 percent of the adults have no knowledge of reading and writing.

The eradication of illiteracy and the spread of knowledge beyond reading, writing and the simplest arithmetic is the first requirement for us to be able to improve fully the utilization of plant nutrients for freedom from hunger in the world. But to begin with an increased use of plant nutrients we need not wait until illiteracy has completely disappeared. If this were the case the prospects for freedom from hunger in the world would be in an evil plight. Fortunately, however, the farmers can at least calculate also where they are illiterate. If a farmer is shown a field, which thanks to the consumption of plant nutrients and highly efficient seeds yields threefold of the usual crops, then the Green Revolution already starts favourably before illiteracy has indeed been eradicated.

But a real victory over hunger and poverty needs besides the elimination of illiteracy also a thorough improvement of the medium and higher grades of education.

The country to which we owe the most important instrument of the Green Revolution, the "miracle wheat", is Mexico. Well, Mexico spends for education and research three times as much as for armament, whereas in the developing countries India and Pakistan the State spends at present three times as much for armament as for education and research. If the Mexican formula will be accepted also by the developing countries, especially by India and Pakistan, then a decisive victory is gained over the battle for freedom from hunger in the world.

Pope Paul VI in His Encyclopedia "Populorum Progressio" has clearly defined the humanitarian aims of mankind, namely that not only must we overcome hunger and prevent hunger, but that we must build a world in which every man can lead a real human life. In chapter 51 He also suggested to "constitute a large universal fund which ought to be raised by part of the means up to now spent for military purposes so as to help the weaker peoples". To this end not only must the helping countries energetically reduce their armament expenses but particularly also those peoples who need to be helped.

The technical means: "better plant nutrition particularly with fertilizers" has been known to us for 150 years. Decisive, however, for putting this technical means into effect is, to take the necessary steps in the domain of human morality, therefore the real progress of the people.

CONCLUSIONS

CONCLUSIONS OF THE STUDY WEEK

Introduction

The problem of overcoming hunger in the world is closely linked to the efficient use of fertilizers. The developing countries, where hunger is more prevalent, either use fertilizers inadequately or not at all.

Fertilizer use to increase food supplies involves a panorama of necessary components of which fertilizer appplication is the central core. An infrastructure involving everything from extension to education of the farmers, to financing and importation of necessary fertilizer supplies, to transportation of the fertilizer and produce, and to marketing, are absolute requirements for efficient fertilizer use to relieve hunger.

In addition, a large number of other management practices are necessary components of yield, ranging from physical structure of the soil, to water and pest control, cultural practices, adapted varieties, seed qualities, etc.

The Study Week could concern itself only with the core of the problem; namely efficient fertilizer use and closely related components. It has reached the following conclusions:

1. Efficient fertilizer use within a country of large to medium size requires that the country itself establish the necessary research and extension organization to determine the local problems and their solution.

2. Much can, should and must be done by regional and

international organizations to help set up these countries' research and extension organizations, to help train local staff, to disseminate not only new information but already accumulated information and expertise into the local system, and even to help in carrying out adaptive research while the local system is being developed.

3. Economic fertilizer use must take into account the differences in values associated with the various inputs and outputs such as the cost and availability of money, improved seed, fertilizer, labour, land and water, or the value placed on yield, quality and even potential pollution; e.g., in developing countries the only input generally available is labour. In developed countries, labour is one of the main limiting inputs.

4. Research is still required at all levels including understanding basic processes, nutrient balance, soil structure, effects of time of planting, disease control measures, response obtained in the field, efficiency of fertilizer use, diagnostic techniques and calibration of methods for prediction of response obtained in farmers' fields. Recently developed methodology can give more precise answers and can evaluate accumulated information more effectively than ever before and it should be used wherever possible.

5. Because fertilizer may be the only cash cost to the farmer in developing countries, because it must often be imported, and because the cost of fertilizer is much higher in most developing countries, the investigation of efficiency of fertilizer use including the effect of kind, placement, method of distribution, time of application and nutrient or environment interaction is of prime importance in these areas.

6. Increasing yields are invariably associated with increased fertilizer use. The magnitude of the increase is normally a direct response to a nutrient requirement which may have been enhanced by the concurrent elimination of other limiting

factors such as water or genetic potential. Thus the establishment of yield potentials is necessary for rational fertilizer use.

7. Fertilizer use is affected by the organic matter complex. However organic matter and fertility of the soil was the subject of a similar Study Week in 1968 and the proceedings and conclusions were published by the Pontifical Academy of Science. The conclusions reached are endorsed by the participants of the present Study Week.

8. For food production to keep pace with projected needs for an increasing population, yields of food crops will have to increase substantialy. Most of this increase will not be feasible without very large increases in the present level of fertilizer use. In the short period from 1970 to 1980 the production and use of fertilizer is expected to more than double in the developing countries. The rationl utilization of these supplies will require a very large effort at the international, national and farmer level.

9. The inventory of the land resources of the world indicates that the amount of land available for agriculture is considerably greater than that being used. This represents a base to cushion food supplies for the world, although much of this potential exists in areas where the population pressure and therefore the food production pressure is low.

10. Increased use of fertilizers and concurrent increased pesticide use must be carefully implemented taking into account any local or general problems of pollution in the environment. The efficient use of fertilizers particularly at high levels and recycling of human and animal waste will help conserve both the environment and scarce resources.

11. After considering the accumulated knowledge and experience, after considering the potential of solving fertilizer use problems, and after considering the problem of food supply in a hungry world, the participants of the Study Week have

reached the consensus that in this century there is reason to expect that with rational agricultural practice including the necessary increase in fertilizer use, food supplies per capita can definitely be maintained and even improved. Technologically this can be achieved.

Suggestions on the necessary research and the adoption of improved practices by farmers follow.

Research Needs

Research involving fertilizer use of necessity is concerned with the obtaining of knowledge, both basic and applied, which will enable the prediction of the effect of fertilizer application on both the yield and quality of crops. This requires an interdisciplinary approach and must include fundamental studies on plant physiology and soil-plant-climate relationships. The following research needs can be highlighted.

In Relation to Environment.

The total environment determines the limits to yield. It is necessary that research determines the maximum potential yield of crops in a particular environment both when water is not limiting and under natural rainfall (maximum yield plots) so that the factors limiting yield can be identified.

The effect of the various components of the climate, i.e., radiation, rainfall distribution, temperature and even day length for photosensitive varieties, on the response of crops to added fertilizers, should be determined as accurately as possible.

In Relation to the Plant.

a) To breed varieties capable of responding to high levels of fertilizer use.

b) To do research on the nutrient requirements of different varieties of a given crop at different stages in the development of the crop.

c) To study the effect of fertilizers on the susceptibility of the crop to different pests and diseases.

d) To determine the economics of adding fertilizers and various growth substances to the crop.

In Relation to the Soil.

a) To determine management for optimum control of water from natural rainfall (maintaining permeability, prevention of erosion.

b) To determine the means and need to a good soil structure to allow easy production of a good seedbed, ease of cultivation, good root development, etc.

c) To do research on how to make the most efficient use of fertilizers in areas liable to drought.

d) To evaluate the ability of soil to supply all the nutrients needed by the crop other than those supplied in the fertilizer (possibility of deficiencies arising from continuous use of simple NPK fertilizers). This includes a study of the constitution of the available fraction of each nutrient in the soil.

e) To do research on the interactions between the fertilizer constituents and the soil.

f) To evaluate the sulphur budget in soils, including sulphur inputs from rain and the atmosphere, the turnover rate of sulphur in soil organic matter, and the losses of sulphur.

g) The Working Party noted the Conclusions of the participants of a previous Study Week on Soil Organic Matter and agreed with their principal conclusions. It noted that the efficient use of fertilizers allows economic crop production on soils whose organic carbon content has fallen much below the level in the virgin soil, but there is still little agreement on the minimal level necessary in any given soil for the profitable production of high quality crop. It noted that soil organic matter consists of many constituents which have very different effects in producing and stabilizing soil structure, and it recommends that, as far as possible, future research on the importance of the organic matter status of the soils should pay more attention to the relative role played by the various fractions.

In Relation to Human and Animal Health

a) To study the effect of fertilizers on crop quality, including total protein, amino-acid composition and other organic substances such as those contributing to flavour and keeping quality, etc.

b) To evaluate the effect of fertilizers on the inorganic constituents of the harvested crop.

c) To emphasize the need for medical research on the effect on human health of crops having different mineral compositions.

d) To make surveys of trace element contents of soils to identify those on which animals may suffer from their lack, imbalance of excess.

e) To investigate the effect of fertilizers on the oestrogenic and other organic substances in relation to animal health and production.

In Relation to Increasing the Efficiency of Fertilizers Use.

a) To determine the efficiency of fertilizer application and fertilizer uptake by plants, including the proper placement of fertilizer, the splitting of dressings, time of application, and the production of fertilizers in the most effective form for uptake.

b) To do research on ways of improving the agronomy of crop production to enable the crop to make the most efficient use of the added fertilizer.

c) To adapt fertilizer application practices to the cropping rotation, including the development of more intensive rotations based on a high level of fertilizer inputs.

d) To further develop the design of fertilizer distributors to ensure a more uniform spreading of fertilizers than is possible at present.

In Relation to Reducing the Drain on the Natural Resources of the World.

a) To do research on the recycling of nutrients present in farm and human wastes in ways that cause miuimum hazard to health or to the pollution of water draining off the land.

b) To develop new processes for fertilizer manufacture that make minimum demands on the natural resources of the world.

In Relation to Extension Work.

a) To expand research on the barriers to the acceptance of research findings on efficient methods of fertilizer application by the farmer.

b) To conduct research on developing methods for improving active cooperation between the extension research services to ensure that adequate research on increasing crop yields through the efficient use of fertilizers is carried out within the framework involving the minimum disturbance to deep-seated social customs.

c) To initiate research on improving methods of the efficiency of extension practices, including the extension learning process of farmers in accepting new ideas, and to establish the extent to which this process differs among farmers in different regions in the world.

d) To develop methods for the synthesis of efficient systems of farm production.

e) To do research on introducing new methods of agricnltural production into traditional systems of agriculture through the use of a "package deal". A "package deal" involves the simultaneous introduction of a number of improved practices or new practices appropriate to the required level of production.

Fertilizer requirement

Fertilizer use is a key factor in the race to produce adequate food and fiber for the increasing world population. The economics and reality of the situation require that efficiency of fertilizer use be an initial and continuing goal while total production is increased. This is important to remember because expanding the area of land or increasing the area of intensive land use in agriculture is still an open alternative in most developing countries as well as in some highly developed ones. Also, fertilizer is secured at significant cost to the national economy of many countries and investment in it is in direct competition with investment in other human needs.

A limited technical personnel base for research, demonstration and extension requires that initial fertilizer use investigations be by the simplest methods to determine the most limiting factor(s). Not all soils are uniformly deficient in all essential elements, being most deficient in only one or two, and the addition of the most limiting ones bring forth major changes in yields at very low cost per unit of production.

At the same time various studies should be initiated to secure a better understanding of the influence of other fertilizer, edaphic, environmental and management factors upon fertilizer use efficiency, e.g., moisture supply variation among years will cause a difference in response to fertilizers, especially nitrogen, etc.

More complex studies might be directed toward the special solutions of unique soil management problems of the geographic regions of the individual countries.

Much knowledge is already available on tropical agriculture. This knowledge must be fully exploited — something which requires communication among individuals, disciplines and institntions. Joint planning of research should be encouraged, perhaps demanded, so that scarce scientific resources are used most efficiently.

Soil Testing.

Assay of the soil fertility status of soils is among tbe relatively simple procedures which are useful to guide farmers and governments in formulating a sound fertilizer-use policy. Soil analyses are also useful in avoiding potential pollution by inappropriate fertilizer application.

Soil testing procedures for phosphorus, potassium, magnesium, pH, calcium carbonate requirement and physical properties have been and should be continued to be utilized as one of the factors to consider in making fertilizer recommendations. There are several published tests in use for making these determinations and some of these have been demonstrated to be of use in tropical and subtropical regions. No suitable routine tests for soil nitrogen are generally available. Suitable recommendations usually can be made, based on the quantities of nitrogen known to be needed for a given yield of a given crop taking into account the efficiency of uptake of applied fertilizer, losses of nitrogen that are likely to occur, the cropping sequence, and the environment. These data are derived from experimental trials and experience.

Correlation of the soil analysis results is first made by relatively inexpensive soil-plant pot cultures (followed by more costly and time-consuming calibration in field trials with the crops actually to be grown). This must be done under local conditions with local soils. Soil in these cultures should include a complete range of possible soil, physico-chemical, and biological conditions. The soil-plant culture results must include both nutrient element yields and the yields of dry matter. Radioisotopes (e.g., P-32) or stable isotopes (e.g., H-15) may be employed at this stage to refine the procedure, in some cases, to remove ambiguity of observation.

Field Trials.

In addition to the determination of crop responses to fertilizers the purpose of field trials is also to check the reliability of the results obtained in pot tests, to calibrate the soil test, to determine the ratios of nutrients optimum for yield and quality, to make regional fertilizer recommendations, and to secure some understanding of the influence of other soil and climatic and management factors on the response to fertilizer. The degree of complexity is governed by the degree of original uncertainty of fertilizer needs and their prediction. If there is confidence in these, then the field trials may be of such design that makes them useful for simple or more sophisticated agronomic and economic analyses for use in making fertilizer recommendations for fields of geographical areas. Economic analyses, for generalized application later, also require rather detailed observations on climate, soil properties, and management factors.

Experiments should be located on selected major representative soil types and include several fertilizations and cropping systems. In addition to observations on the crops, soils and climate, the soil should initially be characterized in adequate detail. The changes in the physical (e.g., soil structure), biological (e.g., organic matter content changes) and chemical properties should be followed.

The use of soil analyses calibrated by field trials as a basis for fertilizer recommendations for the major nutrients can set the stage for great strides in increasing food production and in helping governments formulate food production policy. This is the simplest scientific approach to fertilizer use. Examples of the execution of this system are available for observation in many places.

Sap and Tissue Analyses.

The use of sap and plant tissue analyses of various types may be necessary for the study of micro-element deficiences and for their correction. The use of these procedures for N, P or K is a sophistication which is of use in refining fertilizer use at superior levels of management and for the amelioration of deficiencies of these for crops of high economic value. Because vegetable and flower production is an important commercial activity in almost all countries, a tissue analysis service to help refine practices for these crops is of significant priority.

A major exception to the previous statement on tissue analysis is the perennial crops of the bush, vine or tree types. Soil tests are not generally utilized as routine indices of the nutritive status of these long-lived plants. Tissue analyses are utilized and needed to evaluate and plan a fertilizer program. While important everywhere this is of particular importance in many developing countries because these crops are an important source of foreign exchange. A tissue analysis research program with the most important of these crops should have a high priority, where applicable, for assessing the management program for essential mineral elements.

For many crops there are established quality standards for marketing and utilization. Examples are sugar-beets, sugar-cans, wheat, potatoes, etc... Where routine quality tests of tisues are a requirement in marketing, these tests must be a part of the observations made in the fertilizer experiments. Even if they are not, it is worthwhile to include some chemical and biochemical analyses of the edible portions of fertilized crops to help demonstrate how modern production technology effects "hidden" or ignored quality factors, e.g., protein content, thus relating quality factors to fertilization.

Increasing fertilizer use by farmers

The sum total of research and knowledge of fertilizer requirement will have no effect on fertilizer use unless this knowledge reaches the farmer and he is convinced that this will benefit him both economically and socially. The participants of the Study Week wish to highlight that all planning is in vain unless the farmer is reached and his total situation encourages his rational use of fertilizers. The following are suggested areas of emphasis:

a) National agricultural institutions must obtain information leading to the understanding of the factors affecting the adoption and acceptance of new agricultural practices. This knowledge should be used by the extension services to ensure that the new information on improved agricultural production is carried to the farmer in a way acceptable to him. Continuous education for the whole farm family and a permanent extension service should be maintained to adapt research results and improve continuously the production practices. These should be demonstrated on economically operated pilot farms, to the extent possible under local farm conditions, and possibly even on actual farmers' fields. The information of fertilizer use should be accompanied by other techniques necessary for progressive farm operation in a "package" of improved practices.

b) Marketing services and guaranteed prices for essential farm products are basic conditions to promote progress of agriculture.

c) The increased investment needed for the adaptation of modern techniques requires that the farmer who is capable of making use of credit have it available to him on easy terms.

d) Increased production requires improved infrastructures such as transport, communications, storage etc. which must exist to make possible agricultural progress.

e) Technical personnel should also be prepared to support the farmers with the materials needed for increased production and its efficient marketing.

CONCLUSION DE LA SEMAINE D'ETUDE

Introduction

Le problème de surmonter la faim dans le monde est étroitement lié à l'utilisation efficace des engrais. Dans les pays en voie de développement où la faim est la plus préoccupante, les engrais sont peu ou mal utilisés.

L'emploi des engrais pour accroître les ressources alimentaires implique tout un ensemble de conditions nécessaires, parmi lesquelles l'application de la fumure est le point dominant. Une infrastructure comprenant tout un ensemble depuis la vulgarisation pour le perfectionnement des agriculteurs, le financement et l'importation des engrais nécessaires, le transport des engrais et des produits, et la commercialisation, est un impératif absolu pour une utilisation efficace des engrais afin de lutter contre la faim.

En outre, un grand nombre d'autres techniques culturales sont des facteurs indispensables du rendement, depuis la structure physique des sols jusqu'au contrôle de l'eau et des parasites, aux pratiques culturales, à des variétés adaptées, à des semences de qualité, etc.

La Semaine d'Etude concernait seulement le point central de ce problème, c'est-à-dire l'utilisation efficace des engrais et ses conséquences très directes. Elle a retenu les conclusions suivantes:

1. L'utilisation efficace des engrais dans une région de dimension grande ou moyenne nécessite que le pays lui-même

établisse les organismes de recherche et de vulgarisation nécessaires pour bien déterminer les problèmes locaux et leurs solutions.

2. Beaucoup peut et doit être fait par les organismes internationaux pour aider à mettre sur pied ces organismes nationaux de recherche et de vulgarisation, pour aider leur encadrement, pour faire connaître non seulement l'information nouvelle mais aussi les connaissances déjà accumulées et l'avis des experts quant à la situation locale, et même pour aider le démarrage de recherches bien adaptées aux problèmes locaux.

3. La meilleure utilisation économique des engrais doit prendre en considération les différences de valeurs associées aux divers « inputs » et « outputs » tels que les coûts et disponibilités financières, semences éprouvées, engrais, travail, terre et eau, ou les valeurs relatives au rendement, à la qualité et même aux possibilités de pollution. Dans les pays en voie de développement, le seul « input » généralement disponible est le travail; dans les pays développés, le travail est l'un des « inputs » le plus limitant.

4. La recherche est toujours nécessaire à tous les niveaux, notamment la compréhension des processus de base, les bilans d'éléments nutritifs, la structure du sol, les effets de dates d'implantation, le contrôle des maladies, la réponse obtenue au champ, l'efficience des engrais, les techniques de diagnostic et l'étalonnage de méthodes pour la prévision de la réponse obtenue dans les exploitations agricoles. Des méthodologies récemment développées peuvent donner des réponses plus précises et peuvent valoriser l'information accumulée plus efficacement qu'autrefois, et elles doivent être utilisées partout où cela est possible.

5. Les engrais constituent généralement une dépense immédiate de l'agriculteur; dans les pays en voie de développement, ils doivent souvent être importés et leur coût est généralement élevé; aussi, la recherche de l'efficience de ces

engrais est primordiale dans ces régions: effets de formes, localisation, méthodes de distribution, dates d'application et interaction avec les autres éléments nutritifs ou l'environnement.

6. Des rendements croissants sont invariablement associés avec des emplois croissants d'engrais. L'ampleur de cet accroissement est normalement une fonction directe de besoins nutritifs qui ont été accrus par l'élimination d'autres facteurs limitants tels que l'eau ou le potentiel génétique. Aussi, la détermination de rendements potentiels est nécessaire pour une fertilisation rationnelle.

7. L'utilisation des engrais présente des relations avec la matière organique du sol. La matière organique et la fertilité du sol étaient le sujet d'une Semaine d'Etude similaire en 1968 et les compte-rendus et conclusions furent publiés par l'Académie Pontificale des Sciences. Les conclusions qui en résultèrent sont également adoptées par les participants de la présente Semaine d'Etude.

8. Pour obtenir une production alimentaire susceptible de conserver la paix dans le cadre des besoins prévus pour une population croissante, les rendements des cultures vivrières doivent augmenter substantiellement. L'essentiel de cet accroissement ne sera pas réalisable sans une très forte augmentation de la consommation actuelle d'engrais. Dans la courte période de 1970-1980, il est prévu que la production et l'emploi des engrais doivent plus que doubler dans les pays en voie de développement. L'utilisation rationnelle de ces engrais demandera un très gros effort aux niveaux international, national, et local (agriculteurs).

9. L'inventaire de ressources en terres cultivables dans le monde indique que les surfaces utilisables pour l'agriculture sont considérablement plus grandes que celles qui sont utilisées actuellement. Cela représente une possibilité supplémentaire de production de denrées alimentaires pour le monde, quoiqu'une forte proportion de ce potentiel existe dans des ré-

gions où la densité de population et par conséquent le besoin de production alimentaire soient bas.

10. L'utilisation croissante des engrais et celle qui est concomitante des pesticides, doivent être soigneusement prévues en prenant en considération tous problèmes locaux ou nationaux de pollution de l'environnement. L'usage efficace des engrais, particulièrement à de hauts niveaux, et le recyclage des déchets humains et animaux, aideront à conserver à la fois l'environnement et les ressources.

11. Après avoir considéré les connaissances et expériences accumulées, les perspectives de solution des problèmes de fertilisation et les problèmes d'approvisionnement alimentaire d'un monde qui a faim, les participants de la Semaine d'Etude ont abouti à la conclusion que jusqu'à la fin de ce siècle il y a des raisons d'espérer qu'avec une agriculture rationnelle comportant l'augmentation nécessaire de l'emploi des engrais, les disponibilités alimentaires par habitant peuvent être maintenues et même augmentées. Cela est technologiquement possible.

Les suggestions relatives aux recherches nécessaires et à l'adoption par les agriculteurs de meilleures pratiques sont exposées ensuite.

Les besoins de recherche

La recherche relative à la fertilisation concerne nécessairement l'obtention de connaissances à la fois théoriques et appliquées, qui permettront de prédire l'effet des fumures à la fois sur les rendements et la qualité des récoltes. Cela demande une approche inter-disciplinaire et comprend des études fondamentales de physiologie végétale et de relations sol-plante-climat. Les besoins suivants de recherche peuvent être dégagés.

En relation avec l'environnement.

L'environnement disponible détermine les limites des rendements. Il est nécessaire que les chercheurs déterminent les rendements potentiels maxima des cultures dans un environnement donné, à la fois quand l'eau n'est pas limitante et sous les précipitations naturelles (parcelles à rendements maxima), de telle sorte que les facteurs limitant le rendement puissent être identifiés.

A l'égard de la réponse des cultures aux engrais apportés, l'effet des diverses composantes du climat, c'est-à-dire radiation, distribution des pluies, température et même longueur du jour pour les espèces photosensibles, doit être déterminé aussi sûrement que possible.

En relation avec la plante.

a) Pour croiser des variétés capables de répondre à de hauts niveaux de fertilisation.

b) Pour rechercher les besoins en éléments nutritifs de diverses variétés d'une culture donnée, à différents stades de développement de la culture.

c) Pour étudier l'effet des engrais sur la sensibilité de la culture à divers parasites et maladies.

d) Pour étudier l'économie des engrais et des diverses substances de croissance apportés à la culture.

En relation avec le sol.

a) Pour déterminer l'aménagement en vue d'un contrôle optimum de l'eau provenant des pluies naturelles (maintien de la perméabilité, prévision de l'érosion).

b) Pour déterminer les moyens d'obtention d'une bonne structure du sol permettant de réaliser aisément un bon lit de semences, une culture facile, un bon développement racinaire, etc. etc.

c) Pour faire des recherches en vue de réaliser l'utilisation la plus efficace des engrais dans les zones sensibles à la sècheresse.

d) Pour évaluer l'aptitude du sol à fournir tous les éléments nutritifs nécessaires aux cultures, autres que ceux apportés par les engrais (possibilité de déficiences induites par un usage continu d'engrais N P K seuls). Cela inclut l'étude de la constitution de la fraction assimilable de chaque élément nutritif du sol.

e) Pour conduire les recherches sur les interactions entre les constituants des engrais et le sol.

f) Pour établir le bilan du soufre dans le sol, compte-tenu des apports de soufre par la pluie et l'atmosphère, de la vitesse de renouvellement du soufre dans la matière organique du sol, et des pertes de soufre.

g) La réunion de travail a noté les conclusions des participants d'une précédente Semaine d'Etude sur la matière organique des sols et a été d'accord avec ses principales conclusions. Elle a noté que l'utilisation efficace des engrais permet la culture dans de bonnes conditions économiques sur des sols dont la teneur en carbone organique s'est abaissée bien au-dessous du niveau du sol vierge, mais il y a encore peu d'accord sur le niveau minimum nécessaire dans un sol donné pour une bonne production de cultures de qualité. Elle a noté que la matière organique du sol comporte de nombreux constituants qui ont des effets très différents dans la production et la stabilisation de la structure du sol, et elle recommande que, autant que possible, les recherches futures sur l'importance de la matière organique du sol attachent plus d'attention aux rôles relatifs exercés par les diverses fractions.

En relation avec la santé humaine et animale.

a) Pour l'étude de l'effet des engrais sur la qualité des récoltes, notamment protéines totales, composition en acides aminés et autres substances organiques telles que celles qui contribuent à la saveur et au maintien de la qualité, etc.

b) Pour apprécier l'effet des engrais sur les constituants minéraux des récoltes.

c) Pour faire apparaître le besoin de recherche médicale sur l'effet de récoltes ayant différentes compositions minérales sur la santé humaine.

d) Pour diagnostiquer la teneur en oligo-éléments des sols afin d'identifier ceux sur lesquels les animaux peuvent souffrir de carence, déséquilibre ou excès.

e) Pour approfondir l'effet des engrais sur les oestrogènes et autres substances organiques en relation avec la santé et la production des animaux.

En relation avec l'accroissement de l'efficacité de la fertilisation.

a) Pour déterminer l'efficacité des applications d'engrais et leur absorption par les plantes, notamment la localisation, le fractionnement des apports, les dates d'application, et la production d'engrais sous les formes les plus efficaces pour l'absorption.

b) Pour faire des recherches sur les moyens d'améliorer les conditions agronomiques des cultures afin de permettre à celles-ci d'utiliser plus efficacement les engrais apportés.

c) Pour adapter la pratique de la fertilisation aux rotations de cultures, notamment au développement de rotations plus intensives basées sur un haut niveau d'apport d'engrais.

d) Pour développer l'étude de distributeurs d'engrais assurant un épandage plus uniforme de ceux-ci.

En relation avec la préservation des ressources naturelles du monde.

a) Pour réaliser des recherches sur le recyclage des éléments nutritifs présents dans les déchets agricoles et humains, de manière à ce qu'ils causent le minimum d'aléas pour la santé ou pour la pollution des eaux de drainage des terres.

b) Pour développer de nouveaux procédés de fabrication des engrais entraînant le minimum de demandes à l'égard des ressources naturelles du monde.

En relation avec le travail de vulgarisation.

a) Pour développer les recherches sur les difficultés d'acceptation des découvertes scientifiques à l'égard des méthodes efficaces d'application des engrais par l'agriculteur.

b) Pour conduire des recherches permettant de développer des méthodes de coopération active entre les services de vulgarisation et de recherche, de manière à obtenir que les recherches adéquates sur les rendements croissants des cultures à travers l'utilisation efficace des engrais soient réalisées avec des lignes de force entraînant le minimum de troubles dans les coutumes sociales bien établies.

c) Pour instaurer des recherches relatives à l'efficacité des techniques de vulgarisation, notamment des procédés d'enseignement aux agriculteurs de nouvelles idées, et pour établir le degré de différenciation de ce processus auprès d'agriculteurs de différentes régions du monde.

d) Pour développer des méthodes pour la synthèse de système de production agricole efficaces.

e) Pour condnire des recherches sur l'introduction de nouvelles méthodes de production agricole dans les systèmes d'agriculture traditionnels, par l'utilisation de tout un ensemble de techniques appropriées. Cet ensemble de techniques comprend l'introduction simultanée d'un bon nombre de pratiques éprouvées ou de nouvelles pratiques appropriées au niveau de production demandé.

Besoins en engrais

L'emploi des engrais est un facteur-clé dans la course à la production de quantités suffisantes d'aliments et de fibres pour une population mondiale croissante. Une vue réaliste et économique de la situation exige que l'efficacité de la fertilisation soit considérée tant au départ qu'ensuite comme un but accompagnant l'augmentation de la production totale. Le rappel de ce point est important car l'extension des terres cultivées ou l'accroissement des surfaces de cultures intensives est toujours une alternative ouverte dans beaucoup de pays en voie de développement, aussi bien que dans certains pays très développés. Par ailleurs, la place des engrais dans l'économie nationale de beaucoup de pays est assurée, quoique l'investissement dans ce domaine soit en compétition directe avec l'investissement dans d'autres besoin humains.

La limitation du personnel technique de base affecté aux recherches, démonstrations et vulgarisations exige que les investigations initiales sur la fertilisation soient réalisées par les méthodes les plus simples, pour déterminer le ou les principaux facteurs limitants. Tous les sols ne sont pas uniformément déficients en tous les éléments essentiels, mais généralement déficients en un ou deux de ceux-ci, et l'apport des plus limitants apporte ainsi une forte élévation des rendements pour un faible coût par unité de production.

En même temps, diverses études doivent être entreprises pour assurer une meilleure connaissance de l'influence des autres facteurs (édaphiques, nutritionnels, environnement, aménagement) sur l'efficacité des engrais; ainsi, les variations annuelles de régime hydrique entraînent des différences de réponse aux engrais, notamment à l'azote, etc.

Des études plus complexes pourraient être orientées vers la résolution de problèmes particuliers d'aménagement des sols selon les régions naturelles de chaque pays.

Beauconp de connaissances sont déjà disponibles sur l'agriculture tropicale. Ces connaissances doivent être pleinement exploitées, ce qui exige la communication entre les individus, les disciplines et les institutions. Les plans de recherches concertés doivent être encouragés, peut-être demandés, de sorte que les précieuses ressources scientifiques soient utilisées le plus efficacement.

Tests appliqués au sol.

L'évaluation de l'état de fertilité des sols par des tests est l'un des procédés relativement simples qui sont utiles pour guider les agriculteurs et les gouvernements dans la formulation d'une politique judicieuse de fertilisation. Les analyses de sol sont également utiles en prévenant des pollutions possibles par des fertilisations mal appropriées.

Les tests relatifs au phosphore, au potassium, au magnésium, au pH, au besoin en chaux et aux propriétés physiques ont été utilisés et doivent continuer à l'être comme l'un des facteurs à considérer en établissant les recommandations de fertilisation. Divers tests publiés sont utilisés pour faire ces déterminations, et l'utilité de certains d'entre eux a été démontrée dans les régions tropicales et sub-tropicales. Pour l'azote du sol, il n'y a pas de bons tests de routine qui soient généralement utilisables. Des recommandations valables peuvent habituellement être faites en les basant sur les quantités connues d'azote nécessaires pour un rendement donné d'une culture donnée, en considérant l'efficacité de l'absorption de l'engrais appliqué, les pertes d'azote qui interviennent habituellement, la succession de cultures et l'environnement. Ces données sont fournies par les champs d'expérimentation et l'expérience.

L'étalonnage des résultats d'analyses de sols est d'abord réalisé par des expériences en pots relativement peu coûteuses (suivies par des essais au champ avec les cultures habituelles, plus coûteux en temps et en moyens). Cela doit être réalisé sous les conditions locales avec les sols locaux. Dans ces cultures, les sols doivent inclure l'éventail possible des variantes et des conditions physico-chimiques et biologiques. Les résultats doivent comprendre à la fois les rendements en matière sèche et les éléments absorbés par la récolte. Les radioisotopes (ex. P-32), ou les isotopes stables (ex. N-15) peuvent être employés à ce stade pour affiner la démarche, et en certains cas, pour lever l'ambiguité des observations.

Expérimentations au champ.

Outre la détermination de la réponse des cultures aux engrais, le but des essais au champ est aussi de tester la validité des résultats obtenus en pots, d'étalonner les tests de sol, de déterminer les taux d'éléments nutritifs optima pour le rendement et la qualité, d'établir des recommandations régionales pour la fertilisation et d'assurer une certaine compréhension de l'influence d'autres conditions de sol, de climat et d'aménagement sur la réponse aux engrais. Le degré de complexité dépend du degré d'incertitude à l'égard des besoins en engrais et de leur prédiction. Si l'on a confiance dans ceux-ci, l'essai au champ peut être alors d'un type tel qu'il soit utilisable pour des analyses agronomiques et économiques plus ou moins élaborées, et permette des recommandations de fertilisation pour une aire géographique. L'analyse économique, pour une application ultérieure généralisée, demande aussi des observations plus détaillées sur le climat, les propriétés du sol et les facteurs d'aménagement.

Les expérimentations doivent être localisées sur les principaux types de sols représentatifs, et comprendre diverses fertilisations et systèmes de cultures. Outre les observations relatives aux cultures, au sol et au climat, le sol doit être initialement caractérisé avec les détails voulus. Les modifications dans les propriétés physiques (ex. structure), biologiques (ex. modification de teneur en matière organique) et chimiques doivent être suivies.

L'utilisation d'analyses de sol étalonnées par des essais au champ comme bases de recommandations de fertilisation pour les éléments majeurs peut promouvoir à grands pas l'accroissement de la production alimentaire et aider les gouvernements à formuler une politique de production alimentaire. C'est l'approche scientifique la plus simple de la fertilisation. Des exemples de réalisation de ce système sont disponibles pour l'observation en de nombreux endroits.

Analyses de sève et de tissus.

L'utilisation de divers types d'analyses de sève et de tissus peut être nécessaire pour l'étude de déficiences en oligo-éléments et pour leur correction. L'usage de ces procédés pour l'azote, le phosphore ou le potassium est une complication qui est utile en précisant la fertilisation à des niveaux supérieurs d'aménagement, et pour l'amélioration de déficiences dans des cultures de haute valeur économique. La production de légumes et de fleurs étant une activité commerciale importante dans presque tous les pays, un service d'analyses de tissus permettant d'affiner les techniques relatives à ces cultures présente une priorité marquée.

Une exception importante à l'opinion ci-dessus concernant l'analyse des tissus est relative aux cultures pérennes de types arbustif, viticole ou arboricole. Les tests relatifs au sol ne sont pas utilisés généralement comme indices de routine de l'état nutritif de ces plantes pérennes. Les analyses de tissus sont employées, et nécessitent l'établissement d'un plan de fertilisation. Si ce problème est important partout, il l'est particulièrement dans beaucoup de pays en voie de développement car ces cultures sont une source importante d'échanges avec l'étranger. Un programme de recherche sur l'analyse de tissus concernant les cultures les plus importantes doit avoir une haute priorité, lorsqu'il est applicable, pour établir le plan d'organisation concernant les éléments minéraux essentiels.

Pour beaucoup de cultures, des critères de qualité sont établis pour la commercialisation (ex. betterave à sucre, canne à sucre, blé, pommes de terre, etc.). Si des tests de routine de qualité des tissus sont nécessaires dans la commercialisation, ces tests doivent figurer parmi les observations réalisées dans les expérimentations de fertilisation. Si ce n'est pas le cas, il est judicieux d'inclure diverses analyses chimiques et biochimiques d'organes appropriés provenant des cultures fertilisées, pour aider à montrer les effets de la technologie moderne de production sur les facteurs de qualité tels que la teneur en protéines (parfois ignorée) et les relations entre qualité et fertilisation.

Accroissement de l'utilisation des engrais par les agriculteurs

La somme totale de recherches et de connaissances sur les besoins en engrais n'aura pas d'effet sur leur utilisation sans que cette connaissance atteigne l'agriculteur, et qu'il soit convaincu que cela lui est bénéfique à la fois économiquement et socialement. Les participants de la Semaine d'Etude souhaitent mettre en lumière que toute planification est vaine tant que l'agriculteur n'est pas atteint, et que sa situation d'ensemble n'encourage pas de sa part l'usage rationnel des engrais. Les grandes lignes suivantes sont dégagées:

a) Les institutions agricoles nationales doivent réunir l'information relative à la compréhension des facteurs liés à l'adoption et à l'acceptation de nouvelles pratiques agricoles. Cette connaissance doit être utilisée par les services de vulgarisation en s'assurant que l'information nouvelle sur l'amélioration de la production agricole est donnée à l'agriculteur sous une forme qui lui soit acceptable. La formation continue pour l'ensemble de la famille rurale et un service de vulgarisation permanent doivent être maintenus pour adapter les résultats de la recherche et améliorer continuellement les pratiques de production. Cela doit être démontré sur des fermes pilotes travaillant dans les conditions économiques réelles, dans la mesure du possible dans les conditions locales des fermes, et peut-être même sur les champs habituels des agriculteurs. L'information sur la fertilisation doit être accompagnée de celle relative aux autres techniques nécessaires au progrès agricole, en un ensemble de pratiques éprouvées.

b) Les services commerciaux et des prix garantis pour les produits agricoles essentiels sont les conditions de base pour promouvoir le progrès de l'agriculture.

c) Les investissements croissants nécessaires pour l'adaptation des techniques modernes exigent que l'agriculteur qui est capable d'utiliser le crédit en dispose de manière facile.

d) L'accroissement de la production nécessite des infrastructures également croissantes telles que transport, commercialisation, stockage, etc., qui doivent exister pour que le progrès agricole soit possible.

e) Le personnel technique doit aussi être préparé, pour aider les agriculteurs avec les matériels nécessaires à une production croissante, efficacement commercialisée.

APPENDICE

PREFACIO

El problema del hambre en el mundo está estrechamente vinculado con el uso racional de los fertilizantes. Precisamente en los paises más atrasados donde hay una población más necesitada, es donde ó no se usan fertilizantes ó se usan de una forma inadecuada.

Este problema se ha hecho hoy día tan acuciante que ha llamado la atención de todos aquellos que de alguna manera pueden contribuir a su solución.

La Academia Pontificia de Ciencias ha promovido dentro de ésta línea una Semana de Estudios bajo el título « Uso de fertilizantes y su efecto en el aumento de las cosechas con especial atención a la calidad y economía », en la que se ha tratado de obtener unas conclusiones que contribuyan al mejor uso de fertilizantes, tanto desde el aspecto de aplicación técnica, como desde el punto de vista económico, tratando de extender los resultados de las discusiones y confrontación de opiniones, a todo el mundo y especialmente a las circustancias de los paises menos desarrollados.

Con éste fín la Semana de Estudios se dividió en seis aspectos diferentes que abarcaron toda la problemática relacionada con el tema y al mismo tiempo facilitaron la discusión.

Se procuró reunir dentro de cada materia, especialistas procedentes de diversas partes del mundo, con variedad de puntos de vista y destacados internacionalmente, procurando en lo posible que pertenecieran a paises de las distintas áreas geográficas que presentan una problemática diferente dentro de la temática de la Semana.

Los seis temas que se han considerado, en el orden que se han tratado han sido los siguientes:

Primero: « Aplicación de las diferentes clases de técnicas en el análisis de suelos y plantas con el fín de determinar la necesidad de fertilizantes ».

Dentro de este campo el problema de la utilización más adecuada de los fertilizantes ha sido considerado por varios especialistas con el empleo de las técnicas más modernas, discutiéndose las ventajas e inconvenientes de cada una y el enfoque que debe darse al problema para su mejor aprovechamiento en un futuro inmediato.

Segundo: « Uso de fertilizantes en áreas del mundo con diferentes condiciones climáticas ».

Los aspectos tratados fueron los relativos a los trópicos y subtrópicos húmedos en su conjunto, aspectos particulares de la América Latina, de Africa, de las regiones semiáridas y subhúmedas, así como el conjunto de los problemas de la fertilización de las zonas templadas. Finalmente se presentó la labor que la FAO en forma general viene realizando para mejorar el empleo de fertilizantes e incrementar la producción de alimentos.

La discusión de los diferentes matices y aspectos que surgieron como consecuencia de todo lo presentado condujo a consideraciones de gran interés.

Tercero: « Los aspectos relacionados con la ecología y las condiciones de crecimiento de las plantas ». Hoy día tiene mucha importancia y cada vez la tendrá más, la consideración de las condiciones ecológicas como factores que controlan la rentabilidad de los fertilizantes y los límites de su aplicación.

En la presentación y discusión de las distintas ponencias, tratadas dentro del tema, se han resaltado los factores ecológicos limitantes y su acción sobre la potencialidad de los fertilizantes.

La experiencia adquirida hasta el momento puede y debe ser de gran utilidad, al extender en lo posible al resto del mundo los conocimientos logrados en zonas muy limitadas de paises desarrollados.

Cuarto: « Los efectos de los fertilizantes sobre la calidad de las cosechas ». Un aspecto de gran importancia, porque abarca una temática que hasta fechas recientes no ha adquirido la consideración que merece y que sin duda en un futuro inmediato tendrá aún más importancia.

Dentro de este campo se resaltó como factor importante la necesidad de emplear un número de elementos fertilizantes mayor que el ya clásico (NPK) pues cada día se está poniendo más de manifiesto las consecuencias del uso casi exclusivo del NPK sobre el equilibrio nutritivo y la calidad de las cosechas.

A medida que los rendimientos van aumentando por las nuevas variedades de híbridos, los métodos más adecuados de laboreo del suelo, de siembra y aplicación de fertilizantes, la necesidad de aplicación de una gama más amplia de elementos fertilizantes, se va haciendo cada vez más acuciante, coadyuvando a esto el que la aplicación de estiércoles y residuos animales ha disminuido extraordinariamente.

Con el fín de resolver estos problemas se han desarrollado y presentado nuevas técnicas y procedimientos para realizar fertilizaciones equilibradas.

Se discutió las posibilidades de generalización, así como las directrices a seguir en un futuro próximo.

Se señaló la importancia de que los paises premien la calidad de las cosechas con precios remunerativos con el fín de que el agricultor aumente sus esfuerzos para obtener mejores calidades que indudablemente redundarán en unas condiciones de salud más beneficiosas para los individuos.

Quinto: « Nuevos fertilizantes y aspectos especiales y futuros en el uso de los mismos ». Dentro del mismo, se consideraron las perspectivas del uso de nuevos fertilizantes y su posible importancia económica en el futuro, así como los resultados y alcances posibles de la llamada « revolución verde ». Los recursos previsibles futuros son tales que pueden compensar las dificultades de alimentación previsibles.

Los aspectos económicos han sido los más destacados y sugerentes de la discusión.

Se puso claramente de manifiesto que es fundamentalmente un problema económico (compra y transporte de fertilizantes), lo que realmente limita las posibilidades de incremento de rendimientos en las cosechas de los paises subdesarrollados.

Por el contrario, no existe ninguna limitación inmediata en la posibilidad de fabricación de fertilizantes, pero ésta se centra principalmente en los paises desarrollados que son exportadores y de aquí el problema económico que hemos citado anteriormente como limitante.

Sexto: « Uso de técnicas con computadoras y nuevos métodos en la determinación de las necesidades de fertilización ».

Incluyó en empleo de los isótopos radiactivos en los fertilizantes, con los resultados obtenidos para conocer la eficacia de los mismos en invernaderos y en campos experimentales.

Se destacaron las posibilidades futuras en el empleo de estos procedimientos especiales, tanto desde el punto de vista de la fertilización inorgánica como orgánica.

Las posibilidades que el empleo de las modernas computadoras ofrecen para el estudio de la influencia del gran número de factores que intervienen en la producción vegetal, fué una parte muy importante de lo tratado bajo el último epígrafe.

Sin el empleo de dichas computadoras, resultaba de todo punto imposible que tantos factores como pueden afectar a las cosechas se pudieran tener en cuenta en la experimentación y menos aún en los cultivos normales, siendo practicamente imposible conseguir una buena correlación entre la fertilización y los rendimientos. Ahora este problema puede quedar aceptablemente subsanado por lo que resultará factible llevar a cabo una predicción de rendimientos en función de la fertilización con garantía de una buena exactitud.

Una intensa discusión final del conjunto de los temas tratados condujo a la preparación de las Conclusiones. En éstas se resaltaron los puntos más importantes en los que se llegó a un acuerdo entre los asistentes.

Destacan los referentes a las necesidades futuras de investigación en relación con los distintos aspectos del ambiente, plantas, suelos, salud del hombre y de los animales, con el fin de incrementar en cada caso la eficacia del empleo de fertilizantes y reducir al máximo la pérdida de recursos naturales en el mundo.

Respecto al control de las necesidades de fertilizantes se resaltó la importancia de alcanzar una buena correlación entre los análisis de suelos y plantas y los resultados de la experimentación en campo y sobre todo en invernadero.

Se señaló lo fundamental que es para la eficacia de todo lo anterior, la conveniencia de la divulgación de los conocimientos de forma que alcancen a los agricultores, convenciéndoles de sus ventajas económicas y sociales.

Es de señalar el optimismo con que los científicos ven el futuro de la producción de cosechas en el mundo; resaltando que el problema del hambre solamente puede ser paliado por una mejor distribución de los medios de producción, en especial de los fertilizantes, ó lo que en el fondo es lo mismo, ayudas económicas a los paises subdesarrollados concedidas por entidades internacionales ó por los paises más desarrollados y económicamente más fuertes, que les permita disponer de los medios necesarios para fertilizar adecuadamente sus cosechas.

Esperamos que el buen criterio se imponga y se llegue en un futuro próximo a esta recta distribución que se propone.

Con todo ello creemos se ha contribuido de acuerdo con el pensamiento del Santo Padre a presentar directrices, y en suma las posibles soluciones que pueden ofrecerse para resolver este acuciante problema que aqueja de una forma tan aguda a la Humanidad.

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WIRTSCHAFTLICHKEIT UND OPTIMALER EINSATZ DER MINERALDUENGER IN LANDWIRTSCHAFTLICHEN BETRIEBEN UNTERSCHIEDLICHER NUTZUNGSINTENSITAET

ERWIN WELTE (*)

Der Kampf zum Erwerb und zur Sicherung des täglichen Nahrungsbedarfs hat die historische Entwicklung der menschlichen Siedlungen in ihrer geographischen Verteilung und Strukturierung sowie auch in ihrem Wachstum massgeblich bestimmt. Trotz ungeheurer Anstrengungen und technischer Fortschritte sind immer wieder Hungersnöte über die Menschheit hereingebrochen und haben Millionen menschlicher Existenzen vernichtet. Auch in unserem modernen technischen Zeitalter, das uns aufgrund der wissenschaftlichen Erkenntnisse auf dem Gebiet der Pflanzenernährung ungeahnte Möglichkeiten zur Steigerung der Nahrungsmittelproduktion erschlossen hat, ist es bisher nicht gelungen, eine ausreichende Ernährung der Weltbevölkerung sicherzustellen.

Noch heute ist der Hunger weit verbreitet und Ursache so vielen Elends insbesondere in der Dritten Welt, in der das

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Bevölkerungswachstum als Folge des rasanten medizinischen Fortschritts in bedrückendem Ausmass zunimmt, demgegenüber die notwendige Mehrerzeugung von Nahrungsmitteln jedoch nicht Schritt hält.

Die grossen christlichen Organisationen « Miserior » und « Brot für die Welt » treffen alle erdenklichen Anstrengungen, im Verein mit anderen Hilfsorganisationen auf nationaler und internationaler Basis die unmittelbare Not in vielen Entwicklungsländern zu lindern. Einer ungenügenden Nahrungsmittelproduktion in den Entwicklungsländern steht in den hochentwickelten Ländern eine Überproduktion als ein typisches Kennzeichen ihrer technischen Entwicklung gegenüber.

Die wesentlichen Ursachen für diese Diskrepanz sind in erster Linie darin zu erblicken, dass der technische Fortschritt in der Erzeugung von Nahrungsmitteln nicht in dem Masse in den Entwicklungsländern voranschreitet, wie dies von der steigenden Nachfrage her erforderlich wäre. Der Vorschlag, diese chronische Unterproduktion durch die permanenten Agrarüberschüsse der Industrieländer auszugleichen, ist theoretisch plausibel, aber als Dauerlösung nicht praktikabel. Transport, Lagerung und Verteilung dieser Überschüsse stellen nicht nur Kosten- sondern auch Sozialprobleme dar, die kaum zur Entspannung beitragen.

Ziel aller Anstrengungen sollte vielmehr sein, in den Entwicklungsländern die Produktion von Nahrungsmitteln vorrangig zu betreiben und zu verbessern, damit die vom Hunger heimgesuchten Länder und Völker selbst in die Lage versetzt werden, den benötigten Nahrungsbedarf im eigenen Lande weitgehend zu decken.

Dies aber setzt voraus, dass die Ursachen der geringen Agrarproduktion beseitigt und diejenigen Massnahmen getroffen werden, die sich am schnellsten und wirksamsten durchsetzen lassen. Gerade gegen diese ökonomischen Prinzipien wird vielfach verstossen, weil ideologische Vorstellungen einer baldigen Realisierung dieses Ziels entgegenstehen und auch die politischen Interessen vieler Staaten sich nicht an dem wirtschaftlich Möglichen und Erreichbaren orientieren.

Viele Entwicklungsprojekte sind in den letzten beiden Jahrzehnten mit grossem Eifer und Elan von den Industrieländern für die Dritte Welt in Angriff genommen worden, und viele von ihnen sind auf halbem Wege stecken geblieben, weil entweder die Voraussetzungen nicht erfüllt waren oder Vorstellungen zugrunde gelegt wurden, bei denen das zu lösende Problem der Steigerung der Agrarproduktion an Massstäben der Industrieländer orientiert und gemessen wurde.

Ausgangspunkt einer kritischen Betrachtung des Welternährungsproblems muss in erster Linie eine Analyse der agrarbiologischen Situation sein, die darüber Auskunft gibt, in welchem Umfang und Ausmass der zu Verfügung stehende Boden bei Anwendung moderner Erkenntnisse und Bewirtschaftungsmethoden zu einer höheren Ertragsleistung gebracht werden kann. Agrarsoziologische und agrarökonomische Gesichtspunkte sind wichtig, aber doch in dieser Phase der Entwicklung nicht ausschlaggebend.

Es existieren genügend Beispiele — vor allem im Zusammenhang mit dem Fertilizer Program der FAO —, die erfolgreiche Wege aufzeigen, auf denen ohne Änderung der Besitzverhältnisse und der vorgegebenen Agrarstrukturen allein durch organisatorisch fundierte Entwicklungspläne und durch einen dem Ausbildungsstand der Landwirte angepassten Beratungsdienst entscheidende Fortschritte in der pflanzlichen Erzeugnng erzielt werden konnten. Der Erfolg war dadurch gesichert, dass die sachliche Beurteilung der Probleme Vorrang vor ideologischen Vorstellungen erhielt.

Die wesentlichen Ursachen der unzureichenden Nahrungsmittelerzeugung sind die nährstoffarmen Böden, die in den dicht besiedelten Gebieten der Tropen und Subtropen weit verbreitet sind. Seit Jahrhunderten sind sie übermässig stark in Anspruch genommen und ihres natürlichen Nährstoffvorrates weitgehend beraubt worden. Nur dort, wo durch Überschwemmungen in den Deltagebieten der grossen Ströme oder durch Aschenregen vulkanischen Ursprungs (z.B. auf Java) periodisch eine Erneuerung des Bodens eintrat, waren auch relativ hohe Erträge zu erwarten. Blieb diese natürliche Düngung oder der benötigte Regen aus, waren Missernten unausbleiblich und für die betroffene Menschheit von katastrophalen Folgen.

Der Schwerpunkt agrarwirtschaftlicher Massnahmen muss sich daher vorrangig auf die Versorgung der Böden mit Pflanzennährstoffen konzentrieren. Der Nährstoffversorgungszustand der in den Entwicklungsländern für die pflanzliche Produktion verfügbaren Böden ist denkbar schlecht und ein ausreichendes Nährstoffspeichervermögen wegen zu geringer Humusversorgung meistens nicht vorhanden. Die Nachlieferung von Nährstoffen — insbesondere von Stickstoff und Phosphat — im Wege der Verwitterung und Mineralisierung reicht aber nicht aus, um ein dem Nahrungsbedarf angepasstes Ertragsniveau zu erreichen.

Alle Anstrengungen, den Boden mit Hilfe motorisierter Zugkräfte und verbesserter technischer Geräte intensiver zu bearbeiten, führen kaum zu einer Verbesserung, in den meisten Fällen sogar zu einer Verschlechterung der Ertragsverhältnisse.

Eine intensivere Bodenbearbeitung bewirkt eine verstärkte Durchlüftung und Oxidation der organischen Substanzen und damit vorübergehend einen verbesserten Mineralstoff-Fluss. Dieser geht jedoch auf Kosten des Humusgehaltes, der rasch absinkt und dann zu keiner nennenswerten Nährstoffnachlieferung mehr in der Lage ist. Auf einige bessere Ertragsjahre folgen auf die Dauer schlechtere, die unter dem anfänglichen Niveau liegen.

Mit dem Humusabbau gehen verschiedene chemische Prozesse einher, die u.a. zur Festlegung von Nährstoffen durch Bildung schwerlöslicher anorganischer Verbindungen führen. Hierzu gehören die Phosphate der Sesquioxidhydrate, die sich insbesondere auf den tropischen und subtropischen Standorten bilden, weil diese in der Regel über hohe Gehalte an P_2O_5-fixierenden Kationen (Fe, Mn, Al) verfügen.

Ausserdem erfährt die Schutzkolloidwirkung sowie die Komplexbildung von Nährionen durch organische Komponenten mit dem Abbau der Humusstoffe eine fortgesetzte Verminderung.

Neben der Verschlechterung des Nährstoffspeichervolumens tritt somit auch eine Verminderung der Nährstoffmobilität ein, woraus eine erschwerte Aufnahme von Nährionen durch die Pflanze resultiert. Die intensivere Bodenbearbeitung, die in den Entwicklungsländern durch den Ersatz der tierischen Zugkräfte durch Maschinen vorgenommen wurde, hat zu folgenschweren Strukturschäden vieler Böden geführt und eine Verschlechterung ihrer Nährstoffdynamik mit sich gebracht.

Ähnliche nachteilige Veränderungen haben viele Böden erfahren, die bewässert werden müssen. Auch hier war die Unkenntnis der Folgen des Einsatzes technischer Hilfsmittel und Einrichtungen die Ursache der Fehlentwicklung. Da in diesem Beitrag im wesentlichen auf Ernährungsfragen der Pflanze eingegangen werden soll, können die Folgen falscher Bewässerungsmassnahmen hier nicht behandelt werden.

Das Problem der Steigerung der Pflanzenproduktion muss vorrangig von dem Nährstoffversorgungszustand des Bodens aus angefasst werden. Nur so lässt sich unter vorgegebenen Klimaverhältnissen eine zutreffende Aussage darüber machen, wie und in welchem Ausmass das vorhandene Ertragsniveau verbessert und bis zu welcher Intensität der Boden genutzt werden kann. Auf dieser Grundlage lassen sich in Verbindung mit dem Ertragsgesetz nach Mitscherlich realisierbare Vorstellungen über die Wirtschaftlichkeit und den optimalen Einsatz von Handelsdüngern gewinnen.

Welche Bedeutung der Zufuhr von Pflanzennährstoffen für die Steigerung der pflanzlichen Produktion durch Einsatz von Handelsdüngern im Vergleich zu anderen produktionssteigernden Massnahmen zukommt, geht aus einer umfangreichen statistichen Untersuchung in den USA im Zeitraum 1940 bis 1955 eindrucksvoll hervor. (Abb. 1)

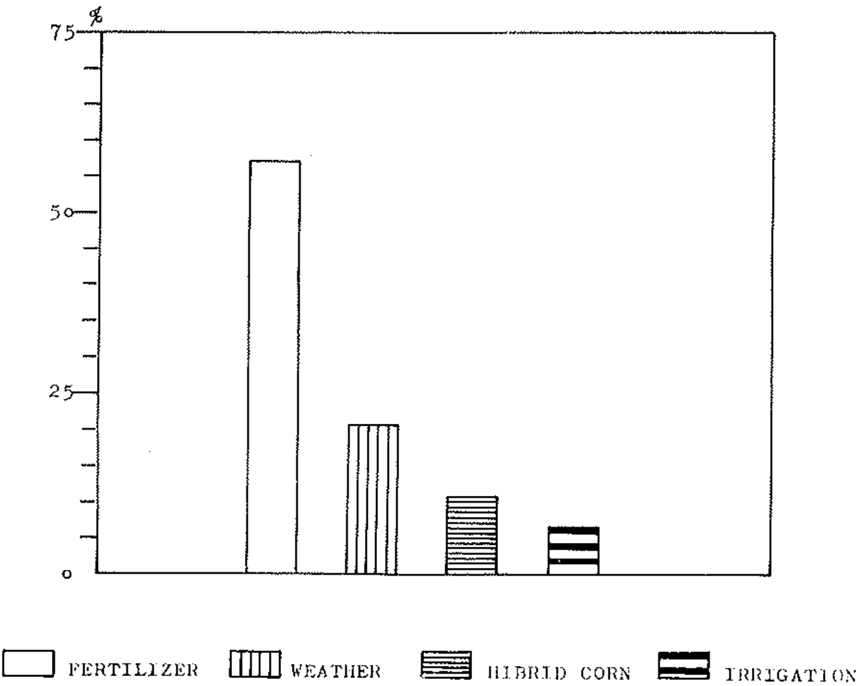


ABB. 1 — Ursachen der Steigerung der Flächenproduktion in den USA im Zeitraum 1940-1955.

Die Handelsdünger, die überwiegend als Mineraldünger eingesetzt werden, gestatten es dem Landwirt, nicht nur unzureichende Mengen der im Boden vorhandenen Pflanzennährstoffe aufzubessern sondern auch disharmonische Verhältnisse der Nährstoffe untereinander auszugleichen und sich dabei den Nährstoffansprüchen der jeweils anzubauenden Kulturpflanze anzupassen.

In landwirtschaftlichen Betrieben ohne Anwendung von Handelsdüngern ist dies nicht möglich. Hier bestimmen die im Boden verfügbaren und aus der Mineral- und Humusreserve nachlieferbaren Nährstoffe Art und Umfang des Anbaus sowie das zu erzielende Ertragsniveau. Dies wird um so höher liegen, je günstiger die mobilisierbaren Nährstoffreserven des Bodens und je geringer die Nährstoffentzüge sind. Das solchen Bedingungen entsprechende landwirtschaftliche Nutzungssystem wird unter der Voraussetzung einer gleichbleibenden Nährstoffdynamik im Boden durch nachfolgende Gleichung bestimmt:

$$(N_E - N_W) = (N_N - N_V)$$

wobei bedeuten

N_E = Brutto-Nährstoffentzug durch die Ernte,

N_W = Nährstoff-Rückfuhr durch wirtschaftseigene Düngemittel wie Stallmist, Jauche, Gülle, Stroh u.a.m.,

N_N = Nährstoff-Nachlieferung des Bodens durch Verwitterung und Mineralisierung,

N_V = Nährstoffverluste im Boden durch Auswaschung, Verflüchtigung und Fixierung.

Dem Nettoentzug ($N_E - N_W$), der durch Verkauf von landwirtschaftlichen Produkten und durch innerbetriebliche Nährstoffverluste im Stall und auf dem Hof verursacht wird, steht zum Ausgleich das Nettoangebot ($N_N - N_V$) gegenüber.

Da N_N keine beliebig zu verändernde Grösse ist, vielmehr über eine durch die Verwitterungsintensität und Mineralisierung begrenzte maximale Höhe hinaus nicht gesteigert werden kann, wird das Ertragsniveau entscheidend durch diese Grösse limitiert.

Soweit es die Pflanzennährstoffe in organischer Bindung betrifft, steht die Grösse N_W in direktem Zusammenhang mit N_N. Durch die Rückführung von Nährstoffen über den Einsatz von wirtschaftseigenen Düngemitteln wird das Nachlieferungsvermögen von N_N begünstigt. Ausserdem können die durch Auswaschung entstehenden Nährstoffverluste wegen der verbesserten Speicherleistung des Bodens reduziert werden.

Eine Zunahme der Grösse N_W hat eine Reduzierung des Nettoentzuges zur Folge und zwingt dazu, möglichst nur solche Produkte diesem Nutzungssystem zu entziehen, die die geringste Nährstoffzufuhr bedingen. Andererseits ist die Nachfrage nach pflanzlichen Erzeugnissen auf dieser Stufe der landwirtschaftlichen Entwicklung in den dicht besiedelten Gebieten so gross, dass möglichst die gesamte Ernte für den menschlichen Bedarf verwertet wird d.h. nicht nur für die Ernährung, sondern auch für die tierische Produktion, für Wohnung, Kleidung und Heizung.

Bei der Nutzung eines Teils der Ernte durch das Tier werden die anfallenden Exkremente dem Boden selten zurückgegeben, vielmehr als Brennmaterial genutzt.

Die Grösse N_W hat also eine wichtige Schlüsselposition in dem Nährstoffgleichgewicht dieses Nutzungsystems inne. Vom Bedarf her ist bei der Knappheit der pflanzlichen Erzeugnisse in den dicht besiedelten Entwicklungsländern die Tendenz vorherrschend, die Grösse N_W zugunsten eines möglichst hohen Nettoertrages klein zu halten. Auf der anderen Seite erfordert aber die Erhaltung der Bodenleistung und damit des Ertragsniveaus einen ausreichenden Einsatz wirtschaftseigener Düngemittel zur Sicherung der nachfolgenden Ernte. Die sich aus den gegensätzlichen Interessen ergebende Lage des Gleichgewichtes ist in der Regel durch ein Ertragsniveau gekennzeichnet, das zwischen 6 und 10 dz Getreideeinheiten / ha liegt.

Die Produktionsverhältnisse sind um so günstiger, je grösser das Nährstoff-Nachlieferungsvermögen des Bodens ist. Dies hängt ab vom mineralogischen Aufbau, vom Humusgehalt des Bodens, dem Alter der Nutzung und von der Art der Wirtschaftsweise. In jedem Fall ist die obere Grenze durch die maximal mögliche Inanspruchnahme des natürlichen Nährstoff-Flusses gegeben, solange ausreichende Wasserverhältnisse vorhanden sind. Wo diese Grenze überschritten wird, liegen besonders günstige und nicht zu verallgemeinernde Produktionsverhältnisse vor.

Eine Steigerung der Erträge über diese natürliche Begrenzung hinaus kann erst durch Einführung einer zusätzlichen Grösse in die Nährstoffbilanz-Gleichung erreicht werden, nämlich durch Zufuhr betriebsfremder Nährstoffe (N_Z). Die Grundgleichung der pflanzlichen Produktion wird damit um eine Grösse von fundamentaler Bedeutung erweitert:

$$(N_E - N_W) = N_N + N_Z - N_V.$$

Durch die Zufuhr betriebsfremder Pflanzennährstoffe (Handelsdünger u.a. wird das bisherige Nutzungssystem, das annähernd einen geschlossenen Kreislauf darstellt, geöffnet und zwar um so stärker, je grösser N_Z gewählt wird.

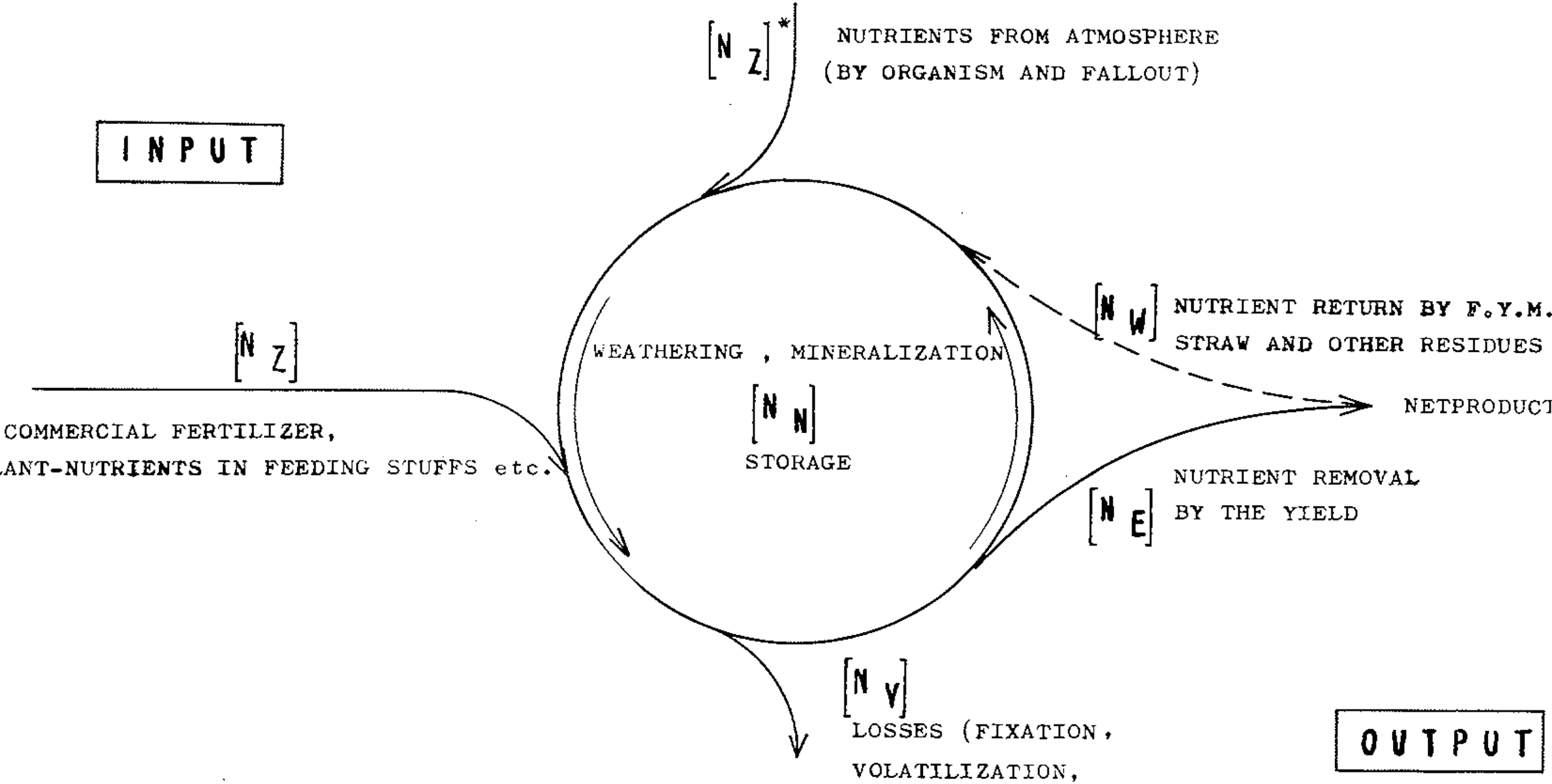
Hierdurch wird gleichzeitig der Übergang von der Subsistenz-Phase, in der der Mensch die selbsterzeugten Nahrungsmittel auch weitgehend selbst verbraucht, zu einer Produktions-Phase vollzogen, die durch die Lieferung von Agrarprodukten an nicht in der Landwirtschaft tätige Bevölkerungsteile, also an den Markt schlechthin gekennzeichnet ist und die sich daher auch absatzmässig am Markt zu orientieren beginnt.

Mit der Einführung der Grösse N_Z wird die Vorstellung eines « input-output » - Modells realisiert und hierdurch eine weitgehende Unabhängigkeit der Nährstoffversorgung der Pflanzen von den bodeneigenen Nährstoffen sichergestellt. Die Wesenszüge dieses Modells seien durch nachfolgendes Diagramm schematisch wiedergegeben. (Abb. 2)

Mit zunehmendem Aufwand von Handelsdüngemitteln sinkt die Bedeutung der bodeneigenen Nährstoffe, d.h. jener Nährstoffe, die von Natur aus in Form der Mineralien und der organischen Substanz vor Inkulturnahme des Bodens vorhanden gewesen sind. In einer durch hohe Flächenproduktivität ausgezeichneten Landwirtschaft gilt daher

$$N_Z \gg N_N$$

Damit hat sich die Rolle des Bodens von der ursprünglichen Funktion eines Nährstofflieferanten zu der eines Transformators gewandelt mit der Aufgabe, die zugeführten Nährstoffe (N_Z) mit möglichst grossem Nutzeffekt für die Ertragsbildung zu verwerten.



*INCLUDED IN N_Z OF THE GENERAL EQUATION(LEFT)

ABB. 2 — Der Boden als Nährstofftransformator im input-output-Model bei intensiver landwirtschaftlicher Nutzung.

Das Modell des fast geschlossenen Kreislaufs in der Subsistenz-Phase der Landwirtschaft benötigt zum Ausgleich der unvermeidlichen Verluste und des Nährstoffentzuges einer Brache- und Regenerierungsphase. Dies ist im in- und output-Modell nicht mehr erforderlich, da der Ersatz, der Nährstoffe über eine entsprechende Zufuhr kompensiert wird. Darüberhinaus entfällt eine Orientierung der anzubauenden Kulturpflanzen an dem verfügbaren Nährstoffvorrat des Bodens; vielmehr tritt die Befriedigung der verschiedenen Nährstoffansprüche der Pflanzen in den Mittelpunkt der Düngungsmassnahmen.

Durch die Anwendung von Handelsdüngern ist es auch zum ersten Mal möglich geworden, das genetisch vorhandene Ertragspotential der Kulturpflanzen durch eine gezielte Nährstoffversorgung unter den jeweils vorgegebenen klimatischen Bedingungen auszuschöpfen.

Somit stellt die Einführung der Grösse N_Z die wichtigste Voraussetzung für die Entwicklung zur modernen Industriegesellschaft dar und zwar aus folgenden Gründen:

1. Durch den Einsatz der Handelsdünger (d.h. durch N_Z) wird die ertragsbegrenzende Funktion des *bodeneigenen* pflanzenverfügbaren Nährstoffkapitals aufgehoben. Für die Begrenzung der Erträge verbleiben lediglich die vom Menschen nicht zu verändernden Wachstumsfaktoren wie Strahlung, Temperatur und allgemeiner Witterungsverlauf sowie das durch die Genetik festgelegte Ertragspotential der jeweiligen Kulturpflanzen.

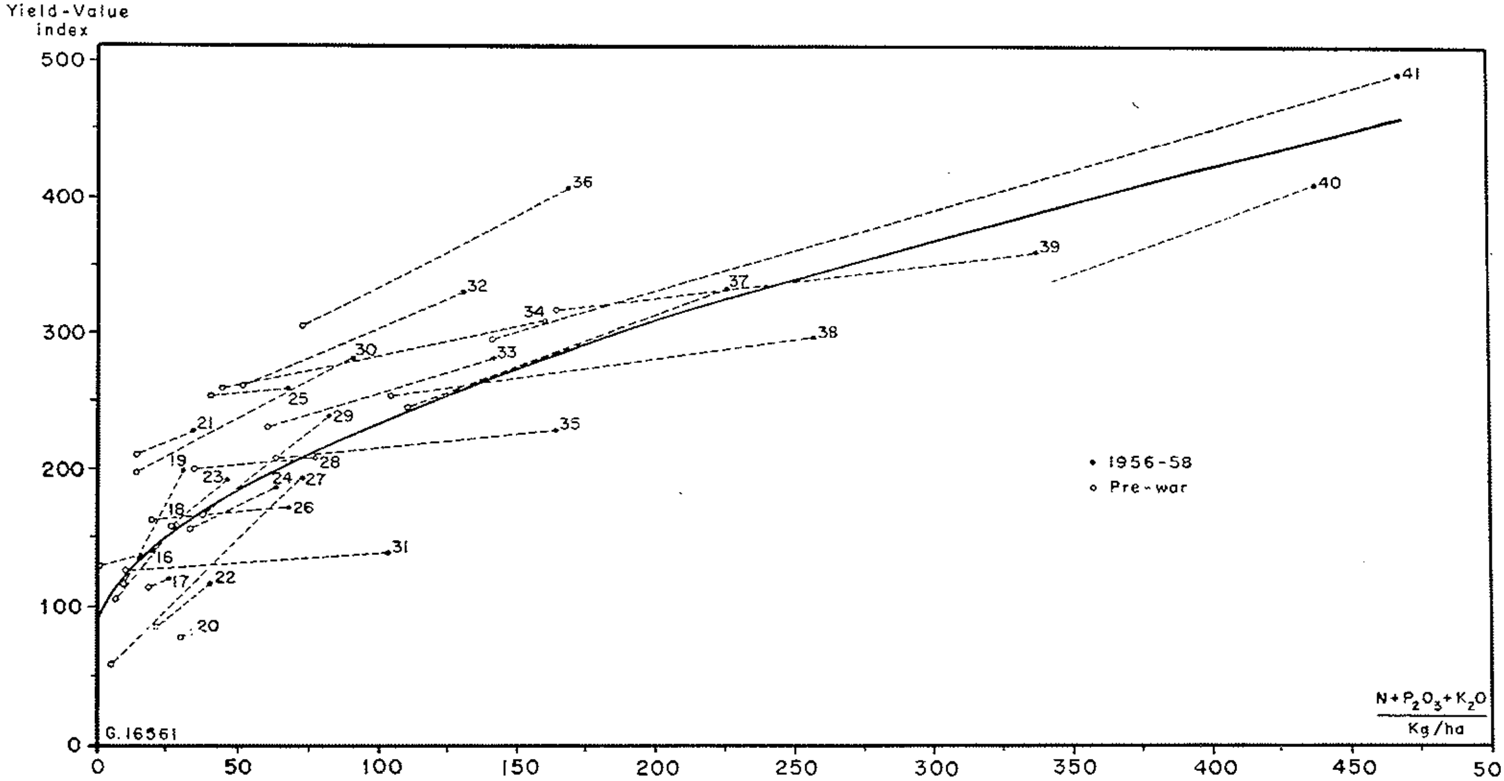
Durch die Möglichkeit, über die Grösse N_Z entsprechend dem Ertragsgesetz von Mitscherlich die Erträge unabhängig von der Grösse N_N su verbessern, wird bei gleichem Arbeitsaufwand die Flächenproduktivität und damit die Wirtschaftlichkeit der Agrarerzeugung wesentlich gesteigert. Es können die in der Landwirtschaft tätigen Menschen besser ernährt, darüberhinaus betriebliche Agrarüberschüsse erwirtschaftet werden, die der Ernährung der nicht in der Landwirtschaft tätigen Bevölkerung zugute kommen.

3. Es werden die Voraussetzungen geschaffen, die technischen Hilfsmittel für die Agrarerzeugung verstärkt einzusetzen und Arbeitskräfte aus der Landwirtschaft abzuziehen, um sie anderen Produktionsprozessen zuzuführen. Der den Wohlstand der modernen Industriegesellschaft begründende Produktionsprozess wird dadurch eingeleitet.

Die Herstellung von Handelsdüngemitteln ist somit von ungeheurer wirtschaftlicher Tragweite und die Höhe ihres Verbrauchs ein sicheres Kennzeichen für die erreichte Produktionsstufe im Entwicklungsprozess der Landwirtschaft.
(Abb. 3)

Die Streuungsbreite der Werte wird in erster Linie durch unterschiedliche klimatische Verhältnisse, landwirtschaftliche Nutzungssysteme, Fruchtfolgen und Bodeneigenschaften verursacht. Durch diese Parameter wird auch die Wirtschaftlichkeit des Handelsdüngereinsatzes mehr oder weniger bestimmt. Die Höhe des Aufwandes hängt vor allem davon ab, ob die Kosten für N_z durch die Erlöse des zu erwartenden Mehrertrags gedeckt werden. Um dies feststellen zu können, muss man die Kostenkurve mit der Erlöskurve vergleichen, wie das in der Agrarökonomie allgemein gebräuchlich ist. Der optimale Düngeraufwand liegt dort, wo die Erlös-Kosten-Differenz ein Maximum hat. Eine Steigerung der Düngungsintensität bis zum Schnittpunkt beider Kurven (Erlöse = Kosten) ist nur bei planwirtschaftlichen Massnahmen von Bedeutung, bei denen die Steigerung der pflanzlichen Produktion Vorrang vor einer optimalen Wirtschaftsführung der einzelnen Betriebe hat.

Mit beginnender Anwendung der Handelsdüngemittel stellen sich in den Entwicklungsländern oft erhebliche wirtschaftliche Schwierigkeiten ein. Die Kosten für den Kauf der gewöhnlich importierten Düngemittel und für ihren Transport bis zum Einsatzort sind in der Regel recht hoch — demgegenüber die Mehrerlöse für die teilweise beträchtlichen Ertragssteigerungen sehr niedrig, so dass sie häufig die Düngungskosten gerade decken.



FERTILIZER USE

1. Burma	8. Indonesia	15. South Africa	22. Australia	29. France	36. Switzerland
2. Argentina	9. Philippines	16. Yugoslavia	23. Italy	30. Austria	37. West Germany
3. Thailand	10. Canada	17. Spain	24. Peru	31. South Korea	38. Japan
4. Pakistan	11. Colombia	18. Greece	25. Egypt	32. Denmark	39. Belgium Luxembourg
5. Turkey	12. Mexico	19. U.S.A.	26. Finland	33. United Kingdom	40. Netherlands
6. India	13. Brazil	20. Portugal	27. Israel	34. Norway	41. New Zealand
7. Syria	14. Chile	21. Ceylon	28. Sweden	35. Taiwan	

ABB. 3 — Handelsdüngeraufwand und die Ertragsleistung der Landwirtschaft verschiedener Länder (FAO-Statistik).

Typische Beispiele zur Kennzeichnung der Schwierigkeiten während der Initialphase des Handelsdüngereinsatzes können dem umfangreichen und langjährigen Fertilizer Program der FAO entnommen werden. (Tab. 1)

TAB. 1 — *Ausschnitt aus den Feldversuchen des l. Fünfjahresabschnitts im Fertilizer Program der FAO* (1961/62 - 1965/66).

Region and Plant	Fertilizer kg/ha N - P_2O_5 - K_2O	Increase % of control	Value/ Cost ratio
Ecuador, peanuts	45 - 0 - 0	33	4.1
Highland	45 - 45 - 0	11	0.9
	45 - 45 - 45	9	0.5
Coast	45 - 0 - 0	25	6.4
	45 - 45 - 0	38	5.8
	45 - 45 - 45	30	3.8
Ecuador, corn	45 - 0 - 0	30	2.4
Highland	45 - 90 - 0	63	2.3
	45 - 90 - 45	78	2.6
Coast	45 - 0 - 0	—	—
	45 - 90 - 0	7	0.3
	45 - 90 - 45	14	0.5
West-Nigeria, Yams	22.4 - 0 - 0	4	2.0
Forest	22.4 - 22.4 - 0	6	1.5
	22.4 - 22.4 - 22.4	6	1.4
Savannah	22.4 - 0 - 0	18	9.9
	22.4 - 22.4 - 0	28	7.4
	22.4 - 22.4 - 22.4	30	6.7

Die Ergebnisse der Feldversuche zeigen bemerkenswerte Schwankungen im Erlös/Aufwand-Verhältnis. Die wesentlichen Ursachen liegen im Nährstoffversorgungszustand der Böden, den unterschiedlichen Nährstoffansprüchen der Kulturpflanzen, den klimatischen Verhältnissen und den unterschiedlichen Kosten für die Beschaffung und Anlieferung der Düngemittel.

Trotz teilweise erheblicher Ertragssteigerungen, die mit relativ geringen Mengen mineralischer Nährstoffdünger erzielt werden können, ist aus den vorgenannten Gründen die Wirtschaftlichkeit der Düngung auf dieser Stufe der agrarischen Entwicklung oft infrage gestellt.

In den Entwicklungsländern ist es daher erforderlich, dass die Düngemittel- und Transportpreise in wirtschaftlich tragbarer Höhe von der Regierung festgesetzt werden und die Abnahme der erzielten Mehrerträge zu einem gerechten Preis garantiert wird.

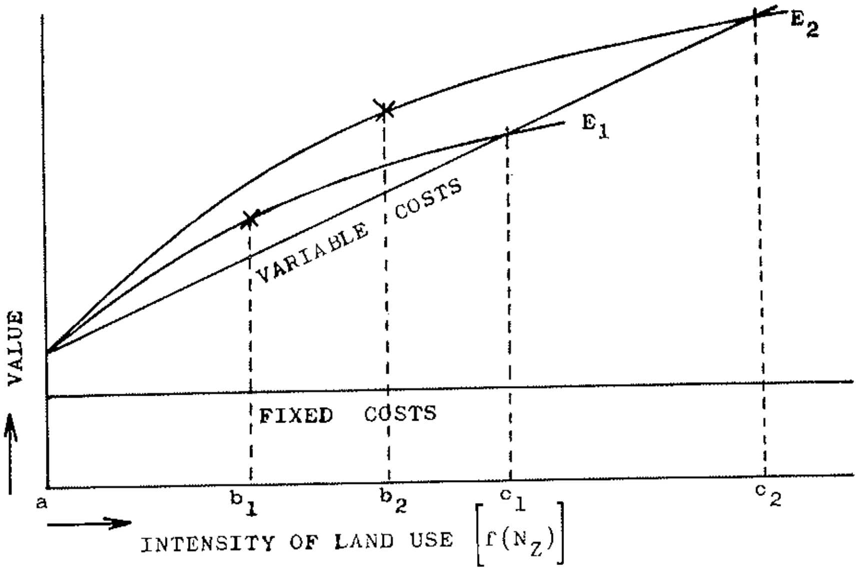
In Ländern mit einer im Aufbau befindlichen Industrie und einem entsprechend niedrigen Lohnniveau können solche agrarpolitische Stützmassnahmen im Zuge der Entwicklung einer freien Marktwirtschaft mehr oder weniger abgebaut werden, da seitens der ausserhalb der Landwirtschaft arbeitenden Bevölkerung eine verstärkte Nachfrage nach Nahrungsmitteln besteht, die von der eigenen Landwirtschaft meist nicht gedeckt werden kann. Im Vergleich zu den Erzeugerpreisen sind die Kosten für Handelsdünger niedrig, so dass in der Steigerung der Grösse N_Z ein Anreiz liegt, die Einkommensverhältnisse zu verbessern (Intensivierungsphase (*) I, Steigerung der Flächenproduktivität).

(*) Intensivierung = Steigerung des ertragssteigernden Aufwandes.

In den hochindustrialisierten Ländern, in denen die landwirtschaftlichen Betriebe aus Mangel an Arbeitskräften erhebliche Investierungen für die Technisierung der Produktionsverfahren durchführen müssen, stehen einem hohen Lohnniveau und den hierdurch bedingten hohen Kosten für Maschinen, Bauten und Energiebedarf Überschüsse in der Agrarproduktion gegenüber.

Um einen völligen Preisverfall und eine damit verbundene Existenzgefährdung der kleinen und mittleren Betribe zu vermeiden, sind Festpreise für Agrarprodukte, Ausgleichszahlungen für die zunehmende Disparität zwischen den Löhnen der Industriearbeiter und den Einkommen der Landwirte sowie Regulierungsmassnahmen zur Drosselung der Überschussproduktion erforderlich. Das aus diesen Massnahmen resultierende Preis-Kosten-Gefüge wirkt sich in der Landwirtschaft so aus, dass in fortschreitendem Masse viele Kleinlandwirte ihre Betriebe aufgeben und zur Erzielung höherer Einkommen (Löhne) in die Industrie abwandern, während die mittleren Betriebe eine Vergrösserung der Nutzfläche durch Zukauf oder Zupacht anstreben. Im Zuge dieser Umstrukturierung der Besitzgrössenverhältnisse werden die leistungsschwächeren Böden aus der Produktion ausgeschieden, so dass der Umfang der « Grenzertragsböden » und der « Sozialbrache » zunimmt. Demgegenüber werden die für die Produktion verbleibenden Flächen intensiver bewirtschaftet. Diese Situation ist heute verbreitet in den Ländern der EWG anzutreffen (Intensivierungsphase II, Fortsetzung von I *und* Steigerung der Arbeitsproduktivität).

Die sich auf die leistungsfähigen Böden konzentrierende intensivere Flächennutzung ist die Folge günstiger Preis-Kostenverhältnisse wie sie einer zu höheren Erträgen führenden Ertragskurve (höherer A-Wert) zugrunde liegen. (Abb. 4)



E_1	= monetäre Ertragskurve mit niedrigem A-Wert.
E_2	= monetäre Ertragskurve mit hohem A-Wert.
a	= minimaler Düngeraufwand bei Gleichheit der monetärem Erträge und Kosten.
b_1 resp. b_2	= optimaler Düngeraufwand für E_1 resp. E_2 (maximale Erlös-Kostendifferenz).
c_1 resp. c_2	= maximaler Düngeraufwand für E_1 resp. E_2 bei Gleichheit der monetären Erträge und Kosten.

ABB. 4 — Optimaler und maximaler Düngeraufwand bei verschiedenen Ertragskurven.

Der optimale und maximale Düngereinsatz verschiebt sich zugunsten höherer Aufwandmengen.

Die durch die Rentabilität des Produktionsfaktors « Mineraldünger » verursachte Steigerung des Nährstoffaufwandes erfährt durch den stagnierenden, teils rückläufigen Einsatz der wirtschaftseigenen Dünger eine weitere Zunahme.

Wegen der hohen Lohnkosten und der ungeregelten Arbeitszeit sind in den letzten Jahren viele Betriebe dazu übergegangen, das Vieh abzuschaffen oder aber sich an einer überbetrieblichen Massentierhaltung zu beteiligen. Dadurch fallen im Betrieb die herkömmlichen Dünger wie Stallmist, Jauche und Gülle nicht mehr im bisherigen Umfang an. Das Stroh verbleibt auf dem Felde; wegen des sehr weiten C/N-Verhältnisses sind zusätzliche N-Gaben zur Sicherung einer ausreichenden Verrottung erforderlich. Die benötigten N-Mengen werden in der Regel in Form der mineralischen Stickstoffdünger eingesetzt, da der Anbau von N-autotrophen Leguminosen als Zwischenfrüchte nicht immer möglich und vielfach auch zu teuer ist. Gewöhnlich ist es billiger, die mit dem Zwischenfruchtbau angestrebte Gründüngung zur Humusverbesserung mit Nichtleguminosen wie Raps, Senf, Grünroggen u.a. vorzunehmen.

Der Ersatz von Stallmist, Jauche und Gülle durch Stroh hat daher zu einer starken Zunahme der N-Düngung geführt. Dabei mussten zusätzlich die Nähstoffe Berücksichtigung finden, die in den zugekauften Futtermitteln enthalten und mit der Abschaffung der Viehhaltung in Fortfall gekommen sind.

Auch in den Betrieben mit Viehhaltung werden die wirtschaftseigenen Düngemittel nicht mehr so eingesetzt wie das früher bei geringeren Lohnkosten der Fall war. Wo in den dörflichen Gemeinden eine Kanalisation zur Ableitung der Abwässer vorhanden ist, werden nicht selten die flüssigen Exkremente der Tiere nicht mehr auf den Acker zurück gebracht, sondern in die Abwässerkanalisation eingeleitet.

Die dem Boden auf diese Weise verlorengehenden Nährstoffe müssen durch zusätzliche Mengen an Stickstoff, Phosphat und Kali ausgeglichen werden. Damit verschiebt sich das Bild der Nährstoffzufuhr immer stärker zugunsten der Handelsdünger, wie das aus der nachfolgenden Übersicht erkennbar ist. (Abb. 5)

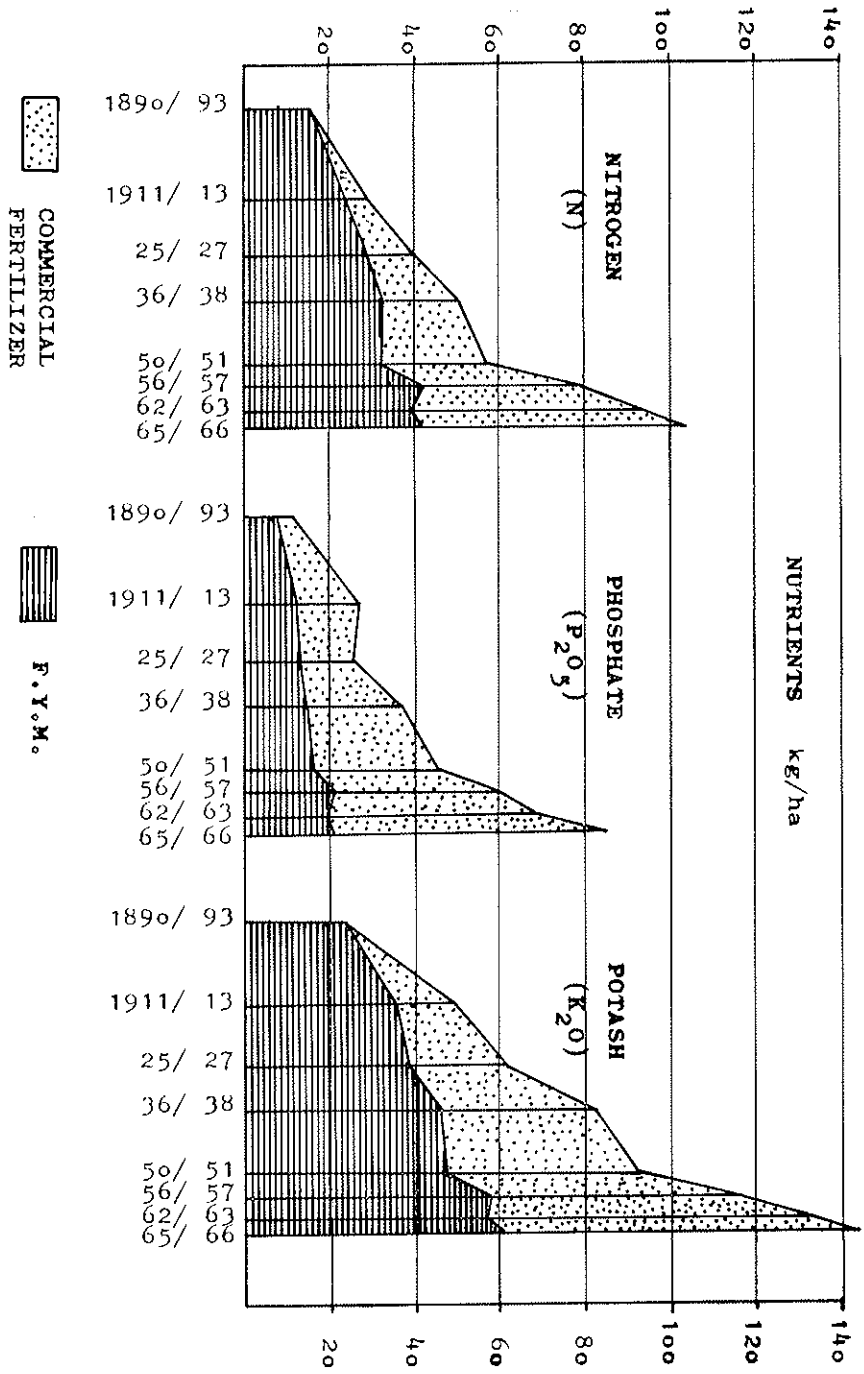


Abb. 5 — Entwicklung des Handelsdüngerverbrauchs und des Stallmistaufwandes in der deutschen Landwirtschaft von 1890-1966.

Bereits heute ist das in der BRD erreichte Ertragsniveau von durchschnittlich 45 dz GE/ha zu rd. 70-80% auf die Nährstoffzufuhr durch Mineraldünger zurückzuführen, wobei pflanzenzüchterische, pflanzenbauliche, wie auch Pflanzenschutzmassnahmen bei der Verwertung der Nährstoffe durch die Pflanze mitgewirkt haben.

Die starke Zunahme der Grösse Nz führt zu neuen Problemen, die bei dem hohen Nährstoffaufwand eine zeitliche Staffelung der Düngergaben, eine sehr sorgfältige Einbringung in den Boden und die Berücksichtigung der Spurenelementdüngung erforderlich machen. Die Düngung muss dabei sämtliche an der Ertrags- und Qualitätsbildung der Pflanze beteiligten Nährstoffe umfassen und sich dem physiologischen Bedarf der jeweils angebauten Kulturpflanzen im Verlauf der Wachstumsperiode unter Wahrung eines ausreichenden Nährstoffausgleichs im Boden anpassen. Die Erfüllung dieser Forderung ist entscheidend vom Ausbildungsstand der Landwirte und von der Qualifikation des benötigten Beratungswesens abhängig. Sie ist zugleich Voraussetzung für die Wirtschaftlichkeit des hohen Mineraldüngeraufwandes in einer weitgehend technisierten Landwirtschaft mit hohem Ertragsniveau.

EFFET DE LA FUMURE COMPLETEMENT EQUILIBREE SUR LA PRODUCTION DE PLANTES DE GRANDE CULTURE

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La fumure minérale, en influençant fortement la productivité végétale, est certainement, avec l'irrigation, le moyen le plus puissant dont l'homme dispose pour améliorer la production. Mais il n'est peut-être pas inutile de rappeler que les essais agronomiques sur la fumure minérale se bornent le plus souvent à prendre en considération les éléments fertilisants classiques, l'azote, le phosphore et la potasse. Il est aussi utile de souligner que la très grosse majorité des essais agronomiques se bornent à établir un éventuel rapport entre la quantité de ces éléments fertilisants et *la production quantitative de la partie du végétal qui intéresse l'agriculteur.*

Ces considérations sont très valables si l'ambition de l'expérimentateur ne dépasse pas l'intention de tirer de ses essais une conclusion de caractère empirique s'appliquant à la situation locale particulière dans laquelle il a conduit son expérience. En fait, toute généralisation reste dangereuse et pourtant le désir, dans la plupart de ces expériences, est de donner aux résultats une portée plus étendue. Reprenons notre première remarque.

Nature et nombre des éléments fertilisants pris en considération.

Personne ne nie que des éléments majeurs autres que N, P et K ainsi que des éléments mineurs, influencent la production végétale. Pour nous en tenir aux premiers, on commence à parler de l'influence du Soufre, du Calcium, du Magnésium. On peut donc se demander pourquoi tant d'essais récents, parfois à très grande échelle, portent seulement sur les fertilisants parfois appelés "essentiels": l'azote, le phosphore, la potasse.

C'est sans doute en partie parce que l'idée est fort ancrée dans beaucoup d'esprits que ces trois éléments sont véritablement essentiels. Cette conviction elle-même repose en partie sur ce que la méthode factorielle, la plus couramment utilisée pour mettre en évidence des interactions, conduit souvent à minimiser celles où interviennent d'autres éléments, ce qui semble justifier que ceux-ci soient négligés dans la plupart des essais. C'est aussi parce que cette même méthode factorielle, pour être raisonnablement appliquée à un nombre plus grand d'éléments fertilisants, sans parti-pris préalable sur leur intérêt où leur importance, exige une extension expérimentale qui dépasse les possibilités réelles. C'est aussi parce que d'autres méthodes, comme celle de MITSCHERLICH, permettent l'étude de l'effet des éléments fertilisants pris un à un et que, dans ces conditions les éléments autres que N, P et K paraissent en effet exercer un effet bien moins important que ceux-ci.

Peut-être oublie-t-on un peu trop, devant les difficultés matérielles, que l'extrapolation, dans la méthode factorielle, est particulièrement dangereuse et que les conclusions négatives auxquelles elle conduit (telles que le caractère négligeable de certaines interactions) ne sont valables que dans la situation explorée et dans les limites (de dose, par exemple) de l'expérimentation. Toute conclusion — surtout négative — étendue à des conditions différentes ou à des doses d'engrais non expérimentées est sujette à caution.

C'est pourquoi une méthode qui ne présente pas une extension expérimentale exagérée, et qui soit susceptible de certaines extrapolations, serait particulièrement précieuse. Nous y revenons plus loin, après avoir repris l'objet de notre seconde remarque.

Production quantitative et production qualitative.

En premier lieu, il faut répéter que la production normalement envisagée est celle d'une partie du végétal, celle qui intéresse l'agriculteur. Or, si les relations quantitatives que les méthodes expérimentales expriment ou font apparaître ont un sens biologique, il faut bien admettre que les facteurs nutritifs, plus que d'autres, doivent affecter la plante entière et, dans celle-ci, peuvent affecter le rapport pondéral entre parties de la plante, ce qui conduit finalement à la production quantitative de l'une de ces parties. Mais si tel est le processus, la simple observation du résultat final traduit le résultat d'un processus caché que la méthode est impuissante à faire apparaître.

En outre, au sein de cette production pondérale, il est à penser que l'action physiologique des éléments nutritifs, qui commande le résultat final, le fait par leur intervention dans le métabolisme ou d'autres processus, lesquels conduisent non seulement à une production pondérale globale, mais aussi à une infinité de situations morphologiques, à une infinité de compositions chimiques, bref à des caractères qui définissent, à côté du poids de la récolte, *sa qualité*.

Certes on possède déjà certaines indications telle que la richesse en sucre de la betterave sucrière selon que l'azote domine ou non dans la fumure, etc... Mais ce sont des indications fort limitées et qui, encore une fois, ne sont jamais liées à la composition complète du milieu nutritif. Il en est de même dans l'aspect extrême qui traduit l'action morphologique, c'est celui des symptômes de carence alimentaire, toujours ramenés à l'action ou à la déficience d'un seul élément nutritif.

Possibilité expérimentale d'étudier l'effet d'un milieu alimentaire complet.

Nous avons mis au point une méthode expérimentale qui permet de déterminer la composition d'un engrais complet comprenant les six éléments majeurs dans les proportions les meilleures possibles (engrais optimum). Pour connaître cet engrais à la dose testée, il suffit de six ou sept traitements expérimentaux et un témoin. Pour en déduire la composition d'un engrais optimum à une dose autre que la dose testée (soit plus élevée, soit moindre) il suffit de six autres traitements. Avec douze ou quatorze traitements, on résout ainsi un problème qu'aucune autre méthode ne permet de résoudre avec cette faible extension expérimentale.

Cette méthode est exposée en détail dans Homès et Van Schoor [4, 6, 7] et complétée par Homès et Van Schoor [8] et [10]. Nous ne pouvons la reprendre entièrement ici. Rappelons toutefois que les traitements expérimentaux sont tous des traitements *complets* en ce qui concerne les éléments majeurs (N, S, P, K, Ca, Mg), qu'ils correspondent tous à la même dose totale exprimée en équivalents chimiques et qu'ils diffèrent entre eux en ce que chacun est caractérisé par la proportion dominante d'un élément, les autres éléments étant tous présents en une autre proportion dite "faible". Cette méthode est d'ailleurs adaptable, si on désire la limiter, au cas d'un engrais où seulement les éléments N, P et K sont en proportion agronomiquement justifiée.

Nous avons appelé cette méthode "Méthode des Variantes Systématiques". Elle est amplement contrôlée par l'expérience. Nous en donnons ici l'exposé succinct et un exemple de calcul.

Exposé succinct de la méthode.

Si nous appelons V la proportion dominante et v la proportion faible, il y a une fois V et autant de fois v qu'il y a au total d'éléments pris en considération.

Par exemple, si l'on désire mettre au point un engrais contenant deux éléments nutritifs, il y aura $V + v$ dans la somme constante. Si nous donnons à cette somme la valeur de 100%, nous aurons $V + v = 100$ (en pour-cent). Il y aura donc lieu d'utiliser deux traitements expérimentaux, l'un où le premier corps est en proportion V et l'autre en proportion v au sein du total $V + v$.

De même, si trois corps sont pris en considération, il y aura trois traitements. Dans le premier, un des corps est en proportion V et chacun des autres en proportion v au sein du total $V + v + v = 100\%$. Dans les deux autres traitements, chacun des deux autres corps est respectivement présent en proportion V.

Dans la méthode préconisée sur le plan agronomique,

v_2 présente la valeur de 20% et V 80% si deux corps sont pris en considération

v_3 présente la valeur de 13% (il y a deux fois v_3) et V 74% (la somme est $74+13+13=100\%$)

De même, on a successivement:

$v_4 = 10\%$ et $V = 70\%$ (somme $70 + (10 \times 3) = 100\%$)
$v_5 = 8$ et $V = 68$ (somme $68 + (8 \times 4) = 100\%$)
$v_6 = 7$ et $V = 65$ (somme $65 + (7 \times 5) = 100\%$)

Ceci est le cas le plus complexe qui permet de résoudre le problème de la fumure la mieux équilibrée pour six éléments majeurs à la fois. Une certaine latitude est possible autour de chacune de ces valeurs, le résultat agronomique n'ayant pas la précision d'un résultat physiologique.

Dans ces conditions, si y_1, y_2, etc... sont les rendements obtenus dans les divers traitements, y_t le rendement témoin, on obtient les proportions à respecter dans la fumure équilibrée par les calculs suivants:

a) Deux éléments nutritifs pris en considération

proportion du premier $\dfrac{y_1}{y_1 + y_2}$

proportion du second $\dfrac{y_2}{y_1 + y_2}$

b) Trois éléments nutritifs pris en considération

proportion du premier $\dfrac{y_1}{y_1 + y_2 + y_3}$

proportion du second $\dfrac{y_2}{y_1 + y_2 + y_3}$

proportion du troisième $\dfrac{y_3}{y_1 + y_2 + y_3}$

N.B. Si on s'écarte des valeurs indiquées ci-dessus pour v et V, il faut faire intervenir un terme correctif comme suit:

$$\text{proportion particulière} = \frac{y - \mathrm{T}}{\Sigma ny - n\mathrm{T}}$$

c) La valeur de T est donnée dans des tables mais, avec une excellente approximation, on peut écrire:

$$\mathrm{T} = 0{,}65\ ym \qquad \text{avec } ym = \frac{\Sigma y}{n}$$

Un seul exemple de calcul sera donné pour permettre au lecteur non averti de se rendre compte de la simplicité des calculs.

Expérience sur la Betterave sucrière.

Objet:

On cherche le meilleur rapport Azote-Phosphore dans la fumure complète, à raison de 25.000 équivalents par hectare (expérience en plein champs).

Traitements:

1) le témoin sans fumure (rendement y_i)

2) les parcelles recevant l'engrais minéral à raison de 25.000 équivalents chimiques par hectare, soit 2,5 équivalents au mètre carré. Les deux traitements semblables en ce qui concerne cette dose, comprennent aussi tous deux 1,34 équivalent des éléments « invariants » répartis comme suit:

$$\left.\begin{array}{ll} 0.17 & S \\ 0.53 & K \\ 0.47 & Ca \\ 0.17 & Mg \end{array}\right\} = 1,34 \text{ (et } 1,16 \text{ de N + P)}$$

Les deux traitements diffèrent entre eux comme suit:

— traitement 1 (N dominant) (rendement y_1)

v_2 = 15% de la somme N + P (le pourcentage idéal n'a pas été réalisé; on utilisera le terme correctif)

V_2 = 85% de cette somme

Cela donne

$0,15 \times 1,16 = 0,17$ équiv. P
$0,85 \times 1,16 = 0,99$ équiv. N

— traitement 2: symétrique du précédent

0,99 équiv. P
0,17 équiv. N

Le tableau suivant résume la composition de la fumure appliquée dans les deux traitements.

Dominance		Traitement 1 N		Traitement 2 P	
Somme totale		2,5		2,5	
Part de l'invariant		1,34		1,34	
Dans cet invariant	S		0,17		0,17
	K		0,53		0,53
	Ca		0,47		0,47
	Mg		0,17		0,17
Part de N + P		1,16		1,16	
Dans cette part	N		0,99		0,17
	P		0,17		0,99

(N.B.: la dose choisie correspond approximativement à une quantité d'une tonne par hectare).

Dans ces conditions, pour la production de racines, on obtient:

y_t = 29,6 (tonnes/hectare)

y_1 = 51,8

y_2 = 34,1

Les calculs se limitent à ce qui suit:

$$y_m = \frac{51.8 + 34.1}{2} = 42.95$$

$$T = 0,65 \times 42,95 - 27,9$$

Ceci donne:

Proportion optima de N / N + P:

$$\frac{51.8 - 27.9}{51.8 + 34.1 - (2 \times 27.9)} = \frac{23.88}{30.06} = .79\ (79\%)$$

Proportion optima de P / N + P:

100 - 71 = 21%

Conclusion:

Sur l'ensemble N + P figurant dans la fumure optima, celle-ci doit contenir:

79% N
21% P

Cette conclusion est valable à la dose expérimentée. Si l'on avait expérimenté *deux doses* (par exemple 1.250 et 2.500 équivalents au mètre carré), on aurait pu trouver la proportion N/P optima à n'importe quelle autre dose.

Grâce à sa simplicité, la méthode permet aisément d'étudier bien d'autres manifestations du végétal que la manifestation pondérale, et notamment les maniféstations qualitatives ou phytosanitaires.

En ce qui concerne les résultats, nous nous limiterons, dans la présente note, à des cas intéressant des plantes de grande culture, mais il est permis de signaler que la méthode a été appliquée avec succès à un cas aussi différent de ceux-là que la culture de Penicillium en vue de la production de pénicilline.

Données expérimentales sur l'effet des fertilisants sur la production végétale.

Les résultats qui sont cités dans ce rapport ont été obtenus par divers collaborateurs et chercheurs au Laboratoire de Physiologie végétale de l'Université de Bruxelles, ainsi que par certains d'entre eux en mission à l'étranger. Ces données sont loin de représenter la totalité de celles qui sont en notre possession et qui sont actuellement à l'étude. Elles nous paraissent toutefois suffire à montrer que la méthode que nous préconisons permet d'obtenir des données précises et nombreuses, qu'elle atteint notamment *l'aspect qualitatif* de la production végétale et qu'il est possible dès à présent d'en tirer des indications utiles pour la pratique.

Les "optima" de la composition d'engrais s'entendent toujours en *pourcentages* du total N + S + P d'une part; K + Ca + Mg d'autre part. Ils s'entendent aussi pour des concentrations ou quantités exprimées en équivalents chimiques et non en poids des divers éléments ni en radicaux tels que P_2O_5, K_2O. Il est compté un équivalent par atome pour N et K; deux équivalents par atome pour S, Ca et Mg; trois équivalents par atome pour P.

Ceci précisé, les points que nous tenterons de toucher sont les suivants:

1) Effet des fertilisants chimiques sur la production pondérale des végétaux.

2) Effet des fertilisants chimiques sur certains caractères qualitatifs de la production végétale.

I. Effet du fertilisant sur la production végétale pondérale.

Nos travaux nous ont permis de rencontrer la question importante qui consiste à savoir si les différences d'exigences que révèle l'expérimentation sont dues principalement à l'espèce cultivée ou à d'autres facteurs.

1. *Caractère spécifique des exigences alimentaires de plantes cultivées dans une même ambiance.*

Pour éviter l'interférence due au fait que les exigences apparentes peuvent différer selon que les parties de plantes diffèrent elles-mêmes, nous considérons ici le cas de la production de *matière végétative verte totale,* que cette matière soit normalement l'objet d'une récolte (fourrage) ou qu'elle soit au contraire abandonnée (fanes). L'ambiance est l'ensemble des conditions maintenues uniformes et constantes et comprend aussi la durée de l'expérience, les exigences alimentaires pouvant varier avec la durée de la culture.

Nous donnons ici quelques résultats.

Ambiance	Plante	Optimum anionique			Optimum cationique		
		N	S	P	K	Ca	Mg
I	Maïs fourrage	70	25	5	39	32	29
(quartz ou	Tabac	77	19	4	36	32	32
verre concassé)	Laitue	80	17	3	41	37	32
II	Maïs fourrage	62	15	23	37	33	30
(sable + terre C)	Tabac	64	17	19	38	30	33
III	Maïs fourrage	66	19	15	37	34	29
(sable + terre A)	Tabac	64	24	12	36	29	35
IV	Valériane	54	24	23	37	36	27
(verre concassé)	Tabac	55	24	21	32	35	33
	Laitue	53	28	20	33	34	33

Bien qu'il ne puisse s'agir ici que de quelques exemples et que la généralisation soit dangereuse, on ne peut manquer de remarquer que, à ambiance égale, les différences spécifiques (pour des récoltes qui sont toutes foliaires) sont minimes. Il se pourrait donc que les exigences alimentaires, à ambiance égale, soient les mêmes pour des espèces très différentes dont la partie récoltée soit de même nature.

Ceci suggère la comparaison suivante.

2. *Exigences alimentaires de récoltes identiques dans des ambiances différentes.*

a) *Pomme de terre.* Chacune des "situations" correspond à un champ différent, désigné par des lettres qui permettent la référence à nos données. Ces champs sont tous situés en Belgique. Le symbole E se rapporte à des expériences sur substrat artificiel.

Situation	Optimum N	Optimum S	Optimum P	Optimum K	Optimum Ca	Optimum Mg
1 (C)	38	31	31	48	21	31
2 (C.F)	45	24	31	46	24	30
3 (C.C)	40	28	32	33	37	30
4 (O.P)	49	31	20	100	0	0
5 (O.R.C)	30	32	38	27	31	42
6 (O.R.C)				29	32	39
7 (A.C)	49	28	23	41	28	31
8 (S)	44	31	25	33	30	37
9 (V.O)	37	30	33	34	33	33
10 (U.E)	59	20	21			
11 (U.E)	62	25	13	28	38	34

On constate que la diversité pour une même plante et selon les situations dépasse celle qui se manifeste pour des plantes différentes dans une même situation.

b) *Maïs* (graine) en Afrique centrale (champs situés au Zaïre, au Rwanda et au Burundi). Situations indiquées par des références [5].

Situation	Optimum N	S	P	Optimum K	Ca	Mg
1 (V)	43	29	28	25	39	36
2 (B)	32	30	38	39	27	34
3 (K)	61	25	14	29	36	35
4 (L)	35	35	30	34	33	33
5 (Ky)	48	28	24	32	36	32
6 (Ka)	47	26	27	35	26	39
7 (N)	31	33	36	30	34	36
8 (H)	30	30	40	28	39	33
9 (R)	22	30	48	38	30	32
10 (Ki)	23	35	42	26	40	34
11 (Li)	42	24	34	38	33	29
12 (Bo)	34	29	47	39	29	32
13 (D)	37	28	35	34	36	30
14 (G1)	21	43	36	32	36	32
15 (G2)	53	28	19	21	31	48
16 (G)	27	36	37	35	28	37
17 (M)	33	33	34	35	33	32

Il semble clairement résulter de ces exemples que l'effet différentiel des situations (sol et climat) est important: l'optimum d'azote varie de 21 à 61% par exemple.

3. *Variations des exigences alimentaires selon les organes récoltés.*

Quelques exemples illustreront ce problème. Les optima des exigences sont toutes exprimées dans l'ordre N-S-P puis K-Ca-Mg, les données exprimant des pourcentages au sein des deux totaux partiels.

	N	S	P	K	Ca	Mg	
a) *Valériane*							
feuilles	53	24	23	37	36	27	
racines	27	38	35	37	23	40	
b) *Betterave*							
feuilles	65	18	17	32	31	37	
racines	41	32	27	31	31	38	
c) *Tomates*							
feuilles	50	24	26	20	42	38	
fruits	40	30	30	24	38	38	
d) *Cotonnier*							
feuilles + tiges	62	20	18	28	46	26	
graines (+ coton)	80	15	5	11	77	12	
(Zaïre) champs à Bambesa	63	15	22	33	47	20	A/C = 1,3

4. *Importance des effets mis en évidence par la méthode utilisée.*

Si l'on rapporte l'effet observé par la meilleure variante expérimentée — effet qui est le plus souvent inférieur et jamais supérieur à celui de l'optimum — au rendement témoin ou à la moyenne générale pour la culture sur substrat artificiel, compté pour 100%, nous observons les résultats suivants.

Sur milieu artificiel

Valériane	129%	de la moyenne générale
Avoine	123%	
Tabac	152%	
Pomme de terre	179%	

En sol réel (champs)

Pomme de terre	124 à 194%	du témoin
Cotonnier [3]	159 à 194%	
Betterave	116 à 125%	

5. *Effet de la dose d'engrais appliquée.*

Deux groupes de résultats ressortent de l'application de la méthode citée:

a) Effet de la dose optimum d'engrais utilisée en pourcent du témoin sans engrais

Pomme de terre	135 à 194%
Cotonnier [3]	194%

b) Possibilité offerte par notre méthode [10] de calculer la composition optimum de l'engrais à une dose quelconque à partir des résultats obtenus à deux doses expérimentées (Maïs, terre).

Doses expérimentées	Composition optima		
	N	S	P
1 (500 meq/vase)	42	32	26
2 (1000 meq/vase)	35	35	30
Composition optima à des doses non testées			
2000 meq	31	37	32
250	56	26	18
125	84	14	2
100	92	8	0
75	100	0	0

L'intérêt de ce calcul est de montrer que les proportions optima varient avec la dose mais surtout qu'en dessous d'une certaine dose (à partir de 115 meq dans l'exemple cité), la proportion optima de l'un des corps devenant nulle, ce corps P, devient superflu et l'engrais optimum ne contient plus, en fait d'anions, que N et S. Plus bas encore, au niveau de 75 meq, deux des corps (S et P) deviennent superflus et seul l'azote reste utile. On comprend ainsi que dans certains essais pratiques on n'ait de réponse qu'à un seul élément fertilisant: c'est un cas limite qui est souvent exprimé par le principe de la loi du mimimum.

Cette possibilité offerte par notre méthode est tellement importante que nous croyons utile de donner un second exemple (Tabac) où les résultats du calcul d'optimum pour la dose non testée de 2000 meq ont pu être contrôlés par l'expérience.

Doses testées (en meq/vase)	Optima N	S	P	K	Ca	Mg
500	64	17	19	38	29	33
1000	49	21	30	34	31	35
Doses non testées						
a) avec contrôle 2000 calculé	42	23	35	32	33	35
contrôle expérimental	46	24	30	32	33	35
b) calculées						
400	71	15	14	40	28	32
300	84	12	4	43	26	30
270	90	10	0	45	26	30
200	95	5	0	50	23	27
160	100	0	0	55	20	25
100				70	13	17
60				96	0	4
55				100	0	0

On constate en effet que le contrôle expérimental confirme le calcul, le plus grand écart, en pourcentage, étant de 4, ce qui tombe dans les limites habituelles de l'erreur.

D'autre part, à partir de la dose de 160 meq, le seul anion nécessaire étant N, c'est un mélange des trois nitrates qui seul produira un effet.

A partir de la dose de 60 meq, seul un mélange des nitrates de K et de Mg produira un effet. Enfin, à partir de 55 meq, seul le nitrate de potassium sera utile.

II. Effet du fertilisant sur les caractères qualitatifs de la production végétale.

1. *Effet sur la production relative de diverses parties d'une plante.*

a) *Le Cotonnier.*

Nous citons à titre d'exemple l'optimum des proportions relatives de K et de Mg dans l'alimentation de la plante, déterminant soit la plus haute production végétative:

K	Mg
60%	40%

soit la plus haute production du coton-graine:

K	Mg
28%	72%

Il est donc important de respecter entre ces deux éléments nutritifs des proportions précises.

b) *Betterave fourragère* (champ à Waterloo, Belgique).

Influence des proportions relatives de N et de P sur les productions de racines et de bouquets foliaires:

Optimum pour la production	N	P
de racines	76%	24%
de feuilles	82%	18%

Les résultats concrétisent ici le fait bien connu de l'influence de l'azote sur la production des feuilles mais ils le traduisent par des *proportions optima* dans la fumure, faisant d'ailleurs apparaître que la production optima d'azote pour la production de racines est loin d'être faible.

2. *Effet du fertilisant sur la teneur de la plante en substances utiles.*

a) *Sucre dans la betterave sucrière.*

En outre de l'action sur la production relative de la racine et des feuilles, le rapport azote-phosphore celui-ci agit, on le sait, sur la teneur en sucre. Comme il agit d'autre part sur la production pondérale, il détermine finalement la production de sucre à l'hectare. Le méthode des variantes systématiques se prête particulièrement bien à déterminer les meilleures proportions en vue des diverses productions.

Optimum des proportions pour la production	N	P
pondérale à l'hectare	68	32
sucre à l'hectare	63	37

La différence est ici faible mais toujours dans le même sens et est parfaitement susceptible d'application pratique.

b) *Production de substance active dans la valériane.*

Il est à remarquer que les teneurs en produit actif sont influencées davantage par les proportions relatives des cations que par celles des anions. Celles-ci ne produisent aucune différence significative. En ce qui concerne les cations, le traitement à Calcium dominant produit la plus haute teneur en extrait éthéré (3.9%) et en extrait alcoolique (31.8%). Par rapport au traitement le moins favorable, les élévations de teneurs sont respectivement de 20 et de 11%.

Il faut noter que le traitement le plus favorable au point de vue de la teneur en substance active est le moins favorable au point de vue de la production pondérale de racines. Cette corrélation n'est toutefois pas générale et la production de drogue par plante se trouve donc diversément affectée par les traitements minéraux. Ainsi, dans une expérience où trois variantes anioniques (désignées par T.N - T.S - T.P) et trois variantes cationiques (T.K - T.Ca - T.Mg) sont appliquées, les productions en pour-cent de la moyenne sont:

Traitements	pour le rendement pondéral	pour l'extrait éthéré	pour l'extrait alcoolique
T.N	78	72	80
T.S	95	102	95
T.P	101	108	99
T.K	108	97	106
T.Ca	84	95	93
T.Mg	133	127	128

La composition de l'alimentation minérale influence donc très nettement la production de substance active extraite de la valériane.

c) *Production d'alcaloïdes.*

c.1. *Nicotiana tabacum*

Les optima de composition anionique et cationique qui figurent ici sont extraits d'une thèse de SEE RYUM CHUNG défendue mais non encore publiée (Laboratoire de Physiologie végétale) [1].

	Optima					
	N	S	P	K	Ca	Mg
Production pondérale (feuilles)	56	29	15	42	34	24
Teneur en alcaloïdes	43	17	40	28	21	51

c.2. *Lycopersicum esculentum*

Les données sont extraites du même travail.

	Optima					
	N	S	P	K	Ca	Mg
Production pondérale (feuilles)	39	31	30	32	34	34
Teneur en alcaloïdes	41	19	40	30	25	45

Il est apparent que l'alimentation minérale influence les teneurs en alcaloïdes et qu'elle le fait différemment de son action sur la production pondérale simple, avec une résultante encore différente sur la production d'alcaloïdes par plante.

d) *Production d'huile de coton.*

Le milieu minéral influence aussi la teneur en huile d'une graine oléagineuse et cela principalement par intervention des ions dans les réactions enzymatiques de la lipogenèse. Les données que nous citons sont déduites des graphiques figurant dans T. VANDENDRIESSCHE [9] dont le travail contient beaucoup d'autres précisions.

L'optimum alimentaire assurant la plus haute teneur en huile des graines du Cotonnier est le suivant:
(en pour-cent dans chaque groupe ionique)

N	S	P	K	Ca	Mg
30	40	30	30	50	20

Il est peut-être utile de signaler que l'optimum alimentaire assurant la plus haute production pondérale de graines dans les mêmes expériences est le suivant:

N	S	P	K	Ca	Mg
80	10	10	10	75	15

Les exigences alimentaires sont donc très différentes selon que l'on désire le plus haut poids de graines ou la teneur en huile la plus élevée.

e) *Teneur en acides aminés des tubercules de pommes de terre.*

Les données suivantes sont extraites d'un travail de D. COUTREZ-GEERINCK [2], où trois traitements alimentaires à dominance respective N, S ou P ont été appliqués à la culture de la plante. Dans les tubercules récoltés, on obtient les résultats suivants:

Acide Aminé	Teneurs en A.A. (micromoles/gr.m.s.)			Proportion des A.A. au sein du total de chaque colonne		
	Traitements			Traitements		
	N	S	P	N	S	P
Glycine	2.66	1.69	2.07	1.20	0.99	1.03
Alanine	5.81	4.61	4.49	2.62	2.69	2.24
Valine	27.46	20.37	24.54	12.36	11.88	12.27
Leucine	5.75	4.69	6.30	2.59	2.74	3.15
Isoleucine	9.57	7.47	11.81	4.31	4.36	5.90
Sérine	17.00	8.95	11.71	7.65	5.22	5.85
Thrionine	9.86	6.67	8.66	4.44	3.89	4.33
Tyrosine	14.30	12.07	14.55	6.44	7.04	7.27
Phénylalanine	12.62	8.86	11.46	5.68	5.17	5.73
A. aspartique	26.28	17.96	23.40	11.83	10.47	11.70
A. glutamique	28.84	27.98	25.15	12.99	16.32	12.57
Lysine	14.39	13.45	15.29	6.48	7.84	7.64
Arginine	20.60	16.15	16.86	9.28	9.42	8.43
Histidine	5.43	4.27	4.96	2.44	2.49	2.48
Methisnine	5.54	3.92	5.78	2.49	2.29	2.89
Proline	15.98	12.36	12.99	7.20	7.21	6.49
Total	222.09	171.47	200.02	100	100	100

On observe que les spectres d'acides aminés sont différents selon l'alimentation reçue par la plante. Les teneurs sont toutes inférieures aux autres dans le traitement à dominance S. La richesse globale en acides aminés s'en trouve naturellement diminuée de façon sensible.

3. *Effet sur certains caractères qualitatifs de la récolte.*

Les exemples sont relatifs au cotonnier et concernent la qualité de l'huile ainsi que celle de la fibre.

a) *Huile*: Les proportions anioniques n'influencent guère l'acidité de l'huile. Au contraire, les proportions cationiques ont une influence marquée, l'acidité pouvant varier sous l'effet des traitements alimentaires de 1.2 à 6.4%.

L'optimum de cette action, c'est-à-dire les proportions cationiques assurant la plus faible acidité, est le suivant:

	K	Ca	Mg
%	30	30	40

b) *Fibres.*

Ce cas est d'autant plus intéressant qu'il s'agit en réalité de poils purement cellulosiques. C'est la qualité de ces poils (ou fibres) qui se trouve influencée par l'alimentation reçue par la plante.

L'indice de dispersion de la longueur des fibres varie, selon les traitements, de 21.9% à 24.6%. Le traitement le plus favorable est celui où domine l'azote parmi les anions et le magnésium parmi les cations.

D'autre part, l'indice "importance des fibres courtes" varie de 10.1% à 16.8%. Le traitement le plus favorable est le même qu'en ce qui concerne l'indice de dispersion.

Conclusions.

1. Dans la composition de l'engrais dont l'effet escompté est le meilleur possible, il n'est pas possible de négliger a priori aucun des constituants majeurs. Pour chacun d'eux, il existe

une proportion optimum qui dépend de la dose d'engrais appliquée. Si la dose est faible, certaines de ces proportions peuvent atteindre la valeur zéro et il n'est alors pas nécessaire de donner un engrais complet.

2. Devant le nécessité de déterminer les proportions optima de *tous* les éléments nutritifs dans un engrais, l'opportunité d'une méthode adéquate se justifie. La méthode des variantes systématiques répond à cette nécessité. Elle constitue une excellente méthode exploratoire des exigences alimentaires des végétaux.

3. Les proportions des constituants du milieu alimentaire semblent différer fort peu d'une espèce à l'autre si un même type d'organe récolté est pris en considération. Elles dépendent par contre fortement de ce type d'organe, des conditions générales de la culture et tout particulièrement du sol.

4. La composition de l'engrais influence les caractères qualitatifs de la récolte. Il peut être utile de s'écarter de l'optimum de production pondérale lorsque le caractère qualitatif est suffisamment important.

5. Le rapport contient plusieurs exemples susceptibles d'application pratique immédiate.

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DIE BEDEUTUNG "AUSGEGLICHENER NAEHRSTOFFANGEBOTE" MIT 12 NAEHRSTOFFEN FUER DIE ERZEUGUNG HOHER ERNTEN VON BESTER QUALITAET

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1. *Die Entwicklung der Düngung*

Eine uralte Erkenntnis der Bauern ist, dass tierische Verdauungsprodukte, Mist, bestimmte grüne Pflanzen und Flussschlamm einen ackerbaulich genutzten Boden verbessern können. Mit der Zufuhr dieser Stoffe in den Boden konnten die Erträge gesteigert werden. Es war bekannt, dass der Erfolg umso geringer würde, je weniger von diesen Verbesserungsmitteln angewandt würde und auch, dass ein Zuviel, z.B. von Taubenmist, die Pflanzen schädigen kann. (Cato, 200 a.D. S. THIELSCHER). Heute würden wir das in einer Optimumkurve darstellen.

Während der Nilschlamm bis zum Bau des Assuan Staudammes das Delta immer wieder neu mit Nährstoffen anreichern konnte, der Kreislauf der Nährstoffe in der chinesischen Landwirtschaft durch Verwendung des Kots zur Düngung nahezu geschlossen war (LIEBIG 1859), konnten durch Mistzufuhr die mitteleuropäischen Böden nicht einmal auf der geringen Höhe ihres alten Ertragsniveaus gehalten werden. Die Bodenfruchtbarkeit reichte nicht mehr aus, um die anwachsende Bevölkerung zu ernähren. Durch Stallmist konnte der Entzug nicht kompensiert werden. Noch weniger was es möglich, Ertragssteigerungen zu erzielen. Hungersnöte führten zur Auswanderung in Gebiete zu ertragreichen, nicht durch lange Ackerkultur ausgelaugten Böden, denn wie die Bodenfruchtbarkeit der alten Böden mit den verfügbaren Mitteln wieder zu steigern wäre, war nicht bekannt. Wohl konnten kurzfristig durch intensive Bearbeitung und Kalkung (Mergel) noch einmal Erfolge erzielt werden, doch dann führte dieser Raubbau zu einer Abnahme der Bodenfruchtbarkeit.

Eine entscheidende Wende in der Landwirtschaft führten erst im vorigen Jahrhundert Boussingault, LAWES, GILBERT und LIEBIG herbei, die Begründer der modernen Agriculturchemie.

LIEBIG *forderte, dass dem Boden die mit der Entfernung der Ernten vom Acker entzogenen Nährstoffe wieder zugeführt werden, damit der Boden seine Fruchtbarkeit behält.*

Einige dieser Nährstoffe wurden in Rohstoffen gefunden, die sonst in grossen Mengen nicht vernünftig verwendbar waren, Kalium in den Abraumsalzen, Phosphor in Knochen und später in der Thomasschlacke. In Rohstoffen also, die wie der Mist irgendwie anfielen, zwar nicht auf dem bäuerlichen Hof, die aber ebenso wenig wie andere bis dahin bekannte Düngemittel für die Ernährung der Pflanzen bewusst entwickelt waren. Man fing an, nach Rohstoffen für die Pflanzenernährung zu suchen. Kaliumsalze wurden planmässig abgebaut. Mit Ammoniumsulfat begann die Entwicklung von Stickstoffdüngemitteln in schon sehr reiner Form. Ein Trend zur Entwicklung immer ballastärmerer Düngemittel begann sich abzuzeichnen. Neue Düngemittel erschienen immer konzentrierter an Nährstoffen und ärmer an Ballaststoffen auf dem Markt. Eine neue Technologie führte zu

Harnstoff, Kalkstickstoff, sowie zu Mineraldüngern mit N, P und K, die umso mehr an Calcium, Magnesium, Sulfat und Spurennährstoffen verloren, je reicher sie an den anderen Nährstoffen hergestellt wurden. Heute kennen wir Düngemittel, die nur noch aus Nährstoff oder Nährstoffen bestehen (vgl. z.B. SLACK 1967). Man ist auf dem Wege, Düngemittel aus mehreren Komponenten so zu konstruieren, dass ihre Wirkung dem Bedarf und Wachstumsverlauf der Pflanze angepasst ist (WANEK, ONDRÁČEK und HAMPL 1971). Die Nährstoffabgabe aus den Düngemitteln wird durch Umhüllen der Granulate gesteuert (vgl. SAALBACH u. Mitarbeiter 1971), durch Fritten (APPIAGYEI-DANKA u. BUSSLER) oder durch Einbau der Nährstoffe in organische Verbindungen, die im Boden langsam abgebaut werden, wie z. B. verschiedene Aldehyde mit Harnstoff.

Diese neuartigen Düngemittel zeigen, dass eine moderne Industrie in der Lage ist, Stoffe zu produzieren, die eine vorausplanende Pflanzenernährung möglich machen. Daneben entstehen in den dichtbevölkerten Gebieten der Industriestaaten auch neue Abfallprodukte: Mülle, Industrieschlämme, Stadtabfälle, die beseitigt werden müssen und die deshalb der Landwirtschaft angeboten werden. Diese Abfallprodukte enthalten auch Nährstoffe (und vieles andere mehr) und können auch zur Strukturverbesserung der Böden beitragen. Verglichen mit den modernen Möglichkeiten der Pflanzenernährung und Düngung, ist diese Anwendung von Abfallprodukten ein Rückschritt in die Anfänge der Agrikultur.

In dem vielfältigen Angebot der zur Düngung einsetzbaren Mittel, welches alle Kombinationen alter und neuer Nährstoffträger und Nährstoffe erlaubt, sind 3 Nährstoffe in besonders grosser Menge vertreten. Es sind Stickstoff, Phosphor und Kalium. Diese drei sind kennzeichnend für den Stand der praktischen Anwendung von Düngemitteln in den Industrieländern.

2. *Der derzeitige Stand der praktischen Anwendung von Düngemitteln in den Industrieländern.*

Rückschauend wissen wir, dass um 1872 sieben unentbehrliche Nährstoffe bekannt waren. Heute wissen wir von zwölf Nährstoffen, die in der praktischen Düngung von Bedeutung sind, aber nur von dreien, die auch tatsächlich *bewusst* ünd *gewollt* in grösseren Mengen dem Boden zugeführt werden. LIEBIG forderte den Ersatz aller entzogenen Nährstoffe.

Ist nun dieses Abweichen von LIEBIGS Forderung berechtigt? Der Erfolg der Landwirte gab und gibt im Ganzen dieser Beschränkung auf nur drei Nährstoffe recht.

Die Erträge sind in einem Ausmass gestiegen, welches vor 100 Jahren nicht vorstellbar war. Man nimmt sogar an, dass die Leistung eines ertragreichen Ackers heute noch verdoppelt werden kann (BUSSLER 1966 u. FINCK 1963, MENGEL u. FORSTER 1971), weil das genetisch fixierte Leistungspotential ertragreicher Sorten noch gar nicht zur Entwicklung kommt. Die Bodenfruchtbarkeit ist durch die modernen landwirtschaftlichen Methoden nicht nur erhalten worden, sondern gesteigert oder sogar erst geschaffen worden. Wir kennen Beispiele, dass als Unland ausgewiesene Flächen zu ertragreichen Böden umgewandelt worden sind (THORMANN u. GOLISCH 1970).

Eine Bevorzugung von 3 Nährstoffen erscheint auch noch aus einem anderen Grunde als berechtigt. Wir wissen, dass nicht alle Nährstoffe in den gleichen Mengen benötigt werden, um den Ertrag zu steigern. Einige Nährstoffe erweisen sich auf bestimmten Böden als wirkungslos, z. Teil sogar als schädlich. Es gibt Böden, die eine grosse Reserve auch an den Nährstoffen besitzen, die nicht in der üblichen Düngung enthalten sind.

Gemessen am Durchschnittsertrag der Länder, brauchten wir uns über die Vereinfachung von LIEBIGS Forderung nicht zu beunruhigen, wenn nicht in letzter Zeit und von Jahr zu Jahr zunehmend Abweichungen vom Trend eines zunehmenden Ertrages bekannt würden.

Selbst bei hohen Gaben von N, P und K nehmen die Erträge auch bei Saat ertragreicher neuer Sorten und Anwendung geeigneter Bestellungsverfahren nicht mehr überall zu. Was früher unbewusst mit den ballastreichen Düngemitteln in den Boden kam, fehlt jetzt in den Mengen, die Entzug und Auswaschung ausgleichen könnten. Die Düngung ist dadurch komplizierter geworden. Auch diese Stoffe müssten jetzt bewusst dem Boden wieder zugeführt werden.

In der Abbildung 1 ist die Entwicklung der Anwendung von Düngemitteln und die damit verbundene Ertragsleistung schematisch (nicht masstäblich) dargestellt.

Die Linie — • — zeigt den zunehmenden Gebrauch von N, P und K (vgl. Die westdeutsche Landwirtschaft).

Die Linie — o — zeigt eine dieser Entwicklung folgende Steigerung der Erträge. Die punktierten Linien weisen auf zunehmend vorkommenden Ertragsrückgang hin, der nicht mehr dem steigenden Einsatz von Düngemitteln entspricht, sondern ihm zuwider läuft. Die gestrichelte Linie weist auf den geringer werdenden Vorrat nicht gedüngter (oder entzogener, festgelegter, ausgewaschener) Nährstoffe hin. Das Verhältnis von "gegebenen Nährstoffen" zu "nicht gegebenen Nährstoffen" wird immer weiter. Es wird umso weiter, in je grösserer Menge einzelne Nährstoffe gegeben werden und je geringer die Nachlieferung der nicht gedüngten Nährstoffe aus dem Vorrat im Boden ist.

Solange die Entzüge noch nicht sehr hoch waren, weil relativ geringe Nährstoffmengen gedüngt wurden, blieben auch die Entzüge an den nicht-gedüngten Nährstoffen gering und wurden z. Teil sogar aus den Nebenbestandteilen der den Pflanzen gegebenen Düngemittel ergänzt. Mit dem Zunehmen der Anwendung von N, P und K, mit dem zunehmenden chemischen Reinheitsgrad dieser Düngemittel wurden höhere

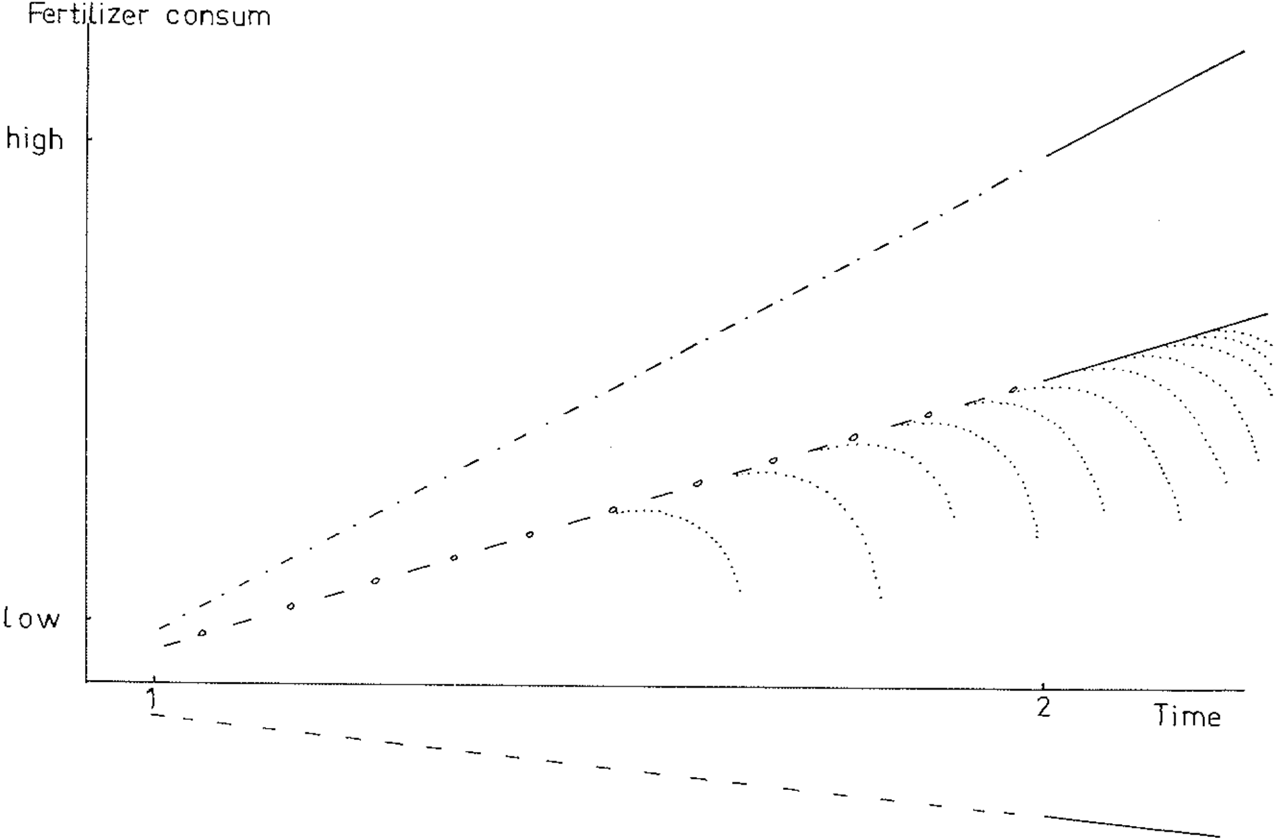

ABBILDUNG 1 — Die zunehmende Erweiterung des Verhältnisses gedüngter Nährstoffe zu nicht gedüngten Nährstoffen.

1 Beginn der allgemeinen Anwendung von Handelsdüngemitteln.
2 Heute
— · — · N — P — K — Düngung
— o — o Erträge
········ Ertragsdepressionen
— — — Verfügbarkeit nicht gedüngter Nährstoffe

Ernten erzielt und gleichzeitig weniger "andere Nährstoffe" unabsichtlich zugeführt, aber in immer höheren Mengen entzogen. Das Gleichgewicht der Nährstoffe wurde immer stärker verändert bis zur Induzierung von Ernährungsstörungen, bis zur Induzierung von Mangel an einem Nährstoff durch Überschuss an einem anderen Nährstoff. Die auch bei Anwendung hoher Gaben von N, P und K rückläufigen Erträge sind z. Teil auf absoluten oder induzierten Mangel an einem oder mehreren der anderen neun Nährstoffe zurückzuführen. Das Nährstoffgleichgewicht ist durch einseitige Düngungsmassnahmen gestört. Wir wissen, dass in sehr vielen Fällen diese Störung durch Ergänzung des Nährstoffangebotes aufgehoben werden kann. Häufig wird die Ursache der Ernährungsstörung aber erst nach längerer Zeit und längerem Ausfall eines Ertragszuwachses erkannt. Schon aus der Erkenntnis LIEBIGS ist es klar, dass früher (z.B. bei Sandböden) oder später (z.B. bei schweren Böden) eine Ertragsstagnation oder ein Ertragsrückgang eintreten muss, wenn in der Düngung nicht alle Nährstoffe berücksichtigt werden, die auf dem entsprechenden Standort berücksichtigt werden müssten. Durch welche Nährstoffe aber die drei meist gegebenen ergänzt werden sollten, kann nur eine auf Standort, Sorte und Verwendungszweck der Ernteprodukte ausgerichtete Untersuchung klären. Diese Untersuchung wird im allgemeinen nicht vorgenommen, sondern erst dann durchgeführt, wenn der Ertragsrückgang sehr auffällig ist oder wenn an der Pflanze sichtbare Symptome von Ernährungsstörungen auftreten.

3. *Zur Verbreitung von Ernährungsstörungen.*

Ernährungsstörungen treten weltweit auf. Sie können Folge einer Degradierüng des Bodens sein, wie auf den sauren ausgewaschenen Lateritböden der Tropen, sie können als Folge einer Versalzung im ariden Klima auftreten und als Folge bestimmter Kulturmassnahmen, die die Festlegung von

Nährstoffen herbeiführen (z. B. Heidemoorböden, deren organische Substanz Kupfer fixiert).

In der intensiv betriebenen Landwirtschaft sind Ernährungsstörungen häufig auf eine Verschiebung des Nährstoffgleichgewichts zurückzuführen. Diese Verschiebung des Nährstoffgleichgewichtes wird z. Zeit auch in denjenigen Entwicklungsländern eingeleitet, die zur Ertragssteigerung vorwiegend einen Nährstoff — nämlich Stickstoff — oft sogar in einer physiologisch ungünstigen Form anwenden. Die Wirtschaftlichkeit misst man dabei am Ertrag der nächsten Ernte.

Nur wenige Beispiele sollen die Verbreitung von Ernährungsstörungen verdeutlichen.

— In den USA gab es 1967 18,7 Millionen ha landwirtschaftlicher Nutzfläche, auf denen Mangelsymptome auftraten (Page). Diese Böden wurden z. Teil als jungfräuliche Böden erst vor 100 Jahren in Kultur genommen. Die auf höchsten Profit ausgerichteten Anbaumassnahmen haben z. Teil die Grundlage der Erzeugung vernichtet.

— 50% aller Böden der BRD bedürfen einer Gesundungskalkung (Henze 1971). In der Saison 1968/69 waren in den für die industrielle Verarbeitung geernteten Kohlpartien teilweise bis zu 30% der Kohlköpfe von Innenblattnekrosen durch ungenügende Ca-Versorgung geschädigt (s. Wehrmann 1971).

— Etwa 40-58% der norddeutschen Böden (DDR) enthielten nicht die zu fordernden Mengen an verfügbarem Kupfer, 30% der Böden waren unterversorgt mit Mangan. (Schnorr und Bergmann, 1967).

— Im Bezirk Weser-Ems waren 60% aller Acker- und Grünlandböden ungenügend mit Magnesium versorgt (Vetter, 1971).

— Primavesi (1972) zeigte in langjährigen Feldversuchen, dass Kupfer bei bestimmten Reissorten den ungünstigen Effekt zu hoher Stickstoffgaben kompensiert, die Resistenz der Pflanzen gegen Pilzbefall erhöht und damit zu einer wesentlichen Ertragssteigerung führt. Durch einen sonst häufig vernachlässigten Nährstoff wird hier

1. das Nährstoffgleichgewicht im Angebot hergestellt,

2. die Qualität der Pflanzen durch Steigerung der Resistenz verbessert,

u. 3. der Ertrag erhöht.

4. *Die Entwicklung von Ernährungsstörungen an der Planze.*

Pflanzen können sich nicht ohne Störungen entwickeln, wenn sich nur ein Nährstoff im Mangel befindet oder nur einer im Überschuss vorliegt. Die Nachlieferung und Verfügbarkeit nicht gedüngter Nährstoffe muss geringer werden und zu Ertragseinbussen führen wenn

1. ein bewusster Ersatz nicht geleistet wird,

2. eine unbewusste Zufuhr des Nährstoffs durch Mist, Schlamm, Nebenbestandteile von Düngemitteln usw. nicht mehr stattfindet,

3. Bodenversäuerung die Auswaschung fördert oder auf andere Weise die Verfügbarkeit herabsetzt, wie bei Molybdän,

4. Versalzung die Aufnahme eines Nährstoffes behindert oder die direkte Wirkung eines im Überschuss gedüngten Nährstoffes die Aufnahme eines anderen durch Antagonismen oder chemische Bindung hemmt (z. B. NH_4 : K, P : Zn),

5. andauernd hohe Erträge zu andauernd hohen Entzügen führen, die nicht ausgeglichen werden.

Dieser Ausgleich ist auch für Spurennährstoffe vorzunehmen. Wenn auch der mittlere Entzug an Spurennährstoffen nur etwa 5 - 500 g/Jahr u. ha beträgt, so ist doch festzustellen, dass auf alten Kulturböden im Lauf der Zeit ein Vielfaches dieser Mengen entzogen und nicht ergänzt wurde und dass auch durch Verwitterung diese Mengen in einer Vegetationsperiode nicht wieder aus der nichtverfügbaren Reserve der Böden frei werden.

Auf eine Ernährungsstörung reagiert eine Pflanze nicht sofort mit einem Symptom. Drei aufeinanderfolgende Stadien sind zu unterscheiden (A, B, C). Die jeweils folgenden Stadien schliessen die vorangegangenen mit ein, sind durch Übergänge miteinander verbunden und auch in sich noch graduierbar:

A. In der Pflanze treten stoffliche Veränderungen auf, die nur analytisch nachweisbar sind. Das Verhältnis der mineralischen Ionen zueinander wird verschoben. Als Folge dieser Verschiebung können Veränderungen im Muster der organischen Bestandteile auftreten, z. B. bei Chloridüberschuss eine Verringerung der organischen Säuren, bei K-Mangel eine Anreicherung niedermolekularer N-haltiger Verbindungen (vgl. Abschnitt 5).

B. In der Pflanze wird die Ordnung der Organellen, Zellen und Gewebe verändert. Diese Veränderungen sind lichtmikroskopisch oder elektronenmikroskopisch nachweisbar, lange bevor die Pflanze sichtbare Schäden zeigt. Bestimmte Strukturen werden nicht mehr gebildet, in ihrer Organisation verändert oder zerstört (vgl. Abschnitt 6).

C. An der Pflanze treten sichtbare Symptome auf. Die Organe können in ihrer Form, ihrer Färbung oder in ihrer Entwicklung von der "Norm der Vergleichspflanze" abweichen

(Chlorosen, Nekrosen, Morphosen). Der Ertrag kann auf Null zurückgehen.

Die Stadien A und B gehören dem verbreitet vorkommenden Bereich latenter Störungen an. Sie werden nur in Ausnahmefällen erkannt. Welche Folgen der Verzehr solcherart geänderter Nahrung hat, ist nur in wenigen Fällen bekannt, meistens in Fällen aus der Tierernährung (Beispiel: Lecksucht bei Kupfermangel, Hinschkrankheit bei Kobaltmangel, Tetanie bei einem gestörten Kationenverhältnis im Serum mit zu geringem Magnesiumanteil, Weidediarrhoe bei Mo-Überschuss).

Durch die in der ganzen Welt nahezu gleichen Produktionsverfahren der intensiv geführten Landwirtschaft, ist auch ein Ausgleich in der menschlichen Ernährung durch optimal mit allen Stoffen versehene Nahrung nicht mehr gesichert.

5. *Stoffliche Veränderungen im ersten Stadium einer Ernährungsstörung.*

Jeder Veränderung der Zellen und Gewebe muss eine stoffliche Umorganisation des Stoffwechsels vorausgehen. Zusammenhänge zwischen stofflicher Veränderung und eingeleiteter Fehlentwicklung sind z. Zeit noch in keinem Fall lückenlos geklärt. Einige leicht nachzuweisende Veränderungen seien genannt, um einen Einblick in die mögliche Vielfalt der Abwege des Stoffwechsels zu geben. (Übersicht Nr. 1).

Fehlerhafte, weil mangelhafte oder einseitig zu hohe Düngung, führt aber nicht nur zur Veränderung der Inhaltsstoffe, sondern auch zu einer Erhöhung der Empfindlichkeit der Pflanzen gegenüber Schädlingsbefall, zu einem erhöhten Bedarf an Pflanzenschutzmitteln und damit auch zu einer stärkeren "Umweltbelastung". (KRAUSS, 1969, GROSSMANN, 1970). Die Erkenntnis dieser Zusammenhänge wird durch unterschiedliche Wirkung der Nährstoffe sowie ungleiches Verhalten der Pflanzenarten erschwert.

ÜBERSICHT I.

Ursache	Stoffliche Veränderung
N - Mangel	Relative Zunahme der Kohlenhydratfraktionen, verstärkte Verholzung.
S - Mangel	Anreicherung von niedermolekularen N-haltigen Verbindungen.
P - Mangel	Anreicherung von sekundären Pflanzenstoffen, z. B. Anthozyanen (BUCHHOLZ, 1962) und von China- und Chikimisäure (COÏC, 1961).
K - Mangel	Anreicherung von schädlichen Stoffen z. B. Putrescin (COLEMAN u. RICHARDS, 1956).
B - Mangel	Anreicherung eines die Zellteilung fördernden Stoffes oder Fehlen eines Stoffes, welcher die Zellteilung hemmt (BUSSLER 1964, 1965).
Mo - Mangel	Anreicherung von Nitrat.
Fe - Mangel	Gehemmte Proteinsynthese, Zunahme löslicher N-haltiger Verbindungen, Anreicherung organischer Säuren (VENTKATRAJU 1971).
Cu - Mangel	Hemmung der Aktivität der Phenoloxydasen, verringerte Ligninbildung (RAHIMI 1971).
NH_4 - Überschuss	Verringerte Bildung organischer Säuren.

6. *Histologische Veränderungen als Folge von Ernährungsstörungen.*

Um die ersten histologischen Folgen eines gestörten Stoffwechsels erkennen zu können, muss man mikroskopische Untersuchungen vornehmen. Die hierfür zu präparierenden Gewebe sind den Organen und Stellen zu entnehmen, die später an der Pflanze auch direkt sichtbare Symptome zeigen. Bei Schnittserien wird man feststellen können, dass die allerersten Veränderungen einzelne Zellen betreffen. Erst wenn viele Zellen geschädigt werden, kann die Entwicklung der Schädigung vom histologischen Beginn bis zum Absterben des Organs verfolgt werden. Die Abbildungen 2-6 zeigen typische Stadien aus der Entwicklungsreihe der Symptome.

In der Rinde sind einige Zellen zusammengefallen und von den sich vergrössernden Nachbarzellen zu gelbbraunen Bändern zusammengepresst worden. Die zusammenfallenden Zellen haben zunächst geringe osmotische Werte und kaum noch nachweisbares Kalium. Die den zusammengefallenen benachbarten Zellen haben sich vergrössert und irregulär geteilt. Die Gewebestruktur in den Leitbündeln, im Kambium und im Mark ist normal (BUSSLER, 1962, 1964, 1970). (Abb. 2).

Parenchymzellen im Mark der jüngeren Stengelteile lösen sich vollkommen auf. Das Mark wird hohl, der Stengel knickt um. Diesem Symptom geht, im elektronenmikroskopischen Präparat sichtbar, eine Zerstörung der Membranen voraus (MARINOS). Dadurch ist das Pektin der Mittellamelle dem Angriff der Pectinasen ausgesetzt, die zunächst einzelne Zellen voneinander trennen. Von den Zellen des Marks bleibt eine nicht strukturierte braune Substanz übrig (BUSSLER, 1962a, b, c, 1963a, b). (Abb. 3).

Die Zahl der Zellen zwischen Siebteil und Xylem nimmt zu. Das Kambium teilt sich fortgesetzt. Die neuen Zellen differenzieren sich aber nicht mehr. Die Gewebevermehrung in diesem Bereich kann so weit gehen, dass der Stengel platzt. Ein homologes Symptom ist bei Sellerie als "cracked stem"

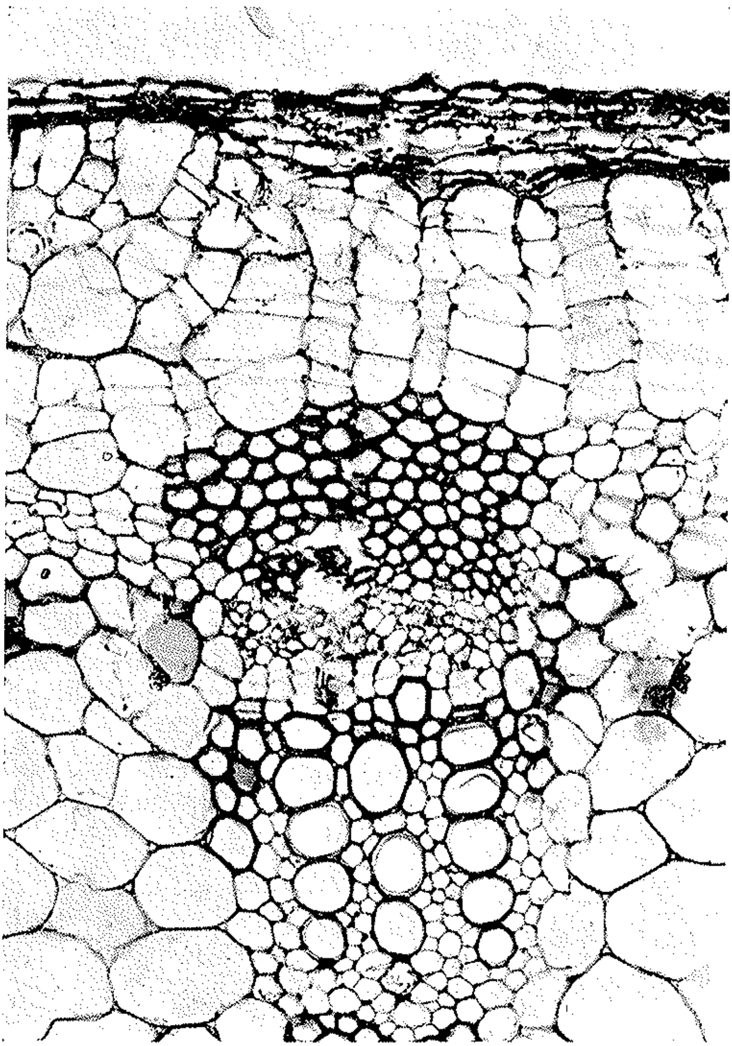

ABBILDUNG 2 — Cosmea Querschnitt im unteren Stengelteil bei Kalium-Mangel 250 ×

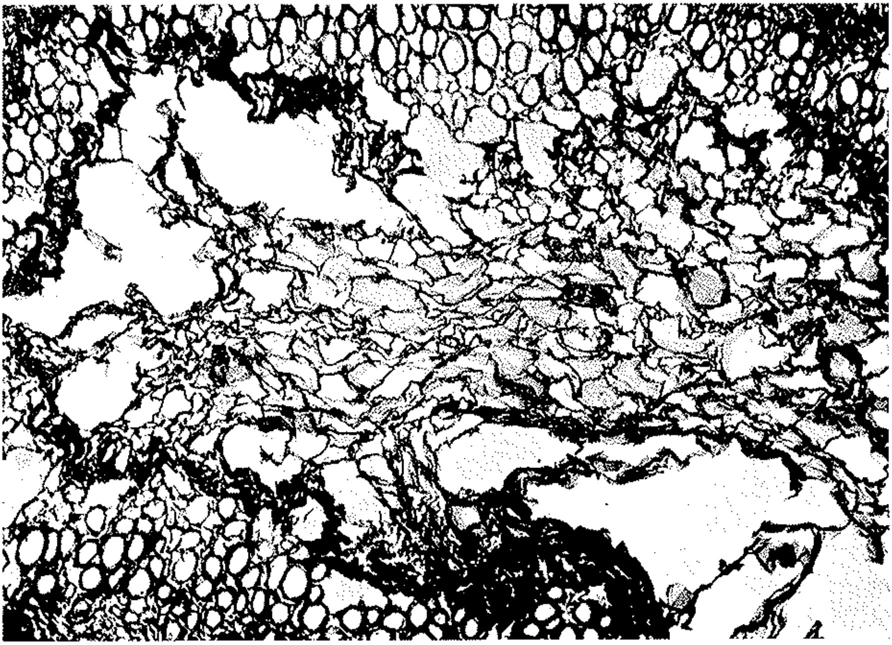

ABBILDUNG 3 — Aubergine — Querschnitt im oberen Stengelteil bei Calcium-Mangel 100 ×

bekannt. Diese Zellwucherung ist der ähnlich, die bei animalischen Neoplasien (Krebs) zu beobachten ist (BUSSLER, 1956a, b, 1960a. b. 1961, 1962a, b, 1964, 1965, 1966, 1968). (Abb. 4).

Zu Beginn eines Molybdän-Mangels werden in junge parenchymatische Zellen Substanzen eingelagert, die diese Zellen zum Absterben bringen. Wenn es sich hierbei um Zellen in Organanlagen handelt, werden ganze Organteile vor der Entwicklung vernichtet. Der Rest überlebender Zellen formt nur noch Organfragmente. Bei Molybdänmangel ist eine als "Whiptail" bekannte vereinfachte aber völlig irreguläre Blattform typisch (BUSSLER 1969a, b, c, 1970). (Abb. 5).

Bei Manganüberschuss wird Mangan in grösseren Konkretionen in Epidermiszellen, besonders in den Fusszellen von

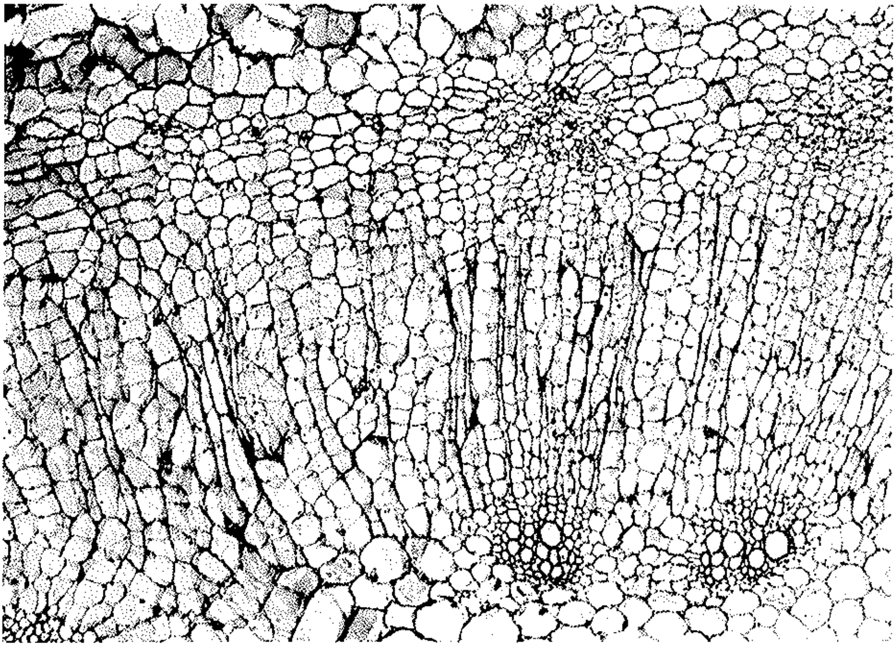

ABBILDUNG 4 — Sonnenblume — Querschnitt durch den Stengel unter der Endknospe bei Bor-Mangel 100 ×

Haaren, abgelagert. Im Gegensatz zu den Veränderungen im Gewebe bei verschiedenen Mangelzuständen haben wir hier keine Störungen in der Organisation der Gewebe feststellen können. Nach Umsetzen der Pflanzen in Mangellösung ist das in den Konkretionen festgelegte Mangan nicht aktivierbar. Die Pflanzen zeigen dann in älteren Organen Manganüberschuss, in jüngeren Organen Manganmangel (BUSSLER, 1958). (Abb. 6).

Wie die Abbildungen 2-6 zeigen, werden bei bestimmten Ernährnngsstörungen ganz bestimmte Symptome induziert. Diese Symptome ermöglichen es, auch bei mehrfachen Ernährungsstörungen noch verschiedene sich makroskopisch überdeckende Symptome zu unterscheiden.

Diese Symptome zeigen auch (das ist nicht neu), dass

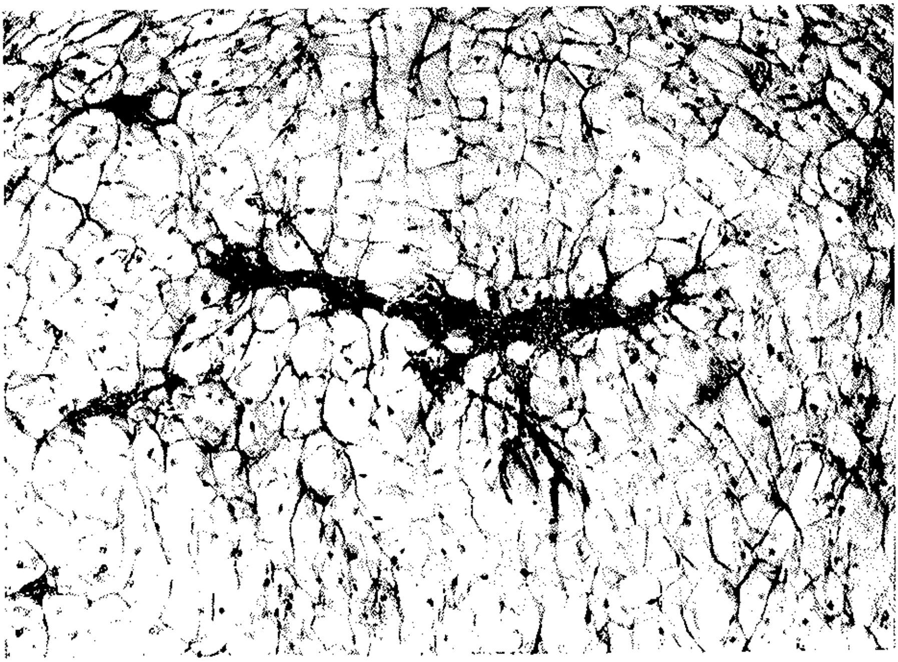

ABBILDUNG 5 — Blumenkohl — Querschnitt durch die Mittelrippe eines jungen Blattes bei Molybdän-Mangel 250 ×

eine Ernährung bei welcher nur *ein* Nährstoff fehlt, für eine normale Entwicklung der Pflanzen nicht genügt. Kann eine Düngung mit überwiegend 3 Nährstoffen die Pflanzenproduktion sichern, wo 12 Nährstoffe entzogen werden?

7. *Direkt sichtbare Symptome von Ernährungsstörungen*

Bei andauernder Ernährungsstörung nehmen die stofflichen Veränderungen in der Pflanze zu, treten immer häufiger Schäden an den Zellen auf, die endlich zum sichtbaren Ausdruck der Ernährungsstörungen führen. Je nach der Beweglichkeit des die Störung veranlassenden Nährstoffes und seiner

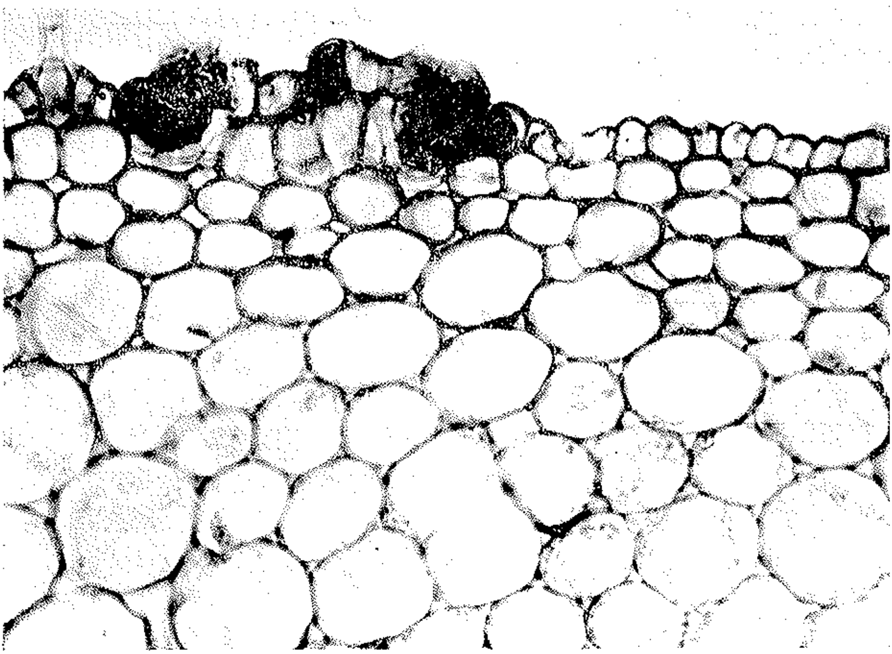

ABBILDUNG 6 — Bohne — Querschnitt im älteren Stengelteil bei Manganüberschuss 250 ×

Funktion im Stoffwechsel der Pflanze, sind die entstehenden Symptome verschieden. Bei Mangelerscheinungen sind die Symptome und Symptomfolgen an der Pflanze typisch für den Mangelzustand. (BUSSLER, 1968) Die Ernährungsstörung kann an diesen Symptomen erkannt werden.

Schon seit langer Zeit wurden diese Symptome beobachtet, beschrieben und abgebildet (z. B. WIMMER um 1900, ECKSTEIN, BRUNO, TURRENTINE 1937, BROEDEL-KITCHEN 1948, HAMBIDGE 1951, MULDER 1956, STENUIT u. PIOT 1960, MALAVOLTA et. al. 1962, PENNINGSFELD 1962, BUSSLER 1962, 1964, DEL RIVERO 1964, SPRAGUE 1964, PRIMAVESI 1965, ROORDA VON EYSINGA u. SMILDE 1968 u. 1969, JUNG u. RIEHLE 1969).

Wenn damit auch noch kein vollständiger Überblick über die bei Ernährungsstörungen möglichen Schadbilder gewonnen ist, so haben sich doch die Erfahrungen über die Entwicklung von Symptomen bei der Bekämpfung von Ernährungsstörungen sehr bewährt. Von Nachteil ist, dass auch bei richtiger Diagnose der Symptome mit der Beseitigung der Schäden erst spät begonnen werden kann. Latenter Mangel (ohne sichtbare Symptome) kann schon viele Jahre lang vorgelegen haben, bevor die Störung erkannt wurde. Anders gesagt, der Verbraucher erhielt in diesen Fällen schon jahrelang Nahrung, die chemisch anders zusammengesetzt war als Nahrung von normal ernährten Pflanzen.

8. *Optimale Nährstoffverhältnisse*

Wenn die in den vorigen 3 Abschnitten beschriebenen Schäden an der Pflanze auftreten, waren die im Nährstoffangebot vorhandenen Nährstoffverhältnisse nach Kombination oder (und) Konzentration nicht optimal.

Da durch den Boden und durch das Pflanzenwachstum ein einmal gegebenes Angebot von Nährstoffen in vielen nicht immer eindeutig erkennbaren Richtungen verändert werden kann, wollen wir zunächst fragen, wie etwa ein optimales Nährstoffangebot in einer Wasserkultur bei konstantem Nährstoffangebot im Durchfluss beschaffen sein sollte.

In der Übersicht 2 sind die Forderungen zusammengestellt, die für ein optimales Nährstoffangebot zu erfüllen sind. Es liesse sich in Worten so ausdrücken:

Ein optimales Nährstoffangebot liegt dann vor, wenn es bei gegebenen sonstigen Bedingungen der Pflanze erlaubt, ihre genetischen Anlagen voll zur Entwicklung zu bringen. In dem vom Herrn Kollegen Coïc vorliegenden Beitrag finden wir:

"Les facteurs qui ont une action sur la Physiologie de la plante ne sont pas indépendants les uns des autres. Il faut donc amener chacun d'entre eux à une valeur correspondante à un équilibre entre tous".

ÜBERSICHT 2 - *Forderungen an ein optimales Nährstoffangebot.*

1. Es muss alle Nährstoffe enthalten.
2. Es muss alle Nährstoffe in geeigneter Form enthalten (z. B. N als NO_3 — oder — NH_4 — Ion).
3. Es soll keine Ballaststoffe und keine störenden Ionen enthalten.
4. Es soll alle Nährstoffe in entsprechend dem Angebot richtigen Mengen enthalten (vgl. Übersicht 3).
5. Es soll im pH-Wert nicht extrem sein.
6. Es soll alle Nährstoffe in zueinander optimalen Verhältnissen enthalten.

Am schwierigsten sind die Forderungen nach Punkt 6 zu erfüllen. Erst mit Hilfe der von HOMÈS entwickelten Methode der systematischen Variationen, ist es überhaupt möglich geworden, mit einer technisch durchführbaren (geringen) Anzahl von Versuchsschritten nahezu optimale Verhältnisse von Nährstoffanionen und Nährstoffkationen zu ermitteln (HOMÈS 1953, 1961, 1963, 1966, RAUTERBERG u. BUSSLER 1960, BUSSLER 1963, 1966a, b,). Wir haben mit der Methode von HOMÈS auch versucht, optimale Spurennährstoffverhältnisse zu finden (FOROUGH u. BUSSLER 1969). Bei sehr unterschiedlichen Angeboten an Spurennährstoffen und Massennährstoffen, fanden wir die in Übersicht 3 dargestellten Nährstoffverhältnisse für Sonnenblumen (Kultur in 40-ml-Gläsern, Lösung nicht belüftet und nicht erneuert, BUSSLER, 1971a, b).

ÜBERSICHT 3 — *Ein "ausgeglichenes Nährstoffangebot" für Sonnenblumen in 40-ml-Gläsern.*

Massennährstoffkationen / Pflanze : 2,4 mval

K : Ca : Mg = 26 — 44 : 29 — 42 : 20 — 37

Massennährstoffanionen / Pflanze : 2,4 mval

N : S : P = 28 — 46 : 33 — 45 : 17 — 31

Kationen : Anionen = 1 : 1

Spurennährstoffkationen / Pflanze : 0,012 mval

Fe : Mn : Cu : Zn = 20 — 41 : 17 — 31 : 14 — 29 : 20 — 33

Spurennährstoffanionen / Pflanze : 0,012 mval

B : Mo = 42 — 72 : 28 — 58

Massennährstoffe : Spurennährstoffe = 400 : 1

Spurennährstoffkationen : Spurennährstoffanionen = unbekannt (hier gegeben 1 : 1, Optimum nicht untersucht).

(BUSSLER, 1971,b)

Je nach der Art des Nährstoffangebotes müssen sich diese Verhältnisse mehr oder weniger verändern. Je geringer das Nährstoffangebot in seiner Gesamtmenge wird, umso bedeutungsvoller wird das Selektionsvermögen der Pflanze. In je grösseren Mengen die Nährstoffe im Angebot vorliegen, umso stärker beeinflusst das Nährstoffangebot selbst die Nährstoffaufnahme (vgl. Übersicht 4). Da für höchste Erträge grosse Mengen von Nährstoffen angeboten werden müssen, die einen grossen Einfluss auf die Nährstoffaufnahme haben, sollten die Nährstoffe schon im Angebot in optimalen Verhältnissen vorliegen. Das gilt auch für die Spurennährstoffe.

ÜBERSICHT 4 — *Arten des Nährstoffangebotes.*

Hohe Nährstoffkonzentration > 50 mval/1 ↑	1. in einer Gabe, ausreichend für Vegetationszeit oder vorgesehene Versuchsdauer	Das Selektionsvermögen der Pflanze nimmt an Bedeutung zu ↓
	2. in mehreren Gaben, der Entwicklung angepasst	
	3. ± konstant gehalten durch häufige Erneuerung	
Nährstoffe < 5 mval	4. konstant gegeben mit verlorenem Durchlauf	

9. *Die Spurennährstoffe im optimalen Nährstoffangebot.*

Je geringer früher das Nährstoffangebot an allen essentiellen Nährstoffen war, umso weniger vertrug es die Pflanze, dass *ein* Nährstoff diesem Angebot in grösserer Menge hinzugefügt wurde. Die ältesten Berichte über die Anwendung von uns heute bekannten Spurennährstoffen handeln von Vergiftungen. Die planmässige Anwendung von Spurennährstoffen setzte sich daher nur in Gebieten durch, in denen Mangelkrankheiten auftraten. Wie bei den Massennährstoffen wird der Ertrag durch ungünstige Kombinationen von Spurennährstoffen aber schon beeinträchtigt, bevor Symptome auftreten (vgl. Übersicht 5).

ÜBERSICHT 5 — *Vergleich der relativen Erträge in Colwell-Lösung und in nach systematischen Variationen zusammengestellter Lösung (Sonnenblumen in 40-ml-Gläsern) bei unterschiedlichen Spurennährstoffangeboten.*

Massen Nährstoffe		Spuren-nährstoffe	Anionen d. Spuren-nährstoffe		Kationen d. Spuren-nährstoffe	Ernteerträge S.V.	C. (reö.)
200	:	1	1	:	1	63	100
200	:	2	1	:	1	80	100
200	:	4	1	:	1	41	100
200	:	2	2	:	1	98	100
200	:	2	10	:	1	180	100

Bei gleichem Angebot von Massennährstoffen führte eine Veränderung des Verhältnisses von Spurennährstoffanionen : Spurennährstoffkationen zu einer ganz erheblichen Verbesserung des Wachstums. Die Verbesserung des Wachstums wurde am Ertrag gemessen. Die verbesserte Wirkung der Spurennährstoffe war hier eindeutig auf die Erhöhung der Borgabe zurückzuführen. Molybdän, schon in zu hoher Gabe, hat den Ertrag nicht beeinflusst.

10. *Zur Beurteilung einer Nährstoffwirkung*

Die Wirkung einer Düngung oder allgemeiner eines Nährstoffangebotes, wird in der Regel am Ertrag gemessen. Damit wird aber nur eine Möglichkeit von vielen benutzt um zu prüfen, ob durch eine Massnahme die Entfaltung der genetischen Anlagen verbessert würde. Andere Möglichkeiten zur Beurteilung einer Nährstoffwirkung sind in der Übersicht 6 dargestellt.

ÜBERSICHT 6 — *Kriterien für eine Beurteilung von Nährstoffwirkungen.*

1. Ertrag
   (ungenügend, schliesst negativ zu beurteilende stoffliche Zusammensetzung nicht aus).
2. Aussehen der Pflanzen
   (ungenügend, N-Überschuss oder P-Mangel-Pflanzen können "normal aussehen").
3. Entwicklungsgeschwindigkeit
   (ungenügend, sagt über das Endergebnis nichts aus).
4. nach physiologischen Kennwerten, z.B. nach Gehalt an löslichen Stickstoffverbindungen.

Jeder einzelne Punkt der Übersicht 6 ist für eine wissenschaftlich begründbare Beurteilung unzureichend. Nur weil der Ertrag das am einfachsten zu ermittelnde Kriterium darstellt, orientieren sich fast alle praktischen Düngungsmassnahmen am Ertrag. Dabei wissen wir, dass höchste Erträge nicht mit bester Qualität verbunden sein müssen. In der menschlichen Ernährung ist es ganz klar, dass die schwersten Menschen nicht die gesündesten sind. Wenn in der praktischen Düngung der Ertrag dennoch als Kriterium für weitere Anbaumassnahmen benutzt wird, so aus der Unkenntnis über die Zusammenhänge der einzelnen den Ertrag bildenden Komponenten und aus betriebswirtschaftlichen Überlegungen.

In diese geht der Ertrag viel häufiger ein, als die Qualität. Die für den menschlichen Verzehr zu beurteilende Nahrungsqualität richtet sich zum grossen Teil nach äusseren, für den Stoffwechsel unwesentlichen Merkmalen oder nach Negativbefunden. Die Ernteprodukte sollen frei sein von schädlichen Stoffen (Rückständen), Krankheiten, Schädlingen. Damit wird eine Produktion hochwertiger Nahrung nicht angeregt.

11. *Dilemma zwischen Rentabilität und Qualitätserzeugung.*

Wenn in Bezug auf Qualität und Quantität optimale Ernten erhalten werden sollen, dann muss unser ganzes Wissen bis zum letzten gesicherten Stand der Erkenntnis in die Praxis umgesetzt werden. Es genügt nicht, dieses Wissen nur bis zur Grenze einer marktwirtschaftlichen Veränderungen unterliegenden kurzfristig gesehenen Rentabilität zu verwirklichen. Versauerte Böden, Pflanzen mit gestörten Garnituren von organischen und anorganischen Inhaltsstoffen sind die Folge eines nur auf Ertrag und Rentabilität gerichteten Denkens.

Wie Coïc (1972) es ausdrückt: "... en agriculture, on se préoccupe plus de rendement que de la qualité, car pour beaucoup de produits agricoles, l'amélioration de la qualité est peu payée".

Der Pflanzenproduzent wäre aber durchaus gewillt, seine Produkte optimal zu ernähren, wenn er dafür auch honoriert werden würde. Ein Beispiel dafür bildet der Blumen- und Zierpflanzenbau, der seine Aufwendungen für modernste Produktionsverfahren auch wieder hereinbekommt. Der Verbraucher ist jedoch noch nicht bereit, für die ihn nährenden pflanzlichen Produkte so viel auszugeben, wie für die "Blumen für die Dame". Der Verbraucher unterliegt immer noch der falschen Meinung, die Landwirtschaft müsse billig und nach Möglichkeit mit Hilfe von Abfällen, wie Müllen, hochwertige Nahrungsmittel produzieren. Die Worte von VIRTANEN sind noch nicht Allgemeingut menschlichen Bewusstseins:

"Neue Einsicht in die Aufgaben und die Bedeutung der Ernährung lässt die Behauptung gerechtfertigt erscheinen, dass die Nahrung offenbar der mächtigste vom Menschen beherrschte Faktor ist, durch den er auf seine Gesundheit, seine Arbeitskraft und seine Aktivität überhaupt einwirken kann. Eine ausreichend und harmonisch abgestimmte Zufuhr der von Mensch und Tier benötigten Nährstoffe ist in ausschlaggebendem Mass von der chemischen Zusammensetzung der Kulturpflanzen abhängig". — Diese wird erheblich von der Düngung beeinflusst.

Durch die Anwendung von Düngemitteln kann heute der Hunger bekämpft werden. Unsere Ernährung wird aber nicht gesichert, wenn wir nicht alle Nährstoffe in der Düngung berücksichtigen und nur in geringem Umfang die Grundlagen der Ernährung erforschen können. Der in der Abb. 1 gezeigte Trend wird sich fortsetzen. Ernährungsstörungen werden auch da an den Pflanzen auftreten, wo sie heute noch nicht bekannt sind.

12. *Zusammenfassung.*

1. Es wurde gezeigt, dass bei der derzeitigen praxisüblichen Anwendung von Düngemitteln zunehmend Ernäh-

rungsstörungen auftreten müssen. Die zunehmende Verbreitung von Ernährungsstörungen wird darauf zurückgeführt, dass die alte Forderung von LIEBIG, "*alle* entzogenen Nährstoffe seien zu ersetzen", nicht erfüllt wird. Der Ersatz von nur 3 Nährstoffen genügt nicht.

2. Bei Mangel an nur einem Nährstoff treten an der Pflanze stoffliche und histologische Veränderungen auf, die neben der Herabsetzung der Erträge auch eine Verminderung der Qualität der Ernteprodukte herbeiführen.

3. Eine optimale Entwicklung der Pflanzen, die zu hohen Erträgen und guter Qualität führt, ist nur möglich, wenn die Nährstoffe in ausgeglichenen Verhältnissen angeboten werden. Eine Möglichkeit, solche optimalen Verhältnisse erkennen zu können, bildet die Anwendung der Methode der systematischen Variationen von HOMÈS.

4. Die Grundlagenforschung sollte auf dem Gebiet der Ernährung und Pflanzenernährung verstärkt werden. Die Beurteilung einer Pflanze, ob sie wirklich optimal entwickelt ist, ist uns z. Zeit nach wissenschaftlichen Gesichtspunkten nicht möglich, auch nicht die Empfehlung optimaler Nährstoffangebote. Wir kennen nicht das Ertragsmaximum einer Art. Wir kennen kein grundsätzlich gültiges Kriterium für die Beurteilung der Qualität von Nahrungspflanzen.

5. Optimale Erträge in Bezug auf Qualität und Quantität scheinen bei Orientierung landwirtschaftlicher Massnahmen an der Rentabilität nicht erzeugt werden zu können. Die Ausrichtung auf billige Produktionsverfahren, Anwendung von Abfällen anstelle von dem Produktionsziel angepassten Düngemitteln, schliesst eine optimale Nahrungsqualität fast immer aus.

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FERTILISATION MINERALE ET QUALITE DES RECOLTES

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I - Introduction.

L'Agriculture a pour but d'obtenir de manière rentable, sur une aire déterminée, la plus grande quantité de produits utiles et la meilleure qualité de ceux-ci.

Evidemment, nous essayons continuellement de remplacer le "qualitatif" par le "quantitatif"; autrement dit, de substituer à la notion abstraite de qualité, la notion concrète de "composition biochimique", lorsque cela est possible. Nous progressons rapidement dans ce sens lorsqu'il s'agit de valeur alimentaire et technologique des récoltes. Les progrès sont très lents lorsqu'il s'agit de propriétés organoleptiques qui sont des données très subjectives. Dans bien des cas il est si difficile de trouver des caractères concrets de qualité que l'on est amené à définir, non le produit, mais les conditions qui influencent cette qualité, d'où les dénominations de crû, d'appellation d'origine qui essaient de définir l'ensemble "variété - sol - climat" donc l'ensemble "variété - surface délimitée - année de production".

Il n'est pas question de traiter le problème dans toute son étendue, mais de donner une vue générale des problèmes qui se posent et de montrer, grâce à quelques exemples concrets, pris plus spécialement dans nos propres travaux, comment on peut résoudre ces problèmes.

Le rendement et la composition biochimique de la récolte dépendent d'une part de l'hérédité, c'est-à-dire de l'espèce, de la variété végétale et d'autre par du milieu extérieur. Ils sont, en définitive, le résultat du fonctionnement de la variété dans le milieu extérieur considéré.

Les facteurs qui ont une action sur la physiologie de la plante ne sont pas indépendants les uns des autres. Il faut donc amener chacun d'entre eux à une valeur correspondant à un équilibre optimum entre tous. Parmi tous ces facteurs nous devons distinguer ceux sur lesquels nous pouvons avoir une action, de ceux indépendants de nous. La nutrition minérale fait partie des facteurs que nous pouvons contrôler, grâce aux travaux des physiologistes et des agronomes de la science du sol. Les facteurs indépendants de nous (climat, certaines conditions de sol) doivent donc être seuls à limiter le rendement ou à limiter notre action sur la qualité; et les facteurs sur lesquels nous pouvons agir (l'hérédité, la nutrition minérale) doivent être "adaptés" aux facteurs indépendants de nous actuellement.

Notre action sur le rendement et la qualité est aussi limitée d'une part par la faiblesse de nos connaissances dans toutes les disciplines agronomiques (Amélioration des plantes, Physiologie et Biochimie végétales, Science du sol...) et, d'autre part, par les nécessités économiques, la rentabilité.

L'apport d'éléments minéraux a pour but fondamental d'augmenter *la production de substances organiques*. La fertilisation minérale peut aussi faire varier la *composition biochimique* des récoltes et le but de cette communication est d'exposer comment elle fait varier cette composition et en conséquence comment on peut s'en servir pour associer rendement et qualité des récoltes.

II - DIVERSITÉ DES CONDITIONS D'ALIMENTATION MINÉRALE DANS LES SOLS NATURELS. EFFET DE LA SUPPRESSION DES DÉFICIENCES.

En raison de la grande diversité des roches-mères qui ont donné naissance aux sols et aux éléments minéraux nutritifs assimilables (calcaires, granites, schistes, gneiss, etc.), on pourrait penser que la composition des espèces végétales est extrêmement variable en fonction du type de sol, en conséquence de la différence considérable de l'alimentation minérale qu'elles ont à leur disposition. Ce n'est pas le cas.

En effet, la plante possède un certain pouvoir de discrimination dans l'absorption des éléments minéraux. Ce pouvoir de discrimination se présente par exemple de la façon suivante: une plante déficiente en un élément comme le Phosphore, absorbera préférentiellement et rapidement l'ion phosphorique lorsqu'elle sera placée dans un milieu nutritif complet et équilibré.

Inversement l'élément nutritif sera absorbé à une vitesse très réduite lorsque la plante est riche en cet élément; elle peut même l'excréter dans un milieu pauvre (Y. COÏC et G. VANDERWALLE 1956).

Ce pouvoir discriminatoire, qui se traduit par ce que l'on pourrait appeler un pouvoir "tampon", a certaines limites dont l'étude fait d'ailleurs l'objet de cet exposé.

D'autre part les aptitudes et "exigences" des genres, espèces ou variétés végétales sont très différentes, ce qui permet, par le *choix de la plante cultivée,* une certaine adaptation aux conditions d'alimentation minérale dans les sols naturels.

Ceci dit, le manque de tel ou tel élément minéral est un facteur primordial de limitation du rendement à la surface de la terre. *Comment ces déficiences se traduisent-elles du point de vue composition chimique des récoltes?*

Prenons comme exemple la déficience en acide phosphorique. La déficience en acide phosphorique diminue la photosynthèse et donc la production de matières organiques, de sorte que la dilution de l'acide phosphorique se trouve limitée.

On conçoit d'ailleurs qu'elle ne puisse descendre au-dessous d'une certaine limite. C'est ce que nous montre le tableau relatant une expérience sur blé, en vases de végétation contenant une terre carencée en acide phosphorique et comportant une variation de la nutrition azotée à partir du début de la montaison du blé.

TABLEAU I.

	Récolte (en g par pot)	N % de mat. sèche du grain	P_2O_5 % de mat. sèche du grain	Matières azotées du grain en g par pot (N × 5,7)
Sans phosphate				
0 nitrate	16,4	2,43	0,44	1,95
1/2 nitrate	17,0	2,78	0,42	2,32
Avec phosphate				
1/2 nitrate	71	1,63	0,61	5,67
1 nitrate	93	1,92	0,58	8,75

Le manque de phosphates a tellement abaissé le rendement (4 fois), que la teneur du grain est encore les 2/3 de la teneur normale. Autrement dit, la diminution considérable de l'absorption de PO_4^{---} ne s'est traduite que par une diminution relativement faible de la teneur du grain en phosphore. Parallèlement, la teneur en protides du grain a considérablement augmenté (2,78 au lieu de 1,63 d'azote pour 100 de matière sèche, pour une même nutrition azotée) ce qui signifie que la protéosynthèse a été beaucoup moins touchée que la photosynthèse par la déficience en acide phosphorique. Cette expérience nous montre aussi *qu'il est plus difficile d'obtenir une forte teneur en protides du grain par une bonne alimentation azotée que par la déficience en acide phosphorique.*

En Agriculture la déficience en un élément qui, par définition pourrait-on dire, abaisse le rendement, accroit généralement la concentration des autres éléments dans la plante et finalement dans la récolte.

Par cet exemple, on conçoit combien l'interprétation de l'action d'un engrais sur la qualité nutritionnelle des récoltes peut être difficile. En effet, l'apport d'un engrais phosphaté pour remédier à une carence en phosphore conduit dans l'exemple choisi à une augmentation de la teneur en acide phosphorique du grain mais aussi à une diminution de sa teneur en matières azotées.

L'apport d'amendements calcaires à un sol peut avoir des effets sur la composition chimique de la récolte bien plus importants que ceux résultant seulement de l'amélioration de la nutrition en calcium de la plante: l'élévation du pH change les possibilités alimentaires du sol par libération d'éléments nutritifs assimilables et, en particulier, d'azote par minéralisation d'une partie de la matière organique; elle peut créer des antagonismes entre éléments nutritifs, diminuer ou augmenter l'assimilabilité de certains d'entre eux, et ainsi faire disparaître des toxicités (Aluminium, Manganèse, Fluor, ...) ou créer des déficiences (Manganèse, Zinc, Bore...).

III - La composition minérale des récoltes.

La composition minérale des récoltes intéresse plus particulièrement la nutrition des herbivores, d'autant plus que les techniques modernes de culture des prairies ont pour conséquence une nourriture moins variée.

Mais elle intéresse aussi la nutrition des autres animaux et aussi de l'homme dans les régions où son alimentation est surtout à base de végétaux (graines, fruits).

Les nouvelles recherches concernent plus spécialement les oligo-éléments. Les chercheurs travaillant sur la production végétale se sont intéressés tout d'abord aux micro-éléments nutritifs essentiels à la physiologie des plantes supérieures c'est à dire à Fe, Cu, Zn, Mn, B, Mo, Cl; puis aux éléments essentiels ou inutiles à la physiologie de la plante lorsque leur concentration est faible mais qui peuvent causer une toxicité si leur concentration devient élevée, notamment Ca, Mn, B, Cl, Al, Cr, F, Pb, Li, As. Les besoins alimentaires en oligo-éléments de l'homme et des animaux sont en partie différents de ceux des plantes. Ceux indispensables ou utiles à leur physiologie sont les suivants: Co, Cr, Cu, F, I, Mn, Mo, Se, Zn, Sr; tandis que As trivalent, Be, Bi, Cd, F, Pb, Mo, Se sont parfois toxiques lorsqu'ils sont absorbés en quantité plus ou moins élevée. Or, les plantes cultivées servant à l'alimentation peuvent avoir une croissance optimum même lorsqu'elles contiennent des teneurs en Co, Cr, Cu, I, Mn, Se, Zn, insuffisantes pour subvenir aux besoins de certains animaux, ou lorsqu'elles contiennent, au contraire, des teneurs en Se, Cd, Mo ou Pb qui causent une toxicité directe ou un déséquilibre métabolique chez les animaux sans nuire à la plante.

1) *Effet indirect de la fertilisation minérale par la variation qu'elle provoque sur la composition botanique des prairies.*

L'influence de l'espèce sur la teneur en éléments minéraux est déterminante. On peut dire que dans une prairie les légumineuses sont beaucoup plus riches que les graminées en Calcium et Magnésium, en Fe, B, Mo, Cu et Co alors qu'elles sont moins riches en Potassium et Sodium.

Les différences entre espèces sont très grandes et l'on parle même de plantes accumulatrices pour le Cobalt, le Zinc, le Sélénium...

Ces différences entre espèces est si grande que l'action des engrais minéraux sur la variation de composition minérale de la pâture ou du foin est le plus souvent causée par la variation qu'ils provoquent dans la composition botanique de la prairie.

2) *Influence de la nature de l'alimentation azotée.*

L'alimentation azotée de nos plantes peut s'effectuer sous forme ammoniacale ou nitrique. En général elle est surtout nitrique en raison de la nitrification de la forme ammoniacale et de la migration facile de l'ion NO_3^- dans le sol.

Puisque, dans un cas l'azote est absorbé sous forme de cation NH_4^+, et dans l'autre sous forme d'anion NO_3^-, on comprend l'antagonisme, à l'absorption, de NO_3^- vis-à-vis des autres anions, et de NH_4^+ vis à vis des autres cations; d'autant plus que l'ion azoté est absorbé préférentiellement aux autres ions. En alimentation nitrique, il y a moins d'autres anions et en particulier d'acide phosphorique absorbé, et moins de cations en alimentation ammoniacale.

On conçoit bien, d'autre part, que le métabolisme de NO_3^- dans les feuilles, qui modifie l'équilibre électrostatique cellulaire, va entraîner de grosses modifications dans la production d'acides organiques qui assurent cet équilibre: en nutrition ammoniacale, faible quantité de cations et d'acides organiques; en nutrition nitrique, plus forte quantité de cations et d'acides organiques dans les feuilles (Y. Coïc et al. 1961).

TABLEAU II.

Valeur en milliéquivalents pour 100 g de matière fraîche	Maïs (feuilles)		Tomates (feuilles)	
	NH_4^+	NO_3^-	NH_4^+	NO_3^-
N total	49	45	63	43,1
P total (en PO_4^{3-})	12,4	7,5	15	6,6
K	13,1	13,1	8,3	11,1
Ca	4,0	6,2	4,1	26,8
Mg	3,3	5,2	2,9	8,6
Cations totaux	20,4	24,5	13,3	46,5
Acidité organique	3,6	12,4	0,6	26,8

En comparant le maïs et la tomate, nous voyons que la tomate est particulièrement sensible à l'influence de la nature de la nutrition azotée: la teneur et la composition des anions (minéraux et organiques) et des cations minéraux des feuilles présentent des variations considérables.

L'action du type de nutrition azotée sur la teneur et composition en cations minéraux, ainsi que sur la teneur en acides organiques des feuilles est donc différente suivant les types de plantes. Nous attribuons cette différence à la différence relative de la puissance du métabolisme de NO_3^- dans les racines et les feuilles, les plantes du type Maïs (graminées de prairie, blé, asperge...) en réduisant une plus forte proportion dans les racines (et donc moins dans les feuilles) que les plantes du type tomate (tabac, pomme de terre...).

Il faut de nouveau signaler, qu'en Agriculture, la nutrition exclusivement "ammoniacale" se rencontre rarement et que si l'on passe d'une nutrition "ammoniacale" à une nutrition "nitrique" la composition cationique et en acides organiques des feuilles adultes ou jeunes se modifie rapidement (Y. Coïc et al.).

3) *Enrichissement en certains oligo-éléments* (Y. Coïc et C. Tendille, 1971).

L'enrichissement des récoltes en oligo-éléments est un problème important qui doit susciter l'intérêt des Agronomes, d'autant plus que les engrais usuels étant de plus en plus concentrés en éléments N. P, K, contiennent en général du moins en moins d'autres éléments. Chaque oligo-élément constitue un problème en soi: problème lié à sa dynamique dans les divers sols, sa facilité d'absorption et de migration dans la plante qui dépend d'ailleurs de la plante elle-même et de sa rhizosphère, des antagonismes (PO_4 vis à vis de Zn ou du Cu ou du Co) ou synergismes (PO_4 vis à vis de Mn) rencontrés.

IV - La composition en substance organiques.

Ce sont évidemment les substances organiques des récoltes qui nous intéressent le plus au point de vue nutritionnel et technologique. Le problème de la modification de la composition des récoltes en ces substances est aussi le plus complexe.

Nous parlerons seulement de la modification apportée par les engrais à *la teneur en protides* et à *la composition de ceux-ci,* car ce groupe de substances organiques occupe une place de choix au point de vue *nutritionnel* et *technologique*.

Remarque: Lorsque les agronomes s'occupent de l'influence de la nutrition minérale sur la "qualité" des récoltes, ils ont tendance à n'étudier que l'influence d'une déficience en un élément ou plutôt l'effet de la suppression de cette déficience par l'apport d'un engrais approprié.

Or, généralement, en Agriculture, on se préoccupe plus du rendement que de la qualité, car pour beaucoup de produits agricoles, l'amélioration de la qualité est peu payée. Il en résulte que la suppression de la déficience en un élément est rémunératrice par l'augmentation de rendement qu'elle procure; et que la définition *agronomique* d'une déficience se rapporte surtout au rendement. Mais, il est très important pour l'Agriculture moderne de savoir si, au-delà de la quantité d'un élément nécessaire pour obtenir un rendement maximum (ou optimum du point de vue économique), une quantité supplémentaire de cet élément n'améliore pas la qualité sans modifier le rendement. Cet aspect fondamental apparaitra dans l'exemple que nous avons choisi: accroissement de la teneur en matières azotées du grain de blé. L'aspect inverse doit, évidemment, faire partie aussi de nos préoccupations, à savoir: fournir une quantité d'un élément inférieure à celle conduisant au maximum de rendement pour obtenir une combinaison "rendement-qualité" économiquement rentable.

1) *Variation de la teneur en matières azotées.*

La proportion de matières azotées parmi la matière organique totale synthétisée traduit le résultat de l'interaction entre la nutrition azotée de la plante et la photosynthèse nette.

Prenons comme exemple le blé. La teneur en matières azotées du grain $= \frac{\text{Matières azotées}}{\text{Matière sèche}} \times 100$ varie en général comme le rapport $\frac{\text{Azote métabolisé}}{\text{Photosynthèse nette}}$. Elle sera donc fonction des variations relatives du numérateur et du dénominateur de cette fraction.

Toutes les conditions et facteurs agronomiques qui diminuent plus la photosynthèse que la protidosynthèse augmentent le taux de protides du grain. Nous avons vu l'effet d'une déficience du sol en phosphore et la plupart des déficiences en ions nutritifs ont le même effet; il en est de même du manque de lumière, du manque d'eau, des maladies cryptogamiques...

a) *Action de la fumure azotée sur la teneur en protides du grain.*

La fumure azotée augmente la quantité d'azote métabolisée par la plante, mais, heureusement, elle augmente aussi la photosynthèse nette. D'après la loi de MITSCHERLICH, dite "des rendements moins que proportionnels" elle devrait toujours aboutir à une augmentation de la teneur en azote des récoltes. Cela n'est pas toujours vrai et dépend de la quantité d'azote et de la date d'apport par rapport au stade de développement.

TABLEAU III.

	0 kg N	30 kg N/ha début mars	30 kg N/ha fin mai	30 kg N début mai + 30 kg N fin mai
Taux d'azote du grain (% de matière sèche)	1,62	1,51	2,35	2,09
Rendement (quintaux à l'hectare)	19	32	21	36

Une fumure azotée modérée du blé au moment de la croissance active permet la constitution d'une surface foliaire photosynthétique conduisant à une forte photosynthèse à l'unité de surface du terrain. Mais plus tard (après que l'azote de la fumure azotée aura été utilisée) l'accroissement de la photosynthèse par rapport à celle du témoin ne sera pas suivie d'une augmentation de la protidosynthèse puisque l'azote minéral disponible, provenant alors de la minéralisation d'une faible fraction de l'azote organique du sol, sera en même quantité pour la parcelle témoin et la parcelle ayant reçu la fumure; la teneur en protides du grain sera abaissée par cette fumure (Y. Coïc 1950).

Par contre, la même quantité d'azote apportée à la fin de la croissance active augmente relativement peu la photosynthèse nette à l'hectare et accroit considérablement la teneur en azote du grain, ce qui montre que la protidosynthèse est encore très active dans la dernière phase de développement du blé (après floraison). Nous attribuons ce maintien de la puissance de la protéosynthèse globale au *maintien du travail de la racine* qui joue un rôle important dans la protidosynthèse chez le blé. En effet, ainsi que nous l'avons dit, les racines de certains genres de plantes (Maïs, Blé) peuvent transformer en acides aminés et amides une bonne partie des nitrates absorbés. Or cette transformation est la phase la plus difficile, la plus énergétiquement coûteuse de la protéosynthèse, et c'est à partir de ces chainons organiques que le grain va synthétiser ses protéines.

Une double fumure, pendant et après la période de croissance active permet de conjuguer l'augmentation du rendement et l'obtention d'une teneur en azote élevée du grain (Tableaux III et IV).

Cette variation de la teneur en protides, que l'on peut contrôler dans une certaine mesure par la fumure azotée, a l'importance que l'on connaît pour les industries de la brasserie, de la sucrerie de betterave, et pour la panification et la fabrication des pâtes alimentaires.

b) *Interaction variété - fertilisation azotée.*

Pour une alimentation donnée et limitée en azote, la teneur dépend du rendement de la variété: plus le rendement est faible, plus la teneur en azote du grain est forte. Réciproquement, plus une variété est productive, plus ses besoins en azote sont grands, non seulement pour manifester sa productivité mais aussi pour que la teneur en azote des récoltes ne soit pas amoindrie en raison de cette productivité.

D'autre part l'on doit se poser la question suivante: Existe-t-il une aptitude variétale à l'enrichissement en azote du grain, lorsque l'alimentation azotée est très abondante? Cela est vraisemblable; et cette possibilité est fonction des aptitudes comparées de la variété vis à vis de la photosynthèse et de la synthèse des protides. En régime d'abondance de l'alimentation azotée le taux d'azote du grain varierait en gros comme le rapport $\frac{\text{Azote métabolisé}}{\text{photosyntèse nette}}$.

Nous avons dit que pour certaines plantes et en particulier pour la plupart des céréales, la racine jouait un rôle fondamental. Or, on s'est surtout préoccupé de sélectionner les variétés de plantes d'après leurs capacités photosynthétiques, leur rendement à l'hectare en produits utiles (grain par exemple) dans les diverses conditions agricoles. Peu de travaux ont été réalisés en ce qui concerne les capacités protidosynthétiques, et en particulier sur la puissance du métabolisme de l'azote minéral dans la racine. Il est vrai que l'on peut supposer que la sélection pour la productivité est peut-être elle même dépendante ou corrélative d'une sélection pour la puissance de protéosynthèse.

c) *Fertilisation azotée et qualité meunière-boulangère du grain* (Y. Coïc et W. Alexinsky 1953, W. Alexinsky et Y. Coïc 1954).

La qualité technologique du blé est fonction d'une part de la proportion de farine que l'on pourra normalement extraire du grain (taux d'extraction) et d'autre part, de la valeur de cette farine pour fabriquer le pain.

Poids à l'hectolitre: on admet généralement que le taux d'extraction dépend du poids à l'hectolitre: plus le poids à l'hectolitre est élevé, plus le taux d'extraction est grand. En réalité, c'est la densité du grain qui est la donnée importante, mais elle est difficile à mesurer dans la pratique car l'hectolitre de grain comprend à la fois le volume propre du grain et le volume de l'air dans les interstices. Le poids à l'hectolitre est donc fonction de la densité du grain et aussi du volume occupé par le grain, celui-ci dépendant de nombreux facteurs comme, par exemple, de la rugosité du grain, en relation elle-même avec sa propreté et de son humidité, en sorte que le poids à l'hectolitre est un critère de qualité commode mais dont la valeur n'est pas absolue.

Le tableau IV montre que la fertilisation azotée tardive accroît nettement le poids à l'hectolitre. Elle accroît le poids à l'hectolitre en augmentant la densité du grain, ce qui est important du point de vue du taux d'extraction.

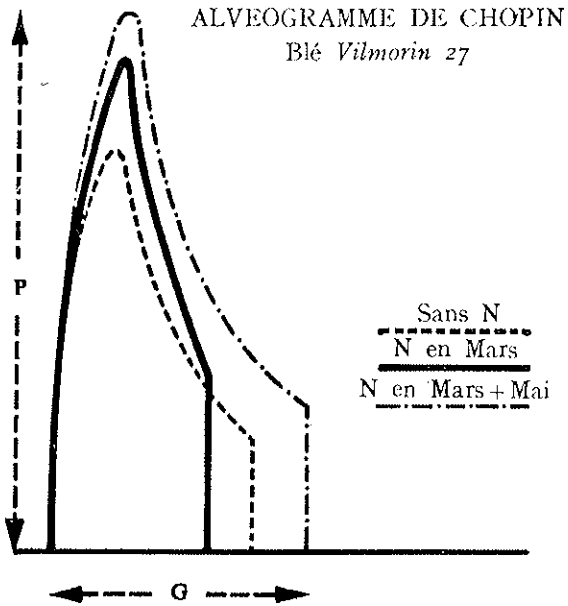
Vitrosité. Les grains enrichis en azote par la fertilisation azotée tardive ont un aspect vitreux (moins amidonneux) et plus anguleux que ceux produits par des blés ayant manqué d'azote après la floraison. Les données du tableau IV montrent que les différences entre variétés sont grandes à ce point de vue (différence entre *Yga* et Hybride 40). Cette vitrosité (absence de "mitadinage" du grain est une qualité essentielle des "blés durs" car elle conditionne le rendement en "semoules" destinées à la fabrication des pâtes alimentaires. Les différences variétales concernant la vitrosité ont donc été plus spécialement étudiées chez les "blés durs".

Alvéogramme Chopin. La valeur de la farine pour fabriquer le pain dépend essentiellement de son gluten: de sa qualité, qui dépend principalement de la variété, et de sa quantité. Pour le boulanger, la quantité d'eau absorbée par la farine pour obtenir la consistance voulue de la pâte est importante. La qualité élastique et cohésive de cette pâte est exprimée en France par la surface W et les caractéristiques de l'alvéogramme Chopin (où P indique la pression au moment où la bulle de pâte crève, et G le gonflement).

Dans l'expérience relatée au tableau III, on voit que l'azote apporté au Tallage (Mars) conduit à une diminution du taux d'azote du grain et la farine donne un alvéogramme dont le gonflement est inférieur à celui du témoin sans azote. Un supplément d'azote apporté à l'épiaison augmente considérablement le gonflement et le W. (graphique 1).

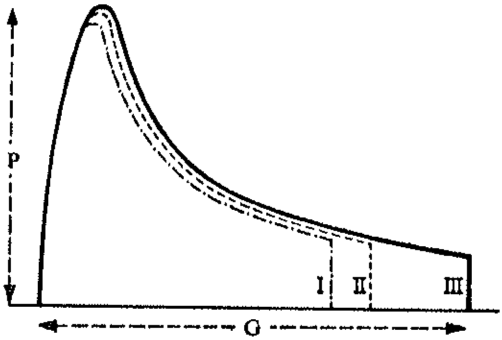
Dans les expériences relatées dans le tableau IV, la fertilisation azotée semie tardive (à la montaison) qui agit fortement sur le rendement modifie peu l'allure de l'alvéogramme et la valeur du W. Par contre la fertilisation tardive en augmentant le taux de gluten améliore le gonflement G et parfois la pression P, le W se trouvant ainsi nettement augmenté (graphiques 2).

Cystéine

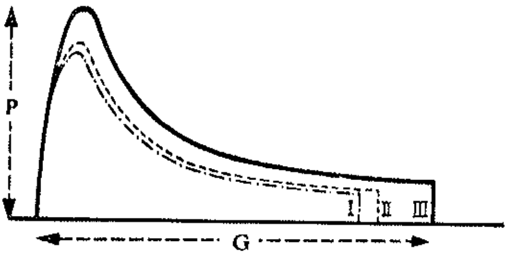


GRAPHIQUE 1

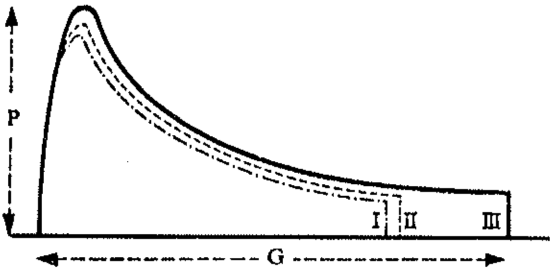
ALVEOGRAMMES



Yga



Hybride de Bersée



Hybride 40

GRAPHIQUES 2

Les essais effectués au *farinographe de Brabender* ont montré que l'absorption d'eau pour amener la pâte à une consistance déterminée est plus forte pour les farines provenant de blés enrichis en azote par la fertilisation azotée tardive (graphiques 3).

Essais de panification: Ces épreuves ont été complétées par des essais de panification et les graphiques correspondant au tableau IV ont eu une influence très bénéfique sur l'absorption d'eau, le volume des pains et la note attribuée par le boulanger (graphiques 3, 4 et 5).

Ces expériences de fumure azotée montrent clairement que l'on peut associer rendement et qualité.

2) *Variation de la composition des protides.*

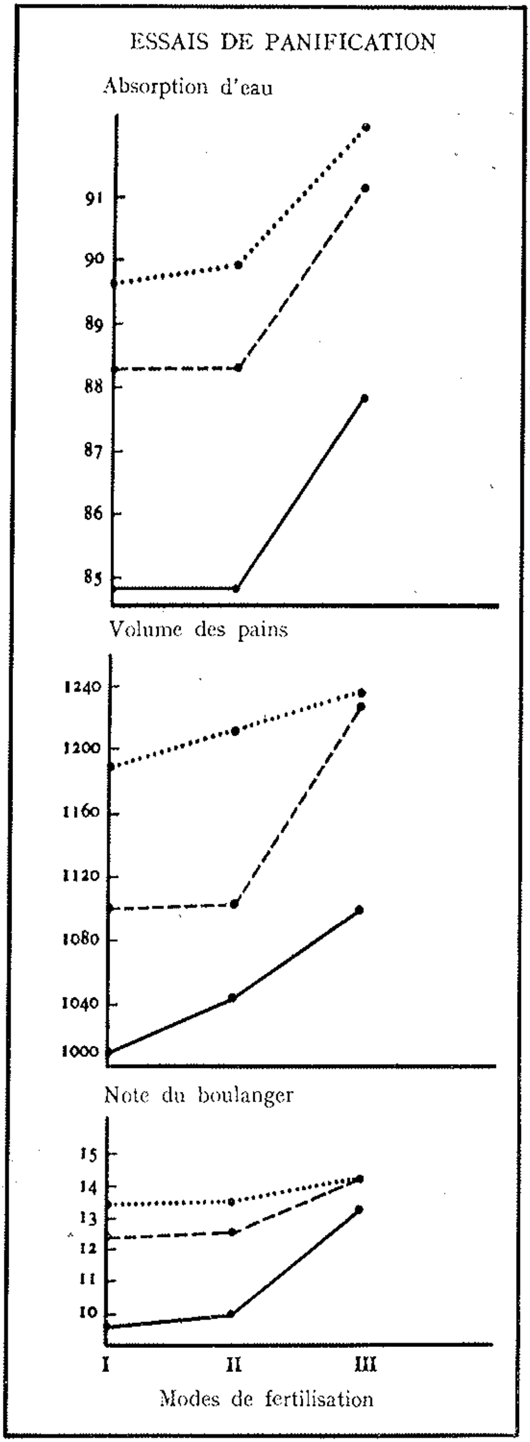
On considère généralement que *les protéines* d'un organe d'une espèce végétale déterminée n'ont pas un grand potentiel de variabilité de leur composition: le tableau V nous permet par exemple de voir que les compositions en acides aminés des protides du grain de trois variétés, une de blé tendre, deux de blé dur, sont très voisines.

Lorsque les protides sont constitués d'une certaine proportion d'azote organique "soluble" la variation de la proportion de cet azote soluble, dont la composition en acides aminés est différente de celle de la protéine, ainsi que *la variation de composition de cet azote soluble* modifient la composition des protides globaux.

a) *Variation de la proportion et composition de l'azote organique soluble.*

— *Influence du type de nutrition azotée: "nitrique" ou "ammoniacale".*

Par rapport à l'alimentation nitrique, l'alimentation ammoniacale conduit à une accumulation d'azote organique soluble et plus particulièrement des amides (glutamine ou asparagine suivant les espèces végétales).



GRAPHIQUES 3, 4 et 5 — I, II et III = Modes de fertilisation correspondant au tableau IV.

— *Déficience et éléments minéraux.*

Les protides sont des constituants fondamentaux de la matière vivante et l'on peut dire que tout grave déficience en un élément quelconque affecte plus ou moins la synthèse protéique.

En dehors de l'azote, le soufre est un élément constitutif des protéines puisqu'il fait partie de deux acides aminés, la cystéine et la méthionine que l'on rencontre dans toutes les protéines. La déficience en soufre se traduit par une accumulation "d'azote soluble", c'est-à-dire d'acides aminés et de peptides qui n'ont pu être utilisés à l'édification des protéines.

Il en est de même de l'action d'autres éléments qui, n'étant pas des constituants des protéines, sont impliqués dans leur synthèse. La déficience en potassium conduit aussi à l'accumulation d'azote soluble dans la plante.

b) *Variation de la composition des protéines.*

α) *effet de la nutrition azotée* (Y. Coïc et al. 1963).

On considère que la composition en acides aminés des protides du grain de blé est peu variable.

Cependant nous avons montré que l'enrichissement en azote du grain par une nutrition azotée tardive, enrichissement allant de 33% pour Florence-Aurore (blé tendre) à 40% pour Oued zénati (blé dur), avait pour conséquence une modification de la composition en acides aminés des protides du grain.

Les proportions d'acide glutamique (ou plutôt de glutamine) et de proline augmentent très nettement (de 6 à 13%), celle de phénylalanine augmente aussi mais moins nettement. Les proportions des autres acides aminés diminuent passivement (de 3 à 4%) mais certains diminuent plus fortement: la lysine (8 à 14%) la glycine et l'alanine (de 8 à 13%).

La variation de la composition en acides aminés des protides du grain de blé traduit l'accumulation préférentielle de la gliadine (groupe des prolamines) qui contient une très forte proportion de glutamine et est très pauvre en lysine (Mossé et al. 1966).

TABLEAU IV.

	Rendements (quintaux à l'hectare)	Poids de l'hl	W	En % du témoin	Matière protéique (N × 5,7) en % de la farine	Matière protéique (N × 5,7) en % du témoin	Vitrosité %
Expérience 1952							
Yga							
I. 70 kg N février — mars	42,5	80,4	96		7,60		10
II. 70 kg février — mars							
+ 25 kg N fin avril	49,5	80,8	108	113	7,85	103	30
fII. 70 kg février — mars							
+ 25 kg N fin avril							
+ 25 kg N fin mai	51	82,4	130	135	9,90	130	70
Hybride de Bersée							
I. Février — mars	41,5	79,6	45		6,70		0
II. Février — mars + avril	52	79,6	47	105	7,20	107	10
III. Février — mars + avril + mai	54,5	80,8	65	144	8,70	130	40
Hybride 40							
I. Février — mars	39 5	79,2	65		7,30		0
II. Février — mars + avril	47,5	80	70	108	7,35	101	10
III. Février — mars + avril + mai	49	81,2	94	145	9,60	131	40

TABLEAU V — *Variation de la composition des protides du grain de variété de blé sous l'effet de l'enrichissement en azote du grain par la fumure azotée tardive.* (Les acides aminés sont exprimés en grammes pour 16 grammes d'azote).

	Florence-Aurore — N tardif	Florence-Aurore + N tardif	Florence-Aurore + N tardif / — N tardif	Oued zénati — N tardif	Oued zénati + N tardif	Oued zénati + N tardif / — N tardif	Mahmoudi — N tardif	Mahmoudi + N tardif	Mahmoudi + N tardif / — N tardif
N × 6,25 % de M.S.	12,0	16,0	1,33	11,7	16,3	1,40	12,0	16,7	1,39
Acide aspartique	4,8	4,2	0,87	4,9	4,5	0,92	4,8	4,5	0,94
Thréonine	3,0	2,6	0,87	3,0	2,8	0,93	2,9	2,7	0,93
Sérine	4,4	4,2	0,95	4,5	4,5	1,0	4,4	4,3	0,98
Acide glutamique	28,5	30,2	1,06	27,6	30,6	1,11	27,7	30,3	1,09
Proline	9,2	10,0	1,09	9,2	10,4	1,13	9,6	10,3	1,07
Glycine	4,1	3,6	0,88	3,9	3,5	0,90	3,8	3,5	0,92
Alanine	3,6	3,0	0,83	3,6	3,3	0,92	3,5	3,2	0,91
Valine	4,3	3,7	0,86	4,4	4,1	0,93	4,4	4,2	0,95
Cystine	3,0	3,0	1,00	2,8	2,6	0,93	2,6	2,4	0,92
Méthionine	1,4	1,1	0,78	1,3	1,6	1,23	1,3	1,3	1,00
Isoleucine	3,4	3,2	0,94	3,4	3,5	1,03	3,5	3,5	1,00
Leucine	6,3	6,1	0,97	6,6	6,7	1,02	6,7	6,6	0,98
Tyrosine	2,8	2,7	0,96	2,5	2,8	1,12	2,8	2,8	1,00
Phénylalanine	4,0	4,1	1,02	4,2	4,5	1,07	4,4	4,5	1,02
Lysine	2,8	2,5	0,89	2,9	2,5	0,86	2,7	2,5	0,92
Histidine	2,2	2,2	1,00	2,6	2,4	0,92	2,3	2,4	1,04
Tryptophane	—	—	—	—	—	—	—	—	—
Arginine	4,8	4,5	0,94	4,9	4,5	0,92	4,6	4,6	1,00

La valeur nutritionnelle des *protides* du grain, enrichi en azote par une nutrition azotée tardive, est diminuée, mais il n'en est pas de même de la valeur nutritionnelle du *grain* car l'enrichissement en protides du grain conduit en définitive à un enrichissement du grain en acides aminés indispensables.

L'effet de la nutrition azotée est le même chez l'orge (Y. Coïc et al. 1963). Mais il n'y a pas que chez les céréales à prolamines où l'on voit baisser la teneur en acides aminés indispensables. Pour le tournesol il en est de même lorsque l'on fait varier considérablement la teneur en azote de l'amande

TABLEAU VI — *Variation de la composition des protides de l'amande de la graine de Tournesol sous l'effet de la variation de la nutrition azotée.* (Les acides aminés sont exprimés en grammes pour 16 grammes d'azote).

	n sans nt	n avec nt	N sans Nt	N avec Nt
ac. aspartique	9,75	9,65	9,65	9,9
ac. glutamique	21,25	22,8	24,05	24,3
Sérine	4,15	4,05	4,05	4,0
Thréonine	3,75	3,45	3,4	3,2
Glycine	6,1	5,65	5,4	5,35
Alanine	4,1	4,0	3,9	3,8
Valine	5,1	5,25	5,0	5,15
Leucine	6,3	6,3	6,35	6,1
Isoleucine	4,0	4,4	4,25	4,1
Tyrosine	2,8	2,65	2,6	2,6
Phénylalanine	4,65	4,65	4,65	4,6
Proline	4,5	4,6	4,4	4,45
Lysine	3,7	3,0	2,9	2,75
Histidine	2,5	2,25	2,25	2,15
Arginine	8,5	8,95	9,2	9,4
Total	94,8	94,85	94,85	95,0

n = 4 milliéquivalents de NO_3^- par litre de solution nutritive.
N = 12 milliéquivalents de NO_3^- par litre de solution nutritive.
t = tardif c'est à dire après floraison.

TABLEAU VII — *Variation de la composition des protides du grain d'orge sous l'effet de la carence en soufre.* (Les acides aminés sont exprimés en grammes pour 16 grammes d'azote).

	+ S	— S	+ S / — S
N × 6,25 % M.S.	15,3	17,4	
Acide aspartique	4,8	6,5	1,35
Thréonine	2,95	2,7	0,91
Sérine	3,9	3,65	0,94
Acide glutamique	24,2	25,9	1,07
Proline	14,0	14,4	1,03
Glycine	3,4	3,15	0,93
Alanine	3,5	3,2	0,91
Valine	4,6	3,95	0,86
Cystine	2,1	1,3	0,62
Méthionine	1,1	1,0	0,91
Isoleucine	3,3	3,1	0,94
Leucine	6,4	5,8	0,91
Tyrosine	2,95	2,7	0,91
Phénylalanine	5,2	6,1	1,17
Lysine	3,2	2,75	0,86
Histidine	2,05	1,8	0,88
Arginine	3,95	3,8	0,96

de la graine par une variation très grande de la fertilisation azotée (voir tableau VI). Comme pour le blé et l'orge, si les teneurs en acides aminés indispensable des protides baissent, celles de la graine augmente.

β) *effet de la déficience en autres éléments minéraux.*

Ces déficiences aboutissent généralement à nn accroissement de la teneur en protides des graines ainsi que nous l'avons montré pour le Phosphore. L'effet constaté sur la qualité des protides du grain est fonction de cette variation de la teneur en protides (Y. Coïc et al. 1963).

γ) *effet de la déficience en Soufre* (Y. Coïc et al. 1963).

Le Soufre a un rôle essentiel dans la synthèse des protides. En plus de l'action de la déficience en Soufre sur accroissement de la teneur en protides du grain, on constate un effet spécifique: augmentation très nette de la proportion d'acide aspartique (ou plutôt asparagine) dans les protides et baisse très forte de la teneur en cystine alors que celle de la teneur en méthionine est faible (Y. Coïc et al.).

V - Les principes de fertilisation minerale.

La fertilisation en Pet K ne pose pas de gros problèmes: amener le sol à un état de richesse dépendant de l'ensemble des cultures entrant dans un assolement; restituer les exportations et les pertes par la fumure annuelle en tenant compte de l'intensité des besoins (besoin par unité de temps) de la culture. Les apports de Calcium et de Magnésium ne posent pas de problème. Il en est de même du Soufre, si ce n'est que d'un point de vue global, il disparait peu à peu de la fumure en tant qu'élément accessoire. Nous avons dit que les oligo-éléments posaient un problème difficile sous l'angle de la qualité des produits agricoles.

La fertilisation azotée pose des problèmes ardus en culture intensive.

Problèmes immédiats:

— on a souvent dit que la fumure azotée était par excellence une fumure annuelle. Elle l'est en effet en raison des considérations suivantes;

— l'azote minéral est en général rapidement utilisé (sous forme NO_3^- qui circule facilement dans le sol) en donnant des substances azotées qui sont les constituants pondéralement essentiels de la matière *vivante*. Il conditionne donc primairement la croissance. En conséquence, l'Agriculteur peut se servir de la fumure azotée pour diriger la croissance de la culture conformément au but poursuivi: c'est ce qu'il fait pour le blé, en recherchant le meilleur équilibre entre densité de semis et fumure azotée (Y. Coïc);

— cette fumure doit complémenter en quantité et au moment voulu la fourniture d'azote minéral fourni par le sol. Comme la minéralisation d'une faible fraction de la matière organique azotée du sol est, d'une part, fort variable en quantité et dans le temps suivant les sols, les climats, les précédents culturaux, les fumures antérieures... et, d'autre part, suivant les conditions climatiques de l'année, on conçoit la difficulté d'assurer une fumure azotée parfaite.

La fumure azotée dépend évidemment du type de culture: parce que les besoins globaux des cultures sont différents; parce que les expressions biochimiques de la qualité des récoltes sont différentes; parce que l'utilisation de l'azote minéral se présente de façon tout à fait différente suivant les plantes. Nous avons indiqué les différences de puissance du métabolisme de l'azote minéral dans la racine des divers genres végétaux. Il faut aussi souligner que certaines plantes peuvent accumuler de grandes quantités de nitrates dans les feuilles et les tiges: par exemple le tabac, le tournesol, peuvent accumuler dans la moelle de leurs tiges de grandes quantités de nitrates (Y. Coïc et al. 1969, 1971).

TABLEAU VIII — *N de NO_3 (‰ de Matière sèche) dans les organes du Tournesol à la récolte.*

	Feuilles jeunes	Feuilles vieilles	Tiges + Pétioles parties jeunes	Tiges + Pétioles parties vieilles
n sans nt	traces	traces	3,3	3,2
n avec nt	traces	0,1	17,1	15,3
N sans Nt	traces	0,3	12,9	17,5
N avec Nt	0,2	0,6	16,6	21,3

Ainsi pour obtenir une forte teneur des graines de Tournesol en matières azotées il suffit d'assurer une bonne alimentation azotée avant floraison car elle a plus d'action que la fumure azotée tardive. Nous avons vu qu'il en était tout autrement pour le blé.

TABLEAU IX.

	Huile (% de l'amande sèche)	récolte de huile (g par plante)	Protéines (N × 6,25) (% de l'amande sèche)	indice	récolte de protides (g par plante)	Protides (% de tourteau d'amande sec)
n sans nt	62,8	7,6	22,0	100	2,65	59
n avec nt	58,4	10,9	29,6	134	5,50	71
N sans Nt	51,9	24,5	34,7	158	16,40	72
N avec Nt	49,0	23,7	37,9	172	18,30	74

Problèmes ultérieurs.

L'accroissement des apports d'engrais et notamment d'engrais azotés pour mieux satisfaire les besoins des cultures, a permis d'augmenter les rendements et corrélativement, les résidus de matières organiques et en particulier de matières organiques azotées. Il en résulte un *accroissement continu de la quantité d'azote minéral fourni par le sol aux culture.* A mesure que la *productivité variétale* croit, l'apport d'engrais azotés, qui, au cours d'un assolement, doit au moins restituer les exportations plus les pertes d'azote, croit parallèlement. Toutefois, il se trouve que la fumure azotée d'une culture particulière (blé par exemple) suivant tel précédent cultural devienne assez difficile, en raison de la grande quantité d'azote fournie par le sol et qui échappe à notre contrôle.

VI - Conclusion.

Grâce aux travaux des physiologistes, nutritionistes, technologistes, nous connaissons mieux les besoins de l'homme, des animaux, des industries agricoles; c'est-à-dire que ces besoins peuvent s'exprimer de façon plus concrète.

Grâce aux recherches faites sur les plantes cultivées et le milieu dans lequel elles vivent, nous pouvons déjà concevoir dans certains cas particuliers des nutritions minérales et réaliser des fumures qui conduisent à l'obtention de rendements élevés de récoltes de bonne qualité.

Il reste beaucoup de progrès à réaliser, et pour les obtenir une collaboration est absolument nécessaire entre les chercheurs s'occupant de production végétale et ceux intéressés aux besoins des utilisateurs.

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FERTILITA' DEL SUOLO E FERTILIZZAZIONE DEI VEGETALI COLTIVATI

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Una settimana di studi sull'impiego dei fertilizzanti richiede in primo luogo un preliminare aggiornamento sul concetto di fertilità e sulle nuove conoscenze relative alla nutrizione delle piante in rapporto al processo di assorbimento e trasporto dei principi nutritivi da parte dei vegetali coltivati. Naturalmente si tratta di una esigenza che con il progresso e l'approfondimento delle conoscenze del suolo e della pianta è divenuta sempre più importante.

Le moderne concezioni dell'assorbimento radicale, le numerose correlazioni che sul piano fisiologico ed agronomico condizionano lo sviluppo e la produttività delle colture e, soprattutto, il rapido cambiamento dei differenti concimi che l'industria mette a disposizione degli agricoltori, reclamano da parte dei tecnici e dei pratici della fertilizzazione una grande considerazione per la coerenza pedologica e fisiologica dei concimi stessi e per i modi e i limiti del loro impiego.

Più della metà dei concimi che venivano impiegati nel primo dopo guerra non si trovano più in commercio e s'impiegano oggi prodotti che allora non esistevano. Per queste ragioni il concetto di fertilità, e la sostanza degli stessi processi di fertilizzazione acquistano dei nuovi e più esatti significati operativi.

In relazione a queste necessità noi abbiamo preferito in questa relazione soffermarci sui problemi generali della fertilità e della fertilizzazione.

Contrapporre la fertilità del suolo alla pratica della fertilizzazione che, nella comune accezione, oggi significa ormai fertilizzazione chimica, costituisce, a mio avviso, una impostazione non del tutto corretta ed aperta a qualche pericolosa interpretazione poiché può facilmente favorire l'illusoria convinzione che la fertilità del suolo possa trovare il suo potenziamento nella sola somministrazione di fertilizzanti chimici.

Anche prescindendo da tale considerazione il tema proposto per la mia relazione richiederebbe per il suo svolgimento non quaranta minuti, ma un intero corso di lezioni. Mi limiterò quindi a svolgere l'argomento in modo riassuntivo sottolineando soprattutto gli aspetti più significativi della fertilità e della fertilizzazione in rapporto alle attuali condizioni dell'esercizio agronomico.

Vorrei, in primo luogo, soffermarmi succintamente sopra la definizione del concetto di fertilità che rappresenta una funzione complessa di numerose variabili, la maggior parte delle quali non risulta né semplice né indipendente.

Molti agronomi illustri, e ne ricordo uno il DEMOLON, sostengono che la fertilità non è suscettibile di una precisa e assoluta definizione, ma costituisce l'espressione di una constatazione sperimentale che si riassume nell'attitudine di un terreno a favorire dei raccolti più o meno elevati.

Senza entrare nel dettaglio e considerandolo globalmente, il concetto di fertilità corrisponde a quella che COSIMO RIDOLFI ha definito a suo tempo "la mirabile attitudine a produrre del terreno agrario". Si tratta come è evidente di un concetto assai polivalente che ha condotto chimici agrari, agronomi ed economisti a considerare tutta una serie di fattori, il cui intervento tende a modificare la produttività del suolo attraverso effetti specifici che, per essere temporanei e per manifestare la loro efficacia entro certi limiti, determinano quasi sempre situazioni essenzialmente dinamiche capaci di mutare più o meno rapidamente. Cosicché la fertilità risulta la componente di una vasta serie di fattori che manifestano la capacità di accrescere la produzione unitaria delle piante coltivate e che non tutti possono venir modificati dall'intervento dell'uomo.

L'*ubicazione*, la *latitudine* e l'*altitudine* del suolo e soprattutto le *condizioni climatiche*, che agiscono sul terreno e sulla vegetazione e sulle quali appunto l'agricoltore non ha possibilità pratiche di intervento, costituiscono dei parametri di particolare importanza per la fissazione degli indici numerici di cui l'esperto può far tesoro per stabilire, in un determinato territorio, una scala che possa agevolare la valutazione della fertilità in accordo con i risultati dell'esperienza.

La *giacitura*, che può venir modificata con lavori di spianamento e di terrazzamento; la *profondità dello strato coltivabile*, che può essere aumentato con opportuni lavori di scasso, e la presenza di un copioso *scheletro grossolano*, sul quale oggi in qualche caso è possibile intervenire in modo soddisfacente, formano invece una categoria di fattori suscettibili di possibili e sostanziali miglioramenti.

Ma quello che vorrei prendere in particolare considerazione, insieme ai dissodamenti è lo stato *sistematorio superficiale del terreno* che, a prescindere dagli altri fattori della fertilità, molto spesso condiziona la produttività delle colture agrarie.

Quando il terreno non è ben livellato, alle prime piogge che si verificano dopo la semina, specie se il terreno contiene costituenti colloidali organici od inorganici che ne frustano la permeabilità, si formano ristagni d'acqua capaci di provocare l'asfissia del seme con conseguenti cospicue riduzioni delle rese unitarie.

Non è difficile constatare anche nelle agricolture della nostra Europa, dove la lavorazione del terreno non viene eseguita a regola d'arte, trascurando per esempio il livellamento del terreno, che le rese unitarie risultano inspiegabilmente basse anche quando non c'è difetto negli altri elementi della fertilità, quale conseguenza appunto di tale vizio costituzionale.

Sempre nell'ambito della sistemazione superficiale del terreno, accanto al livellamento delle superfici, c'è da considerare la conseguente correzione delle pendenze affinché la raccolta frazionata delle acque di sgrondo impedisca rovinose conseguenze a valle.

La disponibilità di acqua nella quantità sufficiente per i bisogni idrici delle colture o l'eccesso di umidità che determinano difficili condizioni di vita per l'apparato radicale delle colture e cioè il generale stato idrico del terreno, sono fattori essenziali per la fertilità. Si tratta comunque di fattori che, generalmente, l'agricoltore può modificare più o meno agevolmente in funzione delle disponibilità e della situazione territoriale in senso favorevole allo sviluppo vegetale e quindi alla promozione di un più elevato livello di fertilità.

Abbiamo fin'ora accennato a quella serie di fattori che riguardano essenzialmente la fertilità di posizione o generale del terreno, parte dei quali risultano suscettibili di agevole modificazione; vorrei ora soffermarmi sulla tessitura e sulla struttura, alle quali risulta legata la capacità per l'acqua e per l'aria del terreno e che danno corpo alla cosiddetta fertilità fisica, la cui importanza appare prioritaria e condizionante della fertilità costituzionale.

Come è noto le proprietà fisiche del suolo risultano fondamentalmente legate alla tessitura e alla struttura. Frequentemente si confonde il significato di tessitura con quello di struttura non tenendo conto della loro profonda diversità. La tessitura infatti è legata alla grandezza delle particelle elementari e corrisponde alla cosiddetta composizione granulometrica. La struttura invece riguarda il modo con il quale le particelle si raggruppano tra di loro. Da questi due fattori dipende, come abbiamo già accennato, il comportamento del suolo rispetto all'aria e all'acqua. Mentre nella definizione di tessitura domina il principio dimensionale, in quello di struttura prevale quello della distribuzione nello spazio dei singoli elementi costitutivi. Nella tessitura le unità sono rappresentate dalle particelle fondamentali: sabbia grossa, sabbia fine, limo e argilla, ma non è inutile ricordare che le caratteristiche fisico-meccaniche del terreno non dipendono soltanto dal fattore dimensionale essendo inoltre legate al tipo di limo e soprattutto al tipo di argilla contenuta nel terreno.

Quando il terreno è troppo leggero o troppo pesante in ordine alla sua costituzione fisico-meccanica si provvede come è noto al suo ammendamento che consiste nell'aggiunta di materiale sabbioso nei terreni troppo pesanti o di materiale argilloso nei terreni troppo leggeri, quando naturalmente si ravvisano le possibilità obiettive ed economiche per la loro realizzazione.

Nella struttura del suolo si riscontrano invece, come unità fondamentali, gli aggregati elementari i quali possono anche riunirsi tra di loro per formare unità strutturali di più elevate dimensioni.

L'importanza della struttura è considerevole per la fertilità perché influisce sulla capacità di immagazzinare acqua e aria e spiega un ruolo di notevole rilievo sulla resistenza del suolo all'erosione, condizionando lo stesso processo di lisciviazione e la stessa permeabilità. Le nuove tecniche colturali, l'impiego sempre più frequente di macchine per la lavorazione del terreno e soprattutto il ridotto apporto di sostanza organica hanno, in questi ultimi decenni, determinato un generale decadimento della struttura dei terreni agrari.

L'insufficiente stabilità di struttura che dipende dalla tenacità dei cementi organici e inorganici nella maggior parte dei suoli coltivati, rende più incisivo il disastroso effetto della erosione idro-meteorica che, in breve tempo, può determinare la perdita di quello strato superficiale nel quale risiede la maggior parte della fertilità chimica del terreno agrario.

Non è qui il caso di approfondire il tema degli aggregati e dei cementi che contribuiscono alla stabilità degli aggregati, ma reputo necessario accennare che tutta una serie di fattori possono rigenerare la struttura ed aumentare la stabilità strutturale, il che si risolve in un aumento della porosità. Incorporando lavoro meccanico, il cui effetto è quello di elevare il centro di gravità dello spessore attivo del suolo aumentando il suo peso specifico apparente, si viene a suscitare il manifestarsi di alcuni fenomeni che possono condizionare positivamente la stessa formazione dei cementi. E' noto che la produzione dei leganti viene favorita da copiose somministrazioni di sostanza organica e da bene indirizzate trasformazioni microbiologiche della sostanza organica stessa, oppure dall'aggiunta di condizionatori come il "Flotal", utilizzato un tempo in Italia o di alcuni polimeri sintetici, come il Krilium e il Vama, ed infine per opera di alcuni composti naturali di origine vegetale che si riscontrano appunto nel terreno e che contengono per loro natura sostanze con costituzione e funzioni analoghe a quelle dei polimeri sintetici.

La piena fertilità del terreno agrario richiede che questo manifesti nella giusta misura alcune attività catalitiche ed enzimatiche capaci di promuovere ed accelerare tutta una serie di trasformazioni dirette alla formazione di numerosi metaboliti che caratterizzano il chimismo attivo del terreno. Tra le attività catalitiche ricordiamo l'attività ossidasica legata prevalentemente alla presenza nel terreno dell'ossido di manganese idrato che determina la trasformazione dell'ossido di carbonio in anidride carbonica e della cianamide in urea secondo il classico schema di CELSO ULPIANI. Cosicché, un terreno che non sia dotato di tale attività come per esempio si è verificato tra l'altro nelle terre fortemente calcaree di Grisolera (Venezia) non si compie quella trasformazione della cianamide nei prodotti più facilmente assimilabili da parte delle colture.

Anche l'ossidazione dell'ammoniaca promossa dal biossido di manganese, studiata nel 1904 da FAUSTO SESTINI e successivamente da DE ROSSI e da RUSSELL e SMITH, costituisce un'attività del terreno capace di formare acido nitrico e mettere quindi questa forma azotata a libera disposizione della pianta. E' noto che i processi di ossidazione catalitica decorrono nel terreno agrario in misura considerevole quando l'azione degli ossidi metallici si manifesta sotto l'influenza delle radiazioni luminose.

A questo proposito dobbiamo ricordare le indagini compiute sull'ossidazione fotochimica nel terreno da GOPAL RAO e da DHAR i quali attribuiscono tale potere anche agli ossidi di titano, alluminio e silice.

Le attività enzimatiche si manifestano nel terreno per la presenza degli enzimi tissulari che i resti vegetali convogliano nel terreno stesso e quelli di origine batterica e fungina. Riguardano l'attività catalasica; quella ureasica, alla quale si deve particolarmente la rapida trasformazione dell'urea fertilizzante in ammoniaca, quella cellulasica, fosfatica, amilasica, proteasica e depolimerizzante. Quest'ultima attività assume un'importanza di notevole rilievo per la trasformazione dei polifosfati che sono oramai entrati largamente nell'uso agricolo e per la degradazione dei surfattanti il cui accumulo e la cui persistenza finirebbe per determinare effetti sfavorevoli per la struttura del terreno insieme ad alcune azioni antimitotiche capaci di mortificare lo sviluppo radicale delle piante.

Vorrei ricordare nel dettaglio anche l'attività fitasica e lecitinasica, che contribuiscono alla mobilità del fosforo organico contenuto nel terreno, ma mi pare sufficiente avere ricordato queste essenziali caratteristiche del terreno che sono intimamente legate alla trasformazione di alcuni composti insolubili nelle forme più facilmente assimilabili da parte delle colture e che conseguentemente costituiscono un importante fattore della fertilità.

Reputo conveniente accennare appena alla fertilità microbica del terreno senza la quale i cicli della mineralizzazione della sostanza organica, della fissazione dell'azoto atmosferico e del processo di nitrificazione non si svolgerebbero in modo economico e tempestivo con grave danno per l'assorbimento nutrizionale delle colture.

Prima di considerare i fattori della fertilità costituzionale che comprendono lo stato chimico-fisico e chimico, vorrei sottolineare che il moderno sviluppo agricolo ci ha condotto negli ultimi decenni all'esercizio agronomico su substrati speciali inerti o come si dice generalmente, con un termine non sempre legittimo, in coltura idroponica.

C'è da rilevare a questo proposito che a causa delle trasformazioni che subisce il materiale solido nel tempo, il concetto della fertilità fisica che potrebbe apparire semplificato per l'assoluta assenza di colloidi di natura organica ed inorganica, riprende invece, per effetto delle trasformazioni pedogenetiche che si manifestano nel substrato, quasi tutte le sue dimensioni strettamente pedologiche. Per tale ragione quando nelle colture idroponiche si impiega come substrato del materiale facilmente decomponibile, risorgono tutti i problemi che investono le correlazioni tra la fertilità e le caratteristiche generali del terreno agrario.

Il rapporto tra proprietà fisico-chimiche e fertilità del terreno è contraddistinto dal valore della concentrazione idrogenionica o dall'indice pH. E' noto che le piante non tollerano gradi di acidità che vanno al di sotto dell'acidità dell'aceto e al di sopra dell'alcalinità dei carbonati di calcio.

D'altra parte in un terreno a reazione anomala gli elementi chimici macro e micro nutritivi possono insolubilizzarsi e così anche qnando la pianta riesce a tollerare tale reazione del mezzo, non riesce tuttavia per questa ragione a beneficare pienamente della fertilizzazione chimica.

Si tratta comunque di condizioni pedologiche in molti casi facilmente suscettibili di correzione. I correttivi dei terreni acidi e dei terreni alcalini riescono nella maggior parte dei casi a modificare favorevolmente la reazione anomala del terreno. Si tratta di operazioni oramai largamente introdotte nella pratica agronomica che reputo appunto sufficiente averne fatto appena un rapido cenno.

Per quanto poi riguarda la fertilità chimica vera e propria, prescindendo da tutti gli altri fattori della fertilità di cui abbiamo già discorso, è opportuno sottolineare che la composizione chimica del mezzo nutritivo agisce sull'aspetto e sulla velocità di accrescimento delle piante, sulla loro morfologia e composizione e quindi sulla configurazione dell'intero paesaggio vegetale, nonché sulla produzione utile delle colture agrarie.

Il tentativo di mettere in relazione il biochimismo della pianta con i componenti minerali del terreno risale agli albori della ricerca e fa parte delle prime meditazioni dei naturalisti; una spiegazione razionale delle varie influenze che i componenti inorganici del terreno spiegano sulla vita dei vegetali è però conquista piuttosto recente e sotto certi aspetti non ancora del tutto definitiva.

Lo spargimento delle ceneri sul terreno è del resto pratica antichissima, già caratteristica delle prime iniziative agronomiche. BERNARDO PALISSY scriveva nel 1563 che la notevole varietà di sali minerali che le piante richiedono per il loro sviluppo, viene prelevata dal terreno attraverso l'apparato radicale, ma i Georgici molto prima avevano intuito che le sostanze fertilizzanti aggiunte al terreno restituiscono ciò che le piante asportano durante il loro ciclo di sviluppo.

L'origine e il significato degli elementi minerali contenuti nelle piante sono rimasti tuttavia ancora per lungo tempo oggetto di controversia e soltanto nello scorso secolo è stata chiaramente dimostrata la indispensabilità di alcuni elementi minerali per la vita delle piante.

La prima esperienza sulla nutrizione minerale delle piante si deve a VAN HELMONT, ma solo nel 1699, uno studioso inglese il WOODWARD imposta una interessante esperienza chiarificatrice, che dirige il problema della nutrizione minerale delle piante sulla strada giusta. Egli puntualizza in primo luogo che le piante possono vivere con le radici immerse nell'acqua attingendo da questa gli elementi utili per il loro accrescimento e, con una serie di esperienze assai acute, dimostra che tale accrescimento risulta diverso a seconda che la pianta viene immersa nell'acqua di fiume, oppure nell'acqua di pioggia o nell'acqua estratta dal terreno.

Sulla base di queste interessanti osservazioni WOODWARD contesta in modo decisivo le conclusioni di VAN HELMONT e scrive in modo abbastanza conseguente, anche se non del tutto legittimo e corretto che "la terra e non l'acqua è la materia che costituisce i vegetali".

Nel 1727, qualche decennio dopo, HALES esegue un'altra serie di ricerche assai convergenti su questo tema, ma solo nel 1804 DE SAUSSURE esprime l'opinione che il suolo fornisce piccoli ma essenziali contributi per il nutrimento delle piante e dimostra sperimentalmente che se una pianta cresce in acqua esente da sostanze minerali, il contenuto in tali sostanze non aumenta se non corrispondentemente alle piccole quantità di materia inorganica che possono pervenire alle piante dal seme o dalla deposizione del pulviscolo presente nell'atmosfera. Malgrado questi chiari risultati sperimentali, permane l'opinione che le sostanze inorganiche presenti nei vegetali siano delle semplici inclusioni accidentali oppure dei misteriosi stimolanti, piuttosto che dei fattori nutritivi. I risultati delle esperienze di DE SAUSSURE vennero presi nella giusta considerazione solo 50 anni dopo. La teoria degli umisti verrà infatti definitivamente scardinata da GIUSTO LIEBIG con una critica molto acuta espressa in un famoso indirizzo che viene presentato nel 1840 all'Associazione Britannica del Progresso delle Scienze.

La pratica agronomica in parte aveva già anticipato queste conclusioni. Il solfato ammonico delle cokerie, il nitro delle caliche cilene, il guano del Perù, la farina di ossa e le fosforiti erano già stati largamente introdotti, insieme al letame, nella concimazione delle colture agrarie. E' evidente che dopo la formulazione della nuova dottrina della nutrizione minerale delle piante, la utilizzazione di queste sostanze, risulterà fortemente incrementata e l'industria chimica verrà così spinta verso quella serie di fruttuosi tentativi, succedutisi sul finire del secolo, che hanno poi condotto alla produzione dei nuovi fertilizzanti di sintesi.

La dottrina della nutrizione minerale delle piante, impostata nei suoi aspetti essenziali da G. LIEBIG nel 1840 trova la sua definitiva formulazione dopo le accurate indagini riguardanti la composizione delle ceneri e dopo lo studio successivo dei rapporti intercorrenti tra lo sviluppo dei vegetali e l'assorbimento degli elementi inorganici presenti nel terreno o nelle soluzioni nutritive

A questi importanti lavori partecipano BOUSSINGAULT e WOLF, WIAGNER, POLSTORFF e KNOP e ad una conclusione definitiva circa la indispensabilità degli elementi minerali per lo sviluppo e l'accrescimento delle piante, si perviene solo dopo il 1840, quando viene inaugurato il metodo di coltura delle piante in soluzione nutritiva che riesce a risolvere questo interrogativo, legittimando la sostanza stessa della nuova dottrina.

Con tali acquisizioni venne chiaramente accertata la funzione del terreno, quale sorgente di sali inorganici per le piante, e i dati della sperimentazione sull'accrescimento dei vegetali in soluzione nutritiva condussero alla conclusione che quando nel mezzo manca uno degli elementi organogeni: carbonio, idrogeno, azoto od il fosforo, solfo, potassio, calcio, magnesio e ferro le piante mostrano delle carenze e non riescono a completare per intero il loro ciclo vegetativo.

Su queste dieci colonne poggia per alcuni decenni la dottrina della nutrizione minerale e della fertilità chimica. Dobbiamo tuttavia rilevare che in queste classiche esperienze era sfuggita l'importanza e la utilità di alcuni elementi inorganici, assunti dalla pianta in quantità estremamente piccola e quasi sempre presenti nelle impurezze dei reagenti e negli stessi recipienti utilizzati per la condotta delle prove.

Le ricerche istituite successivamente e le nuove acquisizioni della moderna fisiologia vegetale, specie quelle riguardanti il ruolo degli enzimi nel chimismo dei processi metabolici, hanno dimostrato che accanto ai dieci macroelementi del Liebig ne vanno aggiunti ancora altri che le piante assorbono solo in tracce e che risultano ugualmente indispensabili allo sviluppo delle piante stesse.

A questi elementi è stato dato il nome di elementi minori o microelementi. A 100 anni dalle importanti scoperte di Liebig, oggi, noi viviamo il secondo rinascimento della nutrizione minerale delle piante. La serie degli elementi indispensabili per le piante è notevolmente aumentata e nel corso di questi ultimi decenni è stata messa in chiara evidenza l'importanza agronomica del manganese, molibdeno, zinco, boro, rame, cobalto e cioè gli elementi micro-nutritivi od oligodinamici, ai quali è legato il nome di Bertrand, di Scharrer e anche quello dell'italiano Gioacchino Carradori che già nel 1749, prima ancora che si fosse affermata la dottrina della nutrizione minerale delle piante, aveva chiaramente intravisto l'importanza di alcuni microelementi, non tanto per la loro azione specifica sul metabolismo vegetale, quanto per la loro influenza sopra lo sviluppo generale delle piante e la produttività stessa delle colture agrarie.

Si apre ora il terzo tempo della dottrina della nutrizione minerale delle piante: quello delle interazioni alimentari semplici e complesse, la cui conoscenza ha già suggerito profonde modifiche nella condotta della fertilizzazione delle colture.

Passando ora alla seconda parte della relazione, quella riguardante la fertilizzazione delle colture, debbo ricordare che a più di cento anni di distanza dalla formulazione della dottrina della nutrizione minerale delle piante permangono ancora comunemente due atteggiamenti opposti rispetto alla fertilizzazione chimica.

C'è l'atteggiamento degli agronomi che si preoccupano soprattutto della resa unitaria e ragionevolmente vedono nella fertilizzazione delle colture, comunque applicata, lo strumento fondamentale per conseguire un più elevato risultato agronomico. C'è poi l'atteggiamento degli igienisti che vedono nella fertilizzazione chimica una forzatura delle attitudini produttive della pianta con svantaggi sul piano qualitativo e sanitario.

Non posso far mio né l'uno né l'altro atteggiamento. Ognuno è in parte giusto e in parte sbagliato. Infatti una concimazione, affinché possa rispondere pienamente alle esigenze delle colture agrarie deve essere completa ed equilibrata. La qualificazione delle colture agrarie per l'alimentazione dell'uomo e degli animali domestici deve oggi tenere presente il gioco degli equilibri nutrizionali, che condizionano la produttività globale delle colture e nello stesso tempo incidono profondamente sulla qualità della produzione stessa. Nei vegetali la volontà di alimentarsi e la preferenza che si esprime attraverso l'assorbimento radicale selettivo, anche se non sono coordinate da una intelligenza razionale, si manifestano ugualmente in un quadro di azioni e reazioni strettamente coordinate e interdipendenti, la cui conoscenza appare condizione indispensabile per poter completare su solide basi la dottrina della nutrizione vegetale e per le norme da seguire ai fini di una economica e produttiva fertilizzazione del suolo.

Lo stesso meccanismo dell'assorbimento e del trasporto degli elementi di fertilità comporta l'esistenza di uno stretto coordinamento tra i diversi fattori che determinano l'accrescimento dei vegetali ed il loro rendimento specifico.

In definitiva occorre tener conto che il ruolo di un determinato elemento di fertilità non dipende soltanto dagli effetti diretti della sua concentrazione, ma anche dalle ripercussioni che esso manifesta su tutti gli altri fattori presenti nel sistema.

Nell'esercizio dell'agricoltura pratica, i fertilizzanti costituiscono senza alcun dubbio, se non il maggiore, uno dei più efficaci fattori tecnici per esaltare la produttività della terra.

La genetica, la meccanizzazione dei lavori agricoli, l'irrigazione, la difesa delle colture dalle cause nemiche, insieme alla fertilizzazione del suolo hanno manifestato, in questi ultimi decenni, un'influenza considerevole sulla produzione agricola globale del mondo intero; non v'è dubbio però che i grandi incrementi registrati nella produzione granaria dell'ultimo mezzo secolo dipendono in gran parte dalla quantità complessiva di fertilizzanti solubili somministrati alle colture.

Anche le notevoli produzioni dei Paesi agricoli di oltre oceano, che hanno determinato grandi disponibilità di prodotti alimentari per il consumo internazionale, sono legate ad una estesa applicazione di concimi solubili alle colture, mentre i Paesi rimasti all'impiego dei concimi insolubili-fosforiti, torba, concimi organici naturali di varia natura — trascurando i concimi a pronto effetto, hanno realizzato incrementi piuttosto modesti della produzione globale e unitaria malgrado i progressi conseguiti nel miglioramento degli altri fattori della produzione.

A questo proposito è interessante rilevare che, sul piano fisiologico, la pianta può nutrirsi anche se gli elementi di fertilità vengono offerti nel mezzo in concentrazioni estremamente piccole; per rispondere però ad esigenze di carattere agrario ed economico, le concentrazioni delle soluzioni del terreno, rispetto ai singoli elementi macro e micro nutrizionali, non devono scendere al di sotto di determinati livelli.

Da tale esigenza deriva la necessità di somministrare al terreno gli elementi di fertilità richiesti dalle colture nella copia e nella forma idonea a determinare nel terreno agrario condizioni ottime di concentrazione dei singoli elementi nutritivi.

E poiché lo sviluppo delle colture agrarie si manifesta soprattutto in relazione ai rapporti nei quali i vari elementi nutritivi si trovano nel terreno, il problema del fabbisogno delle piante va quindi riguardato comparativamente più che in senso assoluto, poiché la carenza di un determinato elemento può manifestarsi anche quando questo elemento viene somministrato in quantità cospicua se la sua quantità risulta sproporzionata rispetto agli altri elementi o comunque non corrispondente ai generali bisogni della nutrizione minerale della pianta.

I livelli della produttività unitaria nelle varie colture mostrano, nei diversi Paesi e nelle differenti regioni agrarie del mondo, differenze molto sensibili. Le produzioni medie di frumento nel periodo 1956/58 hanno avuto, in 40 Paesi scelti tra i più significativi per tale coltura, delle escursioni che variano da un minimo di 6,64 ad un massimo di 36,33 q.li ad ettaro e cioè in un rapporto da uno a sei.

Questa notevole oscillazione dei rendimenti unitari non trova sufficiente giustificazione nelle differenti caratteristiche dell'ambiente fisico; appare infatti legata in primo luogo al grado di sviluppo agricolo ed economico ed in misura ugualmente cospicua all'impiego dei mezzi tecnici. Anche gli aumenti che si sono manifestati in questi ultimi decenni appaiono chiaramente legati alla combinazione di alcuni fattori tra i quali presentano importanza essenziale: il miglioramento genetico, il controllo e la difesa delle colture, l'irrigazione, il miglioramento tecnologico o colturale, ma soprattutto l'impiego dei fertilizzanti.

Evidentemente l'applicazione di tali fattori richiede anche un'adeguata strutturazione delle aziende e condizioni economiche e sociali favorevoli allo sviluppo del processo produttivo. Le ricerche condotte nei maggiori Paesi del mondo hanno infatti dimostrato che le alte rese unitarie si riscontrano prevalentemente nei Paesi dove vengono applicate con grande diligenza le moderne tecniche agronomiche e dove il livello culturale del mondo rurale oltre che elevato risulta accompagnato da una chiara efficienza del settore tecnologico.

Per le riserve degli igenisti occorre ricordare che le esperienze compiute da ZEILER e coll. e da GERICKE in Germania hanno dimostrato che, quando i terreni vengono fertilizzati razionalmente, rispettando gli equilibri nutrizionali, i prodotti agricoli presentano caratteristiche alimentari superiori nei confronti di quelli provenienti dai terreni non concimati.

Consideriamo ora brevemente il complesso problema della scelta dei criteri e dei metodi per la misura della fertilità chimica del terreno.

Malgrado l'esperienza e la ricerca si siano esercitati per oltre un secolo su tale difficile argomento, l'accordo approssimato fra i diversi metodi e cioè l'indice di correlazione statistica tra i risultati conseguiti non possono essere considerati come una soluzione definitiva del problema, ma solo una prova di soddisfacente convergenza tra i metodi oggi più largamente applicati. Infatti né la copia degli elementi nutritivi e neanche la loro solubilità possono assumere pieno significato trattandosi in genere di elementi come fosforo, potassio, calcio e magnesio che, per essere trattenuti nei composti di assorbimento, presentano mutevole comportamento agronomico.

Per l'azoto, alla cui elaborazione concorre anche l'attività microbiologica del terreno — nel quale malgrado la ricchezza in azoto organico possono manifestarsi carenze azotate per la reazione anomala o per il suo stato riducente — l'apprezzamento del concetto di fertilità diviene ancor più difficile.

Considerazioni analoghe risultano valide anche per il fosforo, il potassio, il ferro e gli altri elementi di fertilità macro e micro nutritivi.

Quando la valutazione della fertilità chimica del terreno diviene strumento di guida per la tecnica delle concimazioni il metodo risolutivo ai fini pratici è quello diretto o agronomico delle prove di concimazioni eseguite in campo o in vaso a seconda della posizione del problema.

Anche i metodi indiretti, fisiologici, chimici, di estrazione biochimica, ecc., possono mostrare una certa attendibilità ai fini pratici purché i loro risultati si accordino con quelli del metodo agronomico diretto.

Per quanto riguarda la tecnica della fertilizzazione mi limiterò ad accennare ancora a due problemi generali riguardanti la produzione e l'impiego dei fertilizzanti chimici.

La produzione, come fatto tecnico, specie per il settore degli azotati non potrebbe presentare un panorama più soddisfacente di quello attuale. Altrettanto non si può dire dei fosfatici la cui preparazione, fatta eccezione per gli Stati Uniti dove si è manifestato un grande sviluppo dell'industria dei polifosfati, è rimasta ancorata alle vecchie tecnologie ed ai vecchi prodotti i quali, pur avendo spiegato un ruolo importante nel passato, presentano alcuni gravi inconvenienti nelle loro applicazioni ai terreni acidi o subacidi, dove l'anidride fosforica si insolubilizza facilmente formando fosfato di ferro e di alluminio.

L'esperienza di questi ultimi decenni ha poi dimostrato come, tra le lacune che sul piano tecnologico presenta l'esercizio dell'agricoltura, acquistino un certo significativo rilievo il modo e i limiti della fertilizzazione del suolo.

E' noto come il volume globale della produzione agraria dipenda fondamentalmente dalle attitudini delle specie coltivate ad adattarsi alle condizioni pedoclimatiche, dalla loro resistenza alle cause nemiche e dalla capacità delle colture ad avvantaggiarsi della fertilità del suolo.

Ma il grado di disinformazione su questi temi è ancora molto elevato e ritengo che questa deficienza costi molti cara alla economia dei diversi Paesi. Conviene, nell'interesse di tutti, togliere a certi specialisti l'illusione che per risolvere i problemi della produzione agricola e conseguentemente quelli dell'approvviggionamento di alimenti per tutta l'umanità, sia sufficiente aumentare il parco delle macchine agricole, il consumo dei fertilizzanti o degli antiparassitari, mentre è assolutamente necessario migliorare soprattutto i limiti, i tempi ed i modi di impiego di questi fattori endogeni della produzione per adeguarli alle reali necessità delle colture e della condnzione aziendale.

Nessuno pensa che ci si possa attendere una stretta correlazione tra quantità di fertilizzante impiegato e produzione agraria, dato che le disponibilità idriche, il clima, la lavorazione del terreno, la scelta delle varietà e delle sementi e le stesse pratiche colturali costituiscono, insieme ai fertilizzanti, altrettanti fattori capaci di condizionare la produttività delle colture. Non vi è dubbio però che quando un'ulteriore somministrazione di fertilizzante non determina un adeguato incremento della produzione, come si sta verificando in quasi tutto il mondo, la ragione non può che essere ricercata nel modo, nei tempi o nei limiti, secondo i quali la concimazione viene effettuata.

E' come dire cioè che con grandi sforzi si ottengono piccoli risultati e ciò significa che occorre ancora operare nel settore della fertilità del suolo e nella tecnica delle concimazioni, per adattare il concime al terreno e alla coltura, nel quadro di una più profonda conoscenza della nutrizione minerale delle piante.

I problemi difficili della fertilizzazione delle colture sono sempre stati numerosi e, malgrado il progresso compiuto negli ultimi decenni, alcuni rimangono ancora tali in ordine a cause di natura fisiologica, pedologica ed economica.

Dobbiamo ad esempio chiarire più a fondo la validità dei cosiddetti concimi complessi, conoscere meglio l'azione specifica delle varie forme dell'azoto, rispettare inoltre le relazioni e gli equilibri nutrizionali tra i vari elementi di fertilità ed infine considerare con maggior approfondimento scientifico e pratico le correlazioni esistenti tra concime-terreno e pianta.

Questi problemi richiedono soluzioni chiare che potranno illuminare gli agricoltori e divenire utili per la produttività agricola solo nel caso che le indagini vengano impostate in modo corretto e soprattutto condotte con grande rigore metodologico.

I vecchi fattori della produzione sono oggi in concorrenza con una più vasta serie di fattori conoscitivi, riguardanti il ciclo di sviluppo della vita vegetale in relazione alle condizioni ambientali e nel quadro delle complesse correlazioni esistenti tra tutti i fattori fisiologici che operano nel molteplice gioco degli equilibri naturali.

La scienza agronomica ha fin'ora perseguito quasi esclusivamente obiettivi di carattere quantitativo, ma per l'avvenire occorrerà guardare più addentro alle influenze dei fertilizzanti sulla qualità dei prodotti vegetali e della qualità della produzione animale per corrispondere più strettamente alle esigenze dei consumatori.

Ora è noto che le influenze di ordine qualitativo dipendono essenzialmente dai rapporti secondo i quali i vari elementi di fertilità sono presenti sulla mensa delle colture agrarie, per cui la concimazione equilibrata è condizione prima per il successo agronomico e per la maggiore produttività agricola.

Una più approfondita conoscenza di questi rapporti agevolerà certamente anche il migliore impiego dei fertilizzanti e farà di questo importante strumento della tecnica colturale un fattore di progresso e di prosperità economica per gli operatori agricoli e per le comunità nazionali.

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LA FERTILIZZAZIONE FLUIDA

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Signor Presidente, eminentissimi Colleghi. Delle due relazioni segnate nel programma io svolgerò soltanto la seconda. Ma forse è necessario che io spieghi la filosofia che mi ha portato a svolgere la seconda relazione. Quando, un anno fà, con VALENTINO HERNANDO, abbiamo dovuto scegliere fra le due relazioni che avevo proposto — la prima "Sulla fertilità del suolo e la fertilizzazione delle culture agrarie", la seconda "Sulla fertilizzazione liquida" — si venne nella determinazione di scegliere la fertilizzazione liquida. Successivamente ho fatto un viaggio in Francia e negli Stati Uniti per studiare questo problema e l'entusiasmo per la fertilizzazione liquida si è molto raffreddato per ragioni che spiegherò in seguito. Al mio ritorno da questi viaggi mi è sembrato che non valesse la pena di svolgere un tema che presentava molte incertezze e decisi di svolgere il primo: quello della fertilità. Ritenevo fosse necessario, sul piano filosofico, spiegare e chiarire le diverse componenti che concorrono alla formazione della fertilità del suolo. Generalmente la gente crede che la fertilità chimica coincida perfettamente con la fertilità generale del terreno e cioè la fertilità agronomica. A mio avviso questo costituisce un grande errore, perché può determinare false interpretazioni presso gli agricoltori, lasciando credere che basti aggiungere dei concimi chimici per innalzare la fertilità agronomica del terreno. Il ché non corrisponde alla realtà. Perché la fertilità agronomica, la fertilità del terreno, comprende diverse componenti. Esiste in primo luogo una fertilità fisica del terreno che è legata alla tessitura e alla struttura del terreno. Un terreno non bene strutturato, un terreno che non possegga una struttura resistente nel tempo, mal si presta per una razionale concimazione perché in tale terreno il concime non potrà manifestare tutta intera la sua influenza. Un terreno che non presenti una certa fertilità fisico-chimica, poco si presta a sopportare forti concimazioni, perché in tal caso il terreno può non manifestare in un certo grado quel potere assorbente, capace di trattenere gli ioni ammonio, potassio e quelli di anidride fosforica che altrimenti vengono dilavati dalle acque meteoriche. Il terreno deve, soprattutto, non discostarsi troppo dalla neutralità perché se il terreno presenta reazione anomala, il ché si verifica quando il pH va al di sotto dell'acidità del aceto, e al di sopra dell'alcalinità del carbonato di calcio, è difficile ottenere dalla concimazione risultati economicamente efficienti. In tal caso bisogna prima ricondurre il pH del terreno entro i giusti limiti e solo dopo tale operazione è possibile somministrare utilmente i fertilizzanti. Questi erano i temi che desideravo sviluppare.

D'altra parte, accanto alla fertilità fisica e fisico-chimica, ci sono anche altre componenti di cui non sempre si tiene debitamente conto. Per esempio, le attività chimiche, catalitiche, enzimatiche e microbiologiche, quando difettano, non solo rendono meno efficente la fertilizzazione delle culture, ma in certi casi una somministrazione di fertilizzanti in carenza di tali attività può portare addirittura a risultati diametralmente opposti a quelli che ci si proponeva di ottenere con la concimazione. Io vorrei portare soltanto due esempi per illustrare questo interessante aspetto. Se noi concimiamo con prodotti organici un terreno che non è dotato di una sufficiente carica microbica, la sostanza organica non si trasforma, rimane come mummificata. Ciò avviene, per esempio, nei terreni fortemente argillosi, riducenti, nei quali vengono quindi a mancare tra l'altro quei cementi che concorrono alla formazione delle strutture micellari del terreno. Sono d'accordo con il Collega COLWELL che l'altro giorno ha interloquito su questo argomento per sottolineare l'importanza della fertilizzazione organica. Quando le particelle del terreno in assenza di cementi organici non risultano tenacemente saldate in modo da formare strutture stabili, il terreno non presenta buona struttura né sufficiente stabilità di struttura, ed in tal caso non sarà mai un terreno che presenta una sufficiente capacità per l'aria, e quindi per l'ossigeno, come WELTE ha ragionevolmente ritenuto necessario, e per l'acqua. Senza l'acqua sappiamo come va la produzione agricola. Ognuno di noi sa benissimo che per formazione di un grammo di sostanza organica occorre che attraverso il culmo della pianta passi da 300/350 fino a 1.000/1.200 grammi di acqua. I consumi idrici sono estremamente elevati. Penso che senza considerare bene questi temi riesce molto difficile avere un quadro giusto della fertilità del terreno e ancora più difficile riesce trarre utili insegnamenti per la fertilizzazione delle colture. Un altro esempio desidero illustrare: quello relativo all'impiego dell'urea come fertilizzante azotato. Oggi in tutto il mondo si impiegano quantità molto elevate di urea. Talvolte mi domando se tutti i terreni sono provvisti di ureasi in quantità sufficiente per trasformare rapidamente la urea in carbonato d'ammonio. Quando il terreno è ben provvisto di ureasi l'urea fertilizzante si decompone rapidamente e la concimazione ureica assume il volume di una concimazione ammoniacale. Ma se per caso si tratta di un terreno di vecchia fertilità che non contiene o contiene una scarsa carica ureasica, la trasformazione ureolitica invece di manifestarsi con la velocità che nei casi normali è caraterizzata da una vita media di quattro o cinque giorni — il ché significa che in quattro o cinque giorni la metà dell'urea si trasforma in ammoniaca — procede più lentamente o si arresta del tutto, e allora l'urea, invece di convertirsi in carbonato ammonico, marcia in una altra direzione, che ci ha segnalato WÖHLER nel 1828, un secolo e mezzo fà. L'urea si trasforma in cianato ammonico per una azione di isomerizzazione e quando compare l'ione cianico, che è terribilmente anti-mitotico a concentrazioni dell'ordine del 0,0001%, vengono distrutte radici e plantule con conseguente mortificazione delle colture. Ho portato questi esempi per mettere in evidenza come non sia importante considerare solo la fertilità chimica o fisica o fisico-chimica, o chimico-fisica, ma parimente tutte quelle attività di natura chimica, catalica, enzimatica e microbiologica che il terreno possiede normalmente, ma che possono risultare carenti nei terreni sterili ed in quelli dove l'agricoltore, spargendo irrazionalmente degli insetticidi, fungicidi, o erbicidi, contribuisce a distruggere o mortificare queste attività con la conseguenza di ridurre l'efficacia dei concimi al di sotto della misura che sarebbe auspicabile.

Nella prima parte della mia relazione, che non leggo perché è stata distribuita per tempo, sono contenute in riassunto queste meditazioni sul concetto della fertilità globale, che spero potranno chiarire il senso filosofico delle diverse singole componenti della fertilità del terreno. La seconda parte è stata preparata perché il Collega VALENTINO HERNANDO, giustamente, ha ritenuto fosse opportuno in una Settimana di studio, nella quale si discutono tutti i problemi della fertilizzazione, stimolare e provocare una discussione sui problemi della fertilizzazione liquida. Questa è la ragione per cui è stato deciso di illustrare la seconda e non la prima relazione da me presentata. Della fertilizzazione liquida è stata trattata soprattutto la fertilizzazione con ammoniaca anidra che a mio parere presenta aspetti di maggiore convenienza economica per i paesi che, come l'Italia, hanno bisogno di realizzare una certa economia nella fertilizzazione delle culture. Vorrei sottolineare che il testo da me preparato intende soprattutto suscitare e provocare una discussione tra i Colleghi. Naturalmente io vi ho già detto che per questa nuova forma di fertilizzazione ci sono alcuni elementi favorevoli ed altri meno favorevoli, ci sono insomma delle luci e delle ombre la cui intensità varia profondamente con le condizioni delle varie agricolture, per cui mentre può considerarsi opportuna in certi paesi lo appare meno in certi altri.

1. In epoca abbastanza recente negli Stati Uniti ed in alcuni Paesi europei, si è diffuso un nuovo modo di fertilizzare le colture che, sotto certi aspetti, richiama la cosiddetta "fertirrigazione" già da tempo applicata nelle aziende agrarie di montagna, dove si dispone di una sufficiente quantità di acqua in pressione naturale e di una rilevante massa di letame disponibile.

Si tratta, in questo caso, di valorizzare non solo il letame e cioè le deiezioni solide addizionate alla lettiera, ma anche le egestioni liquide che possiedono un elevato valore fertilizzante per il loro contenuto in azoto, potassa e auxine.

Gino Friedmann, verso gli anni venti, si era dedicato a questa pratica agronomica nelle aziende dell'arco alpino applicando soprattutto un metodo con miscelatore a dosaggio fisso o variabile, consistente in un iniettore idraulico capace di attingere in un liquido fertilizzante organico, formato dalle urine e da una melma di letame raccolti in apposite e distinte vasche. Nelle piccole aziende la "fertirrigazione" veniva realizzata con carri botte contenente il liquido fertilizzante e trainati da un trattore che comandava una pompa di alimentazione collegata all'irrigatore istallato nello stesso carro botte.

Esempi di fertirrigazione dei prati e dei seminativi con soluzioni di ammoniaca si erano, d'altra parte, già riscontrati nel 1853 per l'iniziativa dell'inglese Sohuston ed anche in Italia, nel 1920, da parte di Franco Samarani, allora Direttore della Stazione Agraria di Crema.

Oggi si denomina questo nuovo modo di fertilizzare il suolo con il termine "fertilizzazione liquida", ma forse sarebbe meglio dire "fertilizzazione fluida" per comprendere sotto questa ultima denominazione, anche la somministrazione di prodotti fertilizzanti gassosi, come l'ammoniaca anidra ed anche quelli sotto forma di sospensioni solide come quando si impiegano materiali ad alta concentrazione contenenti composti azotati, fosfatici e potassici poco solubili.

I benefici di questa irrigazione fertilizzante, realizzata mediante fluidi di varia natura, presenta alcuni vantaggi di ordine generale, come:

a) la maggior facilità con la quale il fertilizzante può venire, in qualsiasi momento, distribuito sui campi durante il ciclo di sviluppo della coltura;

b) la sua corrispondenza ad un criterio di maggior tempestività per la messa a disposizione delle colture dei singoli elementi di fertilità;

c) l'aumento dell'efficacia della fertilizzazione per una più rapida velocità di azione ed un più intenso potenziamento del processo della nutrizione minerale, anche attraverso la pratica dell'assorbimento fogliare;

d) la riduzione nel costo delle unità fertilizzanti e, subordinatamente, delle spese di distribuzione, specie quando viene applicato il metodo della fertirrigazione. Secondo le esperienze americane, il costo del servizio per la somministrazione dei fertilizzanti fluidi è pari al 5% del costo del fertilizzante e non differisce gran che da quello dei fertilizzanti solidi;

e) risparmio di fatica da parte dell'agricoltore. Ovviamente, pompare del liquido è molto più semplice e meno faticoso che non dover trasportare sacchi o addirittura masse sfuse di prodotti solidi. Per lo stato di aggregazione caratteristico dei materiali impiegati è evidente come la concimazione fluida consente una manipolazione e una distribuzione interamente meccanizzata;

f) si realizza una distribuzione più uniforme degli elementi fertilizzanti il che consente uno sviluppo vegetativo delle colture più omogeneo;

g) si possono mescolare uniformemente e somministrare con la stessa operazione e quindi con sensibile risparmio di tempo e di mano d'opera elementi secondari: microelementi, diserbanti, insetticidi e anticrittogamici. In ogni caso, i tempi di lavoro risultano notevolmente raccorciati;

h) a questi vantaggi si aggiungano quelli legati alla maggiore facilità di stoccaggio e di dosaggio ed altri, di natura psicologica, come quello di interessare ed attrarre gli agricoltori che desiderano attuare tecniche più opportune ed avanzate.

Vi sono poi altri vantaggi come la maggiore economia nel confezionamento, carico, scarico e trasporto del fertilizzante, minor fatica per l'operatore agricolo e, non ultimo, il minor costo delle unità fertilizzanti rispetto alle stesse unità contenute nei composti convenzionali.

2. Durante questi ultimi decenni, la fertilizzazione fluida ha avuto, in alcuni Paesi, un'espansione veramente singolare ma, mentre agli inizi era sospinta dalla necessità e convenienza di introdurre sistemi di fertilizzazione meno onerosi e di maggior comodità d'impiego, l'iniziativa è passata successivamente nelle mani di organizzazioni produttive e commerciali preoccupate soprattutto di intensificare lo smercio di una maggiore quantità di composti fosfatici o potassici, a seconda dei casi, perdendo di mira quelli che erano stati gli intendimenti originari.

Ora, mentre l'impiego dei fertilizzanti liquidi si è sviluppato rapidamente in U.S.A., dove l'applicazione della forma fluida aveva raggiunto nel 1961, a poco più di un decennio dalla loro introduzione, il 53% del totale, nel nostro Paese ed in generale in tutta l'Europa ci si è attardati in prove o verifiche di carattere preliminare.

Tanto in U.S.A. come anche in Francia, alla base della fertilizzazione con concimi liquidi sta la disponibilità, accanto all'ammoniaca, urea e nitrato ammonico, di alcune materie prime come l'acido superfosforico e i polifosfati, che non tutti i Paesi producono.

La carenza nella preparazione industriale dell'acido superfosforico e dei polifosfati costituisce certo una remora allo sviluppo di una più larga ed estesa applicazione della fertilizzazione liquida.

La preparazione dell'acido superfosforico e dei suoi sali ammoniacali è stata sviluppata dalla Tenesse Valley Authority e si tratta di un acido che contiene il 76% di anidride fosforica nei confronti dell'acido ortofosforico che ne contiene soltanto il 54%.

Il punto di fusione di questo acido è sufficientemente basso da renderlo fluido a temperatura ambiente ed il vantaggio del suo impiego consiste nel fatto che i suoi sali di ammonio sono molto più solubili di quelli dell'ortofosfato. Lo sviluppo e l'impiego di polifosfati ottenuti con i vari metodi consentono di poter disporre di prodotti contenenti fino al 79% di anidride fosforica e, secondo preparazioni recenti realizzate dalla T.V.A., si è giunti ad un composto nel quale il 79% di anidride fosforica risulta così costituito: il 19% presente come acido ortofosforico, 44% come pirofosforico, 21% come trifosforico, 10% come tetrafosforico e 6% come acido a catena ancora più lunga.

Non voglio dilungarmi ad illustrare le proprietà particolari di questi composti e cioè la loro solubilità, idrolizzabilità e possibilità di sequestrare alcuni oligoelementi di altissimo interesse per la nutrizione delle piante, ma desidero sottolineare che non sarà possibile procedere ad un'espansione della fertilizzazione liquida in quei Paesi dove le industrie dei fertilizzanti fosfatici non si impegneranno a puntare decisamente verso la preparazione di questi importanti prodotti.

Per quanto riguarda l'Italia, credo comunque che il ritardo nella realizzazione della fertilizzazione liquida sia legato a tre ordini di ragioni:

1) in primo luogo, non disponiamo di composti del fosforo ad elevata concentrazione in anidride fosforica solubile, indispensabili per la preparazione delle soluzioni fertilizzanti composte.

2) Mancano poi da noi le strutture distributive e cioè l'organizzazione di un servizio agronomico capillare che possa sostituirsi alle iniziative dei singoli agricoltori che non dispongono di regola dei mezzi necessari per provvedere direttamente.

3) Infine, la struttura dell'agricoltura italiana risulta ancorata tutt'oggi ad aziende di dimensioni inadatte a realizzazioni di questo tipo.

Per le condizioni dell'agricoltura italiana, che deve risolvere problemi di struttura piuttosto imponenti sia per il settore agricolo come anche per quello industriale, relativo ai prodotti fosfatici, mi pare opportuno, almeno inizialmente, indirizzare la fertilizzazione liquida verso l'impiego di prodotti quale l'ammoniaca gassosa, la cui unità fertilizzante ha un prezzo di mercato inferiore a quello della unità di azoto presente nei concimi azotati tradizionali.

E' noto come il costo dell'unità dei fertilizzanti azotati solidi, alla produzione, risulti pressoché doppio rispetto all'ammoniaca anidra od in soluzione, la quale presenta anche il vantaggio di non essere gravata da maggiori oneri per le operazioni di essiccazione, granulazione e immagazzinamento caratteristiche dei prodotti solidi.

3. La realizzazione della fertilizzazione fluida con l'ammoniaca anidra ha, tra l'altro, il vantaggio di utilizzare un prodotto che contiene l'87% di azoto e costituisce, com'è

noto, la materia prima per la preparazione della quasi totalità dei fluidi e per la maggior parte dei solidi.

L'impiego delle soluzioni ammoniacali presenta alcuni vantaggi relativi alle apparecchiature di distribuzione, ma ciò malgrado, negli U.S.A. l'ammoniaca anidra continua ad essere il principale fertilizzante fluido azotato.

La corrosione dei serbatoi e delle attrezzature non costituisce un problema per l'ammoniaca anidra, per la quale dobbiamo solo prendere alcune particolari precauzioni data la sua tossicità e la sua azione ustionante. Si tratta comunque di impieghi all'aria aperta per cui, osservando le usuali misure di sicurezza, non è difficile evitare questo tipo di incidenti.

L'ammoniaca anidra viene generalmente iniettata nel suolo ad una profondità che varia da 10 a 20 cm. in relazione alla tessitura e alle altre caratteristiche fisico-meccaniche del terreno. L'operazione consiste nel produrre nel suolo uno stretto solco che viene rapidamente richiuso in modo da interrare l'ammoniaca gassosa che fuoriesce in modo da limitare le perdite al massimo.

Sohn e Peach hanno studiato l'assorbimento dell'ammoniaca sull'argilla e sulla sostanza organica del terreno e sono giunti alla conclusione che tale processo decorre più agevolmente nei terreni limo-argillosi e nei terreni acidi. Anche nei terreni subalcalini fino a pH uguale a 7,3, il terreno assorbe parimenti notevoli quantità di ammoniaca, di cui la quasi totalità si diffonde dal punto di applicazione in un raggio di 5 cm.

L'esperienza ha dimostrato che, anche quando si somministrano quantità di azoto pari a 100-120 chili per ettaro, le perdite non risultano economicamente importanti.

Mac Intosh e Frederick hanno trovato che la diffusione dell'ammoniaca anidra si manifesta con una velocità diversa, a seconda del contenuto, in spazi vani del terreno. La gravità non sembra avere effetto sulla sua diffusione che non varia in modo apprezzabile sotto e sopra il punto di iniezione. Nelle stesse condizioni di umidità, occorrono otto ore perché l'ammoniaca si diffonda in un'area di 27,5 cm. di raggio con 40% di spazi vani; mentre con il 50% impiega solo ore 6,5 a diffondersi nello stesso ambito.

E' stato indagato da parte di GORING e MARTIN il comportamento dell'ammoniaca anidra in un terreno sabbioso posto in differenti condizioni di umidità. La velocità di diffusione dell'ammoniaca diminuisce con l'aumentare dell'umidità del terreno.

Per diffondersi a 12,5 cm. dal punto di iniezione impiega 1^h e 30′ nel terreno secco, 2^h e 30′ quando il terreno contiene 1,5% di umidità, 4^h e 20′ se ne contiene 3,5 e 4^h e 30′ se ne contiene il 6%.

Con il variare della temperatura cambia la velocità di diffusione e, ovviamente, tale velocità aumenta a temperature più elevate: in un tratto lungo cm. 14,5 viene percorso in 3^h e 30′ a 7°C, in 1^h e 30′ a 20°C e in 1^h soltanto a 28°C.

La velocità di diffusione del gas diminuisce invece quando, a parità delle altre condizioni, aumenta nel terreno il tenore in sostanza organica.

Secondo GIFFORD e STRICKLING, l'ammoniaca anidra manifesterebbe un certo effetto sulla stabilizzazione degli aggregati del suolo, in relazione ad una certa interazione specifica dell'ammoniaca con alcuni costituenti organici non ancora bene identificati e che, sciolti dall'ammoniaca, riprecipiterebbero successivamente ripartendosi in modo più omogeneo nel suolo.

Secondo ANDREWS, la fertilizzazione con ammoniaca anidra procede nel migliore dei modi quando si tiene debitamente conto, insieme alla più opportuna profondità dell'iniezione, dell'umidità del suolo, della ventosità, della spaziatura delle file e della temperatura al momento della somministrazione.

Non mancano poi esperienze per quanto concerne la tossicità dell'ammoniaca gassosa. ENO e BLUE hanno accertato infatti che il potere nitrificante del terreno si riduce solo del 10% anche quando l'alcalinità si eleva a pH 9,6. E' evidente che la mortificazione del processo di nitrificazione è legata all'effetto tossico dell'ammoniaca sui microrganismi nitrificanti.

Gli effetti dell'ammoniaca gassosa si spiegano anche nei confronti degli altri membri della popolazione microbica del terreno.

Quando poi si somministrano 100-120 chili di azoto per ettaro come ammoniaca anidra, si nota anche una riduzione del numero dei batteri, ifomiceti e actinomiceti, ma l'effetto tossico risulta limitato a quelli che si trovano nell'intorno di terreno posto a 6 o 7 cm dal punto di iniezione.

Le stesse ricerche hanno però accertato che, a 3 o 4 giorni dal trattamento, la carica batterica e actinomicetica del terreno ritorna pressoché uguale a quella di partenza, mentre l'effetto tossico sui funghi risulta più duraturo e può persistere per qualche settimana. Quando la concentrazione dell'azoto si eleva a 600 p.p.m., il pH raggiunge i 9,4 ed il suo effetto sulla popolazione fungina e sui nematodi risulta piuttosto drastico; si tratta tuttavia di un'attività temporanea che non ha la ben che minima conseguenza sul normale decorso della coltura. Quando la concentrazione dell'ammoniaca arriva a 608 p.p.m., cui corrisponde una concentrazione idrogenionica pari a pH=9,4, quasi tutti i microrganismi soccombono, ma concentrazioni di questo ordine si verificano soltanto nelle zone di fuoruscita dell'ammoniaca anidra in una porzione quindi di terreno che risulta relativamente piccola. Tale effetto ovviamente è soltanto temporaneo perché il pH raggiunto non permane lungamente, ma a seguito del processo di nitrificazione; secondo Bongess e Hawkins, dopo pochi giorni si verifica un ritorno alle condizioni normali ed in certi casi addirittura un abbassamento del pH originario.

E' forse opportuno ricordare la serie di ricerche compiute da Stanley e Smith i quali hanno dimostrato che, con un'applicazione di 100-120 chili di ammoniaca gassosa per ettaro, si determina un aumento considerevole della quantità di anidride fosforica e di ossido di potassio assimilabile in seguito alla azione che l'ammoniaca spiega sopra i componenti fosforici e potassici assorbiti o fissati dai costituenti del terreno.

Questo esame dettagliato del comportamento dell'ammoniaca anidra nel suolo, in relazione alle diverse condizioni di umidità, di stabilità strutturale, ecc. acquista un'importanza rilevante al fine di stabilire le condizioni ottime per la somministrazione del fertilizzante: la quantità, la profondità di iniezione, la distanza tra i denti iniettori e l'esigenza di ridurre al minimo le perdite.

4. Le ricerche agronomiche sugli effetti della concimazione con ammoniaca anidra, hanno dimostrato che non vi è una differenza sensibile tra le forme fluide e solide dell'azoto. A parità di tutte le altre condizioni, la concimazione con ammoniaca anidra ha dato la stessa resa produttiva. Evidentemente, ciò si verifica anche quando l'azoto è somministrato sotto altre forme come quella ureica o nitro-ammoniacale. Malgrado alcune differenze tra le varie forme azotate, nessuna differenza si registra quando esse vengono somministrate in fluidi o allo stato solido.

Un'esame approfondito degli altri fertilizzanti fluidi non mi sembra qui opportuno, date le premesse già fatte. E' mia convinzione che per le condizioni obbiettive della situazione italiana, non si sia ancora maturi per la piena introduzione della fertilizzazione fluida, salvo che per la Pianura Padana e le altre alluvioni del centro e del sud che rappresentano però un'aliquota piuttosto ridotta dell'intera superficie agraria.

La fertilizzazione fluida comunque ha bisogno per il suo sviluppo:

1) di una rete di unità poderali di dimensioni più grandi, che consentano un più agevole sviluppo della meccanizzazione agricola. La pratica della fertilizzazione fluida rientra infatti nelle operazioni meccanizzate e richiede quindi per la sua espansione l'attuazione delle condizioni reali della meccanizzazione stessa. Il ridotto volume delle singole unità poderali e la modesta estensione degli appezzamenti coltivati costituiscono, senza dubbio, un ostacolo al processo di meccanizzazione ed una remora alla introduzione della fertilizzazione liquida.

2) Occorre poi un'efficiente organizzazione dei servizi agronomici per le numerose aziende agricole che, non avendo la convenienza o la possibilità di investire somme rilevanti per le attrezzature, hanno bisogno di ricorrere a questi servizi specializzati capaci di eseguire operazioni agronomiche essenziali e di delicata attuazione come quella della fertilizzazione fluida.

3) Occorre infine che, ai vantaggi di ordine tecnologico caratteristici della fertilizzazione liquida, di cui abbiamo discorso precedentemente, si accompagni un certo vantaggio economico, ciò che nelle condizioni attuali è perseguibile solo con l'impiego dell'ammoniaca anidra.

Successivamente, quando le condizioni organizzative renderanno più efficienti la rete dei servizi agronomici e quando diverranno disponibili tutte le materie prime occorrenti per la preparazione degli altri fertilizzanti fluidi, dalla fertilizzazione con ammoniaca anidra potremo passare alla realizzazione della fertilizzazione fluida con le altre forme.

I costi della fertilizzazione liquida dipendono, evidentemente, anche dall'estensione del suo impiego per cui, un più largo esercizio, condurrà ad una più consistente produttività di questa pratica agronomica. Il miglioramento delle attrezzature ed il perfezionamento della tecnica renderanno inoltre più semplici e più economiche le applicazioni, anche per il maggiore contenimento delle perdite.

Oramai, questo nuovo sistema si è decisamente affermato nelle agricolture più avanzate e l'esperienza degli operatori lascia prevedere che una nuova era si aprirà per la fertilizzazione dei campi e, malgrado alcuni problemi tecnici non ancora risolti, ciò costituirà un progresso non indifferente nei confronti della tecnica del passato.

Vorrei infine concludere questo mio intervento sottolineando ulteriormente come la fertilizzazione fluida costituisca l'unico e il più economico mezzo per fertilizzare il terreno e le colture in una grande azienda agraria dove il processo di meccanizzazione sia arrivato alla sua applicazione integrale.

Nei Paesi che ancora non si trovino nelle condizioni organizzative atte a procedere direttamente in tale indirizzo, le prime applicazioni della fertilizzazione fluida con ammoniaca anidra potranno avere come obbiettivo le colture che, come il mais, richiedono notevoli quantità di azoto. Ciò rappresenterà un forte progresso rispetto alla realtà attuale e, certamente, sarà possibile un ulteriore evoluzione verso le soluzioni fertilizzanti, che segneranno un altro passo avanti verso forme più avanzate nel processo della fertilizzazione dei campi.

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EINHUNDERT JAHRE STEIGENDE ERNTEN DURCH DIE ANWENDUNG VON HANDELSDUENGER

Ein Rückblick auf das Jahr 1900 und ein Ausblick auf das Jahr 2000

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Die wichtigsten Entdeckungen über die Bedeutung der Ernährung der Pflanzen durch industriell und bergbaulich erzeugten Handelsdünger wurden schon in der Mitte des vorigen Jahrhunderts gemacht. Justus v. Liebig mit seinem im Jahre 1840 erschienenen Buch "Die organische Chemie in ihrer Anwendung auf Agriculturchemie und Physiologie" und die Studien der berühmten englischen Versuchsstation Rothamsted haben nachgewiesen, welche Nährstoffe wir den Pflanzen zur Verfügung stellen müssen, um ständig hohe Erträge zu erzielen. Sie haben uns auch gezeigt, wie wir diese Nährstoffe in Bergwerken und Fabrikanlagen in grossen Mengen als Handelsdünger produzieren können.

Es hat aber zunächst ein reichliches halbes Jahrhundert gedauert, bis sich diese Entdeckungen in der landwirtschaftlichen Praxis in der Welt auch nur in einem nennenswerten Umfang durchsetzten.

Am Anfang unseres Jahrhunderts machte die mit Handelsdünger versorgte Anbaufläche weniger als 1 v. H. der

Nutzfläche der Welt aus. Der Verbrauch von Stickstoff hatte eine Menge von etwa 300 000 t. N erreicht. Davon wurden etwa 240 000 t in Form von Chilesalpeter und 88 000 in Form von schwefelsaurem Ammoniak als Nebenprodukt der Koksindustrie geliefert. Der Verbrauch von Phosphorsäure lag in der Grössenordnung von etwa 900 000 t P_2O_5, davon entfielen knapp ein Drittel auf die Vereinigten Staaten, ein weiteres Drittel auf Deutschland und das letzte Drittel auf das übrige Europa. Der Weltverbrauch an Kali lag in der Grössenordnung von 250 000 t K_2O, wovon 117 000 t auf Deutschland, 30 000 t auf die anderen Länder Europas und 80 000 t auf die Vereinigten Staaten entfielen.

Beim Stickstoff beruhte die Versorgung der Welt um die Jahrhundertwende allerdings überwiegend noch auf einem Naturprodukt, nämlich dem Chilesalpeter. Kurz vor der Jahrhundertwende hatte Sir WILLIAM CROOKES auf der Tagung der British Association for the Advancement of Sciences ausgeführt, dass die leicht kultivierbaren jungfräulichen Ländereien der Welt zur Neige gingen und dass die Menschheit etwa im Jahre 1930 angesichts der Bevölkerungszunahme einer Hungersnot gegenüberstehen würde, wenn es nicht gelänge, den in unbegrenzter Menge in der Luft vorhandenen Stickstoff mit Wasserstoff zu Ammoniak zu synthetisieren. Damals war diese Synthese zwar im Laboratorium gelungen, aber Methoden zur industriellen Durchführung waren noch nicht gefunden. Er bezeichnete daher die Erschliessung solcher industriellen Möglichkeiten als den bei weitem wichtigsten Beitrag zur Lösung des Welternährungsproblems. Am Ende des ersten Jahrzehnts unseres Jahrhunderts war eine bescheidene industrielle Produktion von synthetischem Stickstoff im Flammenbogenprozess auf Grund der billigen Hydroelektrizität in Norwegen erschlossen. Der entscheidende Weg aber ist dann während des Ersten Weltkrieges und kurz danach durch die geradezu explosivartige Steigerung der Stickstoffproduktion nach dem Haber-Bosch-Verfahren beschritten worden.

Bei dem Pflanzennährstoff Phosphorsäure hatte bereits Justus v. Liebig gezeigt, dass die im Knochenmehl enthaltene Phosphorsäure in Gestalt von Tricalcium für die Pflanzen wenig aufnahmefähig ist und dass sie aufnahmefähig gemacht werden kann, wenn man sie mit Schwefelsäure aufschliesst. Das war der Beginn der Superphosphatindustrie, die aber solange eine bescheidene Industrie blieb, als man als aufzuschliessenden Rohstoff nur Knochenmehl kannte. Der gewaltige Schritt vorwärts war kurz vor der Jahrhundertwende dadurch erfolgt, dass man an verschiedenen Punkten der Welt, insbesondere in Florida und auf der Südseeinsel Nauru, aber auch in nordafrikanischen Ländern, reiche Lager von Rohphosphaten entdeckte, die dann ebenfalls mit Schwefelsäure aufgeschlossen und in für die Pflanzen aufnehmbares Superphosphat verwandelt wurden. Eine zweite wichtige Quelle für den Pflanzennährstoff Phophorsäure wurde die Thomasschlacke, ein Nebenprodukt der Stahlerzeugung.

Der dritte wichtige Pflanzennährstoff, Kali, ist ebenso wie das Thomasmehl zunächst als ein Abfallprodukt in unseren Gesichtskreis getreten. Die Entwicklung des Kalibergbaus nahm in Deutschland ihren Anfang mit einer Tiefbohrung auf Steinsalz in Stassfurt im Jahre 1843. Anfänglich war man sehr enttäuscht, dass oberhalb des Steinsalzes mächtige Lagen von bitteren Salzen angetroffen wurden, die man zunächst als wertlose Abraumsalze auf die Halden schüttete. Adolf Frank erkannte den Wert dieser Abraumsalze für die Lieferung des Pflanzennährstoffs Kali. Im Jahre 1861 wurde die erste Fabrik für Kalidüngesalze in Stassfurt errichtet. Zu Beginn des neuen Jahrhunderts war aber doch erst eine Gesamtproduktion von einer Viertelmillion t K_2O erreicht, von der mehr als die Hälfte in Deutschland verbraucht wurde.

Den Ausgangspunkt unserer Betrachtung, das Jahr 1900, können wir daher wie folgt charakterisieren: Die wichtigsten wissenschaftlichen Erkenntnisse über die Ernährung der Pflanzen waren schon ein halbes Jahrhundert alt. Industrie und Bergbau standen bereit, die Pflanzennährstoffe Kali und

Phosphorsäure in grossem Umfang zu liefern. Die wichtigste industrielle Entwicklung, nämlich die Grossherstellung von synthetischem Stickstoff, war im Laboratorium gelungen, und die industrielle Grossanwendung stand unmittelbar vor der Tür. Damit war die Voraussetzung dafür geschaffen, dass sich der Weltverbrauch an Pflanzennährstoffen von damals insgesamt knapp 1,5 Mill. t an Reinnährstoffen bis zur Gegenwart auf 65 Mill. t Reinnährstoff, d. h. auf das Vierzigfache steigern konnte.

Über die geographische Verbreitung des damaligen Verbrauchs an Pflanzennährstoffen können wir feststellen, dass der bescheidene Verbrauch völlig auf zwei Gebiete konzentriert war, nämlich auf Teile der Landwirtschaft in Westeuropa, insbesondere den Niederlanden, Belgien und Deutschland, sowie auf die Ostküste der Vereinigten Staaten. Dort wurde ein erheblicher Teil der Pflanzennährstoffe für den Tabakbau verwendet, der Rest überwiegend für Kartoffeln und für Obst und Gemüse. Die Massennahrungsmittel, Brotgetreide, Futtergetreide, Fleisch- und Molkereiprodukte, wurden im Jahre 1900 in der Landwirtschaft der Vereinigten Staaten praktisch noch völlig ohne einen nennenswerten Einsatz von Pflanzennährstoffen produziert. Die einzige Quelle der Produktion war die natürliche Bodenfruchtbarkeit, an der ein nicht unerheblicher Raubbau getrieben wurde.

Die Hektarerträge lagen dementsprechend sehr niedrig. Wir können einen Hektarertrag von 10 dz für fast alle wichtigen Getreidearten im grössten Teil der Welt von 1900 annehmen, und zwar nicht nur in den Entwicklungsländern, wo er auch heute noch grösstenteils in dieser Höhe liegt, sondern auch für den grössten Teil von Europa und Nordamerika.

Die Entwicklung von 1900 bis zur Gegenwart ist in der Hauptsache durch das Faktum einer Vervierfachung der Hektarerträge in immer weiteren Gebieten der Welt charakterisiert, einer Vervierfachung, die überall dort erreicht wurde, wo Pflanzennährstoffe in der erforderlichen Menge eingesetzt wurden. Dabei war aber natürlich eine Kombination mit der Anwendung von leistungsfähigem Saatgut, und, wo nötig, von Bewässerungswasser und Schädlingsbekämpfungsmitteln erforderlich. Die Pflanzennährstoffe sind nicht eine Wunderdroge, die man nur auf den Acker zu werfen braucht, um die Erträge auf das Vierfache zu steigern. Wenn wir trotzdem in unserer Untersuchung immer wieder statistische Angaben über den Einsatz von Handelsdünger in Verbindung mit der Steigerung der Hektarerträge präsentieren, so geschieht dies deshalb, weil der Verbrauch von Pflanzennährstoffen derjenige Faktor ist, der sich statistisch am leichtesten erfassen lässt.

Ungefähr ein Vierteljahrhundert später, im Jahre 1925, war der Verbrauch an Pflanzennährstoffen immer noch sehr gering. Der Stickstoffverbrauch war auf 1,2 Mill. t N, der Phosphorsäureverbrauch auf 2,7 Mill. t und der Kaliverbrauch auf 1,7 Mill. t K_2O gestiegen. Das schienen eindrucksvolle Steigerungen zu sein, sie wurden aber dann weit in den Schatten gestellt durch die Steigerungen, die dann im zweiten und dritten Vierteljahrhundert erreicht wurden.

Von dem Zustand des Einsatzes von Pflanzennährstoffen und dem dadurch erreichten Niveau der Hektarerträge in Europa um das Jahr 1925 geben die Schaubilder 1 und 2 gewissermassen eine Momentfotografie. Der Verfasser hat damals der Weltwirtschaftskonferenz, die in den Jahren 1926 und 1927 in Genf stattfand, ein Gutachten überreicht, in dem die Produktionsreserven der europäischen Landwirtschaft auf Grund des Einsatzes von Pflanzennährstoffen abgeschätzt wurden [1]. Schaubild 1 und 2 sind diesem Gutachten entnommen.

Man sieht auf einen Blick den sehr engen Zusammenhang zwischen dem Einsatz von Pflanzennährstoffen, hier in Gestalt von Stickstoff, und den Hektarerträgen, hier Weizen.

In ganz Europa gab es nur ein sehr kleines Gebiet, in

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(1) FRITZ BAADE, *Produktions- und Kaufkraftreserven in der europäischen Landwirtschaft*. Berlin 1927.

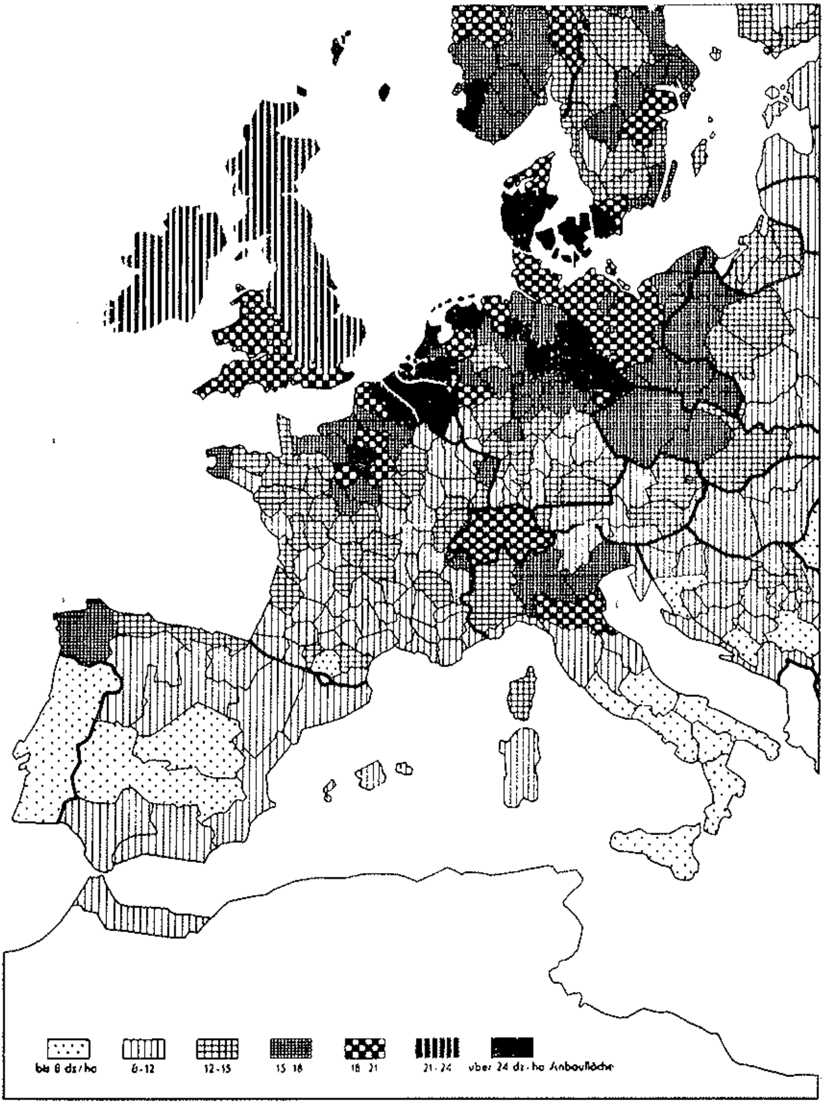


Schaubild 1 — Durchschnittsertrag an Weizen in Europa 1922-24 (dz auf 1 ha Anbaufläche).

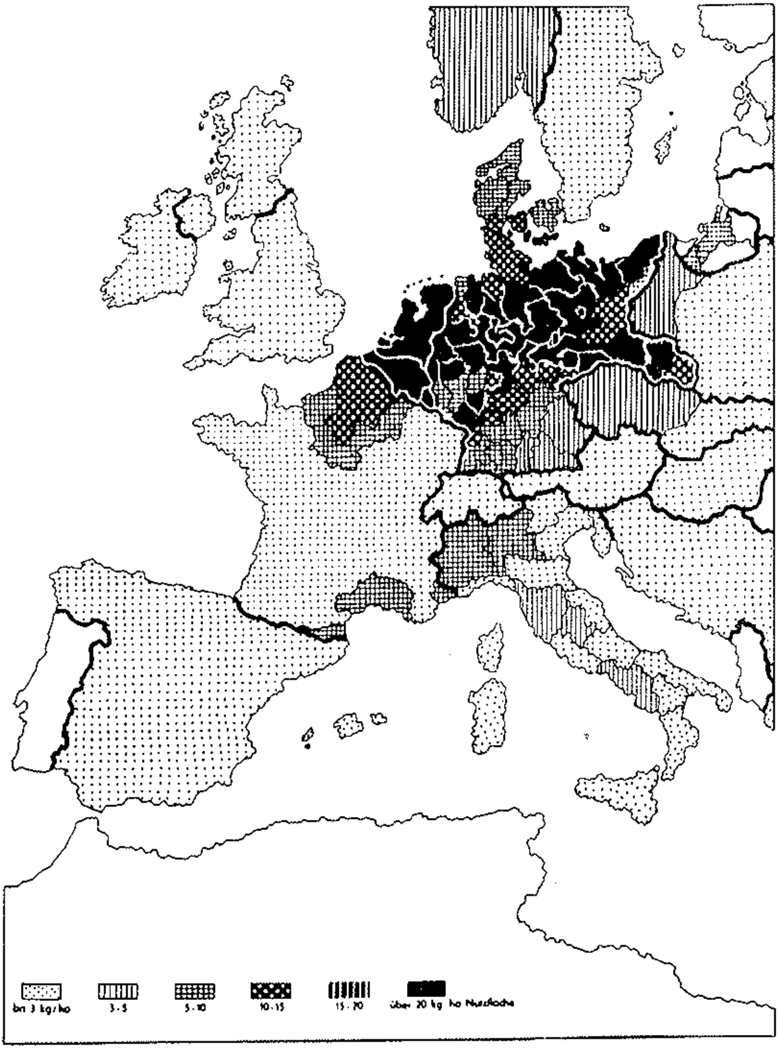


SCHAUBILD 2 — Handelsdüngerverbrauch in der europäischen Landwirtschaft 1922-24: Stickstoff (kg Reinstickstoff auf 1 ha landwirtschaftliche Nutzfläche).

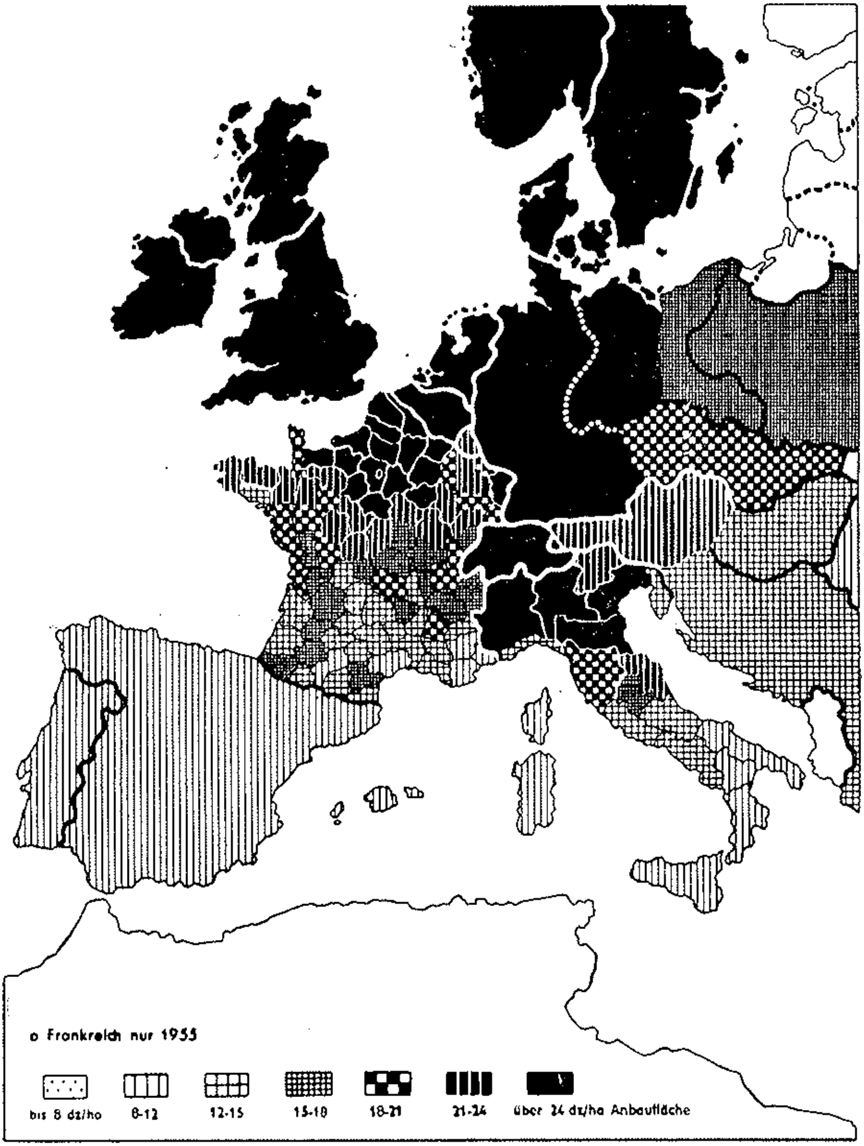
dem die Hektarerträge mit mehr als 21 dz einigermassen hoch waren, während sie in den übrigen Gebieten niedrig, zum Teil erschreckend niedrig lagen. Ein nicht kleiner Teil von Frankreich, Italien und selbst von Süddeutschland hatte damals Hektarerträge des Weizens in der Grössenordnung der heutigen Hektarerträge in den rückständigsten Entwicklungsländern, das heisst 10 bis 12 dz oder gar weniger als 10 dz.

Schaubild 2 zeigt, dass von einem nennenswerten Handelsdüngerverbrauch, in diesem Falle von Stickstoff, nur in den Gebieten Europas gesprochen werden konnte, in denen ein hoher Ertrag des Weizens einen hohen modernen Stand der landwirtschaftlichen Technik aufwies: in Belgien, den Niederlanden, einem kleinen Stück von Nordfrankreich und in Ost- und Mitteldeutschland.

Der Verfasser hat es damals gewagt, aus diesen Schaubildern sehr kühne Schlüsse zu ziehen. Er hat behauptet, dass der Einsatz von Pflanzennährstoffen, beispielsweise von Stickstoff, in dem grössten Teil Europas auf 30 kg je Hektar steigen müsste und steigen würde und dass diese Verbesserung der Ernährung der Pflanzen in der europäischen Landwirtschaft einmal eine Produktionssteigerung bringen würde, die die Abhängigkeit mindestens Kontinentaleuropas von Masseneinfuhren von Getreide aus Übersee beseitigen würde. Diese Voraussage mochte im Jahre 1925 als sehr kühn erscheinen, 25 Jahre später hatte sie sich aber weitgehend als richtig erwiesen.

Die Schaubilder 3 und 4 zeigen, dass sich im Jahre 1955/56 das Gebiet mit Weizenerträgen von mehr als 24 dz/ha in Europa kräftig ausgedehnt hat. Nicht nur Grossbritannien und Irland, die drei skandinavischen Länder und Belgien und die Niederlande gehören jetzt zu diesem Gebiet, sondern ganz Deutschland, und zwar sowohl das Gebiet der Bundesrepublik wie das Gebiet der DDR.

In Italien ist das Gebiet hoher Erträge bis nach Mittelitalien vorgerückt, und der Teil Frankreichs mit hohen Erträgen hat sich mächtig ausgedehnt.



Quelle: Auf Grund amtlicher Statistiken im Institut für Weltwirtschaft gezeichnet, Kiel 1958.

SCHAUBILD 3 — Der Durchschnittsertrag an Weizen in Europa 1955-56 (dz auf 1 ha Anbaufläche).

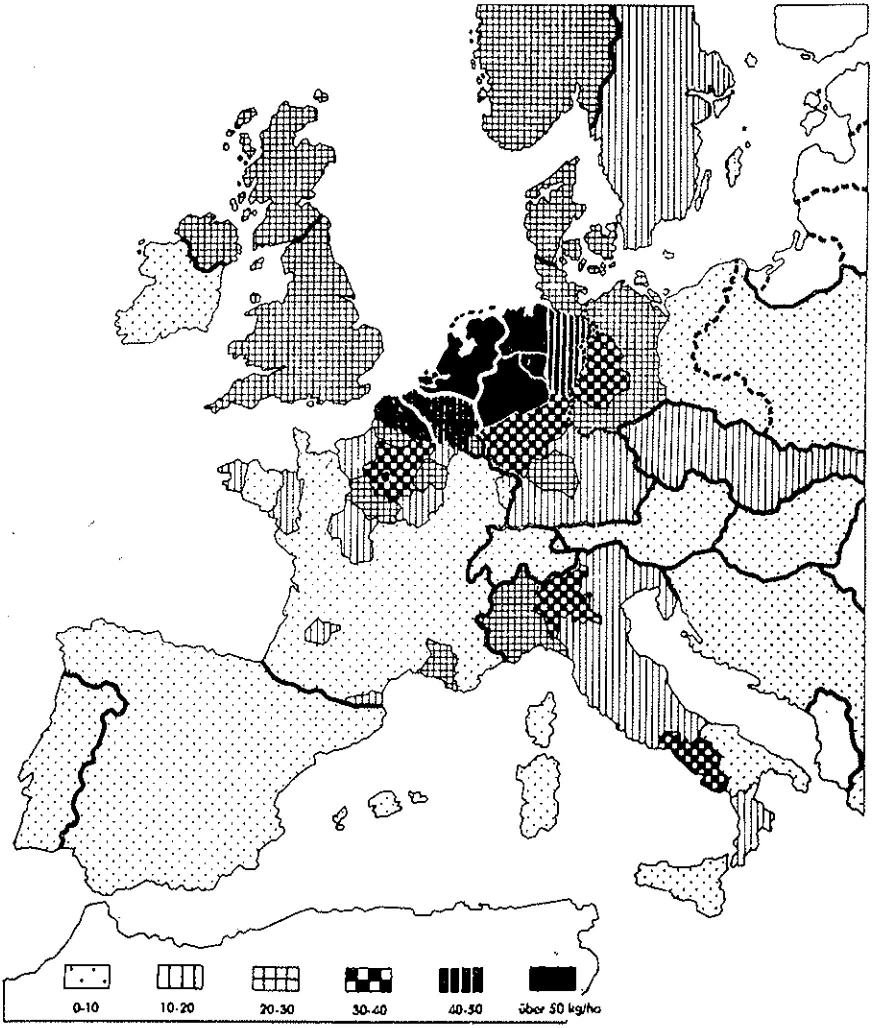


SCHAUBILD 4 — Handelsdüngerverbrauch in der europäischen Landwirtschaft, 1955-56: Stickstoff (kg Stickstoff auf 1 ha landwirtschaftliche Nutzfläche).

In völliger Parallelität dazu hat sich der Einsatz des Pflanzennährstoffs Stickstoff in diesen dreissig Jahren entwickelt. Während es in den Jahren 1922-24 in Europa kein Gebiet mit einem Stickstoffaufwand von mehr als 30 kg/ha gegeben hatte ([2]), hat sich inzwischen ein grosses Gebiet mit einem Stickstoffaufwand von 30 bis 40 kg, von 40 bis 50 kg und von über 50 kg je Hektar entwickelt.

Und nun die Wirkungen auf die Nahrungsversorgung Europas: Schon in der Mitte der fünfziger Jahre war der Zuschussbedarf Kontinentaleuropas an Weizen aus Übersee, wenn man das Gebiet als Ganzes betrachtet, praktisch verschwunden. Die Bundesrepublik Deutschland hatte zwar noch einen Einfuhrbedarf. Dem standen aber Ausfuhrüberschüsse in Schweden und insbesondere in Frankreich gegenüber, so dass der Raum des kontinentalen Westeuropas per Saldo von der Weizeneinfuhr aus Übersee unabhängig geworden war, so wie es in dem Gutachten für die Weltwirtschaftskonferenz im Jahre 1927 vorausgesagt worden war.

Und nun gehen wir nochmals etwa eineinhalb Jahrzehnte weiter und kommen an das Ende der sechziger Jahre. Im Jahre 1967 hatte der Hektarertrag des Weizens die 24-dz-Grenze nicht nur in Skandinavien, Grossbritannien, den Niederlanden und in ganz Deutschland überschritten, sondern auch in Frankreich bis auf ganz kleine Gebiete in Zentralfrankreich und in der Bretagne und der Provence. Aber auch dort waren bereits Hektarerträge von 21 bis 24 dz erreicht. Nur Spanien, Portugal, Sardinien, Korsika und Süditalien einschliesslich Siziliens hatten niedrigere Hektarerträge als 21 dz. In den osteuropäischen Ländern, insbesondere Polen, Tschechoslowakei, Ungarn und Jugoslawien waren teils Erträge von mehr als 24 dz, sonst von 21 bis 24 dz/ha erreicht.

([2]) Schaubild 4 musste anders gezeichnet werden als Schaubild 2, weil sich der Verbrauch so gesteigert hatte. In Schaubild 2 sind schwarz alle Gebiete mit einem Verbrauch von mehr als 20 kg/ha gezeichnet, in Schaubild 4 alle Gebiete mit einem Verbrauch von mehr als 50 kg/ha landwirtschaftliche Nutzfläche.

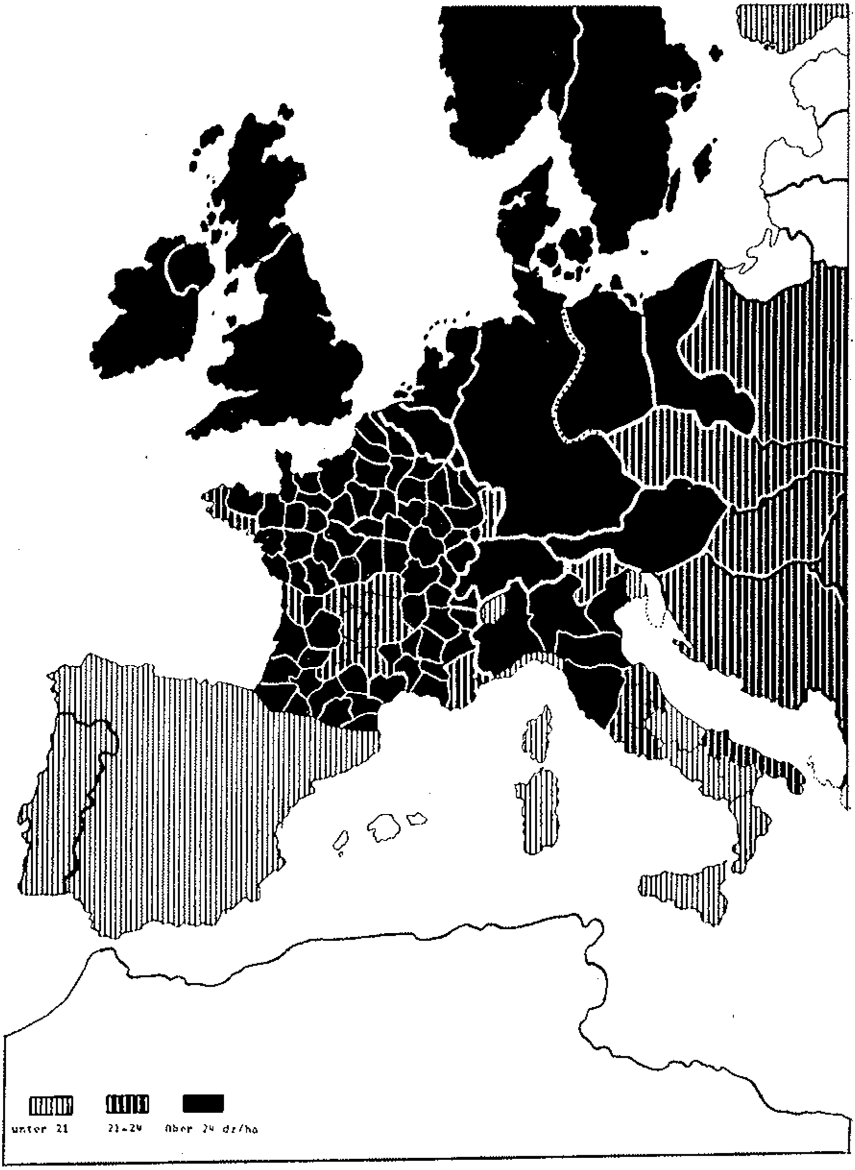


SCHAUBILD 5 — Durchschnittsertrag an Weizen in Europa 1967-68 (dz auf 1 ha Anbaufläche).

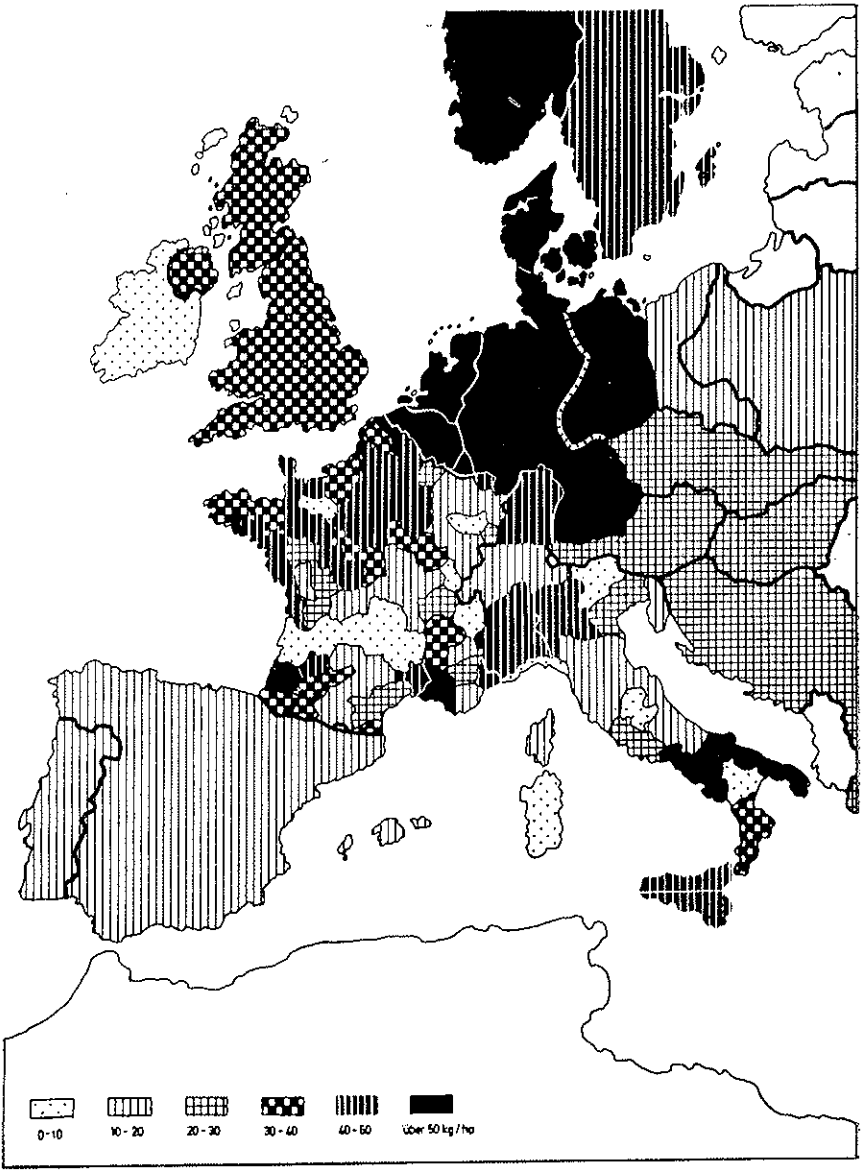


SCHAUBILD 6 — Handelsdüngerverbrauch in der europäischen Landwirtschaft, 1967-68: Stickstoff (kg Reinstickstoff auf 1 ha landwirtschaftl. Nutzfläche).

Dabei zeigt Schaubild 5 noch nicht einmal den ganzen Tatbestand. Denn in den schwarz gezeichneten Gebieten wird grösstenteils nicht ein Ertrag von über 24 dz/ha, sondern ein solcher von über 32 dz, ja, bis zu 40 dz/ha und mehr erzielt.

Dem entspricht der Einsatz des Pflanzennährstoffes Stickstoff. Die Gebiete mit einem Stickstoffaufwand von mehr als 50 kg/ha haben sich in Europa vor allen Dingen dort ausgedehnt, wo auch die Hektarerträge des Weizens auf über 24 dz gestiegen sind. In einem Teil des auf Schaubild 6 schwarz gezeichneten Gebietes wird nicht nur eine Stickstoffmenge von mehr als 50 kg/ha, sondern zum grossen Teil von mehr als 100 kg/ha eingesetzt.

Die Entwicklung der Produktion ist noch weit über das hinausgegangen, was bei der Vorlage der Schaubilder von 1922-24 auf der Weltwirtschaftkonferenz in Genf über die Produktionsreserven der europäischen Landwirtschaft vorausgesagt wurde. Die Hektarerträge nicht nur des Weizens, sondern aller Getreidearten sind in weiten Gebieten Europas auf das Dreifache, ja, auf das Vierfache dessen gestiegen, was sie um das Jahr 1925 im grössten Teil Frankreichs und grossen Teilen Deutschlands sowie in Italien gewesen waren. Auch in den osteuropäischen Ländern ist eine Verdreifachung der Hektarerträge erzielt worden, und dies ganz offensichtlich mit der Ausweitung der Anwendung von Pflanzennährstoffen. Dabei muss nochmals betont werden, dass natürlich diese hohen Hektarerträge nicht nur das Ergebnis des Einsatzes von Pflanzennährstoffen sind, sondern eines ganzen « Pakets von Massnahmen »: Verwendung sehr leistungsfähigen Saatgutes, guter Schädlingsbekämpfung und, mindestens in Teilen Europas, ausreichender Zufuhr von Wasser durch Bewässerung.

Nun wollen wir einen Blick auf die kommenden Jahrzehnte unseres Jahrhunderts richten.

Betrachten wir die Weltgetreidewirtschaft als Ganzes, so können wir feststellen, dass wir zur Zeit in der Welt einen Zustand haben, der weitgehend demjenigen entspricht, der in

Europa vor etwa fünfzig Jahren festzustellen war: Nur in einem Teil der Welt gibt es hohe Hektarerträge, die in der Grössenordnung von 30, sogar 40 oder 50 dz liegen, und das sind die Gebiete, die auch einen hohen Aufwand an Pflanzennährstoffen haben. In dem überwiegenden Teil der Weltgetreidewirtschaft, insbesondere in den Entwicklungsländern, sieht es heute noch so aus, wie es in weiten Teilen von Europa in den Jahren 1922-24 aussah, niedrige, zum Teil erschreckend niedrige Hektarerträge, und dies in völlig klarem Zusammenhang mit einen krass unterentwickelten Zustand der Anbautechnik, charakterisiert durch einen völlig ungenügenden oder sogar ganz fehlenden Einsatz von Pflanzennährstoffen.

Aus dieser Rückständigkeit und der Möglichkeit ihrer Überwindung ergibt sich die Hoffnung, dass wir eine Welthungersnot nicht nur vermeiden müssen, sondern auch vermeiden können. Wir können Nahrung für alle Völker der Erde reichlich produzieren, wenn die landwirtschaftliche Rückständigkeit in allen Teilen der Welt — insbesondere auch in den Entwicklungsländern — überwunden wird.

Der reichliche Einsatz von Pflanzennährstoffen, also von Handelsdünger, wird dabei eine entscheidende Rolle spielen. Der Einsatz von Pflanzennährstoffen muss mit der Verwendung von auf hohe Leistung gezüchtetem Saatgut Hand in Hand gehen. Dort, wo das Land durch Regen nicht genügend Feuchtigkeit erhält, muss die Bewässerung hinzutreten. Da im warmen Klima der Entwicklungsländer bei reichlicher Darbietung von Pflanzennährstoffen und Wasser die Schädlinge ebenso üppig wachsen wie die angebauten Früchte, muss eine intensive Schädlingsbekämpfung hinzukommen. Es müssen also die Massnahmen: Ernährung der Pflanzen, leistungsfähiges Saatgut, ausreichendes Wasser, Verbesserung der Bodenbearbeitung und Schädlingsbekämpfung in einem "Paket" zusammengefasst werden. Dieser "package approach" ist auch deswegen so wirksam, weil man mit der Demonstration eines einzelnen ertragssteigernden Faktors wie dem der Verwendung von Handelsdünger einen analphabetischen Bauern in einem Entwicklungsland kaum in Bewegung bringen kann. Wenn man ihm zeigt, dass er mit diesem Dünger eine 20 bis 25 prozentige Ertragssteigerung erzielen kann, so wird er kaum bereit sein, für diesen Dünger Geld auszugeben oder gar Schulden zu machen. Wenn man ihm aber in seinem eigenen Dorf ein Feld vor Augen führt, das das Doppelte, das Dreifache oder sogar das Vierfache dessen trägt, was er selber, sein Vater und sein Grossvater je gesehen und für möglich gehalten haben, so kommt er in Bewegung und verlangt dieses Saatgut, diesen Dünger und diese Schädlingsbekämpfungsmittel.

Ein ganz besonderes Verdienst kommt bei der Entwicklung dieser Politik des "Pakets" der Rockefeller Foundation zu, die den "Wunderweizen" in Mexiko gezüchtet hat. Das Rezept war eigentlich sehr einfach: Die bisherigen Weizensorten haben ein langes Stroh, und wenn man sie kräftig insbesondere mit Stickstoff düngt, lagern sie sich. Die Mitarbeiter der Rockefeller Foundation haben in Mexiko den sog. Kurzstrohweizen gezüchtet, d. h. einen Weizen, der ein sehr kurzes, aber ausserordentlich kräftiges Stroh hat. Dieser Kurzstrohweizen verträgt Gaben von 100, ja 125 kg Reinstickstoff je Hektar, und er bringt, wenn er neben dem reichlichen Sonnenschein auch mit genügend Wasser versorgt wird, Hektarerträge von 40 bis 50 dz, ja, Erträge bis zu 80 dz sind schon erzielt worden. Mit diesem Geschenk der Rockefeller Foundation, dem « Wunderweizen », ist es Mexiko gelungen, nicht nur die Erträge besonders fortschrittlicher Landwirte, sondern die gesamten Durchschnittserträge des Landes in einer so kurzen Zeit zu vervielfachen, wie man es niemals für möglich gehalten hätte. Während die Erträge um das Jahr 1950 im Durchschnitt des Landes noch bei 8 dz/ha lagen, waren sie zehn Jahre später doppelt so hoch, und in weiteren fünf Jahren hatten sie das Dreifache der Erträge des Jahres 1950 erreicht.

Die Verdreifachung der Hektarerträge in einem ganzen Land in nur fünfzehn Jahren ist etwas, was es in der Weltagrargeschichte noch niemals gegeben hat. Auch in Europa, beispielsweise in der Bundesrepublik Deutschland, sind allerdings die Weizenerträge von 8 dz auf 16 dz und schliesslich auf 24 dz/ha gestiegen, also verdreifacht worden. Aber die Väter, Grossväter und Urgrossväter der heutigen Landwirte haben dazu 150 Jahre gebraucht, während die Mexikaner es mit Hilfe der Rockefeller Foundation in fünfzehn Jahren geschafft haben. Wenn es möglich ist, diesen Weizen auch in den grossen vom Hunger bedrohten Ländern anzubauen — und wir werden sehen, dass das in erstaunlich kurzer Zeit möglich geworden ist —, so hat die Rockefeller Foundation damit allen Völkern der Erde, sowohl den Völkern, die hungern, wie den Völkern, die darüber nachdenken, was sie tun können, um den Hunger abzuschaffen, geradezu eine "Wunderwaffe" für den Sieg über den Hunger in der Welt in die Hand gegeben. Dem genialen Weizenzüchter, Norman Borlaug, der für die Rockefeller Foundation in Mexiko den Wunderweizen nicht nur gezüchtet, sondern in die breite Praxis der Landwirte eingefügt hat, ist die Menschheit zu allergrösstem Dank verpflichtet. Es war daher eine ausgezeichnete Idee, diesem Mann den Friedens-Nobel-Preis zu verleihen.

Die Rockefeller Foundation hat nicht nur diesen Weizen gezüchtet, sondern auch entscheidend dazu beigetragen, dass der Einsatz von hochertragreichem Saatgut mit hohen Gaben von Handelsdünger kombiniert wurde. In den fünfzehn Jahren, in denen in Mexiko die Weizenerträge verdreifacht wurden, ist der Einsatz von Handelsdünger auf das Zwanzigfache gesteigert worden. Das Gleiche muss in allen Ländern geschehen, die Mexiko auf dem Wege zur Grünen Revolution folgen wollen.

Seit Jahren wird daher in der Wirtschaftswissenschaft immer stärker der Zusammenhang zwischen Einsatz von Pflanzennährstoffen und Steigerung der Nahrungsproduktion in den Mittelpunkt aller Betrachtungen gestellt. Der Verfasser hat bereits seit Jahren in Büchern und Artikeln geschätzt, dass der Einsatz in den Entwicklungsländern auf das Zehnfache oder gar auf das Zwanzigfache gesteigert werden muss. Bezüglich der türkischen Landwirtschaft hat er in dem Gutachten des Arbeitsteams der FAO [3] schon im Jahre 1959 geschätzt, dass der Einsatz von Stickstoff auf das Zwanzigfache gesteigert werden muss, und tatsächlich ist die Stickstoffverwendung der Türkei in nur zehn Jahren von 1959 bis 1969 auf das Zwanzigfache gestiegen. Das Gremium der 110 Sachverständigen, das dem Präsidenten der Vereinigten Staaten das Gutachten "The World Food Problem" erstattet hat, schätzte, dass die Nahrungsproduktion in den Entwicklungsländern bis zum Jahre 1980 verdoppelt werden muss und dass dazu der Einsatz von Pflanzennährstoffen von den 6 Mill. t, die in den Entwicklungsländern im Jahre 1967 verbraucht wurden, auf 67 Mill. t, also auf das Elffache, gesteigert werden muss [4].

Diejenigen Entwicklungsländer, in denen bisher wenigstens Anfangserfolge durch die "Grüne Revolution" erreicht worden sind, haben entsprechende Programme der Steigerung des Verbrauchs und schliesslich der Eigenproduktion an Handelsdünger nicht nur aufgestellt, sondern auch kräftig in Angriff genommen.

In *Indien* ist — mindestens beim Weizen — in den für den Weizenanbau besonders geeigneten Gebieten des Punjab die Fläche des Landes, die mit den hochertragreichen aus Mexiko importierten Varietäten besät wird, auf weit mehr als die Hälfte der Weizenanbaufläche gestiegen. Die Verwendung von Nährstoff im Handelsdünger ($N + P_2O_5 + K_2O$) stieg von 97.000 t im Durchschnitt der Jahre 1948-52 auf 1 474 400 t im Jahre 1968/69. Indien hat das Programm aufgestellt, den Stickstoffeinsatz des ganzen Landes bis zum Jahre 1973/74 auf 2,5 Mill. t N zu steigern. Der tatsächlich erreichte Einsatz ist allerdings bisher in jeder Planperiode hinter dem Planziel

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(3) Turkey. Country Report (Food und Agriculture Organization of the United Nations. Mediterranean Development Project.) Rome 1959.

(4) The World Food Problem. A report of the President's Science Advisory Committee. Vol. 1 and 2: Report of the Panel on the World Food Supply. Washington, D. C., The White House, May 1967.

zurückgeblieben. Aber selbst wenn im Jahre 1973/74 nur ein Verbrauch von 2 Mill. t N erreicht werden würde, wäre dies gegenüber dem allerdings sehr niedrigen Ausgangspunkt von 63 100 t im Durchschnitt der Jahre 1948-52 eine eindrucksvolle Steigerung auf das 35fache in wenig mehr als zwei Jahrzehnten.

Im klaren Zusammenhang mit dieser Verbesserung der Ernährung der Pflanzen sind die Ernten Indiens ebenfalls in eindrucksvoller Weise gestiegen. Zu Beginn des ersten Fünfjahresplanes im Jahre 1950 lag die Gesamternte an Nahrungsgetreide bei 52 Mill. t. Bis zum Jahre 1964 war sie auf 89 Mill. t gestiegen. Dann kam durch die Aufeinanderfolge von zwei katastrophalen Dürrejahren ein Rückschlag auf 72 Mill. bzw. 74 Mill. t in den Jahren 1965 und 1966. Als dann wieder normale Regenfälle eintraten, stieg die Gesamtproduktion an Nahrungsgetreide auf 100 Mill. t im Jahre 1968 und auf 106 Mill. t im Jahre 1969/70. Bis zum Jahre 1971/72 hofft man eine Ernte von 113 Mill. t und in den darauffolgenden Jahren von 120 Mill. t zu erreichen. Da trotz der Bohrung von Zehntausenden von Bewässerungsbrunnen die indischen Ernten noch immer von den sehr wechselvollen Monsunregenfällen abhängen, sind Rückschläge nicht ausgeschlossen.

Aber das Gesamtniveau der indischen Ernten hat sich doch auf das Zweieinhalbfache erhöht, und die Steigerung des Verbrauchs von Handelsdünger hat daran einen entscheidenden Anteil. Diese Entwicklung muss angesichts der noch andauernden Bevölkerungsexplosion kräftig weitergehen. Selbst der Stickstoffverbrauch des Jahres 1968/69 bedeutet mit rd. 1,4 Mill. t N bei einer Ackerfläche von 144 Mill. ha nur einen Aufwand von 10 kg/ha. Da alle indischen Kulturen — nicht nur Getreide, sondern auch Zuckerrohr und Baumwolle — dringend düngungsbedürftig sind, wird in den kommenden Jahrzehnten eine nochmalige Steigerung im Handelsdüngerverbrauch zunächst auf das Doppelte und dann auf das Vierfache notwendig.

Ähnlich liegen die Dinge in *Pakistan*. In Westpakistan ist die Weizenproduktion durch die Kombination hochertragreichen Saatguts mit reichlicher Ernährung der Pflanzen und Bereitstellung von Bewässerungswasser durch Rohrbrunnen so gestiegen, dass das Weizendefizit beseitigt und ein Weizenüberschuss erzielt worden ist, der das Nahrungsdefizit Ostpakistans zumindest teilweise decken kann. Vor dem Einsatz der mexikanischen Varietäten und der Verwendung entsprechend grosser Mengen von Handelsdünger lag die Weizenproduktion Westpakistans im Durchschnitt der Jahre bei etwa 4 Mill. t. Sie stieg dann innerhalb von drei Jahren auf 6 Mill. t, also das Eineinhalbfache, und liegt heute bei 7,5 Mill. t. Eine Steigerung auf 8 Mill. t, also auf das Doppelte der früheren Erträge, ist bei einigermassen normalen Witterungsbedingungen im Jahre 1971/72 zu erwarten. Die Voraussage, dass die Weizenernten in fünf Jahren verdoppelt und in zehn Jahren verdreifacht werden können, dürfte, so kühn sie ursprünglich aussah, wohl im Falle Westpakistans verwirklicht werden, aber natürlich nur, wenn auch Pakistan den Einsatz von Pflanzennährstoffen in Form von Handelsdünger entsprechend steigert.

Die Verwendung von Stickstoff ist schon von der allerdings minimalen Menge von 5 000 t im Durchschnitt der Jahre 1948/52 auf das 25fache, nämlich 131 000 t N im Jahre 1968/69 gestiegen. Aber angesichts einer Ackerfläche von 28 Mill. ha bedeutet dies erst einen Aufwand von 4,5 kg/ha.

Von der Reisproduktion Pakistans ist zwar die mengenmässig weniger wichtige Produktion in Westpakistan durch Einsatz leistungsfähigen Saatgutes und hoher Mengen an Handelsdünger kräftig gestiegen. Bei der wesentlich gewichtigeren Reisproduktion in Ostpakistan ist aber bisher nur eine ganz ungenügende Steigerung erfolgt. Da auch in Pakistan ausser Reis auch Zucker und Baumwolle dringend düngungsbedürftig sind, muss in den kommenden Jahrzehnten eine besonders starke Steigerung der Anwendung von Handelsdünger erreicht werden. Eine Steigerung zunächst auf das Doppelte und dann auf das Vierfache wie in Indien wird wohl nicht ausreichend sein.

Diese beiden volkreichen Länder geben einen Begriff davon, in welchem Masse das Mittel: bessere Ernährung der Pflanzen in den Entwicklungsländern eingesetzt werden muss, um den Sieg über den Hunger zu erreichen. Die erwähnte Schätzung in dem Gutachten "The World Food Problem", dass der Einsatz von Pflanzennährstoffen in den Entwicklungsländern von 6 Mill. t des Jahres 1967 auf 67 Mill. t im Jahre 1980 gesteigert werden muss, bleibt vielleicht noch hinter der Notwendigkeit zurück.

Damit ergibt sich die Frage nach der Rohstoffversorgung. Bei dem für die Ertragssteigerung besonders wichtigen Stickstoffdünger wird der Faktor Stickstoff (N) aus dem unbegrenzten Vorrat der atmosphärischen Luft entnommen. Stickstoffdünger wird dadurch produziert, dass man zunächst durch Synthese Ammoniak herstellt, das die Formel NH_3 hat, wobei also für einen Gewichtsteil Stickstoff drei Gewichtsteile Wasserstoff erforderlich sind. Dieser Wasserstoff für die Ammoniaksynthese wurde in Indien ebenso wie überall in der Welt zunächst durch Kohle bereitgestellt. Da man aber in allen entwickelten Ländern der Welt bei der Stickstoffproduktion von der Kohle zum Erdgas oder zu Abfällen der Erdölraffination (Naphtha) übergegangen ist, gehen auch die Entwicklungsländer diesen Weg. Eine besonders erfolgversprechende Möglichkeit zur reichlichen Versorgung mit dem Pflanzennährstoff Stickstoff ergibt sich dadurch, dass das in den Erdölländern des Nahen Ostens und Nordafrikas ungenutzt in die Luft gehende Erdgas in steigendem Masse zur Herstellung von synthetischen Ammoniak benutzt wird. Es ist berechnet worden, dass das bisher im Nahen Osten und in Nordafrika in die Luft gehende Erdgas ausreichen würde, um 40 Mill. t Ammoniak herzustellen, also eine Menge, die grösser ist, als die gegenwärtige Weltproduktion an Ammoniak. Die Erschliessung immer neuer Erdölquellen führt natürlich auch zur Erschliessung immer neuer Mengen an Erdgas, und so kann ein sehr grosser Teil des noch gewaltig anschwellenden Handelsdüngerbedarfs der asiatischen Länder durch die Nutzbarmachung eines in die Luft gehenden Rohstoffes gedeckt werden. Die Umstellung der Produktion von Stickstoff von der Kohle auf das Erdgas hat ausserdem eine grosse Senkung der Investitionskosten und eine sehr erhebliche Senkung der gesamten Produktionskosten zur Folge, so dass wir hoffen können, dass das für die Steigerung der Nahrungsproduktion wichtigste Produktionsmittel, nämlich Stickstoffdünger, gerade den asiatischen und afrikanischen Entwicklungsländern in unbegrenzter Menge und zu niedrigen Produktionskosten zur Verfügung gestellt werden kann.

Etwas schwieriger liegt es mit der Versorgung mit Phosphorsäure. Um das nicht wasserlösliche Trikalziumphosphat der Rohphosphate in Superphosphat umzuwandeln, wird Schwefelsäure benötigt. Wenn aber die bisher in die Luft gehenden Erdgase bei ihrer Umwandlung in Ammoniak gleichzeitig entschwefelt werden und der Prozess der Entschwefelung auch auf einen möglichst grossen Teil des verwandten schweren Heizöls ausgedehnt wird, so kann aus dieser Rohstoffquelle der Schwefelsäureanteil für eine auf ein Vielfaches ansteigende Weltversorgung mit Phosphorsäuredünger gewonnen werden. Natürliche Vorkommen an Rohphosphaten sind in den letzten Jahrzehnten in grosser Menge entdeckt worden, insbesondere in Jordanien und in Ägypten. Aber auch gerade Indien hat reiche Vorkommen an Rohphosphaten entdeckt, so dass eine Weltknappheit nicht zu befürchten ist, auch wenn der Weltverbrauch an Phosphorsäuredünger auf ein Vielfaches steigt.

Ganz besonders günstig sind die Versorgungsmöglichkeiten mit Kali. Im Zuge unserer hundertjährigen Betrachtung mag darauf hingewiesen werden, dass im Anfang unseres Jahrhunderts Deutschland ein Weltmonopol in der bergbaulichen Produktion von Kali hatte. Mit der Abtretung des Elsass und der dort liegenden Kaligruben an Frankreich wurde daraus ein deutsch-französisches Weltmonopol. Schon im Ersten Weltkrieg und ganz besonders im Zweiten Weltkrieg fingen dann die Vereinigten Staaten an, ihre reichen Vorkommnisse an Kalisalzen abzubauen, und im letzten Jahrzehnt sind in Kanada Vorkommnisse an Kalisalzen entdeckt und bergbaulich erschlossen worden, die eine Versorgung der Weltlandwirtschaft mit diesem Pflanzennährstoff auch dann zu billigen Preisen sicherstellen, wenn der Verbrauch sich bis zum Ende des Jahrhunderts auf das Sieben- bis Achtfache steigern sollte.

Wir wollen unsere Betrachtung mit einer Abschätzung der Steigerung des Weltverbrauchs an Handelsdünger bis zum Ende unseres Jahrhunderts schliessen. Im Jahre 1965 veröffentlichte die International Mineral & Chemical Corporation einen Artikel "The Quiet Revolution" ([5]). Hier wurde in einem Schaubild der steil in den Himmel schiessenden Fontäne der Entwicklung der Weltbevölkerung die ebenso steil in den Himmel schiessende Fontäne des Verbrauchs an Pflanzennährstoffen gegenübergestellt. Wer sich Sorgen über die Bevölkerungsexplosion macht, dem mag es ein guter Trost sein, dass auch beim Handelsdünger eine explosive Steigerung des Einsatzes zu erwarten ist. (s. Schaubild 7).

Allerdings werden beide Kurven bis zum Jahre 2000 bzw. 2050 wesentlich anders aussehen als unbegrenzt in den Himmel schiessende Fontänen. Die Kurve der Steigerung der Weltbevölkerung wird im letzten Jahrzehnt, vielleicht sogar schon in den letzten eineinhalb Jahrzehnten unseres Jahrhunderts, eine gewisse Abflachung erfahren, und diese Abflachung wird sich in den ersten Jahrzehnten des neuen Jahrhunderts kräftig fortsetzen.

Völlig grundlos sind die häufig geäusserten Befürchtungen, dass die Erdbevölkerung bis zum Jahre 2300 auf eine Zahl anwachsen könnte, bei der für diese Erdbevölkerung nicht einmal Platz zum Stehen auf der festen Erdoberfläche vorhan-

([5]) The Quiet Revolution. A call for action in world agriculture. With a review and projection of chemical fertilizers' role in helping a hungry world win the war on want. Publ. by IMC (International Mineral & Chemical Corporation), Skokie, Ill., 1965.

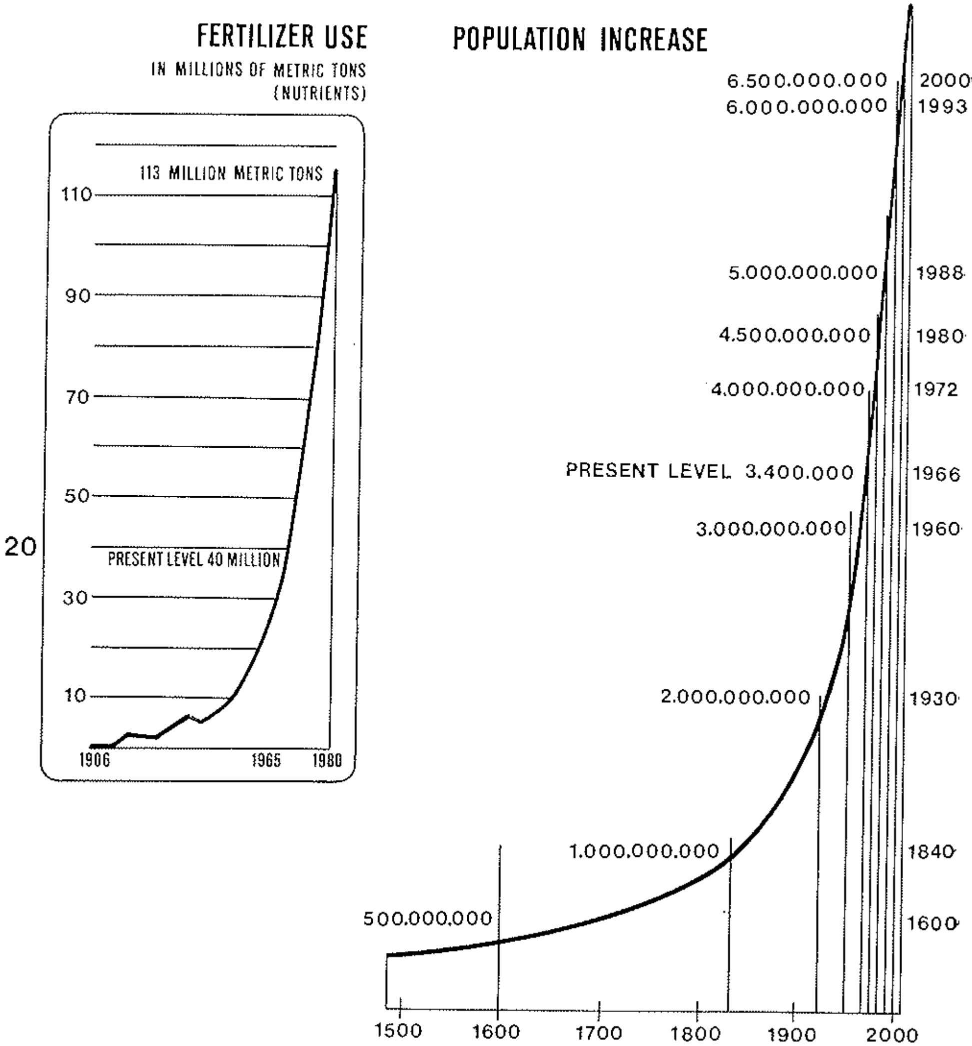

SCHAUBILD 7

Chart above shows total world consumption of chemical fertilizers from 1906 to 1965, and projected to the year 1980.
World population climb from the Middle Ages through this century is shown in chart at right.
Use of chemical fertilizers has been increasing even faster than population, as world agriculture moves into a new era of much more intensive farming.

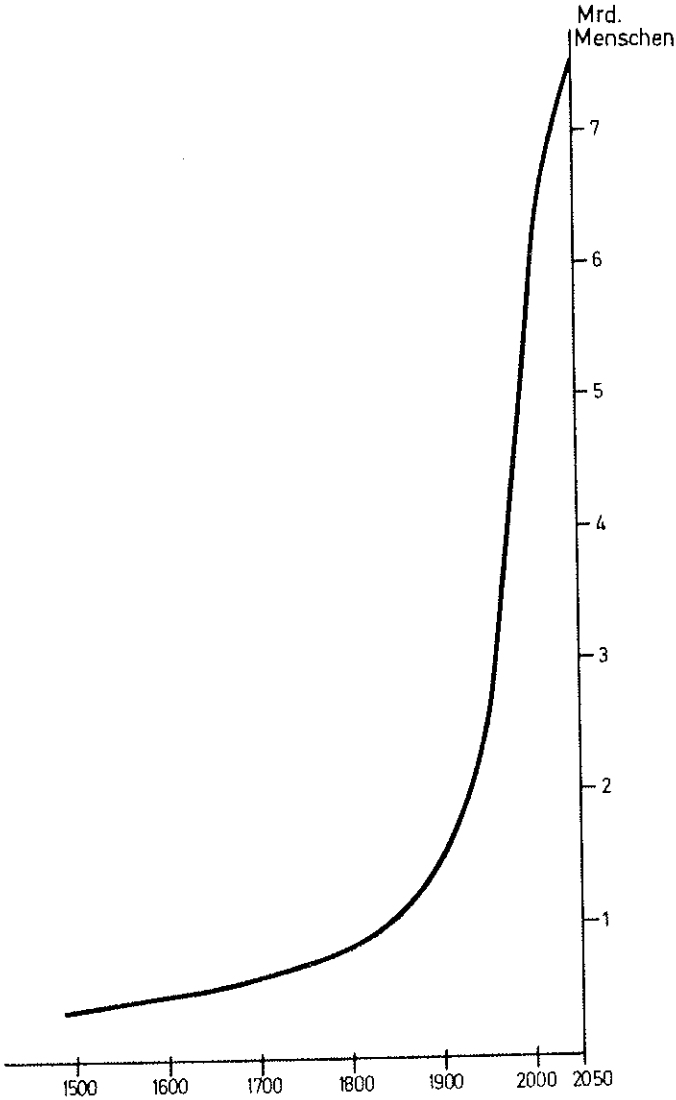

SCHAUBILD 8 — Entwicklung der Erdbevölkerung von 1500 bis 2050.

Quelle: Bis zum Jahre 2000: The Quiet Revolution, a.a.O., vom Jahre 2000 bis 2050: eigene Schätzung.

den seine würde. In allen Ländern, bei denen durch Rückgang der Sterblichkeit, insbesondere auch der Kindersterblichkeit, eine rapide Zunahme der Bevölkerung erfolgt war, weil die Geburtenraten zunächst hoch blieben, hat sich, wenn auch erst nach Jahrzehnten, die Kurve der Geburtenraten der Kurve der Sterblichkeit weitgehend angepasst. Eine solche Voraussage können wir vor allem deswegen wagen, weil gerade in den letzten Jahrzehnten in vielen Ländern eine entscheidende Verringerung der Zuwachsrate der Bevölkerung eingetreten ist. Die Mittelmeerländer waren vor gar nicht allzu langer Zeit Länder mit einer Bevölkerungsexplosion. Heute sind die Zuwachsraten der Bevölkerung in Griechenland auf 1,0, in Spanien auf 1,2 und in Italien auf 0,8% gesunken. In den osteuropäischen Ländern liegen die Zuwachsraten heute in der Sowjetunion nur noch bei 0,9%, in Polen bei 0,8%, in Bulgarien bei 0,6% und in Ungarn sogar nur noch bei 0,4%, also niedriger sogar als in der Bundesrepublik Deutschland.

Ähnlich liegen die Dinge aber auch in einigen asiatischen Ländern. In Japan ist die Geburtenrate so gesunken, dass man für das Ende des Jahrhunderts eher einen Rückgang als einen Anstieg der heutigen Bevölkerungszahl voraussagen müsste, wenn es nicht wieder zu einem Anstieg der Geburtenrate kommt. Auch in einigen anderen asiatischen Ländern, etwa in Südkorea und in Taiwan, können wir heute schon eine sehr starke Verringerung der Geburtenraten und des Bevölkerungswachstums verzeichnen. Charakteristischerweise sind dies Gebiete, die eine zeitlang unter japanischer Herrschaft gestanden haben und in dieser Zeit eine kräftige Verringerung des Analphabetentums erreichen konnten. Beide Länder erleben jetzt einen erheblichen Wohlstandsanstieg.

In direktem Zusammenhang mit steigendem Wohlstand und Überwindung des Analphabetentums sind die Geburtenzahlen kräftig zurückgegangen.

In den Ländern, in denen Hunger und Not noch heute herrschen und in denen von der Dorfbevölkerung 80 v. H. der Männer und mehr als 90 v. H. der Frauen Analphabeten sind, wird das Abstoppen der Bevölkerungsexplosion länger dauern. Aber auch dort ist mit fortschreitender Beseitigung des Analphabetentums wohl für das letzte Jahrzehnt unseres Jahrhunderts eine Verringerung der Geburtenziffern zu erwarten.

Während also die Kurve der Bevölkerungsentwicklung sich im letzten Jahrzehnt unseres Jahrhunderts und vor allem in den ersten Jahrzehnten des 21. Jahrhunderts abflachen wird, können wir in der Kurve des Einsatzes von Handelsdünger schon für die Jahrzehnte bis zum Jahre 2000 eine kräftige Abflachung erwarten. Während in dem Jahrzehnt 1960 bis 1970 der Einsatz von Handelsdünger in der Welt sich mehr als verdoppelt hat, nämlich von etwa 27,8 Mill. t auf 62,8 Mill. t gestiegen ist, kann sich diese Entwicklung in den kommenden Jahrzehnten bis zum Ende des Jahrhunderts unter keinen Umständen fortsetzen. Das ist schon arithmetisch klar, denn ein weiteres Anwachsen dieser Mengen würde bis zur Jahrhundertwende zu einem Verbrauch von 764.3 Mill. t führen.

Im Schaubild 9 ist geschätzt worden, dass der Einsatz von Handelsdünger in dem Jahrzehnt von 1970 bis 1980 in demselben Masse wie in dem Jahrzehnt von 1960 bis 1970, d. h. auf 145 Mill. t, steigt und dass auch in den beiden folgenden Jahrzehnten sich die Steigerung so verlangsamt, dass um das Jahr 2000 nur ein Handelsdüngereinsatz in der Grössenordnung von 250 Mill. t erfolgt.

Die Kurve wird sich also schon bis zum Jahre 2000 aus einer in den Himmel schiessenden Fontäne in eine S-Kurve verwandeln. Aber auch diese reduzierten Zahlen versprechen uns einen Überfluss an Nahrung in der Welt. Wenn in dem Jahrzehnt von 1970 bis 1980 der Einsatz von Pflanzennährstoffen sich auf 150 Mill. t vergrössert, so wird eine inzwischen auf 4,5 Mrd. angewachsene Erdbevölkerung pro Kopf eine

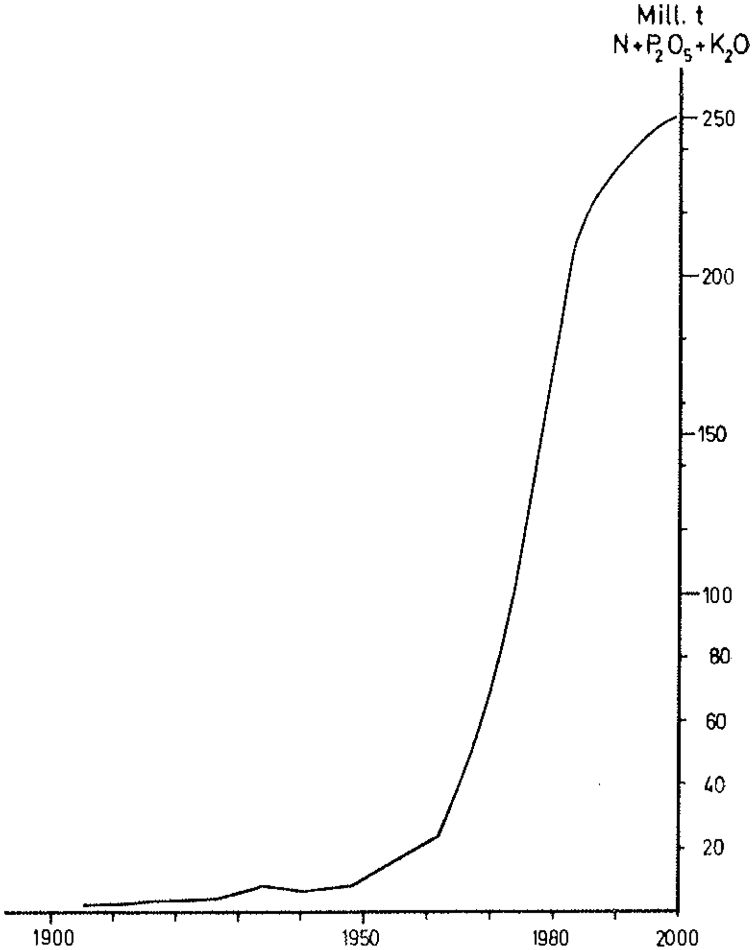

SCHAUBILD 9 — Der Handelsdüngerverbrauch in der Weltlandwirtschaft 1900-2000 (bis 1970 F.A.O., ab 1970 eigene Schätzung).

wesentlich grössere Nahrungsreserve zur Verfügung haben als heute. Und wenn bis zum Jahre 2000 der Einsatz von Pflanzennährstoffen auf etwa 250 Mill. t steigt, so werden bei einer auf 7 Mrd. Menschen angewachsenen Erdbevölkerung selbst die ärmsten Länder der Welt sich einen Nahrungsverbrauch gestatten können, der dem heutigen Nahrungsverbrauch in Westeuropa entspricht. Die reichliche Ernährung der Pflanzen durch Einsatz von Handelsdünger wird also auch in den vor uns liegenden Jahrzehnten einen entscheidenden Beitrag dazu leisten, dass der Zustand der Welternährung von Mangel in Überfluss verwandelt wird.

Diese optimistische Vorausschätzung baut auch auf der Tatsache auf, dass durch Kombination von sehr leistungsfähigem Saatgut mit grossen Gaben von Handelsdünger der Erntezuwachs, der mit einer Gewichtseinheit Handelsdünger erzielt wird, sehr gestiegen ist. Wir waren gewohnt, mit der Faustzahl zu rechnen, dass 1 kg Nährstoffe im Handelsdünger unter durchschnittlichen Bedingungen eine Steigerung um 10 kg Getreidewert bewirken. Heute aber kann man — dank dem auf Hochleistung gezüchteten Saatgut — damit rechnen, dass durch 1 kg zusätzlichen Einsatz von Nährstoffen eine Produktionssteigerung um 20 kg Getreidewert erzielt wird.

Um am Ende unseres Jahrhunderts eine Weltbevölkerung von voraussichtlich 7 Mrd. Menschen zu ernähren, und zwar nicht knapp zu ernähren wie heute, sondern ausreichend, wird man etwa 3,5 Mrd. t Getreidewert brauchen. Darin ist schon eine erhebliche Verbesserung der Ernährung enthalten. Denn während wir in Europa zur Ernährung eines Menschen etwa 0,5 t Getreidewert brauchen, rechnet man in Indien nur mit einem Verbrauch von 0,2 t pro Kopf der Bevölkerung. Wenn wir also bis zum Ende unseres Jahrhunderts für die gesamte Menschheit mit einer Menge von 0,5 t Getreidewert rechnen, so haben wir, wie oben gesagt wurde, "selbst für die ärmsten Länder der Welt mit einem Getreideverbrauch gerechnet, der dem heutigen Nahrungsverbrauch in Westeuropa entspricht". Wenn wir nun unterstellen, dass bei allgemein reichlicher Düngung und dort, wo es nötig ist, mit Bewässerung von den neuen Varietäten ein Durchschnittsertrag von 40 dz/ha an Weizen, Reis, Mais und Hirse erzielt wird — und das erscheint als ein bescheidenes Ziel —, so würden von der Ackerfläche der Erde, die heute in der Grössenordnung von 1,3 Mrd. ha liegt, nur eine Milliarde Hektar mit diesen hohen Erträgen gebraucht werden, um 4 Mrd. t Getreidewert, also die reichliche Nahrung für 7 Mrd. Menschen, zu produzieren. Das übrige Land würde dann überwiegend für andere Zwecke zur Verfügung stehen bzw., wie es ja die Vereinigten Staaten und Europa schon praktizieren, aus der Kultur genommen werden können.

Unsere Betrachtung der Entwicklung des Handelsdüngereinsatzes in unserem Jahrhundert zeigt also, dass der Menschheit hier ein Werkzeug geschenkt worden ist, mit dem die Nahrungsproduktion nicht nur kräftig, sondern sogar explosiv gesteigert werden kann. In den ersten drei Vierteln unseres Jahrhunderts ist diese Steigerung vor allem in den wohlhabenden Industrieländern erfolgt. Sie hat dazu geführt, dass die Industrieländer der Welt — zunächst die Vereinigten Staaten, aber jetzt auch Westeuropa — eine Nahrungsproduktion haben, die nicht nur zur Ernährung ihrer Bevölkerung ausreicht, sondern Überschüsse liefert, mit denen sie ihrerseits einen Teil des Defizits in den Entwicklungsländern decken können. Im letzten Viertel unseres Jahrhunderts werden wir nun den gleichen Vorgang im Weltmasstab erleben, indem die gegenwärtig von Hunger bedrohten Entwicklungsländer ihre Produktion weniger durch Ausdehnung der Anbaufläche, sondern in erster Linie durch Steigerung der Hektarerträge verbessern. Das Nahrungsdefizit der Entwicklungsländer wird vielleicht schon in den siebziger Jahren, restlos aber wohl in den achtziger Jahren verschwinden, und die bessere und reichliche Ernährung der Pflanzen insbesondere durch Verwendung von

Handelsdünger wird dabei eines der wichtigsten Instrumente sein.

Soviel zu den technischen und materiellen Seiten des Problems. Aber letzten Endes handelt es sich hier nicht um eine technische Frage, sondern um eine humanitäre Frage. Die entscheidend wichtige Frage besteht darin, wie wir die Landwirte in den Entwicklungsländern, die bisher von einer der wichtigsten Erfindungen der Menschheitsgeschichte, nämlich der Ernährung der Pflanzen durch Handelsdünger, noch kaum Gebrauch machen, dazu bringen können, nicht nur die nötige Menge an Pflanzennährstoffen zu verwenden, sondern dies auch mit dem nötigen Mass an Verstand zu tun.

Der Verbrauch von Pflanzennährstoffen in der Welt konzentriert sich auf diejenigen Gebiete, in denen wir eine dichte Bevölkerung haben, aber eine Bevölkerung, die lesen und schreiben kann. Vollkommen ungenügend ist der Verbrauch an Pflanzennährstoffen in denjenigen Teilen der Welt, die dicht bevölkert sind, in denen aber der grösste Teil dieser Bevölkerung aus Analphabeten besteht.

Einen guten Einblick in die Zusammenhänge zwischen Bildungsniveau, Pflanzenernährung und menschlicher Ernährung erhält man, wenn man die folgenden Zahlen einander gegenüberstellt:

In Japan betragen die Reiserträge mehr als 50 dz/ha. Der japanische Verbrauch an Handelsdünger erreicht mit 100 kg Reinstickstoff je Hektar den Höchstverbrauch in Europa, und das Analphabetentum ist in Japan praktisch ausgerottet.

In China betrugen bis vor wenigen Jahren die Reiserträge etwa die Hälfte der japanischen. Der Handelsdüngerverbrauch war bescheiden, aber eine kräftige Steigerung bahnte sich an. Die Überwindung des Analphabetentums war erst eben in Gang gekommen.

In Indien, Indonesien und Burma liegen die Reiserträge bei einem Viertel der japanischen. Der Handelsdüngerverbrauch war bis vor etwa 20 Jahren fast gleich Null, und auf den Dörfern sind etwa 80 v. H. der Erwachsenen des Lesens und Schreibens unkundig.

Die Überwindung des Analphabetentums und die Verbreitung auch eines über das blosse Lesen, Schreiben und einfachste Rechnen hinausgehenden Wissens ist also die Voraussetzung dafür, dass wir die Steigerung des Einsatzes von Pflanzennährstoffen für die Überwindung des Hungers in der Welt voll nutzbar machen können. Aber wir brauchen mit dem steigenden Einsatz von Pflanzennährstoffen nicht solange zu warten, bis das Analphabetentum völlig überwunden ist. Wäre dies der Fall, so wäre es mit den Aussichten des Kampfes gegen die Welthungersnot schlecht bestellt. Zum Glück aber können Bauern auch dort, wo sie Analphabeten sind, wenigstens rechnen. Wenn man einem Bauern ein Feld vor Augen führt, auf dem durch den Einsatz von Pflanzennährstoffen und auf Höchstleistung gezüchtetem Saatgut das Dreifache der gewohnten Erträge erzielt wird, so läuft die Grüne Revolution auch schon vor der völligen Überwindung des Analphabetentums erfolgreich an.

Aber zu einem wirklichen Sieg über Hunger und Armut brauchen wir ausser einer Überwindung des Analphabetentums auch eine starke Verbesserung in den mittleren und oberen Stufen des Erziehungswesens.

Das Land, dem wir die wichtigsten Instrumente der Grünen Revolution, den "Wunderweizen" und den "package approach" verdanken, ist Mexiko. Mexiko gibt für Erziehung und Forschung dreimal soviel aus wie für die Rüstung, während in den Entwicklungsländern Indien und Pakistan der Staat für Rüstung zur Zeit dreimal so viel ausgibt wie für Erziehung und Forschung. Wenn die mexikanische Formel auch von den Entwicklungsländern, insbesondere von Indien und Pakistan angenommen wird, so ist dies ein entscheidender Sieg im Weltkampf gegen den Hunger.

Papst PAUL VI. hat in der Enzyklika "Populorum Progressio" die humanitären Ziele der Menschheit formuliert, dass wir nicht nur den Hunger besiegen und die Armut eindämmen müssen, sondern dass wir eine Welt bauen müssen, wo jeder Mensch ein wirklich menschliches Leben führen kann. Im Abschnitt 51 hat er vorgeschlagen, einen "grossen Weltfonds zu errichten, der durch einen Teil der bisher für militärische Zwecke ausgegebenen Gelder aufgebracht werden sollte, um den schwächeren Völkern zu helfen". Dazu müssen nicht nur die helfenden Länder ihre Rüstungsausgaben kräftig senken, sondern auch gerade die Völker, denen geholfen werden soll.

Das technische Mittel: "bessere Ernährung der Pflanzen insbesondere auch durch Handelsdünger" kennen wir seit 150 Jahren. Um das technische Mittel aber zur Anwendung zu bringen, sind die nötigen Schritte auf dem Gebiet der menschlichen Sittlichkeit, also der wirkliche Fortschritt der Völker, das Entscheidende.

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