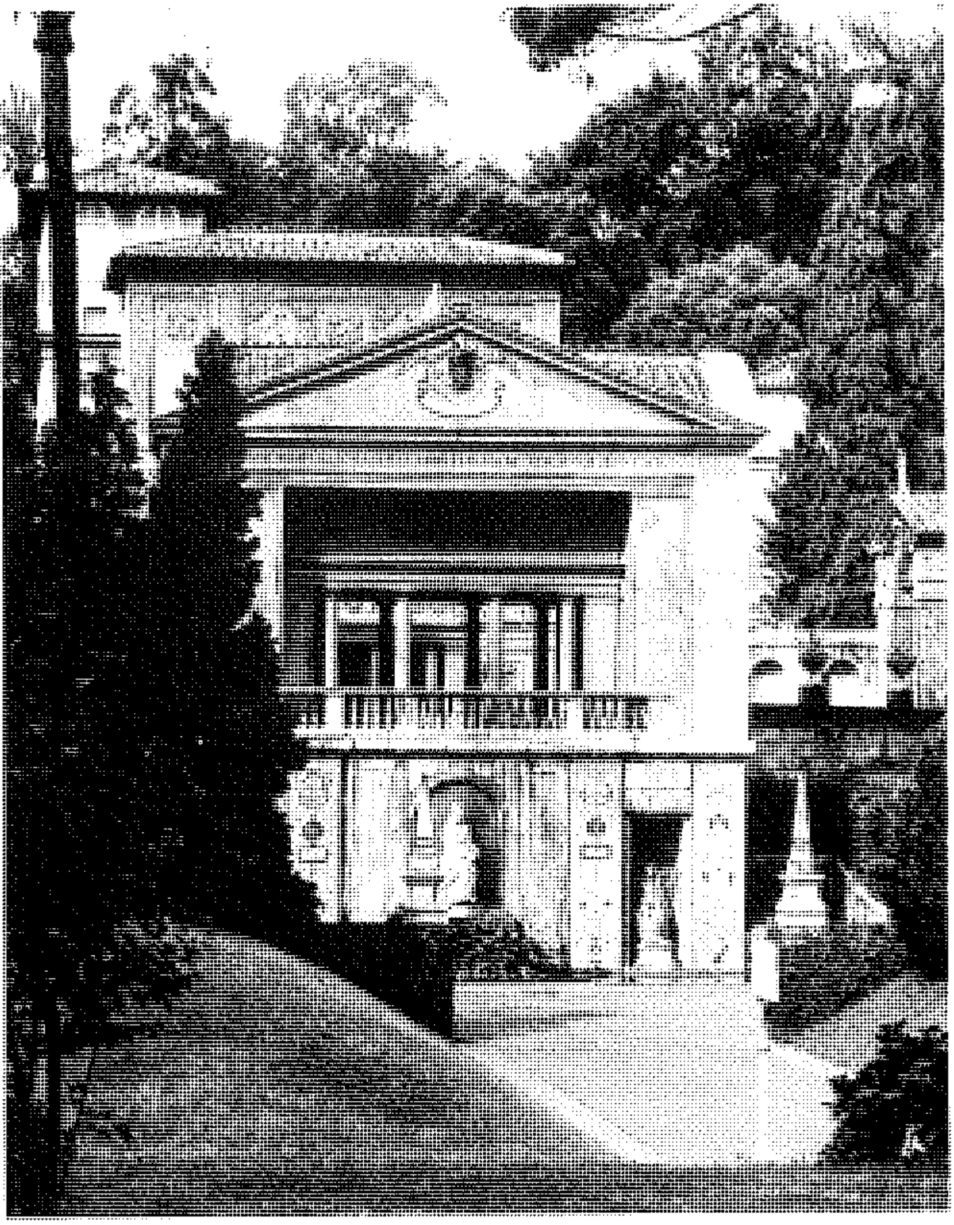

Casina Pio IV - Vatican Gardens
Seat of the Pontifical Academy of Sciences

PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA
77

STUDY WEEK

ON:

AGRICULTURE AND THE QUALITY OF LIFE
NEW GLOBAL TRENDS

October 17-22, 1988

EDITED BY

G.B. MARINI-BETTÒLO

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CONTENTS

CARLOS CHAGAS: *Foreword* XI

List of participants XIII

Pontifical Audience XVII

SCIENTIFIC PAPERS

G.B. MARINI-BETTÒLO: Agriculture and the Quality of Life: New Global Trends. (Introductory Remarks) 1

I.

AGRICULTURE AND THE QUALITY OF LIFE: NEW TRENDS

J.W. MELLOR (*): Problems and Tendencies of Modern Agriculture in Developed and Developing Countries 13

R. MORENO: Effects of Incentives on Agricultural Production and Their Impact in the Third World 23

P. PICCARDI: Impact of New Technologies on Small and Large Farming Systems 33

B.N. OKIGBO: The African Dilemma and the Quest for Appropriate Technologies for Sustainable Agriculture and Food 53

(*) Was not able to attend the meeting but contributed this paper.

II

SCIENCE AND THE FUTURE OF AGRICULTURE

Y. De Malach - D. Pasternak: Agriculture in a Desert Saline Environment — A Case Study 97

J. Döbereiner: Soil Fertility Alternatives in Tropical Agriculture . 127

T.R. Odhiambo: Pest and Disease Control Alternatives 139

III

DEVELOPMENT OF AGRICULTURE SYSTEMS FOR SPECIFIC ENVIRONMENTS

E.G. Hallsworth: Agroforestry 151

E.H.M. Hartmans: Alternatives in Agriculture in the Tropics . . 159

C.-G. Hedén: Coastal Deserts — A Challenge for a Proposed Biological Resource Development Corporation 169

A. Richmond: An Agricultural Approach for the Upliftment of the Quality of Life in Arid Lands 187

H.A. Fitzhugh - R.E. Hudgens: Small, Medium, and Large Farming Systems: Improving Productivity and Ensuring Sustainability. . 195

E.G. Hallsworth: Traditional Systems of Soil Conservation . . . 205

IV

TECHNOLOGIES AND INDUSTRIALIZATION

D. Zylbersztajn: Biotechnology and Technological Innovation in Agroindustry 221

N.B. Araujo: Seed Production and Commercialization: An Analysis of Brazil 231

M. wa Kalenga (*): Interconnexion energy-nourriture: l'Afrique peut-elle atteindre l'auto-suffisance alimentaire? 239

(*) Was not able to attend the meeting but contributed this paper.

V

PROSPECTS FOR A NEX WORLD AGRICULTURE WHICH IMPROVES THE QUALITY OF LIFE

H. UNMOLE: Energy and Agriculture in Africa 251

R.. GARCÍA: «Modernization» and Socio-Environmental Deterioration 271

U. COLOMBO: Some Observations on Energy and Agriculture . . 281

E.G. HALLSWORTH: Education with Responsibility Towards the Environment and the Value of Life on the Land 295

A. BOZZINI: Formation and Research: the Role of FAO 307

Conclusions 325

FOREWORD

Since the neolithic age, i.e. 10,000 years ago, agriculture has represented the main linkage of man with nature, and his principal source of food.

The growth of humankind since then has been made possible by the parallel development of agriculture through the continuous input of experience and later of science and technology.

At the present time, the products of world agriculture could be sufficient to cope with the needs of humankind if the agricultural areas were equally distributed on the various continents, whereas in many countries hunger, malnutrition and even famine still exist. This is mainly the case in the poorer regions of the world, in particular in Africa and South America.

The Pontifical Academy of Sciences, following its traditional lines of action, i.e. the promotion of agricultural improvement and the solution of the problems facing the developing countries, organized the Study Week Agriculture and the Quality of Life *in October 1988, with the participation of scientists and experts from all over the world.*

The object of this meeting was to analyze the relationship between agricultural progress and the quality of life, particularly in the tropics, and to suggest solutions leading to more efficient systems of tropical agriculture and resource management, and a greater respect for the environment.

The Pontifical Academy of Sciences is pleased to present the results of this important broad-based effort by publishing the proceedings of this meeting, for they constitute a significant contribution to the solution of the problems of hunger and poverty in the tropics.

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President of the Pontifical Academy of Sciences, 1972-1988

October 1988

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PONTIFICAL AUDIENCE

On Monday, October 31, 1988, His Holiness John Paul II granted an Audience in the "Sala Regia" of the Apostolic Palace in the Vatican to Members of the Pontifical Academy of Sciences gathered in Plenary Session to discuss the theme of the responsibility of science as regards the topic of "Agriculture and the Quality of Life" and "The Principles of Design and Operation of the Brain". His Holiness John Paul II addressed the President, Prof. Carlos Chagas, and the Participants on the importantance of scientific research and development in both these areas.

Monsieur le Président,
Messieurs les Cardinaux,
Excellences,

1. Je suis heureux de saluer les Membres de l'Académie pontificale des Sciences, à l'occasion de la session plénière où a été traité le thème de la responsabilité de la science. L'importance de cette rencontre est soulignée par la présence des Cardinaux et des Chefs des Missions diplomatiques accréditées auprès du Saint-Siège. Je les remercie de cette marque d'intérêt pour les travaux de l'Académie.

Cette assemblée plénière a lieu à la suite de la semaine d'étude au cours de laquelle deux groupes d'experts venus du monde entier ont débattu d'une part sur «l'agriculture et la qualité de la vie», et d'autre part sur «la structure et la fonction du cerveau».

Au sujet de l'agriculture, les experts ont pu établir un large bilan où les aspects scientifiques et techniques du problème rejoignent finalement les aspects éthiques. D'une part, la recherche scientifique a permis un développement considérable de la production alimentaire dans le monde. A l'échelle globale, la production agricole serait aujourd'hui suffisante pour subvenir aux besoins de l'humanité entière. Cette constatation soulève par contraste le problème dramatique de la faim et de la malnutrition dans le monde. Certes, il faut tenir compte des obstacles physiques et matériels, tels que les grandes différences de fertilité suivant les régions. Mais la répartition très inégale des ressources alimentaires n'a pas suscité jusqu'ici une politique d'ensemble, ni des projets assez efficaces pour que la production agricole bénéficie à tous les peuples et à tous les hommes. Encore une fois, nous devons observer que le problème du développement requiert avant tout une volonté politique et une action de nature éthique et culturelle, comme je le disais dans l'encyclique «Sollicitudo Rei Socialis». La clé de tout développement humain est à trouver dans un effort généreux de solidarité entre tous les groupes et tous les hommes et les femmes de bonne volonté. A bon droit, vous avez souligné que les interventions nécessaires en cette grave question doivent respecter les personnes et leurs traditions propres, c'est-à-dire dépasser le plan strictement économique et technique pour tenir compte des principes de la justice sociale et du développement authentique de la personne humaine.

2. Un second groupe de savants a fait le bilan des études sur le cerveau humain et ses admirables fonctions. Les recherches permettent de mieux connaître aujourd'hui les structures et les processus organiques qui servent de base aux opérations cognitives et affectives de l'être humain. Mais, au-delà de toute observation empirique, apparaît le mystère de l'esprit, irréductible aux supports biologiques mis en œuvre dans le comportement de l'être intelligent ouvert à la transcendance. Devant ce que l'on connaît maintenant du cerveau, le croyant ne peut oublier les paroles du Livre de la Genèse: «Dieu modela l'homme avec la glaise du sol, il insuffla dans ses narines une haleine de vie et l'homme devint un

être vivant».[1] En termes anthropomorphiques, l'antique récit de la création évoque bien le lien intime de l'organe et de l'esprit en l'homme. Aussi étail-il opportun que des savants confrontent les résultats de leurs études expérimentales avec la réflexion de philosophes et de théologiens sur le rapport entre l'esprit et l'appareil cérébral. Niels Stensen, dans son «Discours sur l'anatomie du cerveau», avait déjà dit du cerveau qu'il était «le plus beau chef-d'œuvre de la nature».

3. Vous avez voulu vous associer à la célébration récente de la béatification de Niels Stensen, ce grand savant qui a cherché, dans toute sa vie et dans toute son œuvre, à réconcilier les divers ordres de la connaissance qui font la grandeur de l'être humain. Votre Académie, conjointement avec le Danemark, a voulu que le souvenir de cet événement demeure et soit commémoré par une plaque apposée dans ses propres locaux. Je tiens à exprimer à la nation danoise et à l'Académie ma vive gratitude pour ce geste.

4. Aujourd'hui, ayant présent à l'esprit l'itinéraire que parcourut Niels Stensen au long de sa vie, je voudrais y relever quelques éléments qui contribuent à approfondir le sens, la valeur et la responsabilité de la science. Ce savant explora les merveilles de la nature, particulièrement dans les domaines de l'anatomie, de la physiologie et de la géologie. En poursuivant ses études sur les phénomènes naturels, il ne perdait jamais de vue ce qui transcende la nature elle-même et, tout en portant son attention sur l'infiniment petit et sur les données mesurables, il demeurait sans cesse ouvert aux grandeurs qui dépassent toute mesure.

Pour lui, la synthèse de la connaissance réunit les données recueillies grâce aux expériences sur la nature et les valeurs qui, bien qu'inaccessibles à l'expérimentation sensible, font partie de la

[1] *Gen.* 2, 7.

réalité. Stensen était profondément attiré par la beauté de l'univers physique, mais plus encore par les valeurs spirituelles et la noblesse du comportement humain. Il étudiait avec soin les certitudes d'ordre mathématique, mais il était tout autant attiré par d'autres certitudes d'ordre historique, moral et spirituel.

5. La science expérimentale suscite une légitime admiration, et l'Eglise encourage volontiers les recherches des savants qui nous aident à comprendre les énigmes de l'univers physique et biologique. Mais la science expérimentale n'épuise pas toute la connaissance de la réalité. Au-delà du visible et du sensible, il existe une autre dimension du réel, attestée par notre expérience la plus profonde: c'est le monde de l'esprit, des valeurs morales et spirituelles. Au-dessus de tout, il y a l'ordre de la charité, qui nous relie les uns aux autres et à Dieu dont le nom est Amour et Vérité.

Même avec la fragilité de sa condition de créature, l'homme garde en effet l'empreinte de l'unité divine originelle dans laquelle toutes les richesses sont unies sans confusion. Dans le monde sensible, ces richesses semblent dispersées et amoindries, mais elles n'en rappellent pas moins, particulièrement en l'homme, l'image de l'unité véritable du Créateur. Cette image est celle de la Vérité elle-même.

Telles sont les caractéristiques de la synthèse globale qui établit l'unité du savoir et qui inspire, par voie de conséquence, l'unité et la cohérence du comportement. Il s'agit là d'une unité à construire en permanence, en fonction des caractéristiques dynamiques de la vie.

6. Mon prédécesseur, le Pape Pie XI, dans un des premiers discours qu'il adressa à l'Académie pontificale des Sciences après sa reconstitution, développa longuement le thème de la vérité. Il disait qu'il est important de concevoir et d'affirmer la vérité, mais qu'il est encore plus important de rappeler que «celui qui *fait* la

vérité vient à la lumière».[2] Telle est la règle fondamentale de la pensée et de l'action qui trasforme toute œuvre en un reflet visible de la vérité. C'est en s'inspirant de cet idéal que Pie XI nomma, en 1936, les soixante-dix premiers membres de l'Académie rénovée, les ayant invités à en faire partie eu égard à l'importance de leurs études scientifiques originales et à leur haute qualité morale, sans aucune discrimination ethnique et religieuse. C'est ainsi que s'expriment toujours vos Statuts et c'est dans le même esprit que je vous invite à poursuivre vos travaux et vos recherches.

7. Le Pape, aujourd'hui encore, demande à votre Académie de contribuer à «faire la vérité», c'est-à-dire à rechercher l'unité du savoir dans la solidarité scientifique internationale, dans la solidarité humaine, dans l'ouverture à toutes les valeurs, pour le bien de l'homme.

Certes, comme savants, vous avez à appliquer rigoureusement les règles propres à chacune de vos disciplines pour aboutir à des conclusions valides et vérifiables par tout autre spécialiste dans vos domaines. Mais, tout en respectant les nécessités de l'abstraction méthodologique et l'autonomie de chaque discipline, vous êtes invités à examiner les résultats de vos recherches à la lumière des autres sciences. Tout savant est aujourd'hui appelé à participer à une patiente recomposition des connaissances humaines. Il y va de l'avenir de l'homme et de la culture.

Votre Académie, qui est internationale, présente une caractéristique propre: elle a d'une part le devoir de travailler en lien avec la communauté scientifique internationale et, d'autre part, elle est appelée à collaborer avec les organismes de l'Eglise afin de leur fournir des éléments utiles dans le champ de leurs compétences.

C'est dans cet esprit que je voudrais renouveler aux illustres Membres de l'Académie la requête que je formulais lors de

[2] *Io.* 3, 21.

l'audience du cinquantenaire, en les invitant à promouvoir des propositions concrètes pour favoriser à tous les niveaux la collaboration interdisciplinaire. Tout en poursuivant vos programmes spécialisés, il serait utile aussi que vous élaboriez des projets conjoints de recherche, en concertation étroite avec d'autres organismes culturels, scientifiques et universitaires du Saint-Siège. L'Eglise a besoin de vos recherches pour approfondir sa connaissance de l'homme et de l'univers. Elle compte également sur vos études pour affronter les graves problèmes techniques, culturels et spirituels qui touchent à l'avenir de la société humaine. D'avance, je vous remercie de votre apport indispensable à notre approfondissement commun de l'énigme de l'homme et de son destin, dans l'ordre de la création et dans l'ordre du salut.

8. Avant de terminer, je désire saluer très spécialement Monsieur le Professeur Carlos Chagas qui, au terme de seize années de présidence, quitte des responsabilités auxquelles il a fait face avec tant de distinction, de générosité et de désintéressement. Je tiens à lui rendre un hommage tout particulier, en prenant acte de l'œuvre considérable accomplie sous sa conduite. Grâce à lui, l'Académie a connu un développement important quant au nombre de ses membres et à la diversité des pays d'où ils viennent: on peut maintenant parler d'une représentativité universelle. Sous son impulsion, l'Académie est devenue le centre d'une continuelle activité, prenant contact avec les autres Académies et avec les savants de nombreux pays, abordant des thèmes importants dans le domaine des sciences historiques, par example les études sur Galilée et Albert Einstein, dans le domaine des sciences fondamentales, ainsi les recherches sur la cosmologie, l'astronomie, les microsciences, la structure de la matière, l'origine de la vie, les processus biologiques, ou encore dans le domaine des sciences appliquées aux problèmes du monde moderne, notamment en ce qui concerne la paix et le désarmement. On peut dire que les préoccupations importantes de notre monde actuel n'ont pas

échappé à son attention. Aujourd'hui, le Saint-Siège remercie Monsieur le Professeur Chagas, pour la vitalité qu'il a su communiquer à l'Académie, pour le rayonnement qu'il lui a donné, pour son action très appréciée grâce à laquelle l'Eglise est devenue beaucoup plus présente au monde de la science. Et je lui sais gré moi-même de bien vouloir continuer à la faire bénéficier de ses hautes compétences.

J'ai appelé Monsieur le Professeur Giovanni Battista Marini-Bettòlo à prendre la succession du Professeur Chagas. Il a collaboré activement aux travaux de l'Académie depuis plus de vingt ans; dans ses nouvelles responsabilités, je lui souhaite un travail fructueux. Je suis sûr qu'il poursuivra, avec l'aide des Membres de l'Académie, l'œuvre entreprise par ses prédécesseurs.

En renouvelant l'expression de mon estime pour les travaux de l'Académie et de ma gratitude pour le service qu'elle rend au Saint-Siège, j'invoque sur vous la Bénédiction de Dieu.

SCIENTIFIC PAPERS

AGRICULTURE AND THE QUALITY OF LIFE: NEW GLOBAL TRENDS

INTRODUCTORY REMARKS

G.B. MARINI-BETTÒLO (*)
Pontifical Academician

The present Study Week on "Agriculture and the Quality of Life" has the aim to analyse and debate how agriculture and related activities may improve the quality of life in our present world, and mainly in the developing countries.

During its long evolution humankind has used for millenia as the principal source of its food, the fruits and the vegetables spontaneously growing, as well as the game obtained through hunting. About ten thousand years ago in the neolithic era man began to cultivate wild plants and to domesticate animals to obtain the main source of food. The introduction of agriculture marks one of the turning points of human progress which is now known as the neolithic revolution.

Since then, the progress in quality and in extension of agriculture has marked the development of humankind and has made possible the existence of past and present societies.

Under a scientific aspect, agriculture represents the most important natural system, adopted and then mastered by man, in order to purchase renewable resources by transforming solar energy into more manageable forms of chemical energy present in cereal and legume crops, in wood fibers — cotton, jute, linen — and other raw materials.

Thus agriculture represents the main source, direct or indirect, for

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feeding human-kind, considering also the agricultural products used for growing livestock.

The development of human-kind was made possible, during several millenia, by the availability of food obtained through the continuous improvement of agriculture. Agricultural production is closely related to soil fertility and thus to adequate soil management. In the past many historical events, e.g. the great migrations in Europe of northern populations toward the south, recorded generally as the barbarian invasions, were caused by the need of fertile lands for a growing population.

In the late XVIIIth century, Malthus observed that the improvement of land management and the betterment in agricultural techniques could not, in the future, satisfy the needs of the increasing population because whereas the rate of growth of the population followed a quadratic law, food production was characterised only by a linear increase.

Therefore world development was in danger of facing an indiscriminate food shortage.

It was most fortunate that this dramatic period coincided with the development of science and of its applications. Maybe it is too limiting to call this period the first industrial revolution. Certanly the reaserch in plant physiology, developed in these years by Liebig and Boussingault, indicated to agriculture that an increased crop yield could be obtained through supplying the plant with nitrogen in forms such as the nitrates or the guano furnished in these years by Chile and Peru, and later obtained from synthetic chemical fertilizers.

A further scientific advance in the betterment of agriculture was due to the research of Mendel on genetics. Later Pasteur establishing the role of enzymes in biochemical processes made possible the understanding of the natural transformations occurring in plants and soil.

The equilibrium between the growth of human-kind and crop production was maintained for many years, although not in an adequately distributed way throughout the world.

Whereas in North America, the "corn belt" produced cereals and other crops for all the world, difficulties in cultivation related to severe meteorological conditions or mismanagement of the soil (drought, floods, soil erosion etc.) caused in many regions shortages of food, and thus hunger and famine.

In the forties a limiting factor for the further increase of agricultural productivity was identified in the massive destruction of crops in the fields by pests — arthropods, insects, molds, bacteria fungi, viruses — and after the harvest during storage. The losses could be assessed at more than 30% of production.

Since then, the use of chemicals and advanced pesticides has limited the figures of the losses. The production of food and animal fodder in the world has again been increasing at a rate higher than that of the population growth. This has also been due to genetic improvement, especially regarding the yield and the quality of the more important crop plants: rice, maize and wheat in the first place, as well as many others such as soybeans and other legumes, and root-crops.

Modern techniques based on genetically improved varieties of plants, on better soil management and on plant protection from pests — techniques which are also referred to as *the green revolution* — have, in the last twenty years, reversed the trends of a poor agriculture in the tropics, resulting in full independence of many countries with regard to food supply. This has been achieved through a long but successful effort in South East Asia, and particularly in India.

From a purely statistical point of view, the present production of primary food and fodder from agriculture is even higher than the quantity needed for the five billion persons living in the world. Therefore it should no longer be necessary to speak about hunger and famine in the world. Nevertheless, for a number of reasons e.g. — mainly poverty and inadequate distribution of the agricultural production — about twenty percent of the world population is at present undernourished and hungry.

In 1950 world cereal production was 700 million tons. By 1985 it has reached 1,800 million tons with an annual growth rate estimated at 2.7%. Thus, world production is now of a capacity to supply sufficient food to everyone. If we analyse the distribution of this production increase we notice that it was substantial in every continent — due in part to a massive input of agrichemicals and high yielding varieties of plants — except for Africa. There the per capita production has decreased in the last twenty years by about 1% per year. However, we must remember that the rate of population growth in this area has been the highest in the world — about 2.5-3% per year.

Grain production is not only destined for human alimentation. The present quality of life in the world requires more and more meat and dairy products. According to statistics, meat production has risen from two million tons in the fifties to eleven million in the eighties. This requires a great amount of feed-grain for livestock.

All these achievements were due to an increase in productivity obtained through a continuous betterment of agricultural techniques already mentioned above, e.g. genetic improvement of plants, more extensive use of fertilizers (a ninefold increase) and of pesticides (a thirty-twofold increase), and also a greater use of irrigation.

This means that agriculture has become highly technological and is now more than ever industry dependent if high yields are required. The negative aspect of this approach is represented by a progressive effect on the quality of the environment.

At present, we can identify three main approaches to agriculture in the world:

1) *Industrial agriculture*, which needs great inputs of capital, mechanization, chemicals and advanced agricultural technology. It requires vast areas for easy cropping, and is peculiar to the "grain belt" in North America, in Australia, in New Zealand, in Eastern Europe and in Western Europe.

2) *Green Revolution agriculture* is particularly well adapted to regions where flat and irrigated lands are available, as in South East Asia, Latin America and North Africa. It requires a great input of labour, mainly human or animal supplied, plus pesticides, fertilizers and naturally selected seeds.

3) *Resource-poor agriculture* is common in drylands, highlands, and in regions where there is soil erosion or the soil is very fragile and does not permit the formation of sufficient humus. This type of agriculture is characteristic of sub-Saharan Africa and many regions in Latin America and Asia.

I — The first model, industrial agriculture, generally leads to overproduction and thus to surpluses. The Green Revolution model, after twenty years of experience, has led to self-sustainability and even to the possibility of exporting part of a crop. The last type, resource-poor agriculture, has led to insufficient production for the local food demand, and thus requires a large import from abroad.

Thus, the grain flows from the richest countries to the poorest, and this is also a cause of the continuous economic dependence of the latter on foreign debt, and a reason for the failure of any effort to establish a self-supporting economy.

So far, only the food production aspect of agriculture has been considered. Agriculture may also provide raw materials in the form of fibers (e.g., cotton, jute, linen), of cellulose, sugar and other fermentable materials for the production of ethanol, of oils and fats, etc.

All these forms of production may also into the above-mentioned three classes.

This very rough sketch of the present trends in agriculture has been presented in order to focus our meeting on the questions related to quality of life. It is also important to assess agriculture's future capacity to cope witb population growth and to overcome the negative tendency of agricultural development in Africa and in depressed areas of Latin America, Asia and other continents.

To this end, we should examine the social, economic and environmental aspects of agriculture. This includes present-day land use, the search for new lands, and energy availability. As scientists we are interested in the development of new technologies for the betterment of agricultural productivity, but we must also face a number of prohlems which threaten the present satisfactory stage reached, in the world, by agricultural production.

There are no problems regarding quality of life for the farmers cultivating their lands according to the industrial model. They support a wealthy society which relies on the large-scale availability of food and raw materials obtained as the primary transformation of solar energy. Their surplus is not only a source of wealth, but it is also a cause for concern.

Self-sufficient agriculture, where man's — or better, woman's — contribution is very great, relies on the principles of the Green Revolution. It is the second model of agricultural development, and it has gained independence from imported food for a great number of countries in South East Asia and especially in India. It was a great effort, sustained by scientists in those countries, such as our friend M.L.S. Swaminathan, to whom we must be grateful.

It is the *resource poor agriculture*, insufficient to support the present needs for the local population's food, which should receive our particular attention and consideration in this meeting, because in this case it is not only the quality of life that is in question, but survival itself.

World agricultural production has shown an incredible increase in the last thirty years. This is not only due to scientific advances and to the adoption of modern technologies, but also in great part to the subsidies and incentives given by governments, though unequally distributed, and to the international prices of raw materials.

Thus an economic factor must be considered in every proposed solution for different countries. For example a diagnosis of the insufficient development of African agriculture should take into account not only the technical aspects but also international prices and the level of subsidies. In effect, a poor reward limits the farmer's interest in his work, independent of geo-meteorological and environmental conditions such as soil fragility, frequent drought and pests. This does not facilitate the development of an adequate agriculture. It is thus most important that new models should be studied to overcome these difficulties for the different African regions.

II — Our work could be greatly facilitated if in our presentations, and even more in the following discussions, we consider how we can maintain the rate of growth in agricultural production in order to sustain a population which will double in the next sixty years, and how we shall improve the distribution of the production in the various geographical areas. For this purpose, in addition to advanced techniques, the traditional integrated systems like agroforestry should also be studied. We should consider too, that according to the United Nations projections, 90% of the population growth will take place in the poorest countries, and of this growth 90% will take place in the cities.

We should also bear in mind that the scope of agriculture is not limited to crop production alone, but that it includes maintenance and augmentation of soil fertility. In the present emergency case of Ethiopia, the famine is due more to lack of soil fertility than to drought.

For the future development of agriculture the major points of concern are:

1) the degradation of the soil, and thus of soil fertility, caused by intensive soil cultivation, by the overuse of chemicals in the form of fertilizers and pesticides which compell people to find lands by clearing — with the slash and burn technique — tropical forests where the fragile soil will not support crop cultivation for more than a few years. Such a policy not only leads to deforestation with all its implications, but will not even meet the survival needs of the new settlements;

2) the ever growing need for arable lands in many countries, China for example, where fertile soils are subtracted from agriculture for the building of new cities and industries;

3) the degradation of soil resources which, through erosion, acidification, desertification and loss of fertility, represents the most potent threat to the future of agriculture;

4) the mismanagement of irrigation systems which, in severe climatic conditions, leads to soil alkalinization and salinization;

5) desertification, which is the result of climatic conditions, but also of an erroneous use of the soil by man;

6) mountain and highland mismanagement and deforestation,

causing the breakdown of ecosystems which for centuries have protected the lowlands from tragic floods in many regions of the world.

It is important to overcome these difficulties with an accurate land management and adequate use of fertilizers and pesticides as well as the use of selected varieties of crop plants in order to protect the soil and to increase the yields.

We should concentrate scientific and technological efforts on recovering marginal lands, and on supporting the self-sustaining farmers in developing countries, in order to improve and rationalize their agricultural production; the same applies to ranchers and herders — and also to transnational companies — in order to lessen the burden of livestock on poor soils that are overgrazed. Genetic improvement in certain animal breeds could enhance their productivity and thus reduce their number.

III — The present situation indicates that the positive state of today's agriculture which provides food and feed for all the world rests on a very fragile and delicate equilibrium which should definitely be defended so that agriculture and related activities may double their production in the near future in order to meet the needs of a rapidly growing population. This is the point in our deliberations where we should remember the statement made by the U.N. Commission on Environment and Development: "that the planet is passing through a dramatic growth and fundamental change" (1987).

Agricultural planning, which in some countries has become quite an industry, should take into account its impact on the environment and its economic aspects in order to achieve an improvement in the quality of life in poor lands (in marginal and dry lands, in mountain districts) or in difficult conditions, and to fight poverty in developing countries, also by means of international agreements.

Incentives for agricultural production in developing countries, especially in Africa, should mainly have the function of establishing equitable prices to farmers for their crops, and of avoiding food imports from other regions of the world except in emergency conditions. A better distribution in the balance between the cultivation of cash-crops — a colonial inheritance — and food crops should be encouraged, the former being subject to the oscillations of the international markets.

Scientific, technological and economic efforts should participate in the first stage of the program to restore food productivity in resource-poor agricultural areas and to stop the transfer of manpower from rural areas to the tragic shanty-towns of tbe megalopolis.

Tropical lands need more technology — not only fertilizers and pesticides — but new varieties of crop plants resistant to insects and diseases, to severe climatic conditions and to drought. The soil in fragile land areas should be particularly studied in order to maintain and develop organic matter whose physical, chemical and biological properties make up the most important element in soil fertility.

Agriculture has had a fundamental role untill 50 years ago in protecting the environment, providing crops, food, fibers, wood and other renewable resources to a growing humankind.

Even more, agriculture has created a special link between man and land, developing particular cultures and traditions in different countries, which represent an important contribution to the present civilization and to the delicate equilibria in the society and between man and natural resources.

In some areas in the last years agriculture has become excessively dependant from industry (mechanization, fertilizers, pesticides, herbicides).

The advancement of science and the use of biotechnologies may be of help in changing this dependance introducing new bioengeneered varieties of crop plants, insect, fungi and virus resistant, as well organisms to restore soil fertility.

The aim of present line of research in the world is to reach new equilibria with a self sustainable agriculture.

Your contributions — both in the presentations and in the discussion — should highlight the possible ways to follow — ways which should always respect the environment and the ethical use of our present scientific and technological resources, and which are consistent with a sound international economy. The goal is to eliminate poverty in areas poor in resources through a better use of scientific and technological resources. Food security should sustain continuing population growth in a world where everyone has the right to an acceptable quality of life.

This is a great challenge, both present and future, which has been taken up by many international institutions, the United Nations, FAO, UNIDO, UNEP, UNESCO and the World Bank in their respective capacities.

In the present meeting you will bring your contributions of ideas, knowledge and experience to the better understanding of the present and future role and possibilities of agriculture. This meeting will not only have a scientific basis but — mindful of being at the Pontifical Academy of Sciences — it will consider the ethical and social issues of the problems of poverty, hunger, malnutrition and disease afflicting a substantial part of the world's population, problems which have been presented so clearly to world opinion by Pope Paul VI in the encyclica « *Populorum progressio* » twenty years ago, and now again by John Paul II in «*Solicitudo rei socialis* ».

I

AGRICULTURE AND THE QUALITY OF LIFE: NEW TRENDS

PROBLEMS AND TENDENCIES OF MODERN AGRICULTURE IN DEVELOPED AND DEVELOPING COUNTRIES

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It is perhaps the dominant view in development circles that the 1960s and the 1970s were the golden age of development, and that developing countries cannot now achieve as rapid rates of growth as were achieved at that time. This pessimistic view arises because growth in developing countries is seen as dependent on exports to developed countries, which, in turn, finance essential capital goods imports. Unfortunately, the developed countries are now growing less rapidly and have restricted their trade. Furthermore, developing countries' massive debt crisis prevents export earnings from being used to finance growth. Since these circumstances seem so intractable, the growth rates of the 1960s and 1970s are seen as an aberration on the development road.

I argue, strongly to the contrary, that the aberration along the road to development is the 1980s. This has been a period of massive structural imbalances generated out of the circumstances of the 1970s. Some of these imbalances were internal to developing countries, others to developed countries. In particular, the imbalances in the budget and trade balance of the United States have had large global effects. The successive oil shocks were also difficult to absorb. In particular, the second shock created serious problems for oil-importing countries and, indeed, was disruptive to a number of oil-exporting countries as well. The sharp decline in oil prices after the second shock was not widely predicted and again created a number of adjustment problems for both oil exporters and importers. As is normally the case, the burden of these disruptions fell on the primary commodity exporters, particularly the developing countries.

Growth in developing countries is a process of technological development, institutional development, and human-capital formation, all of which rapidly increase the productivity of resources. To turn the point around, countries are poor because the productivity of their resources is poor. The basic engine of growth is not exports to developed countries, but processes that increase productivity. Like any complex economic process, they can be set back or put off track completely by the kinds of structural problems that occurred globally in the 1980s.

Development Strategies and Foreign Assistance

The 1980s were also a period of searching for the most effective types of foreign assistance. Foreign assistance, like everything else, takes on the characteristics of the environment in which it operates. If the host institutions and human capital are underdeveloped in recipient countries, they do not use foreign assistance much more effectively than their own resources. In the context of structural distortions in the 1980s, the deficiencies of foreign assistance became spotlighted. First, foreign assistance underemphasized investment in human capital and basic physical infrastructure. Second, because of rapid growth in the number of donors in recent years, it has suffered from lack of coordination within the donor community (Mellor and Masters, 1988). In the 1950s, the United States dominated foreign assistance and hence coordination was little or no problem. Now the United States only provides 29 percent of the total official development assistance (OECD, 1987). Since that is heavily concentrated on just a few countries, the ability to direct, coordinate, and influence foreign assistance in the bulk of the developing world is very small indeed. For example, the United States provides only 9 percent of total official development flows to India.[1]

The number of actors on the foreign assistance stage is so large that we must turn to something more analogous to market processes than meetings if we are to have proper coordination. What is needed is broad agreement among donors on an appropriate development strategy. That strategy must meet both growth and equity needs, and although foreign trade can be a very important part of the strategy, it cannot be an export-led strategy. This means that a growing domestic market,

[1] 1.5 percent of total U.S. ODA, $ 152 million, went to India in 1985/86 (OECD, 1987).

rather than foreign markets, must be the driving force for growth in the domestic economy of most developing countries.

Rapid growth in a large domestic market is possible in low-income countries dominated by agriculture only if incomes are rising in the agricultural sector. That is why agriculture must be the initial engine of growth. Increased factor productivity in that sector then gives a stimulus to effective demand and even more rapid growth in the nonagricultural sector (Mellor, 1986). In effect, public support, particularly of technological change in agriculture, provides the most important source of overall agricultural growth. That process leads to a rapid transformation of the economy, such that the more rapid the rate of growth in agriculture, the more rapid its relative decline as a percentage of the total economy. This conundrum is one of the most clearly documented facts of economic development (Mellor and Johnston, 1984; Mellor, 1976). In turn, in the context of such a broadly agreed upon strategy, various donor countries will find their foreign assistance supported by somewhat differing constituencies, applying their resources in response to deal with different aspects of development. With an agreed overall strategy, there will be a natural coordination of assistance efforts.

This is in sharp contrast to the situation in the last few decades, in which we have gone from one development fad to another with each representing only a small portion of the developmental process, and all donors clustering around that particular fad. In moving from one fad to another, recipient countries were overwhelmed with far too much assistance for certain aspects of their development, and with gross neglect of others. These fads, the infrastructure orientation of the 1950s, the poverty orientation of the 1970s, and the free market orientation of the 1980s, are each important elements of development but do not constitute an overall strategy.

I now want to proceed within the context of a broadly accepted development strategy to discuss four specific problem areas with particular opportunities for progress in the 1990s: hunger, agricultural factor productivity, trade and instability.

Abolition of Hunger

World hunger can be abolished in a relatively short period of time, that is, over the next 15 to 20 years. In the 1990s, we should be able to break hunger's grip on the poor, completing the job in the early part of the next century. To abolish hunger, we must recognize the following:

(1) It is a large task, not a small one. A minimum of 700 million people in the world are so poor that they cannot obtain adequate food for even a minimally active life.

(2) Because the problem is large and requires substancial resources, it must be seen in the context of development that leads to self-reliance for the poor.

(3) The development process for dealing with this problem of poverty will, under the best circumstances and the clearest diagnosis, take 15 to 20 years to achieve.

(4) The basic goods, particularly the food, to eliminate poverty and hunger are currently being produced — much of it in the developed countries. However, building the institutions to transfer those resources and to provide self-reliant growth for the poor will themselves take 3 to 5 years.

(5) Finally, the world has changed in the last 20 to 30 years in a way that makes tackling this task feasible. Poverty has been greatly reduced in countries that have already experienced rapid growth. And a large majority of the world's people are in countries that are now experiencing or about to experience rapid growth. We understand far better than we did 20 or 30 years ago the processes of rural, agriculture-based growth which will most benefit the poor. And we see that process in a total development strategy, not just as an isolated case. The world itself is now a far wealthier place, so that a much smaller proportion of its resources will be needed to tackle a problem that is more clearly definable, more clearly solvable than it was in the past.

At this point, I must clarify a popular misunderstanding. Notwithstanding the drought in the United States this past year, there is a correct perception in the world that we are holding large surpluses of food in developed countries, that food prices have been relatively low and that many developing countries which used to be deficient in food now have surpluses. This has led to a view that hunger and poverty in the world are problems not of production but of inequitable distribution (Sen, 1981). The implication is that all we need to do is to redistribute existing resources in order to take care of poverty. This is a view which distracts attention from half of the problem and it does so because it is only half the truth.

The view that hunger is mainly a distribution problem begs the question: "How are the poor to generate the purchasing power to effect an equitable distribution of food?" In large part, the poor live in rural areas and make their living in agriculture. Therefore, the only way to get purchasing power into their hands, at least in a way that can be sustained, is through increasing the productivity of their labor and their land so that they can produce more agricultural products than in the past. Where agriculture dominates as a source of income, efforts to increase agricultural production are inseparable from efforts to increase the means to purchase food. The process, of course, involves complex interactions between the agricultural and nonagricultural sectors.

We now have studies that indicate clearly that a major constraint to bringing the Third World's rural poor into the development process is the lack of infrastructure (Ahmed and Hossain, 1987). Roads, electrification, and communication facilities integrate rural areas into larger society and provide farmers with access to modern agricultural technology, particularly high-yielding varieties, as well as other necessary inputs such as fertilizers and consumption goods. Roads and other infrastructures in very poor countries are built substantially on food. That is to say, they can be built labor-intensively, and those laborers will spend practically all of their additional income on food. Therefore, food surpluses from the developed countries can be used effectively to pay a major portion of the cost of building the infrastructure in rural areas, providing an important connection between short-term alleviation of poverty through relief efforts and the long-term effort to achieve self-reliant growth. As long as surpluses of labor in poor countries and surpluses of food in rich countries are not put together, we will be grossly constrained in our efforts to remove hunger and poverty.

The development processes we are discussing can also reduce the growing concern for environmental decay in Third World countries. While in developed countries, environmental destruction is primarily a product of wealth, in the poorest countries it is a product of poverty. The most serious environmental problem in developing countries is the increasing population pressure on limited land resources, pushing cultivation out into more and more fragile areas and resulting in deforested land that is vulnerable to erosion. Public works programs with a high employment content can rehabilitate the land through reforestation, contour bunding, and other practices. In addition, improved agricultural technology, by raising the productivity of land, can allow farmers to grow more food on less land.

Technological development is crucial to long-term agricultural growth and the self-reliant elimination of poverty. Foremost in that endeavor should be the accumulation of human capital and its organization into effective institutions: the development of agricultural universities, national agricultural research systems, institutions for fertilizer distribution in both the public and the private sectors, and for seed production. It is essential that these activities expand and that the extraordinary opportunities they provide be grasped and realized.

A final element for bringing about the reduction of poverty in a way which is oriented towards long-term development is a feeding program for the young people of the developing countries, or what we would call a school-lunch program. This has now been tested in a wide variety of locations and on all scales, including the very large scale. It is clear that, in the very poor countries, school lunch programs bring children to school. The money the child earns in the form of being fed in school becomes fully competitive with the money the child earns in gathering grass, herding cattle and the other kinds of activities which very poor children in developing countries do all day, day after day. Thus, school-lunch programs reduce hunger in the world immediately and build human capital over the long term.

Reduced Cost of Production in Agriculture

Agriculture is naturally a sector of decreasing returns, as the efforts to increase production with a rising population cause greater intensification of production on a limited land area, driving down the returns to the factors of production. There is one way to defeat this process and that is by new technology which allows intensification without reducing productivity. That is what the green revolution is all about. Without improved technology, food costs more and more as populations grow.

But there is a more important reason to reduce the cost of production in agriculture or to increase factor productivity. If agriculture is to stimulate other sectors, it must do so through increased real incomes generated in the agricultural sector. Through the increased expenditure they create, those higher incomes act as a stimulus to other sectors of the economy.

We, of course, have had major breakthroughs in productivity of cereals with the high-yielding crop varieties. The breakthroughs in biotechnology facilitate further progress in these areas, but there is another issue emerging for agricultural technology. Increasingly, developing countries must intensify their agriculture beyond the basic food staples. They must produce more fruit and vegetables and livestock commodities, which allow them to generate more income per hectare of land. They can then use those profits to finance cereal imports which can be more efficiently produced in countries like the United States, Europe, and Australia, or a few developing countries such as Argentina and Thailand. However, to succeed in labor-intensive agricultural activities, there must also be research in developing more appropriate varieties which give higher yields, are more resistant to disease, and are able to deal with the complex problems of processing, marketing, and storage.

Trade

It is not likely that development can be led by export growth, in the sense that the bulk of the demand for increased output from a developing country will come from abroad. Nevertheless, trade is extremely important to the development process. Most obviously, we know that once low-income countries accelerate their growth substantially, they cannot keep up with the domestic growth in demand even with the best of efforts in their agricultural sector (Mellor and Johnston, 1984). This is true at least as long as their low-income consumers are spending 60 to 80 percent of increments to income on agricultural commodities. Thus trade is needed to facilitate imports of basic food staples, including cereals and vegetable oils, into developing countries. Of course, they must be able to export in order to pay for those commodities.

Second, if developing countries are to grow rapidly, they must spread their own capital resources across a high proportion of their labor force. That means they cannot concentrate on capital-intensive industries like steel, petrochemicals, and fertilizer. They must import those capital-intensive goods and services. And again, they must be able to export something to pay for those imports.

Stability of Agricultural Supplies

Food production and food prices have become increasingly unstable over the last few decades (Mellor, 1988). The instability could possibly lie, at least in part, with climate change, but it may also be partly technologically based. Increasing input dependence of new technologies has meant that fluctuating and inappropriate government policies with regard to input prices and supply may greatly add to the instability of production growth. It is also generally true that new technologies give a bigger response to good weather than to poor weather, thus increasing fluctuations from changes in weather.

On top of increasing instability of production is an increase in price instability, arising, on the one hand, from policies of the European Community which, in a sense, export their production instability and on the other hand, from the gradual withdrawal of the United States from serving as the storer and supplier of last resort.

This increasing instability has very important implications. First of all, it has an extraordinary impact on the poor. When supplies are reduced, most of the adjustment in consumption is made by very poor people in the world. The adjustment, of course, occurs through rising prices. We find that, with a given increase in the price of food, the rich reduce their consumption by less than one-tenth as much as do the poor (Mellor, 1978).

In this, the International Monetary Fund cereal facility is an important institution that provides poor countries with more ready access to the world food supplies through concessionary borrowing from the IMF. This facility is grossly imperfect at the present time, explaining why few countries make use of it. It should be improved and seen as something that is very separate from other aspects of trade stabilization.

Conclusions

I have indicated two major opportunities arising in the 1990s. The opportunity to abolish hunger in the world and the opportunity to greatly reduce the cost of production in agriculture in developing countries so as to serve the cause of hunger reduction. I have indicated two problem areas. The problem of instability and the problem of trade. In each, the evolving capacities of foreign assistance play a constructive role. As we move out of the turbulent and in many ways unpleasant 1980s, with structural adjustment fairly well under our belts, with the observation of the substantial number of developing countries that have now returned to 7 to 9 percent growth, we can have a vision of that growth spreading to provide a prosperity in which all can share.

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EFFECTS OF INCENTIVES ON AGRICULTURAL PRODUCTION AND THEIR IMPACT IN THE THIRD WORLD

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Introduction

Only 10 days ago, on 6 October 1988, headlines of all the mass media of the world were dedicated to news coming from Moscow: the new chief ideologist of the Kremlin called for expansion of current experiments with cooperative ownership and renting property to farmers and small entrepreneurs. He stated, moreover, that the key to positive economic change was — and I quote — "instilling a sense of ownership" in workers and farmers. By doing so, Mr. Medvedev, in the name of an influential ideology and a powerful political party, confirmed (1) that personal material interest does have a critical impact on the economic performance of individuals and societies and (2) that private ownership and prospects for more direct access to economic profit did have positive effects on the will of producers to produce, to produce more and produce better.

Market-oriented economic systems have long ago recognized the importance of certain stimuli for economic life in general and for agricultural production in particular. It is significant that economic systems built on common property and on centralized planning seem to be coming around to this view now.

Definition of Incentives

What precisely are incentives? Definitions differ according to the source of information or the type of economic dictionary one consults. How often does one say that decrease of the price of fertilizer is an incentive to higher production? Yet the Africa Study of FAO on African agriculture [1], that received an excellent reception in 1986, recommends to the African continent a policy of the so-called four "I"'s. That is the promotion of agricultural production through incentives, inputs, institutions and infrastructure. According to this classification, fertilizer would be rather an input and if so, incentives comprise practically only price and perhaps fiscal policy measures.

I suspect — and you may wish to join me — that incentives are being understood and used sometimes in a wider and sometimes in a stricter sense of the word. The term is not employed consistently. Not even in FAO. Instead of getting lost in a terminological maze, I propose, for the purpose of the present discussion, to understand incentives as measures designed and applied for the purpose of increasing/improving agricultural production by inciting human reasoning and inviting human decision-making and will to react, individually and collectively, with the ultimate objective of improving the quality of life. That means, we would understand incentives as practical measures for motivating agricultural producers.

Classification of Incentives

There are, of course, various ways of classifying incentives. I shall take the liberty of putting forward for this discussion a rather unconventional, but purposeful, classification. We would then say: there are production-promotional measures that act and achieve their effects:

1. through the production factors (land and water, inputs, capital/credit);
2. through the gains, that is, the quantity and quality of benefits the producer can expect to obtain by increased/improved production (e.g., prices);
3. through the institutional setting, infrastructure, economic and organizational system and the general environment of production and product valorization; and

4. through the "human factor", that is, the labour, the intellectual input and the managerial performance of the producer.

Traditionally, economic thinking has centred for generations on the first two categories, while important aspects of the latter two have not been recognized and hence were neglected for a long time. This has, of course, something to do with the measurability of causes and effects. The complexity of organizational and environmental influence and the fluidity in the human factor do not lend themselves as easily to systematic observation, let alone quantitative conclusions.

But let us review the above four groups of incentives one by one.

Production-Factor Incentives

Crop yields and production in a number of developed and developing countries have double or more, over the past 10-20 years. Much of this increase has come from the use of fertilizer and of modern varieties. In Western Europe and the more humid parts of the USA, approximately one third of the increase in cereal yields came from improved varieties, about one third from fertilizer and the rest from mechanization, pesticides and improved management. Gains in Asia follow a similar pattern. It has been estimated, for example, that in 1980 in eight Asian countries (Bangladesh, China, India, Indonesia, Myanmar, Philippines, Sri Lanka and Thailand), modern varieties added 27 million tons to the production of rice, fertilizer added another 29 million tons, while irrigation contributed 34 million tons. On a micro scale, the same effects of use of improved seeds, fertilizers and land and water improvement can be proven in Latin America and in Africa. Regional statistics do not, however, reflect these results that clearly, as fertilizer and pesticide use, irrigation, and mechanization have reached only a segment of agricultural producers. While latifundistas in Latin America have been in a position to benefit largely from modern techniques and inputs, minifundistas had virtually no access to advanced means or production. The situation is even worse in Africa, where productivity per agricultural population unit has shown a negative growth of 0.7% from 1970-1980. In absolute terms, while in 1970 an agricultural population unit produced 272 kgs of staple food (in wheat equivalent), in 1980 it was only 253 kgs. The low productivity is due not only to extremely backward farming practices, but to generally high costs of inputs and factors of production. According to FAO sources, the grain/fertilizer ratio in

1973/75 in sub-Saharan Africa was 76 when compared to 100 of the 1969-1971 base; while the grain producer price index has increased by 17%, the retail price index of fertilizers increased by 47%. This, in fact, proves again that the profitability of the use of fertilizers, that is, the fertilizer incentive, has indeed a direct impact on agricultural production output. Production decreased in Africa when the fertilizer incentive weakened.

Access to credit is another important producer incentive, particularly in the developing country context, and in promotion of cash crops. Credit incentives to food crops are generally far less effective, though experience varies and depends to a great extent on the administration of the credit schemes.

We can, without going into further detail, conclude that the impact production-factor incentives have on agricultural production is rather straightforward and very significant. These stimuli have, however, a drawback. They are rather costly. These incentives are, for all practical purposes, a transfer of resources to the producer, the cost of which has to be borne by someone: the community of consumers, the state or external sources. The painful discovery that fertilizer, pesticides, land improvement subsidies and production-stimulating credit schemes do represent a heavy load on public budgets, ended, especially in the 1970s, more than a few ambitious subsidy schemes. Therefore, while recognizing that production-factor-incentives can be a powerful means of increasing food and agricultural output, and are likely to yield results also on the short term, their use needs to be planned with care and financial skill. Their administration, too, calls for circumspect handling as these schemes tend to favour, by nature, the bigger producer and disadvantage the small ones, leading thus to discrimination and economic/social inequity.

Price or Market Incentives

Prices and related incentives are the second important area meriting our attention. In a free market economy, producer prices for food crops tend to be set by supply and demand interplay. They generally exceed the lower prices governments often set for food crops, particularly staples, in the interest of the consumers. For the past decades price policies had generally two basic objectives. The first and most important has been to attain a certain stability regarding both consumer and producer prices. The second objective has been to influence price levels, so that on the one hand consumer food prices were kept low while, on the other, production of export crops and some food crops was encouraged by attractive prices. In addition, price controls and export taxes have often been a means of maximizing government revenues from export commodities. In this context, little room was left for a price policy to truly encourage agricultural production. Equally, inter-sectorial income parity — and farmer purchasing power in particular — have generally not been explicit policy objectives.

There is a whole arsenal of price policy measures, from price fixing to establishing price stabilization bodies. They have different effects in different conditions, and in all cases policies and policy impacts are very complex. The general observation one can make, which is important for us here, is that the producer price system at large has offered relatively little stimulus for agricultural production during the past decades. This was so, less for the reason that price/market incentives would not work, and more because they were not used, or not designed so as to encourage agricultural production. The FAO Agricultural Price Policy Study, published in 1987 [2], that I wish to recommend to all those interested in the subject, does contain some very pertinent information on the effects of these incentives. This study reports that statistically significant aggregate supply responses to price movements were found in almost all regions and countries. While the results varied quite widely for individual countries, due to the differences in underlying national conditions, elasticities were found to be within the ranges of 0.1 to 0.3 for the short run and 0.2 to 0.5 for the long run. These observations constitute strong evidence that total production responses to price are large enough for prices to matter, but low enough to rule out the possibility of fueling sustained growth in agricultural production by positive pricing inducements alone.

The FAO study found that in the long run a 10% increase in average prices received by farmers could raise output by 2-5%. High producer prices imply naturally a sort of taxing of the non-agricultural sector. This is problematic and unsustainable in developing countries with relatively small non-agricultural sectors. The contrary, that is very low farm product prices, implies, of course, taxing of the agricultural sector with considerable adverse consequences for the total agricultural output. A fall in the price of agricultural products relative to other products — that is a fall in the terms of trade for agriculture — of around 20% may, under certain circumstances, bring about a reduction in total agricultural production of the order of 4-10%. This is a very significant reduction viewed against the size of the current national food deficits confronting countries in all four developing regions. Such reduction in output would have a far reaching impact on the consumption of the poor strata of populations, on the agricultural trade balance, on the balance of payments, and ultimately on the ability of the country to continue the policy of cheap food without impeding economic growth.

It is important to note that price incentives function differently in different conditions. Production response is generally larger when additional output can be obtained from expansion of the cultivated area, rather than yield increments. Further, the supply response tends to be greater among large farmers than among small farmers, partly because in practice, large farmers have greater access to supplies of inputs and usually also better access to markets. In any case, the importance of price signals for influencing output is likely to grow in the future as a result of improved communications, transport and other types of infrastructure which facilitate the development of markets.

A lot ought to be said under this heading on the incentive and disincentive effects of international prices on national economies and agricultural output. All developed countries intervene in the pricing of their food and agricultural products. Their major objectives are to improve or stabilize farm incomes to raise self-sufficiency or to expand exports. The global result is generally protectionism, that has serious impacts on developing countries: severe losses of export earnings from both lower world prices and limited access to external markets, influence of lower prices on domestic producer price incentives, increased internal price instability and uncertainty as to the continued availability of major food imports at protection reduced prices. Also, a developing country that exports, for example sugar or beef, but imports little or no grain, suffers from both the import and the export side conditions.

"Macro-Economic" Incentives

Let us turn now to incentive measures that are related to the institutional setting, to infrastructure, to the economic and organizational mechanisms at work and the general environment of agricultural production and product valorization. Basically, while under the first mentioned class of incentives, which we called production-factor inventives, we examined the individual farmer and farmer group reactions to stimuli affecting the means they use to produce (land, water, machines, energy, credit, etc.), and while in the second class of incentives we tried to understand farmer reaction to changes in the reward for his investments and effort, that is, in changes of prices the agricultural products fetch, the point under our present heading is that agricultural growth can also be influenced decisively by changing the environment of the productive activity. Legislation and practices concerning land rights and tenure systems, legislation governing inheritance, transport and communication facilities, availability of public services such as agricultural extension, education and health facilities, access to markets, the nature and degree of complexity of production and market-related administrative facilities (e.g., licensing) and administrative control and, perhaps the least obvious, the availability of attractive exchange products, all have a critical influence on agricultural production.

What could motivate a subsistence farmer to produce more? Naturally the prospect for sufficient, wholesome and diversified food, the prospect for advantageous barter for some utensils, clothing or services. However, if his response remains at that level, he would live better, yet remain at subsistence level and outside the market economy. What would incite the subsistence farmer to produce for the market? The availability of a transistor radio or textile products on a nearby market might. Today there is scientific evidence that the prospect of increased and improved consumption acts as a production incentive. (This mechanism cannot function, of course, in systems that take away the agricultural surplus for investing into the development of other sectors, like industry).

This class of production incentives — for the sake of ease allow me to call them macro-economic incentives — is less direct than the incentives on production factor and price. They are likely to have medium and long term effects rather than a short term impact.

This class of incentives is admittedly a very uneven conglomerate of all kinds of measures. The purpose of grouping them this way was only to make clear that production factor and price incentives, even if in principle very effective and powerful, cannot work well, if at all, without a conducive macro-economic environment, the importance of which one senses best if one simulates the functioning of factor and price incentives without a favourable macro-economic environment. To give an example, Libya and Guinea had at times economies where production incentives failed to obtain much response due to the absence of non-agricultural exchange products on the market.

How much agricultural production incentives and macro-economy are interwoven, was clearly demonstrated by the study FAO recently completed on the Latin American and Caribbean region [3]. The main finding of the study was that in the absence of promising external markets economic growth cannot be achieved unless, through some redistribution of physical and financial resources and a different division of labour, the poor strata of populations receive greater access to income. Following Schwab's law, they would spend in first line on food products, which in turn would boost agricultural production. In consequence, in Latin America and the Caribbean today, income distribution measures alone, regardless of whether done in rural or urban areas, could act as an incentive for agricultural production growth.

The "Human-Factor" Incentives

The three packages of incentives we have discussed up to now might together still not lead to the desired production increase as long as the human factor is not up to the task and not instrumental.

How real the impact of the human factor it is clearly illustrated by enquiries into effects of fertilizer incentives. Measures implemented in Gambia indicate that, given optimal conditions but no subsidy, the additional gross income has to be 2.3 times bigger than the fertilizer cost in case of groundnut, 3.9 times higher in the case of maize and 2.0 times higher in the case of millet for the incentive mechanism to function. Studies in the Sudan and Zambia have given similar results. Subsidies are needed to enhance these ratios, otherwise farmers are reluctant or, to say the least, slow to respond to the incentives.

Factor incentives, price incentives and macro-economic incentives, and any mix of those, have natural mechanisms of functioning. Does, however, the producer follow other values than the one underlying these measures (e.g., traditionally thinking existence farmers not seeing the point in education of children), or does the producer lack the knowhow for appropriate response (e.g., for the handling of improved seeds) or does the farmer lack information (e.g., on availability of new technology or consumer goods of interest), let alone if he intentionally opposes the pursued objectives (for reasons of ideology or political creed), the incentive mechanisms will cease to work.

Right to property is definitely one important element for the human factor. Another is participation in decision making, now known in development jargon as people's participation. To own, to shoulder responsibility, to be informed, the right and the de facto possibility to make individual decisions are, among others, factors that count most.

Chief ideologist Medvedev must also have arrived at this point of argumentation when he declared that it is indispensable for the rural economy to "instill a sense of ownership" into the farmers.

Conclusion

Incentives are powerful tools. But they have to be fine-tuned. The failures of incentive policies have been to have often neglected or mismanaged the macro-economic and the human-centred incentives. A classic example of the latter case is the intensive agricultural extension effort made throughout the developing world focusing on man, while, as it has now been proved, a greater part of the agricultural work in most developing regions is done by women. You may note that in Africa, in the age group of 25-30, women do one-third more work than men.

The order case of deficiency is the lack of circumspect and comprehensive packaging of incentives. Price and factor incentives have been in fashion without supporting incentives from the macro-economic and the human area. The high art of incentive policy is to offer a well balanced mix. To do so, economists and politicians need what St. Thomas of Aquinas rated highest among the cardinal virtues: Sapientia.

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IMPACT OF NEW TECHNOLOGIES ON SMALL AND LARGE FARMING SYSTEMS

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1. Introduction and Summary

The new tools of biotechnology are changing the way scientists can address problems in agriculture. They do not change the purpose of agriculture, which is to produce needed food, fiber, timber, and chemical feedstocks efficiently. Instead, they offer new techniques to complement, rather than replace, the traditional methods used to enhance crop productivity. However, over recent years, many heralded as revolutionary the changes that biotechnology would bring about in agriculture. The new findings have often been widely publicized, with little effort to place them in a realistic context of their potential importance and impact. While this helped to raise capital for the new biotechnology firms, it gave rise to expectations of a quick return on investment and rapid product sales. Project proposals were sold on anything ranging from wild exaggerations to programmes supported by solid commercial facts. Many who viewed biotechnology as a revolution also feared that it would be used in ways that would further disrupt the troubled agricultural communities of both developed and developing countries. This argument rejected by others, aroused the debate over who would control biotechnology and how it would be used.

Today, the initial excitement has been cut down to more realistic proportions and a sober view of biotechnology prevails as investors in agricultural projects are finding that, despite the new breakthroughs, product development is very slow and expensive. Partly as a consequence of this more considered appraisal, new biotechnology firms have not found it easy to raise capital. However, biotechnology remains a great opportunity for those investors who have selected their projects carefully and are prepared to commit themselves to long term research.

This lecture attempts to develop a realistic assessment of what biotechnology will bring to farming and to review the technical and commercial limitations that might exist in applying these technologies.

2. Biotechnology on the Farm

An Office of Technology Assessment (OTA, 1986) report, released in the USA in 1986, analyzes the new technologies in detail and comes to some startling conclusions. According to the report, although the rates of change will vary from commodity to commodity, the development and adoption of emerging technologies will, in the short run, cause enormous production increases throughout U.S. agriculture. These increases will lower prices for both consumers and farmers and thus accelerate a trend toward fewer and larger farms. In particular, smaller farms will disappear, because they "lack access to the information and finances necessary for adopting the new technologies effectively".

I do not agree with this conclusion. In my opinion, farm size will have no effect on the impact of agricultural biotechnology.

Products developed through biotechnology do not require additional capital expenditures by farmers for new equipment or land. Farmers can buy these products, use them, and derive comparable benefits, irrespective of the area of their land. Biotechnology will not revolutionize agriculture. Rather it will open up numerous opportunities, becoming a key element of competition botb among farmers and among companies that sell to them.

What can we expect biotechnology to do for agriculture? To illustrate the new applications and their impact on farming, two main areas have been selected. These are: crop-protection and plant quality improvement.

3. Applications of Biotechnology in Crop Protection

3.1 *Development of New Biorational Products*

Some professional analysts are inclined to conclude that the so-called "era of chemical protection" is over or has already passed its climax. Wbilst this may be true in strictly economic terms for certain highly developed or industrialized areas, this opinion is not acceptable from the scientific and technical viewpoint. Lack of ideal solutions for existing problems, changing pest and weed populations, the development of resistance, and changing agricultural techniques are challenging chemists and biochemists to apply their ingenuity and perseverance to find out more economical, more efficient, and safer practical solutions (Piccardi, 1987).

However, there is a growing feeling that agriculture can benefit immensely from increased inputs of biotechnology. It remains to be seen whether the new approaches can provide solutions to crop protection problems, which will be acceptable to the farmers and his advisors for both their control effectiveness and their cost. Certainly, many people believe that the potential benefits surely justify the diversion of research and development capital into the biotechnology field, a trend which is already quite apparent in public agricultural research, the food industry, and in fact in the agrochemical industry itself.

At the moment, I feel that some of the basic research being undertaken in agricultural biotechnology will lead to the design and the development of a number of novel agrochemicals, rather than their outright substitution. The more we understand about interactions between chemical compounds and the physiological or biochemical reactions of living organisms, the more we are able to translate this information into practical and biorational solutions. In this respect scientific knowledge is still at an early stage, but the growing number of sophisticated, quick, biochemical tests will allow the identification of new target sites for chemical action. Three-dimensional studies of the interactions between a protein and an inhibitor would ultimately identify more effective inhibitors through the systematic applications of the computerized molecular modelling procedures. Moreover, not only the inhibitor, but the target protein could be restructured through such studies. That is, in contrast to an exclusively chemical approach, it will be possible to even further enhance the potency and specificity of inactivation.

3.2 *Biological Pest Control Methods*

Biotechnology in the broad sense has long been practiced in agricultural science in general, and pest control in particular. Breeding programmes have produced disease and insect-tolerant crops; and biological control agents have proved their worth as components of pest control arsenals. The new biotechnologies will build upon these leads, and carry them to superior levels of efficacy.

3.2.1 *Bacterial Insecticides*

The most successful bacterial insecticides have been those based on *Bacillus thuringiensis*, commonly known as BT, accounting for sales of around $50 million last year. The major commercial BT insecticides that have been produced (Table 1) since the early 70's are variety *kurstaki*, 3a3b of HD-1 strain or its variants, with annual sales of about $30 million.

BT is an aerobic, spore-forming, bacillus characterized by the formation of protein crystals in the course of sporulation. These crystals consist of large proteins which are partially broken down in the digestive tract of the insect pest to yield proteins which bind specifically to a receptor site of the epithelial cell membrane, whose ionic balance is consequently disrupted. These events lead to feeding inhibition within a few minutes and eventual disintegration of gut walls (Luthy and Ebersold, 1981). Since the active toxin is formed only in the mid-gut of the insects, the protein crystals themselves are not toxic to non-target organisms.

Formulations of BT toxins have been sold for many years and shown to control the larvae of a number of Lepidoptera, Diptera, and Coleoptera species of economic importance (Aronson *et al.*, 1986). The most recent discovery has been the isolation of a variety, *Tenebrionis* serotype 8a8b, which controls the Colorado potato beetle (Krieg *et al.*, 1984; Herrnstadt *et al.*, 1986).

Bacterial insecticides offer major advantages over chemical insecticides. They show little or no toxicity to mammals, and usually do not cause a build-up of resistance in insects. In spite of these favorable characteristics and of the importance which has been accorded to biological control systems within the concepts of Integrated Pest Management (IPM), it is perhaps surprising that the bioinsecticides share of the total market for insecticides is less than 1%. This commercial weakness can be broken down into three general categories: a lack of persistence in field situations, a highly specific activity, which often makes their usage uneconomical in multipest situations, and a slow speed of control, which allows pest damage to continue.

Recent advances in genetic engineering techniques may be applied to overcome some of these constraints. *In vitro* recombination of different genes or their mutagenesis could potentially improve not only

TABLE 1 - *Commercial Bacterial Insecticides.*

Micro-organism	Target	Trade name	Company
Bacillus popilliae *B. lentimorbus*	Japanese beetle *(Popillia japonica)*	Doom Milky Spore	Fairfax Reuter Labs.
B. thuringiensis serotype 8a8b var. *tenebrionis* and *San Diego*	Coleoptera *(Leptinotarsa decemlineata)*	Foil (1) M-One Trident	Ecogen Mycogen Sandoz
B. thuringiensis (HD 1) serotype 3a3b var. *kurstaki*	Lepidoptera	Bactucide Biobit Dipel Thuricide Condor (1) Bactospeine In Cide (3)	CRC Novo-MRL (2) Abbott Sandoz Ecogen Biochem Prods. Crop Genetics Int.
B. thuringiensis (HD 1) var. *kurstaki* (SA-6 variant)	Lepidoptera (*Heliothis* spp.)	SAN 414	Sandoz
B. thuringiensis (NRD 12) serotype 3a3b var. *berliner*	Lepidoptera (*Spodoptera* spp.)	Javelin	Sandoz
B. thuringiensis serotype 7 var. *aizawa*	Lepidoptera (wax moth on bee hives)	Certan	Sandoz
B. thuringiensis var. *israelensis* (HD 567) serotype 14	Diptera (mosquitoes and black fly)	Bactimos Skeetal Teknar Vectobac Bactis	Biochem Prods. Novo-MRL (1) Sandoz Abbott CRC
B. thuringiensis serotype 1	Diptera (mosquitoes and black fly)	Muscabac	Farmos
B. sphaericus	Diptera (mosquitoes)	(4)	

(1) Genetically altered strain produced by bacterial conjugation.
(2) MRL = Microbial Resources Ltd.
(3) The product consists of maize endophyte CG 102, incorporating the BT toxin gene.
(4) In advanced development stage by many companies.

the spectrum of applications, but also the potency per unit of toxin produced. The latter effect might result in more rapid toxic action.

Many companies are developing formulation technologies of BT products to avoid the easy denaturation of the protein toxin on storage or after its release into the environment. A unique microencapsulation technique is based on a delivery system consisting of dead, genetically-engineered *Pseudomonas* cells that contain BT (Kim, 1987). The system creates a sort of biological package that protects the fragile toxin. Another exciting approach involves an endophytic bacterium, *Clavibacter xyli* (a micro-organism which lives inside maize plants), containing the insecticidal toxin gene from a strain of BT with activity against European corn borer (Anonymous, 1988). It is designed to be incorporated into the plant vascular system and to reduce the damage to corn production caused by the pest. If the recently approved field trials are successful, the benefits of this type of control agent to agricultural production and to society will be significant.

3.2.2 *Viral Insecticides*

Viral insecticides contain viruses which infect and kill certain species of insects. Unlike fungi or bacteria, which can exist freely in the environment, viruses exhibit very low persistence and are incapable of replication outside a host. This provides an added margin of safety to nontarget organisms. Most of the research activity has been centred on Baculoviruses because they are known to cause lethal infections only on invertebrates and have the virus particles occluded in proteinaceous crystals that protect them from rapid inactivation on plant leaf surfaces.

Several pathogens have been approved for use in the U.S. (Table 2). However, the nuclear polyhedrosis viruses of European pine sawfly (*Neodiprion sertifer*) and cotton bollworm (*Heliothis* spp.) are the only ones currently being sold, though in very small quantities (Klausner, 1985).

The high degree of specificity of viruses and their high cost of production have greatly limited their commercial success. In addition these organisms are generally slow acting, and for high infestations of a pest, significant crop damage may occur. In the future, these problems will probably be mitigated using biotechnology. The efforts are focused on the introduction of an insect-specific toxin into the genoma of the virus, in order to hasten the rate of action and broaden the host range. However, there is still a long way to go before any such engineered viral strain can be described as commercial products. Significant concern has

TABLE 2 - *Viral Insecticides.*

Micro-organism	Target	Trade name	Registrant
NPV (1) of *Neodiprion sertifer*	Pine sawfly	Virox Preserve	Novo-MRL (2) MicroGeneSys
NPV (1) of *Mamestra brassicae*	Vegetable caterpillars	Mamestrin	Calliope
NPV (1) of *Lymantria dispar*	Gypsy moth	Gypcheck	USDA Forest Service
NPV (1) of *Orgya pseudotsugata*	Douglas fir tussock moth	TM Biocontrol-1	USDA Forest Service
NPV (1) of *Heliothis zea*	Cotton caterpillars	Elcar	Sandoz
GV (3) of *Cydia pomonella*	Codling moth	Decyde	MycroGeneSys

(1) NPV = Nuclear polyhedrosis virus.
(2) MRL = Microbial Resources Ltd.
(3) GV = Granulosis virus.

been expressed regarding the release of genetically engineered viruses into the environment, and this may result in additional restrictions on research and product commercialization.

3.2.3 *Fungi as Pest Control Agents*

Natural infections by fungi are well known to play a major role in the control of many economic pests. However, their use in crop protection is very limited (Table 3).

Current research has focused primarily on the use of fungi as weed pathogens, since fungal diseases of weeds are readily observed and provide an easy source of material to draw on. Recently, a mycoherbicide has captured media attention (Klassen, 1987). This product, under development, is based on a fungal pathogen, *Alternaria cassiae*, and it has been shown capable of effective, post-emergence, sickle-pod control in greenhouse and field trials when applied both alone and in combination with chemical herbicides. Sickle-pod is a resistant weed that

TABLE 3 - *Commercial Mycopesticides.*

Fungi	Usage	Trade name	Company
Verticillium lecanii	Aphids	Vertalec	Novo-MRL
Verticillium lecanii	Whiteflies (*Trialeurodes vaporariorum*)	Mycotal	Novo-MRL
Beauveria bassiana	Colorado beetle (*Leptinotarsa decemlineata*)	Boverin	(USSR)
Beauveria brongniartii	Cockchafer larvae on woodland	(1)	
Hirsutella thompsonii	Citrus rust mite (*Phyllocoptruta oleivora*)	Mycar (1)	Abbott
Metarhizium anisopliae	Spittle bug, sugarcane frog hopper	Metaquino	Embrapa (Brazil)
Paecilomyces lilacinus	Nematodes	Biocon	Asiatic Technologies (Manila)
Pseudomonas spp.	Seed cotton fungicide	Dagger	Ecogen
Trichoderma harzianum	Seed treatment fungicide	(2)	Eastman Kodak Bio-Technology General Makhteshim
Phytophthora palmivora	Milkweed vine (*Morrenia odorata*)	Devine	Abbott
Colletotrichum gloeosporioides	Northern joint vetch	Collego	Nor-Am (Schering)
Alternaria cassiae	Sickle-pod (*Cassia obtusifolia*)	Casst (2)	Mycogen
Fusarium lateritium	Velvetleaf plants	Velgo (2)	Mycogen

(1) Commercial trials in Europe.
(2) Under application for registration

infests about 4 million hectares of soybeans and peanuts in the Southeast of the U.S. A problem of poor control under dry conditions, common to all mycopesticides, is being tackled using different formulations.

As in the case of biological insecticides, several of the benefits of mycoherbicides can also be seen as disadvantages when compared to chemical products. For example, low persistence of any toxic residue in the environment is a bonus, but would probably involve the need for more numerous applications of a biological herbicide than are necessary with a conventional product to achieve residual control of weeds. Even if product costs per hectare of application were comparable (an unlikely situation, since the technology for their large-scale production is difficult), total product costs per season would be higher. The second drawback results from the very high degree of selective action, which is almost contrary to the goal of an herbicide. Although only one weed may dominate in a field, the elimination of this single type would only help other weeds to flourish. Suppliers of mycoherbicides are attempting to overcome these limitations by developing formulated products that are compatible with commonly used chemical herbicides, so that they may be used in tank-mix combinations. I do not expect the application of advanced biotechnology to alter this situation in the near or intermediate term.

3.2.4 *Microbial Antiparasitic Agents*

Screening of fermentation broths for antibacterial activity has been the backbone of the fermentation-pharmaceutical industry for many years. Rapid advances in isolation techniques, structure elucidation, and recognition of the structural diversity of natural products of microbial origin have recently encouraged their exploitation as pest control agents in agriculture (Misato, 1983).

It is obvious that the success of this approach depends primarily on the availability of an appropriate number of simple, sensitive, and specific assays. Until recently, such testing systems were technically rather complex, labour-intensive, and often neither very reliable nor reproducible. As mentioned earlier, this impediment of technical complexity is now being rapidly overcome by continuous and impressive advances in the acquisition of basic scientific knowledge on the growth, development, and reproduction of crop plants, insect pests, diseases, and weeds. The intelligent exploitation of this knowledge will provide efficient and accurate physiological and biochemical assay procedures.

Already we have several new pest control agents that are produced by fermentation (Table 4). There are reasons to believe that, with the increasing interest in minimizing the quantity of material potentially available for residue contamination, products of this type will play a more significant role in the future.

3.3 *Modification of Plant Responses to Chemicals*

Chemicals for weed control have long been and will continue to be a well-established agricultural practice. By eliminating weeds that compete with crops for nutrients and water, herbicides have helped farmers

TABLE 4 - *Microbial Antiparasitic Agents.*

Micro-organism	Target	Trade name	Company
Streptoverticillium rimofaciens	Powdery mildew	Mildiomycin	Takeda
Micromonospora spp.	Rice blast (*Pyricularia Oryzae*)	SF-1917	Meiji Seika
S. avermitilis	Insecticide, miticide	Avermectin	Merck S&D
S. hygroscopicus	Miticide	Milbemycin	Sankyo
S. aureus	Miticide	Tetranactin	Chugai Phar.
S. tendae	Rice blast (*P. Oryzae*) IGR (1)	Nikkomycin	Bayer
S. viridochromogens	Non-selective post-em. herbicide	Bialaphos	Meiji Seika
	Non-selective post-em. herbicide	Glufosinate (2)	Hoechst
S. pastorianus	Rice blast (*P. Oryzae*) PGR (3)	Cycloheximide	Upjohn

(1) IGR = Insect growth regulator.
(2) Bialaphos synthetic metabolite.
(3) PGR = Plant growth regulator.

to substantially raise their yields. However, herbicides can cause serious environmental problems. The recurrent detection of certain products in surface and ground-water supplies creates widespread public health worries and forces regulatory restrictions.

New and highly effective herbicides were recently introduced (Randel, 1987). They kill plants by inhibiting the action of specific enzymes that synthesize aminoacids, and thus do not do any harm to fish, insects, and mammals which lack such enzymes. Moreover, the herbicides either break down rapidly in the environment, or do not leach appreciably into water.

Products of this type are highly desirable from an environmental perspective. But their broad spectrum of activity is an obstacle to widespread use. Many of the chemicals discriminate poorly, if at all, between weeds and crops. They are not likely to be used to their full potential unless crops can be made to resist the toxic effects.

Recently, gene transfer and cell selection techniques have been used successfully to create crop plants tolerant to these products (Shah *et al.*, 1986; Fillatti *et al.*, 1987). The rapid progress (Table 5) that has been made in the engineering of selective herbicide tolerance has surprised even the most optimistic researcher in the field. This research has been facilitated by the knowledge of the mode of action of the chemicals and by the identification and molecular cloning of genes encoding herbicide-sensitive and insensitive target proteins or encoding enzymes which detoxify the herbicides. As the methods for gene transfer and for trait incorporation into commercial germplasm become routine, the engineering of selective herbicide tolerance will become an accepted and essential strategy for the development of weed control systems. Such technology will accelerate a trend towards commercializing fewer, but more effective, less costly, and environmentally more acceptable products.

4. Applying Biotechnology in Plant Quality Improvement

The potential of plant molecular biology is enormous. Thus by inducing pest resistance in plants, it could lead to lower input costs for farmers and fewer environmental problems. By speeding germplasm screening and varietal development, it could bring new crops into cultivation more quickly and make agriculture more diverse and less vulnerable. The challenge is to turn this potential into commercial reality. In this section I would like to discuss the advances and the problems recently identified in applying this technology.

TABLE 5 - *1988 Field Tests of herbicide-tolerant plants.*

Applicant	Genetically-engineered organism to be tested	Proposed Location
Du Pont	sulfonylurea-tolerant tomato	Florida
Monsanto	glyphosate-tolerant tomato	California, Illinois
	glyphosate-tolerant rapeseed	Canada
Plant Genetic Systems	glufosinate-tolerant potato and alfalfa	Europe
	glufosinate-tolerant tobacco	Europe
	glufosinate-tolerant sugar beet	Europe
Sandoz	sulfonylurea-tolerant tobacco	North Carolina

The current capability of molecular biology is to isolate a gene, to incorporate this gene into a vector, and to achieve transformation of the recipient plant by the gene. In contrast with the practice of plant breeding, where crosses of two parental strains mix the genetic material and therefore a period of selection is necessary in order to place the desired trait in the genetic background, the methodology of genetic engineering can move a single desired gene directly into the appropriate genetic background. Furthermore the methods of genetic engineering make it possible to transform plants by means of genes from totally unrelated species, whereas the traditional breeding methods are restricted to parental strains which are sexually compatible. The transformation of plants with genes of other plants and bacteria has now been successfully carried out in many laboratories around the world, and in several cases field trials have demonstrated the practicability of the transformation technology.

However, it is important to realize the current limitations of genetic engineering as applied to agricultural crops. At the moment it has been possible to transfer one or two genes at a time to a recipient plant. No one has yet attempted to transform plants with sets of genes coding for enzymes that act in a concerted fashion as in the case of complex traits, such as those governing drought-resistance or yield. It is also obvious that the immediate products of transformation are only new forms of germplasm that the breeder will use in a conventional way. Thus the validity of the traditional plant breeding remains unchanged.

The tools of plant genetic engineering can also speed up the breeding process by helping researchers to obtain genetic "fingerprints" of plant varieties and individuals. Gene mapping techniques based on restriction fragment length polymorphism (RFLP) is fast becoming a powerful tool for creating linkage maps and recognizing individual chromosome segments (Reid, 1987).

4.1 *Plants Resistant to Insect Pests*

Several approaches may be used to genetically engineer crop plants with greater insect resistance. Advances are currently being made in genetically engineering plants to produce BT toxins constitutively (Fischoff *et al.*, 1987; Vaeck *et al.*, 1987). The expression in plants of genes coding BT toxins could provide a novel form of protection not only against defoliating larvae, but also against the larvae of species that bore into the plant tissues. A number of research groups have been trying this approach, and tests have gone as far as field trials (Table 6).

Considerable effort is now being expended to identify other single clonable genes that can be used to protect plants from insect damage. A promising gene, which has been isolated from a variety of cow-pea bred in Nigeria, could be used to protect stored beans from the attack of beetles (Newmark, 1987). This gene, which encodes a protein that is an inhibitor of insect *trypsin*, has already been transferred into tobacco. In greenhouse tests the transgenic plants were protected well enough against insects feeding on leaves. The work with this inhibitor seems potentially more useful than the work with BT toxins because the inhibition can affect a broader range of insect pests.

4.2 *Plants Resistant to Viral Diseases*

Nearly 60 years ago scientists found that a mild strain of tobacco mosaic virus (TMV) could protect tobacco plants against the adverse effects of a subsequently inoculated, virulent strain of the pathogen itself. This phenomenon has been called cross-protection. The mechanism by which cross-protection works is unknown.

Since the structure of several viruses is now known in detail, it is possible to transform plants with different sections of the viral RNA coding for different functions. Plants have been transformed by the gene coding for the coat protein of TMV (Powell *et al.*, 1986), alfalfa mosaic virus (AlMV) (Loesh-Fries *et al.*, 1987; Tumer *et al.*, 1987; Van Dun *et al.*, 1987), and potato virus X (PVX) (Hemenway *et al.*, 1988). There have been reports that transformation by genes coding for other functions of the virus also provide cross protection. It seems likely that this type of cross protection will be attempted many times for different viruses in the next few years. Some transgenic plants resistant to viral diseases are already under field testing (Table 6).

TABLE 6 - *1988 Field Trials of insect and virus-tolerant plants.*

Applicant	Genetically-engineered organism to be tested	Proposed Location
Agri-Genetics Advanced Sciences	AMV-tolerant tobacco	Wisconsin
	tomato tolerant to Lepidoptera	Wisconsin
Crop Genetics International	*Clavibacter xyli* for inducing corn resistance to Lepidoptera	Maryland
Mogen International	PVX-tolerant potato	Europe (Netherlands)
Monsanto	TMV-tolerant tomato	Florida, Illinois
	tomato tolerant to Lepidoptera	Florida, Illinois
Plant Genetic Systems	potato tolerant to Coleoptera	Europe (Spain)
	tobacco tolerant to Lepidoptera	North Carolina
Sandoz	tobacco tolerant to Lepidoptera	North Carolina

AMV = Alfalfa mosaic virus.
PVX = Potato mosaic virus
TMV = Tobacco mosaic virus.

4.3 *Plants with Improved Nutritional Value*

Most of the protein component of human food is derived, directly or indirectly, from the proteins stored in the seeds of cereals, legumes, and other crop plants. In the developing countries seed proteins provide the basic protein component of the diet, whereas in the developed countries a substantial proportion of the dietary protein is derived from animals which were raised on seed proteins. Plant seeds represent abundant sources of proteins in terms of quantity. However, most plant seeds do not represent complete sources of proteins nutritionally. For example, cereals (wheat, oats, maize, rice) are generally composed of 7-14% proteins but are deficient in lysine. Legume seeds (soybeans, field beans, lentils, peas) are composed of 20-40% proteins but are deficient in methionine. Lysine and methionine are essential aminoacids and must be present in the diet of humans and monogastric livestock. As a result, soybean proteins may be mixed with cereal proteins to balance the nutritional deficit for man. For animals, soybeans are supplemented with methionine to achieve a high-protein, nutritionally-complete diet.

For many years, plant breeders have been trying to improve upon the protein quality of plant seeds. In the case of corn, several spontaneous mutants were found which contained high levels of lysine as well as tryptophan (another aminoacid which is co-limiting in corn). Transfer of these mutant genes into commercial varieties of corn would be desirable by using innovative breeding approaches or, in the near future, plant transformation.

In the case of soybeans, no mutants containing high levels of methionine have ever been found. Consequently, classical breeding techniques have not yet afforded a variety of soybeans with an increased content of methionine. We are using a molecular approach to reach this target. A naturally-occurring protein found in the seed of Brazil nut (*Bertholletia excelsa*) contains unusually high levels of the sulfur-containing aminoacid (Altenbach *et al.*, 1987). We believe that the transfer of the gene that codes for this protein to leguminous plants may be a viable way to improve the methionine content of legume-seed proteins.

Although traditional breeding methods have succeeded in modifying the oil composition of many crops, molecular biology opens a broader range of possibilities (Stumpf and Shimikata, 1983). Chemical properties, and thereby the uses of plant oils, vary depending on the length of the fatty acid chains that compose the oil and their degree of saturation. Many of the enzymes controlling the biochemical pathways that regulate molecular chain length and degree of saturation have been well studied, and this reservoir of knowledge now makes it possible to genetically engineer the type of oil a crop will produce. Major results are expected in improving quality and content of oil in rapeseed and sunflower.

5. Conclusions

With the initial excitement now beginning to die down, biotechnology is entering the phase of long, quiet development work. Although only a few broad areas have been considered in my survey, it would seem that biotechnology is already having an impact on the farming system and that this impact will undoubtedly get stronger. The inevitable result of successful products from biotechnology in agriculture will be to reduce input costs and enhance market value and quality of farm production, not solely to increase crop yield. Despite these glowing expectations, commercial success in this field is bound to be an expensive and lengthy process. The high risks and costs, and the long development times involved, call for adequate worldwide patent protection of the results and also appropriate regulatory steps for field release of the new organisms produced. The U.S. case-by-case approach now used reflects the absence of well defined schemes for regulations and is halting progress in applying biotechnologies in agriculture.

Commercial incentive is the driving force behind the current progress of biotechnology, and main beneficiaries will be the growers involved in the already advanced agriculture of the industrially-developed nations. In less developed countries, where agricultural innovation is really most desperately needed, this driving force will not probably be at work and the burden of research and implementation will have to be shouldered by the public sector.

The situation of research in these countries has, however, greatly improved over the past 20 years. A large number of scientists in agricultural disciplines have had the opportunity for advanced education and training abroad and in their home countries. They no longer work in isolation and now directly participate in the international network of research aimed at protecting the world food supply. Programmes of plant genetic improvement are generally possible for them. The most appealing feature of the new plant breeding techniques (see for an excellent review: Yeoman, 1986) is that they are relatively inexpensive and do not require a high degree of sophisticated instrumentation. These qualities make them accessible to the professional capabilities of many research institutions.

Agriculturally-acceptable, resistant cultivars are highly desirable and must be regarded as an ideal way to avoid crop losses. They involve the grower in no additional labour, they reduce the capacity of pest populations to build up in a certain area, they are compatible with all other control methods, and have little, if any, effect on the balance between pest and their natural forms of control.

While the crop improvements provided by the green revolution have not always been of this nature in the third world, there is no reason why the technologies of breeding and genetics cannot accomplish these goals.

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THE AFRICAN DILEMMA AND THE QUEST FOR APPROPRIATE TECHNOLOGIES FOR SUSTAINABLE AGRICULTURE AND FOOD

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The African dilemma arises from the continent's deepening crisis of chronic and transitory food insecurity since the early 1970's. Since then, all studies of trends in food and agricultural production and prognosis about the future point to a gloomy situation of increasing concern within and outside Africa. The problems are most serious in sub-Saharan Africa. Food production for the last two decades has failed to keep pace with population growth. While population growth averages about 3%, agricultural and food production annual rates of growth lie between 1 and 2%. Demand for food has been growing at an annual rate of about 3.8%.

One of the reasons for the food crisis is low agricultural productivity. Mean yields of most staple food crops are usually below the world's average. In 1986 average yields of main agricultural commodities were below the world's averages, except those of yams, lentils, and sugar cane (Table 1). Indices of per capita cereal production have been declining and Table 2 shows that since 1982, the annual production per capita has fallen below that of 1979-81. The Fifth World Food Survey by FAO (1987) noted that during the periods 1961-63, 1969-71, and 1979-81, most of the decline in per capita dietary energy (DES) in the developing countries occurred in African countries, especially in the low-income class. Thus, out of 30 countries with low incomes, the DES declined in 16 countries, and of these, 14 were in Africa. The per capita energy supply per day rose very little from 1961-63 to 1979-81 (Table 3).

TABLE 1 - *Mean Yields of Eighteen Commodities in Africa as Compared to those of the World in 1986.*

Commodities	Average Yields (t/ha)		Percentage of African Average/ World Average
	Africa	World	
Cereals	1.18	2.59	45.6
Rice (paddy)	1.85	3.27	56.6
Maize	1.58	3.66	43.2
Sorghum	0.88	1.53	57.5
Millet	0.71	0.77	92.2
Roots and Tubers	7.89	12.87	61.3
Cassava	7.92	9.66	82.0
Sweet Potato	6.13	14.79	41.0
Yams	11.09	10.94	101.4
Irish Potato	7.91	15.39	51.4
Taro	4.80	6.08	78.9
Pulses or Grain Legumes	0.65	0.81	80.2
Groundnuts (decorticated)	0.82	1.09	75.2
Peas (including cowpeas)	0.77	1.49	75.2
Soybean	1.05	1.83	57.4
Lentils	0.86	0.79	108.9
Chickpeas	0.65	0.75	86.7
Miscellaneous			
Cocoa (beans)	0.29	0.37	78.4
Coffee (green)	0.36	0.49	72.9
Cotton	0.95	1.39	68.3
Sugar Cane	6.54	5.86	111.6

Source: FAO Production Yearbook, 1987.

Annual growth rates observed were 0.3 and 0.4% in 1961-63 to 1969-71 and 1969-71 to 1979-81, respectively. Recommended DES annual rates of growth required to ensure adequate food supplies in three scenarios ranged from 4.1-4.9%. Of the developing countries, the DES in Africa during two decades as measured by the mean per capita caloric consumption per day amounted to 91%, 88%, and 85% of the corresponding world means for 1961-63, 1969-70, and 1979-81, respectively. The mean annual growth rates for Africa amounted to only 43% and 67% of those of the world average for the 1961-63, 1969-71, and

TABLE 2 - *Indices of per capita Cereal Production in Different Regions with 1979-81 as 100* (FAO, 1987).

Region	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Africa	108	99	103	96	101	103	96	83	78	98	99
Asia	95	96	101	99	99	102	103	112	114	111	111
Central America	91	95	98	81	101	118	94	104	103	114	99
South America	109	102	96	97	96	107	116	101	107	104	103
North America	92	92	94	99	91	110	110	73	100	109	103
Western Europe	84	90	99	97	105	98	107	102	125	115	112
Eastern Europe	103	101	107	96	104	101	113	107	123	114	126
Oceania	88	71	124	112	77	111	65	140	127	112	111
WORLD	99	97	104	99	99	102	104	100	108	108	108

TABLE 3 - *Estimated Mean for capita Dietary-Energy Supplies in Different Regions and Economic Groups from 1961 to 1981.*

Region or Economic Group	Per capita kcal per day			Average Annual Rate of Increase	
	1961-63	1969-70	1979-81	1961-63 to 1969-71 (%)	1969-71 to 1979-81 (%)
Developed Countries	3,110	3,280	3,390	0.7	0.3
Developing Countries	1,980	2,140	2,350	1.0	0.9
Africa	2,120	2,170	2,260	0.3	0.4
Far East	1,940	2,020	2,160	0.5	0.7
Latin America	2,370	2,500	2,620	0.7	1.7
Near East	2,230	2,400	2,840	0.7	1.7
World	2,340	2,470	2,630	0.7	0.6
African/World Means (%)	91	88	86	43	67

Source: The Fifth World Food Survey, 1987.

1969-71 to 1979-81, respectively. Mean protein consumption in Africa during 1961-63, 1969-71, and 1979-81 amounted to 53, 54, and 57 g/capita/day, respectively, as compared to the world's corresponding means of 63, 65, and 68, g/capita/day. Out of these, animal protein component of the food consumed amounted to only 10, 11, and 11 g/capita/day, respectively. These values amounted to about 1/3 of the corresponding average world values of 30, 31, and 33 g/capita/day for 1961-63, 1969-71, and 1979-81, respectively (Table 3).

Estimates of the undernourished in Africa ranged from 57 to 81 million 1969-71 and 81-99 million for two levels of basal metabolic supply scenarios (FAO, 1987). Other indicators of malnutrition reported by the Fifth Food Survey include low weight for age values in 22 million children, amounting to 26% annually between 1973 and 1983. Similarly, low weight for height was exhibited by about 4 million children, amounting to 7% of the population for children under 5 years during the same period. Low birth weights were observed in 14% of children and anemia in 40% of the women.

The Administrative Committee on Coordination-Subcommittee on Nutrition (ACC/SCN, 1987) *First Report on the World Nutrition Situation* observed that population expanded more rapidly than food production in Sub-Saharan Africa during the period 1960-1985. But although the proportion of the undernourished population fell slightly from 24 to 23 percent from 1969-71 to 1979-81, respectively, the number of malnourished increased from 60 million to 80 million in 10 years. The average prevalence of malnutrition in preschool-age children was estimated from eight national surveys to be from 17 to 31%. It was further noted that although infant mortality and child death tended to decline during the 1960s and 1970s, the actual numbers of infant and child deaths increased during the decade to the highest in the world, then ranging from 75 to 80 per one thousand live births and child (1-4 years) deaths from 10 to 50 per one thousand children per year. The average infant mortality was then estimated to be 122 per thousand live births, amounting to 2.3 million annually. Similarly, average child death was estimated at 26 per one thousand children per year, equivalent to 1.4 million annually. Although malnutrition may not be the cause of death, in most instances it did contribute to a substantial proportion of the deaths. Micro-nutrient deficiencies were also reported to be prevalent and included deficiency of vitamin A, which causes blindness, in addition to deficiencies of iron and iodine. The level of malnutrition sometimes increased during the period when drought occurred in drought-affected areas, especially in the Sahel in the 1980s.

The overall declining per capita food availability and shortfalls in production were increasingly met with food imports and food aid. The food import requirement in Africa was more than 19 million tons in 1987/88, of which 11.5 million tons were commercially purchased and 6 million were supplied through food aid (Table 4). About half of the world's food aid went to Africa during 1987/88. Since many African countries are bearing very heavy debt burdens and at the same time there is declining foreign exchange earnings due to continuing fall in commodity prices, more and more countries are relying on food to supplement production. In countries where there is drought and/or civil strife, only food aid can prevent famine and loss of lives.

Various reports of the *Global Information and Early Warning System on Food and Agriculture* (GIEWS) during the last two months (FAO, 1987 and 1988a, b, and c) on the food situation in Africa listed several disasters which have resulted in loss of lives, famine, and increasing dependence of many African countries. Floods were reported in parts of Burkina Faso, Chad, Gambia, Niger, Senegal, Sudan, and Nigeria. Invasion by desert locusts were reported in East Africa (Kenya, Ethiopia, and Somalia) and in Chad, Niger, Mauritania, Morocco, Algeria, Tunisia, etc. The campaign against locusts this year is estimated to cost the U.S.

TABLE 4 - *Estimated Import Requirements, Food Aid, and Commercial Imports in Thousands of Tons for 1987/88 or 1988 in Low-Income Food-Deficit Countries as of September 1988.*

Region	Import Requirements	Estimated Imports		Total Commercial and Aid
		Commercial Purchases	Food Aid Allocated or Committed	
Africa	19,220	11,438	5,696	17,134
Asia	26,317	21,438	5,696	27,134
Central America	1,348	412	980	1,392
South America	362	70	240	310
Oceania	199	153	—	153
TOTAL	47,446	33,511	12,612	46,123

Source: FAO: Food Crops and Shortages, Special Report, No. 9, September 1988.

TABLE 5 - *Location of the World's Refugees as of August 1988.*

Region	Number of Refugees	Percentage of Total
Middle East	4,989,700	35.8
Far East	4,368,770	31.9
Africa	4,166,150	30.5
Central America	249,500	1.8
TOTAL	13,774,120	100.0

Source: U.S. Committee for Refugees. Published in the *New York Times Sunday*, August 21, 1988.

$240 million. Drought was reported in some countries, although it was not as severe as that occurring in the United States and Canada this year. Countries in Africa in urgent need of food aid include Angola, Benin, Chad, Malawi, Mozambique, Niger, Somalia, Sudan, in addition to Ethiopia and Djibouti, whose supplies were met by September 1988. In August this year, the total number of refugees in different parts of Africa was 4,166,150, equivalent to about 30% of refugees worldwide (Table 5).

As a conclusion to this brief survey of the African dilemma, it is necessary to emphasize that the most serious aspect of it is the food and agricultural crisis. Related to this are several other crises which synergistically tend to exacerbate the situation. These include:

— The problem of rapid population growth averaging 3.1% — the highest of all regions of the world;
— Rapid rates of urbanization and rising income among segments of the population;
— Deteriorating economic conditions associated with unfavorable balance of payment situations and unprecedented heavy debt burdens;
— Environmental degradation caused by deforestation, farming, overgrazing, uncontrolled burning, erosion, etc.;
— Extreme poverty in many countries with 25 out of 35 least developed countries, and 37 out of the 51 low income food deficit countries located in Africa (FAO, 1987);
— Endemic political instability, which fuels civil strife and has adverse effects on policies and commitment in agricultural development.

Causes of Low Productivity and Constraints to Farmers' Adoption of New Technologies

The current food crisis in Africa is generally interpreted to be the result of farmers' conservatism, resistance to change, and the primitiveness of traditional agriculture. Traditional agriculture is regarded as a stagnant sector that is unresponsive to change. Yet a study of the history and evolution of the prevailing farming systems shows that those production systems are by no means static, and have responded to changes in the past. It is well known that the prevailing farming systems in sub-Saharan Africa have in the past responded to changes and actually consist of a mosaic of crops, ideas and practices, some of indigenous origin, to which have been grafted crops and techniques from different parts of the globe. It is interesting to note that without experimentation, traditional African Agriculture at about the first millennium A.D. has been infused with Asian crops, followed, after the discovery of America by Columbus in 1492, by American crops. Moreover, the spectacular success of such export crops as cocoa, oil palms, and groundnuts in West Africa in response to market forces by small holders is a good indication that the traditional farmer does respond to new opportunities that are significantly rewarding in satisfying the needs of the farmer and adapted to his circumstances.

Colonial powers introduced agricultural research into Africa since 1900 in order to develop technologies for increasing agricultural production, and although some progress was made in research and development of export or cash crops, very limited progress was made in the adoption of new technologies in the production of food crops. Here the term technology is regarded as a method of doing things, including sometimes a new crop variety or breed of livestock. Wharton (1968), based on his experiences in Southeast Asia, has identified the following reasons for farmers' failure to adopt new technology:

— The technology may not be known or understood by the farmer;
— The technology may not be within the farmers' managerial competence;
— The innovation may not be socially or psychologically acceptable;
— The innovation may not be viable or adequately adapted;
— All elements of the new package may not be available.

Risk aversion is a widespread, but natural, phenomenon among farmers worldwide. Consequently, there is no reason for expecting a farmer to adopt a technology whose outcome he does not know, nor does he understand the processes involved. Where the existence of a technology is totally unknown to the farmer, it is impossible for him to adopt it unless, of course, the idea occurs to him by chance. For this reason, there are extension workers whose main task is to make farmers aware of the existence of technologies that can be adopted for increasing crop yields, managing or reducing pest attack and damage, processing of produce, etc. But the number of agricultural family units per extension worker in Africa ranges from 82 in the small island of Mauritius to 3,904 in Mozambique (FAO, 1984). Where there are six people per family unit on the average, the number of individuals who are farming per extension worker ranged from 492 to 23,424 in 1984. Therefore, the effectiveness of the extension worker is greatly reduced because of the low contact time the worker can have with each farmer or farm family even if he has the wherewithal and adequate training and experience to operate effectively.

Extension workers use demonstrations, training sessions, farm schools, newspapers, radio, television, visits, bulletins, and several media to make farmers aware of new technologies and their potentiality for increasing agricultural productivity. But where farmers are illiterate, only a few of these extension methods can be used, and where extension workers have limited resources and logistic support, as in sub-Saharan Africa, it is difficult for them to assist farmers by making them aware of the existence of new technologies. The farmer, then, relies mainly on traditional technologies, many of which, although scientifically sound, economically viable, and ecologically sustainable under conditions of, for example, low population densities and long periods of fallows, have now become increasingly outmoded under many pressures of modernization.

It is true that very often many new technologies are not within the farmer's managerial competence. For example, a farmer who has become used to simple tools, such as the hoe and machete, and manual, physical, and cultural methods of weed control is not in a position at the age of more than 60 years to easily master the use and operation of a tractor and control weeds with herbicides when even the trained extension workers are unable to do so where these technologies are economical. Where the farmer cannot read labels, use of herbicides without close supervision is very hazardous.

Many technologies are sometimes not socially or culturally acceptable to farmers. For example, in the past, farming and the manual work it entails was a manifestation of strength, courage, and industry. A man or woman took pride in clearing land and making mounds or ridges, and one is respected according to the number of mounds or ridges he or she can make in one day. But it involves stooping down and literally breaking one's back. Introduction of long-handled West Indian hoes, which made it possible for one to make mounds or ridges while standing erect did not gain widespread adoption among most farmers, who regarded it as a manifestation of laziness to be cultivating in an upright position.

In traditional agriculture, there is a marked division of labour between the sexes, and most of the post-harvest or food processing operations, which are boring and tedious, are performed by women. This is also true of crop management operations, such as weeding. When these operations become simplified by the introduction of machines, it is usually the man who takes advantage of doing the work which is usually detested as a menial job. Moreover, when machines are introduced by extension workers, the women are not expected to be involved in the operation of machines, and are not taught how to operate them even when they are young and more versatile. With the spread of education and change in values, most young men since more than a decade ago would not go into farming, which was regarded as the work of illiterate rural dwellers. Only recently, since the white collar public service jobs became scarce, many young men are now more ready to farm, especially when there are acceptable technologies to reduce manual labour. Related to these is the fact that labour-intensive technologies acceptable to Asians are often not acceptable to Africans.

There are many situations where new technologies fail to be economically viable or adapted to prevailing environmental or socio-economic conditions. For example, studies on technology adoption in the National Accelerated Food Production Program (NAFPP) in Nigeria in the 1970s which involved on-farm participation of farmers in evaluating and choosing the technologies they liked showed that farmers preferred intercropping of maize with cassava to growing maize alone, even though the yield of maize under sole crop or monoculture is higher. This is, of course, due to the fact that the cassava takes more than 10 months to mature, and maize grown with it as a catch crop is harvested green after about 90-100 days. Moreover, there is much less risk of crop failure where farmers grow more than one crop. It is also known that intercropping gives higher overall total yields, especially of biomass, than sole cropping.

Many new technologies are not adapted to the farmer's needs and circumstances. In savanna areas, new high yielding sorghum varieties are usually short, have compact heads, high harvest index, and are photoperiod insensitive. Farmers do not like those varieties since they lack many characteristics of prevailing local sources. These local varieties are photoperiod sensitive, and take a longer time to head when day lengths are shorter. As a consequence of these, they grow very slowly, and do not compete with cowpeas and earlier maturing millet which are intercropped with the sorghum. Local sorghum varieties have more open heads with spreading panicles and dry out more easily in the field and are easier to store, since they do not get moldy in the field and rot during storage. The local sorghum varieties are tall and supply a lot of stalks which farmers use for fencing, fuel wood, etc.

In the rice zone of West Africa, many new rice varieties being introduced are very high yielding, but short. They are not liked by farmers who have to stoop down to harvest rice with sickles and the short rice varieties are easily covered by weeds. Sometimes the conditions under which crop variations are tested and selected are different from those in farmers' fields. For example, maize varieties are often tested in open fields or research stations. In farmers' fields, such maize varieties are grown under the shade of tree crops which are dotted about the farmers' fields and should not be pruned or cut down since they are equally important. The result is that yields are lower in farmers' fields as compared to those in experiment stations (Table 6).

One of the most common phenomena observed in agronomic trials is the tendency of individual inputs to exhibit limiting factor effects when applied alone. But when several inputs or technologies are applied jointly, they tend to have additive effects and give higher yields up to a limit at which other limiting factors set in. For example, many improved crop varieties give higher yields than locals only when fertilizers are applied, in addition to several other inputs or cultural practices, such as weeding, planting in rows, use of insecticides or pesticides and specific spatial arrangements and populations. But the local varieties, which may give reasonable yields in the absence of fertilizers and pesticides, often do not respond as well to several inputs as do the improved varieties (Table 7).

Various Environmental Factors which Limit Technology Adoption and Increased Agriculture Productivity

The above factors that constrain technology adoption by traditional farmers are by no means exhaustive. There are several physical, developmental, cultural, and policy environmental problems that should also be taken into account. Farmers may be attracted to the use of new tech-

TABLE 6 - *Effect of Shade and Fertilizer on Yields.*

Village	Owerre-Ebeiri (H)	Umuokile (M)	Okwe (L)	Mean yield
	t/ha	t/ha	t/ha	t/ha
Maize (a)				
shade, no fertilizer	.30	.15	.66	.37
no shade, no fertilizer	1.13	.02	.45	.53
shade, with fertilizer	.29	.94	.80	.68
no shade, with fertilizer	1.82	.66	2.01	1.50
Yams				
shade, no fertilizer	1.75	7.90	15.50	8.38
no shade, no fertilizer	2.75	9.20	15.50	9.15
shade, with fertilizer	3.25	12.00	13.00	9.42
no shade, with fertilizer	5.25	12.00	19.00	12.08
Cassava (b)				
shade, no fertilizer	2.43	3.58	2.32	2.78
no shade, no fertilizer	5.00	7.35	14.31	8.89
shade, with fertilizer	4.01	3.58	2.55	3.38
no shade, with fertilizer	11.84	9.42	21.98	14.41

(unreplicated plots)

(a) Maize yields in the medium density village are not representative, due to damage by goats.
(b) Cassava yields on shaded plots in the low density village are not representative, due to falling branches from palm trees.

(*Source*: unpublished data of Okigbo B.N., IITA, Ibadan, Nigeria).

nologies for increasing productivity in order to satisfy subsistence needs and the need for higher incomes through sales of surpluses so as to be able to pay school fees, buy inputs, pay for medical services, and fulfill many social obligations; yet many farmers who live in rural areas with no good roads, transport facilities, adequate marketing and pricing structure have no incentive to produce more. This is because they are unable to take advantage of new technologies to produce more food which may spoil in the field or storage. Moreover, even where the produce is easily evacuated, the farmer may be at the mercy of the middleman, who transports the produce to urban areas, where it is sold at higher prices. Alternatively, he may be able to store them and dispose of them when there is scarcity and relatively higher prices. Farmers do not like to

TABLE 7 - *Productivity of different agricultural systems, energy inputs, and energy output/energy input advantages (Er).*

Area	Crops	Energy (GJ/ha per annum) Output	Input	Er
Shifting cultivation systems				
New Guinea Highlands	Yam, sweet potato, cassava (total kg)	41.	2.5	16.5
Congo	Cassava, plantain, rice (total 2,600 kg)	15.7	0.24	65
Mexico	Maize (1,900 kg)	29.4	0.96	30.6
Partially mechanized systems with fertilizers				
Mexico	Maize (931 kg)	14.2	2.90	4.9
Philippines	Maize (931 kg)	14.2	2.8	5.0
Uttar Pradesh, India	Wheat (756 kg)	11.2	6.6	1.7
Philippines	(Rain fed) Rice (1,500 kg)	22.9	4.2	5.4
Fully mechanized with all necessary inputs, for high yields				
Surinam	(Irrigated) Rice (3,400 kg)	51.5	41.1	1.3
USA	(Irrigated) Rice (5,700 kg)	84.1	65.5	1.3
USA	Maize (5,100 kg)	76.9	29.9	2.6
UK	Wheat (3,900 kg)	56.2	17.8	3.3
UK	Maize (5,000 kg)	61.7	26.4	2.3
UK	Potato (26,300 kg)	56.9	36.2	1.6

Source: Leach (1976) and Greenland and Okigbo (1983).

produce more with new technologies when there are no storage or processing and preservation technologies or facilities that are acceptable to the farmer. Consequently, agricultural development programs, which involve development of rural infrastructure, enhance technology adoption.

One of the most serious constraints to farmers' adoption of new technology is the policy environment. Where there is a policy that makes it possible for urban masses to obtain cheap, imported food at subsidized prices, there is very little incentive for the farmer to produce more. Similarly, where governments use marketing boards to rob farmers of part of their proceeds from the sale of export crops, ostensibly to save money for stabilizing prices when prices are low but fail to do so when the time comes, the farmers are not encouraged to produce more. Similarly, governments often set prices to encourage farmers to produce more, but fail to buy up the produce at the stipulated prices or set lower prices that are economical; then farmers may not adopt technologies that increase costs and yields, resulting in the farmer suffering heavy losses when produce is not sold. The practice of developed countries giving subsidies to their farmers so that their produce commands lower prices in the world markets, where produce from developing countries cannot compete, works to the disadvantage of African farmers and does not encourage them to adopt yield-boosting technologies.

The African Environment and Associated Constraints Faced by African Farmers

Africa has a lot of potential for producing enough food, but against this must be considered so many environmental factors unique to Africa which make it more difficult to achieve higher agricultural productivity than in almost any other continent.

Sub-Saharan Africa is 7,200 km wide at its greatest east-to-west extension and 5,200 km from north to south. It has an area of 22 million km², amounting to 50% that of Asia, and is 10% larger than the area of North America. Thus, this part of Africa has more available cultivable land per capita than farmers in Asia and Europe and the Near East. Most of the land lies within the tropics, and with average temperatures of more than 20° C., except on high mountains, there is no danger of frost. All year round, crop production is therefore possible where moisture is not limiting. There is abundant sunlight, and net annual productivity ranges from 300 to more than 4000 g/m³. Consequently, crops of the rain forest zone and those of savanna areas can be grown as are also subtropical crops in the tropical highlands of eastern and southern Africa. Out of a population of about 400 million, more than 70% on the average are engaged in agriculture. Thus sub-Saharan Africa has the land and human resources that can potentially produce enough food and agricultural products to satisfy the demand for food and attainment of reasonable level of income and economic well-being. This is true to the extent that economic conditions and technological capabilities permit finding solutions for the following constraints to increased agricultural productivity.

Physical Constraints

These consist of factors of edaphic origin in relation to soils and prevailing climatic conditions. Soil-related constraints include:

— Unreliability of rainfall in onset, duration, and intensity — in more than 50% of the land area of tropical Africa; especially in the inland drier areas, percentage of rainfall departure from the normal ranges from 20-40% or more;
— Unpredictable periods of drought, floods, and environmental stresses;
— High soil temperatures for some crops with adverse effects on growth, development, and some biological processes, such as N-fixation;
— Cloudiness and reduced photosynthetic efficiency, especially in humid areas;
— More than 54% of the land area of Africa is deficient in moisture because of insufficient rainfall and 46% has only .0-74 days length of growing period (LGP).

Other soil-related constraints include:

— High degree of weathering, sandiness, deficiency in days, high fragility, and erodibility;
— Several climates and ecological zones resulting in diversity of crops and cropping systems;
— Values of Cation Exchange Capacity (CEC) and rapid rates of organic matter decomposition;
— High levels of soil acidity and high tendencies for P-fixation;
— High subjectivity to multiple nutrient deficiencies and toxicities under increasing intensities of cultivation;
— Leaching processes with high risk of erosion under prevailing rainstorms, especially at the beginning and end of the rains;
— Low inherent fertility with about 32.3% of the land resources of the continent exhibiting specific management problems, and 8.6% having sandy textures and steep slopes;
— About 4.5-5% of the soils are low in nutrient retention, 22.3% exhibit aluminum toxicity, 13.5% phosphorous fixation hazard, 22.4% low in potassium supply, and some have excess calcium carbonate and excess soluble salts (FAO, 1986 a and b);
— Desertification occurs frequently in the semiarid Sahelian areas.

Biological Constraints

— Unimproved crop varieties and breeds of animals that are of low-yield potential, unresponsive to inputs such as fertilizer, feed, etc., and susceptible to pests and diseases;
— High incidence of weeds, parasitic fungi, bacteria, insects, eelworms, and virus diseases in cultivated plants under unfavorable environmental conditions of the tropics (Karmack, 1988);
— Swarms of locusts invade and damage crops in recurrent succession;
— Rampant weed growth, especially where fallows have been drastically shortened or under prolonged cultivation;
— Presence of parasitic diseases, such as schistosomiasis, trypanosomiasis, onchocersiasis, which attack man and animals, thereby reducing work performance and response of livestock to feeding;
— Incidence of livestock diseases, rendering it impossible to use livestock for work or draft in humid areas;
— Prevalence of many vectors of diseases, such as mosquitoes, which transmit malaria from one person to another;
— Toxic factors and unpalatability of feeds, especially in drier arid areas;
— Drastic adverse environmental effects caused by human activities, such as farming, burning, deforestation, overgrazing, etc., resulting in loss of biological equilibrium and genetic diversity.

Kamarck (1988) reviewed in some detail the peculiar environmental characteristics that adversely affect crops, and man.

Socio-Economic Constraints

These include several cultural, economic, psychological, and political factors which directly or indirectly retard agricultural development and production, such as:

— Small farm size and fragmentation of holdings with about 80% not more than 5 ha in area;
— Unfavorable land tenure systems;
— Shortage of labour at peak periods of planting, weeding, and harvesting;
— Division of labour between the sexes and associated male dominance in extension work and neglect of the role and needs of women in agriculture;
— Lack of credit for purchase of inputs;
— Low productivity, low income, and poor living standards;

— Unavailability of inputs in amounts, quality, and timing;
— Illiteracy and superstition, which hamper the adoption of new technologies and response to various agricultural extension methods;
— Weak extension services;
— Widespread poverty among farmers and inability to purchase farm inputs, such as fertilizers;
— Weak research systems and associated deficiencies in capabilities for innovative research;
— Poor linkage of research extension and the farmer;
— Lack of effective farmer organizations and lack of political voice;
— Poor rural infrastructure, marketing, and pricing structure;
— Lack of a package approach to technology generation and testing;
— Poor transportation and communication facilities;
— Poor living conditions in rural areas and high rates of rural/urban migration and farming left to old men and women;
— Political instability and associated deficiencies in commitment, and inconsistencies in agricultural development;
— Colonial legacy of early emphasis on cash crop production to some extent to the neglect of food crops;
— Deficiencies in the educational system and isolation of universities, even those with faculties of agriculture, from the extension staff and farmers;
— Lack of incentives to farmers for increased production and unfavorable policy environment for agricultural development.

Technical Constraints

These relate to lack of scientific culture and often inability of the farmer to understand, manipulate, and use machinery. The lack of a scientific culture has adverse effects on attitudes to research, management of research, and appreciation of the role of research in agricultural development. Use of simple manually operated farm tools. Deficiencies in industry in relation to the support of agricultural production.

The above are by no means exhaustive, but for more detailed discussion on various aspects of African agriculture, reference should be made to Okigbo (1982) and Knight (1976).

Options for Increasing Food and Agricultural Production

In all development programs aimed at finding lasting solutions to the African food and agricultural crises, there are several options that can be used separately or in combination to achieve desired objectives in the most cost-effective manner. These options include:

- Expansion of area under cultivation;
- Increased production per unit area of land, and unit of energy;
- Genetic improvement of crops and farm animals;
- Better and more efficient management of pastures;
- Better management and utilization of forest resources;
- More efficient management and utilization of aquatic resources;
- Nonconventional food production.

Sub-Saharan Africa relies almost exclusively on the expansion of areas under cultivation for achieving increased agricultural and food productivity. In 1979-81, the average yields of most crops in Africa fell below what could be achieved with low inputs in favorable environments (FAO, 1984). Since increases in yield attributable to fertilizer use amounted to about 6% in 1979-81, expansion of areas under cultivation must have accounted for no less than 80-90% of the increase, since low level of inputs were used. Other inputs or technologies that accounted for less than 14% including fertilizers. FAO (1984) projected that at low inputs, Africa should be supporting no more than three times the 1975 population if the entire cultivable land resources were utilized. At the intermediate and high inputs, the total cultivable land resources will be able to support 11.6 and 33 times the 1975 population, respectively. It was calculated that by the year 2000 A.D., the potential cultivable land resources of Africa should be able to support 1.6, 5.8, and 16.5 times the expected population in that year at low, medium, and high input levels, respectively, with very little land available for nonfood crops.

Since the population and land resources of different countries vary, then their critical population-supporting capacities must also vary. In 1975, at low inputs 22 out of 51 African countries had already reached these critical population-supporting capacities. But taking into account the extent of erosion and soil degradation associated with deforestation and the multiple land use needs of countries for timber, fuelwood, urban construction, special and game reserves, industry, etc., it is necessary that land-saving strategies be adopted by increasing cropping intensity in the farming system and reducing the contribution of expansion of area to increased production. FAO (1981) recommended that for tropical

Africa, by the year 2000 only 27% of the total production should be achieved by expansion of area while 22% and 51% should be from increasing cropping intensity and yields, respectively. It would, however, be quite realistic to limit expansion of areas under cultivation to mainly hydromorphic and valley bottom soils that are of high potential for such crops as rice and dry season vegetables. Further expansion of areas under cultivation can be achieved through irrigation in the dry summer and semi-arid areas, provided that adequate drainage is used to ensure that salinization of the soil is prevented. In some areas, drainage of flooded areas could be used to increase production provided that it is cost-effective.

Intensification of cropping systems can be achieved by using cropping patterns that are intensified through different spatial and temporal arrangements in addition to genetic improvement to ensure higher yields and adaptation to soils with some environmental stresses.

Genetic improvement of crops and livestock contributes to quantitative and qualitative yield increases in agricultural production. Through this method, objectives that can be achieved include:

— Increased yields;
— Improved quality of produce;
— More efficient utilization of resources, feed, or fertilizers;
— Resistance to diseases, parasites, and pests;
— Adaptation to environmental stresses;
— Adaptation to different cropping systems;
— Adaptation to mechanization;
— Satisfying local preferences and the needs of producers, processors, and consumers.

In livestock production, there is a need to develop improved management systems for pastures involving different grazing systems and management of vegetation. Genetic improvement of pastures or fodder species can also contribute to increased production of feeds and ultimately high yields of animal products. Improved range management not only involves rotational grazing, but also sowing of pastures with more adapted grasses and legumes. Above all, there is a need to avoid overgrazing, uncontrolled burning, and buildup of livestock numbers in excess of the carrying capacity of the pasture.

Forests and natural vegetation contain species of plants that can be used for food and feed, sources of drugs, sources of timber in addition to support of wildlife. Many forest species in different ecological zones are relatives of cultivated plants and can be used for genetic improvement of crops. Several wild plants of multi-use potential can be domesticated and used as sources of raw materials for industry, food, and various products. In Sub-Saharan Africa today there are more than 200 to 300 species of plants that can be utilized as sources of food. With the rapid loss of genetic diversity and genetic erosion as a result of deforestation, high priority should be given to improved conservation and extending of the range of uses of different spread in addition to reducing the extent of fires that cause destruction of vegetation. Components of this option should include improved forest plantation management and more efficient exploitation with minimum drainage to the environment.

The aquatic resources of our rivers, lakes, streams, seas, and even ponds remain under-exploited or mismanaged. Apart from development of improved aquacultural production systems, a lot can be achieved in increasing productivity through genetic improvement to ensure more efficient utilization of feed, resistance to diseases and parasites, and adaptation to different environmental stresses. Use of improved harvesting gear, better curing storage, and packaging techniques have the potential of contributing a lot to the available animal protein supplies. Moreover, there is room for the integration of aquaculture with crop production and other production systems on the landscape.

Nonconventional production systems and foods include the use of simple cell proteins for food and feed, food fortification, use of synthetic foods, leaf protein, etc.

Extent of Utilization of Various Options for Increasing Agricultural Productivity in Africa

Of the above methods of increasing food production, very limited use is being made of a range of technologies that will facilitate their effective contribution to increasing food production. Expansion of areas under cultivation remains the most widespread use followed by very much limited use of irrigation, mechanization, fertilizers, pesticides, aquaculture, and a range of post-harvest activities. There is very limited use of fertilizers, and even then most of the fertilizers used in Africa are restricted mainly to export crops. Very little fertilizer is used for food crop production. In 1972, for example, the amount of fertilizers used per hectare in Nigeria was about 1 kg per ha as compared to 72 kg for the United States, and 363 kg for West Germany. The percentage of total arable land under irrigation in Africa amounted to only 1 1/2% as compared to 22% in the Near East, 7% in Latin America, and 23% in the Far East in 1979-81. There is no doubt that limited adoption of new technologies by farmers for one reason or another is one of the main reasons for low productivity in African agriculture.

Need for Development of Sustainable Agricultural Systems Based on Integration of Traditional and Modern Technologies

In modern agricultural production systems, productivity has been maximized through the escalation of modern inputs and the use of petroleum-based products and energy sources. In traditional agriculture, very few or low inputs are used. The latter is highly diversified on not more than 5 ha, while the former is specialized on more than 10-100 ha or more. The main differences in input use and resource management are summarized in Table 7A.

Traditional agricultural systems are only sustainable under low population densities and long periods of fallow. Where fallows are short, sustainable systems in the humid tropics are only those involving integration of crops and livestock, multi-storied agroforestry systems, lowland rice culture, and tree crop plantations. With the reduction of fallow periods, there is loss of soil fertility and productivity, increased runoff, erosion, and soil degradation.

Modern agricultural production systems, although highly productive, are no longer sustainable since the escalation of the use of petroleum-based fuels and chemicals in the form of fertilizers and pesticides and the use of mechanical power have resulted in high costs of production and energy use, damage to the soil, and loss of cost effectiveness. Energy output is sometimes only slightly more than the total energy input (Table 7). Since 1962, with publication of Rachel Carson's *Silent Spring*, there has been much concern about damage to the environment caused by fertilizers and pesticides. Of major concern is the extermination of beneficial organisms and development of resistance by target species. Many farmers in developed countries have become bankrupt and cannot survive without subsidies. The overall result is that in both developing and developed countries, there is now a lot of interest in the development of sustainable agricultural production systems which involve less use of pesticides and minimization of damage to the environment.

In this paper a *sustainable agricultural production system is defined as a dynamically stable and continuous production system that achieves a cost effective optimum level of productivity, satisfies prevailing needs and is*

TABLE 7A - *Comparison of Traditional and Modern Agriculture.*

	Traditional Agriculture	*Modern Agriculture*
Land:	Small < 1-5 ha	Large 10-100 ha or more
Tools:	Simple: fire, axe, hoe, digging sticks, machete	Complex: tractors and implements, threshers, combine harvesters, etc.
Crops:	Many species (5-80) Land races, no genetic improvement, wide genetic base	Few species (1-3) Improved narrow genetic base
Animals:	Several species 2-5	Usually 1 or 2
Labor:	Manual, human energy or animal power	Mechanical, petroleum fuels, electrical energy
Soil Fertility Maintenance:	Fallows, ash, organic manures	Inorganic fertilizers, sometimes manure, soil amendments, e.g., lime and gypsum
Weed Control:	Manual, cultural	Mechanical, chemicals (herbicides and petroleum-based products)
Pest and Disease Management:	Physical/Cultural	Mainly mechanical/chemicals — Insecticides Fungicides, Bactericides Nematocides, Rodenticides
Crop Management:	Manual	Growth regulators for defoliation, control of flowering, fruit drop, etc.
Harvesting:	Manual or with simple tools	Mechanical-tractors plus implements: pickers, balers, threshers, combine hervesters
Post-Harvest Handling and Drying:	Simple sun-drying and over fires	Mechanical forced air, artificial drying using petroleum fuels, sometimes refrigeration

constantly adapted to most future pressing needs for increasing the carrying capacity of the resource base. Sustainability can only be achieved when resources, inputs, and technologies involved are within the capacities of the farmer to own, hire, maintain, and orchestrate with increasing efficiency in order to achieve desired levels of productivity in perpetuity without adverse effects on the resource base and environmental quality. It is obvious that what is required is a scaling down of costs and number of inputs in modern agriculture and slightly upgrading input use in traditional agriculture. It calls for the use of integrated resource management systems that minimize energy and chemical use to a level that is economical and has no adverse effects on the environment.

Farming Systems Research and the Strategy of Integrating Traditional and Modern Agricultural Technologies in Development of Sustainable Farming Systems for Africa

The failure of a majority of low resource farmers to adopt new agricultural technologies and the concern about some of the second generation problems of the Green Revolution led to the development of farming systems research (FSR) at the international agricultural research centers (IARCS) under the aegis of the consultative group for international agricultural research and some national agricultural research centers. FSR is a holistic approach to agricultural research that adopts a systems perspective in research, with emphasis on understanding of the farmer's overall environment, his production system, input/output relations, objectives to be satisfied and constraints to adopting new technologies. This forms the basis for setting priorities in research and determining strategies for increasing agricultural productivity. It involves three main phases:

1. *Diagnostic survey and Baseline Data Collection and Analysis*, by which the researcher, through the use of secondary data and special field surveys, studies the farmers' physical, biological, and socioeconomic environments, resource use and management, input/output relations, household dynamics and constraints to increasing production as a basis for designing and preliminarily testing new systems on the research station. This is sometimes designated as the upstream component of FSR since it avoids a top-bottom approach of conventional agricultural research.

2. *On-Station Research*, whereby, on the basis of results of the diagnostic phase of FSR, research station scientists in different disciplines are able to design new and improved production systems and develop component technologies that address the farmers' problems and thus have a greater chance of being adopted. Results of this phase, which is continuous with the following, are the basis of the next phase.

3. *On-Farm Adaptive Research*, whereby new improved production systems and component technologies developed in the research station are redesigned or modified with the participation of the farmer and are then tested on the farmer's field with the farmer playing a major role in resource management and evaluation of the technologies involved. The technology adoption process is monitored and this facilitates modification and fine-tuning of the technology to the farmer's environment and circumstances. It also enhances feedback to research stations. During this phase a special aspect of the research, designated as constraints research, quantifies the various components of the yield gap that exists between the farmer's field and those of the research station and determines how to eliminate or minimize the gap (Tables 8, 8A). Through this activity, the various aspects of the policy environment and the infrastructural deficiencies which cannot be eliminated by the researcher or the farmer are identified. For more details on the value of farming systems in agricultural development programs, reference should be made to Norman *et. al.* (1981).

Through farming systems research, it is possible to develop production systems which are economically viable, economically sound, culturally acceptable, and adapted to the farmer's needs and circumstances. Although much progress has been made in the application of farming systems research to enhance more rapid progression technology adoption by linking it with agricultural development projects, there are problems of incorporating it into national agricultural research systems R&D activities.

Problems of Applying Farming Systems Research Methodologies to Agricultural Research in Africa

Although much progress has been made, the potentials of the FSR approach in contributing to the finding of solutions to the African food crisis have hardly been realized. The reasons for this include:

— Need for cooperation among scientists in different disciplines and problems of managing multi-disciplinary research teams of disciplinarily trained staff;

— Overall general deficiencies in funding, staffing, continuity of commitment, lack of management experience, deficiencies in equipment and high cost of agricultural research. Coupled with these is the generally poor logistics support of research;

TABLE 8 - *Effect of Management on the Production of Millet in Northern Savanna, Nigeria.*

Treatment	Location	
	Kano	Samaru
Improved Var. + optm. popln. + Fert. + good mgmt.	1660	2259
Improved Var. + Farmers' popln. + Fert. + poor mgmt.	48	—
Local Var. + optm. popln. + Fert. + poor mgmt.	76	—
Local Var. + Farmers' popln. + Fert. + good mgmt.	1521	1091
Improved Var. + optm popln. + Fert. + poor mgmt.	77	—
Improved Var. + Farmers' popln. + No Fert. + good mgmt.	1028	1398
Local Var. + optm. popln. + Fert. + good mgmt.	1479	1269
Local Var. + Farmers' popln. + No Fert. + poor mgmt.	69	—

Only the early sown treatments produced grains at Samaru.

Good management: Means seed dressing, early sowing, two timely weedings, early thinning and timely spraying with insecticide.

Poor management: On the other hand means late sowing, late thinning, one weeding and no attempt to control pests attack.

Fertilizer dose: Was 50 kg/ha each of N, P_2O_5 and K_2O. The P_2O_5 and K_2O dosages are being reduced to 25 kg/ha each for further studies. The current recommendation of N — 13 and P_2O_5 — 12 kg/ha is under revision.

Optimum Population: Is 37,000 plants/ha and farmers' population was 12,000 plants/ha.

Source: I.A.R., A.B.U., Zaria, Cropping Scheme Meeting 1977.

TABLE 8A - *Yields in lb per acre, Nigeria. Northern Nigeria (1955-6).*

	1st cycle 1950-52			*2nd cycle* 1953-55		
Bida	*Sorghum*	*Groundnut*	*Cassava*	*Sorghum*	*Groundnut*	*Cassava*
Monocropping	315	272	4544	354	128	2790
Rotation	624**	346	5405**	668**	162	4724**
Samaru	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Groundnut*	*Cotton*
Monocropping	939	717	420	947	781	402
Rotation	1196**	1035**	444	1124**	1027*	489

* Significant increase, $p = 0{\cdot}05$.
** Significant increase, $p = 0{\cdot}01$.

Source: Webster & Wilson, 1966.

— Lack of local capabilities for effective linkage of national agricultural research systems with IARCS. Added to this is the lack of effective linkage of research with extension and the farmer;
— Isolation of university faculties and scientists in many disciplines from agricultural research institutes, extension workers, and the farmer;
— Lack of adequate communication among researchers, policy-makers, and the general public;
— Ignorance of many agricultural scientists in traditional farming systems and indigenous resource management systems. [The need for knowledge of indigenous resource management and indigenous technologies in designing alternatives to traditional farming systems and agricultural development is discussed in detail in Brokensha *et al.* (1980) and Richards (1985)].

The overall result of lack of trained manpower in national agricultural research systems and poor funding of research has resulted in much reliance on socio-economists and anthropologists from developed countries, many of whom are more interested in testing of theories and establishing the importance and role of their disciplines in agricultural research than in achieving objectives of farming systems and enhancing on-farm adoption of results.

The rest of this paper is taken from a paper on *Sustainable Agricultural Systems in Tropical Africa*, recently presented at an international conference on sustainable agriculture in Columbus, Ohio, since it emphasizes that what we require in finding solutions to the agricultural, demographic, economic, environmental, political, and technological crises facing Africa is not just the development of a sustainable agricultural production system for food fiber and export products, but the overall problem of rational planning, improvement, management, processing, and utilization of Africa's natural resources with minimum adverse environmental effects (Okigbo, 1988).

Elements of Traditional and Modern Agricultural Systems

In determining desirable elements of traditional and transitional farming systems, due consideration should be given to the characteristics of the majority of farmers, their production systems, and technologies. These desirable aspects include:

1. The diversification of production through temporal and spatial improvement of multiple cropping patterns that ensure satisfaction of the

farmer's subsistence and increasing cash requirements, while maintaining stability of production and reducing risks;

2. Integration of crop and animal production systems in addition to development of farming systems that involve components of improved agroforestry and agri-silvopastoral systems as circumstances permit;

3. The utilization of nutrient cycling and biological nitrogen fixation potentials of plants wherever possible, in order to reduce the use of costly fertilizers;

4. Cropping systems which make as much use as possible of indigenous and under-utilized African crop plants;

5. The development of improved cropping patterns, grazing systems, and technologies which ensure that soil is kept adequately protected from erosion and degradation;

6. Integrated watershed development, including the development and utilization of relatively more fertile valley bottoms and hydromorphic soils, for which solutions should be found to the various physical, biological, and socioeconomic constraints that limit their use;

7. Use of photoperiod sensitive and insensitive cultivators to achieve flexibility and special objectives in cropping systems;

Similarly, the various aspects of "modern" agricultural production systems and their component technologies that should, as far as practicable, be incorporated into new improved farming systems for sustained yields include:

1. Mechanization and appropriate technology to minimize drudgery in farm work while significantly increasing productivity;

2. Integrated pest management to reduce losses in the field and in storage;

3. Techniques and methods of increasing the efficiency of those fertilizers which cannot yet be replaced by biological processes;

4. Intensification of production and increased productivity per unit area of land, in order to curtail drastically the reliance on expansion of area under cultivation, as the main strategy for increasing production;

5. Increased use of irrigation and water harvesting in semi-arid and arid areas with measures taken to ensure adequate drainage and to minimize salinization;

6. Methods for eliminating tillage altogether or minimizing it;

7. Greater utilization of techniques and potentials of conventional genetic improvement of crops and animals;

8. Judicious use of agricultural chemicals (Okigbo, 1986).

Environmental Hazards Associated with Agricultural Practices

In various traditional and modern farming systems, there are different practices used during certain phases of the production process that adversely interact with the crop, soil, or livestock in such a way as to contribute to sustainability. For example, clearing the land of vegetation and development, planting, fertility maintenance, and soil management including fertilizer and chemical application, water management, weed, pest and disease management. Cultural operations, harvesting, post-harvesting operations, ect., influence the soil and crop-growing on it in one way or cause run off, erosion and soil degradation, thereby influencing the overall performance of subsequent crops.

The method of removal of vegetation with respect to the extent of use of manual cleaning and/or mechanization and the kind of equipment used, in addition to the kind of pre-planting cultivation technique used, cause compaction; sealing up of pore spaces resulting in run-off and erosion. The extent of damage done will cause much disturbance of the subsoil and compaction. The possibility of run-off and erosion increases, depending on the slope, soil type, and subsequent pre-planting cultivation of soil, cover, and so on. Where the plant or crop residue is not burned, but applied as mulch, soil is protected from the beating action of rain, infiltration of water is increased, and the organic matter content of the soil is increased. The overall effect is increased yield and reduced runoff and erosion (Table 9). The effects of mulching vary with the kind of mulch applied and the cropping system and other practices used. They also vary from one place to another. The extent to which various operations can cause soil erosion is roughly indicated in Table 10.

In animal production, the method of pasture establishment, grazing system, pasture management, harvesting methods, and the species of livestock involved, affect soils, soil fertility, and conservation. Uncontrolled burning of pastures could cause erosion and, depending on the time of burning and severity of the burn, soil may become exposed to erosion and the composition of the pasture may be changed. Where burning is delayed, intense heat is generated, and later this causes elimination of grass components of the pasture and dicots become prominent. In the development of sustainable agricultural production systems, it is necessary

TABLE 9 - *Effects of methods of deforestation and tillage techniques on soil erosion* (Lal, 1981).

Method of vegetation removal	Sediment density (g l^{-1})	water runoff (mm y^{-1})	Soil erosion (t ha^{-1} y^{-1})
Traditional farming — incomplete clearing, no-till	0.0	3	0.01
Manual clearing — no-till	3.4	16	0.4
Manual clearing — conventional tillage	8.6	54	4.6
Shear blade — no-till	5.7	86	3.8
Tree pusher root rake — no-till	5.6	153	15.4
Tree pusher root rake — conventional tillage	13.0	250	19.6

to realize that it is not just the production system alone, but also the various component technologies associated with it that by and large determine the extent of environmental breakdown and hazards involved. Similarly, even where a production system is deemed highly sustainable, the use of an unadapted crop variety or breed of animals, outbreak of pests such as the desert locust, may result in at least temporary failure.

Need for an Ecological and Systems Approach in the Development of Sustainable Agricultural Systems

No agricultural production system operates in a vacuum. Each system usually interacts with various factors in the environment. Many activities of man outside the farm may threaten the overall environment quality and the whole ecosystem in which the agricultural system occurs. For example, road construction, urban development, forest logging operations, mining, construction of dams, industrial facilities, etc., may adversely affect agricultural production in adjacent or remote areas. In Nigeria, Grove (1952) noted that in the Anambra state, the erosion hazard is usually high where foot-paths run down the slope.

TABLE 10 - *Different operations performed during different stages of crop production and utilization and extent of likely erosion hazard involved.*

Operations at different stages of crop production and utilization	Extent of possible erosion hazard
Clearing	Very high
Land development	High
Tillage and preplanting cultivations	High
Planting	Low
Subsequent soil management	Low
Water management	Low-high
Fertilization	Low
Weeds, pests and disease management	Negligible to high
Harvesting	Medium to high
Primary processing (e.g., shelling, winnowing)	Negligible
Drying	None
Storage	None
Processing	None
Packaging	None
Preparation	None
Consumption	None
Waste disposal	Low-medium

Note: Extent of erosion hazard depends on interaction of operations with environment and other factors.

EMERGING SUSTAINABLE AGRICULTURAL PRODUCTION SYSTEMS IN TROPICAL AFRICA

As a result of recent developments in farming systems research, concerns about soil erosion and the degradation and need for development of more sustainable agriculture production systems that address the needs and problems of low resource farmers at the International Agriculture Research Centers (IARCS) and elsewhere, the following emergency systems of production are relevant:

— *Zero or Reduced Tillage*: A system of reduced tillage involving good residue management that effectively reduces soil erosion and gives better or as good a yield as conventional tillage;

— *Life Mulching*: A system of growing field crops through hiring mulch of preferably leguminous cover crops such as *Psophocarpus palustris* and *Centrosema*, promises to be good for maintaining soil fertility, conserving the soil, and gives good yields on steep slopes. Good for humid areas with sufficient rainfall, but potentials are not fully explored. This promises to make large-scale plantation production possible;
— *Alley Cropping & Agroforestry*: Systems developed from traditional practices that combine the growing of ligneous species with field crops. Alley cropping, in which rotation of food or arable crops are grown in between hedge rows of preferably leguminous trees or shrubs that are periodically pruned to supply mulch and fuelwood, has many advantages (Figure 1).
— Supplying of mulch for conservation and organic soil maintenance;
— Maintenance of soil fertility through nitrogen fixation and nutrient cycling;

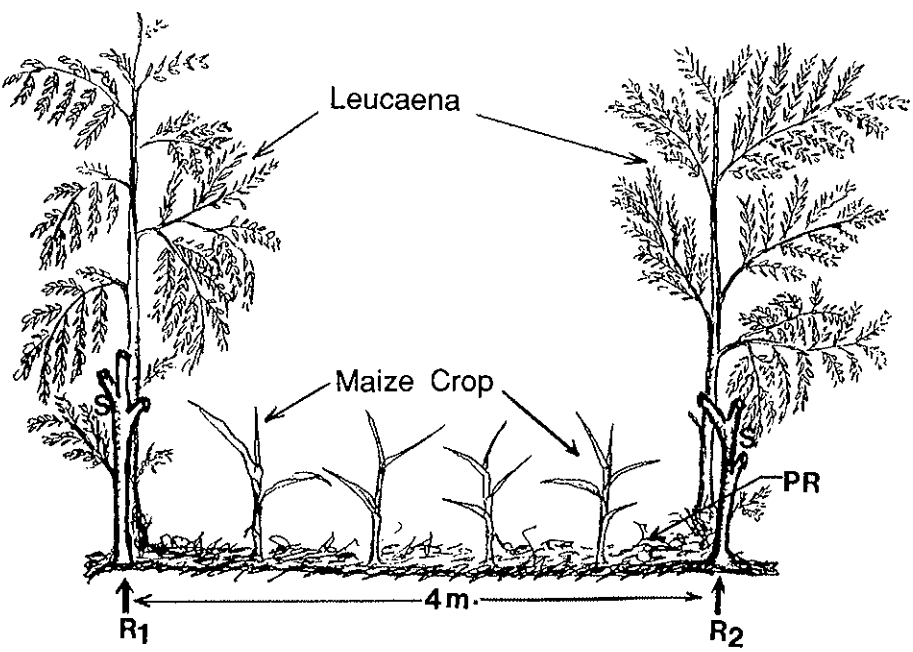

FIG. 1. Alley cropping with the maize crop grown between two rows (R_1 and R_2) of Leucaena planted 4m apart. The Leucaena is pruned down periodically to mere stumps (s) and the prunings (PR) are applied as mulch to the maize crop (Okigbo, 1988).

— Supply of fuelwood and staking material for viney crops;
— Supply of raw materials for crafts and industries, such as paper manufacturing;
— Promises to eliminate or minimize fallowing, thereby increasing area under cultivation without change in land tenure;
— Very likely basis for emerging biomass technology (Figures 2 and 3);
— Other aspects of agroforestry will take it possible for integration of food crops, trees, and pastures/livestock;
— Game Ranching. A method of rearing livestock and game animals in their natural environment by selecting species which compatibly feeds on different strata and species of pasture plants, and judiciously harvesting the animals. Benifits of these exceed many other pasture management systems (Table 11).

Recommendations for Measures to be Taken to Develop Sustainable Agriculture in Africa

1. The current African food crisis and the need for increased agricultural productivity on a sustained basis exist side by side with problems of environmental and soil degradation, deforestation, and desertification, loss of biological diversity and the increasing fuelwood crisis. This calls for priority to be given to policies, strategies, and measures aimed at integrated natural resources, conservation, and management, of which sustainable agricultural production is but an integral component. All efforts to achieve this objective should be based on policies, plans, and programs on multiple land-use so that the following needs are provided for:

— Special Reserves for
  — Hunting and Tourism,
  — Germplasm Conservation,
  — Tree Crop Plantations,
  — Agricultural land, including fallow land,
  — Special Agroforestry systems,
  — Grazing land,
  — Urban Centers, airports, roads, and railways,
  — Landscape uses, including parks in urban areas,
  — Industrial uses,
  — Mining.

2. All agricultural development projects should, in planning and execution, be based on sound ecological principles so as to ensure that each

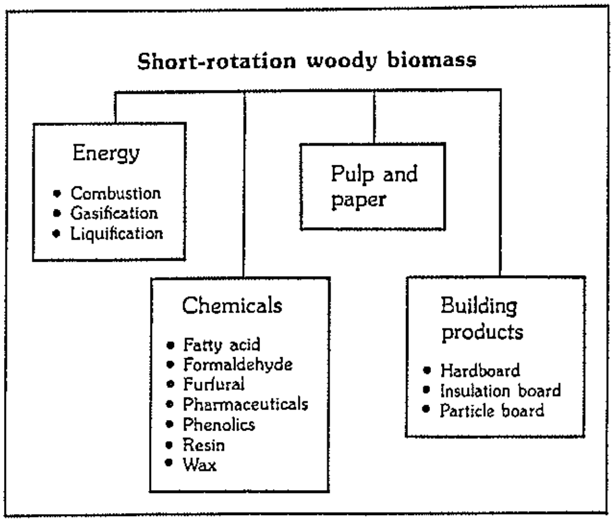

FIG. 2. Biomass from trees grown in short rotations is a source of many products, including chemical feedstocks. Phenolics are used in the manufacture of adhesives, fungicides, and plastics. Furfural is used in making industrial solvents. (*Source*: Chow P., Rolfe G.L. & Arnold, 1983; Okigbo, 1988).

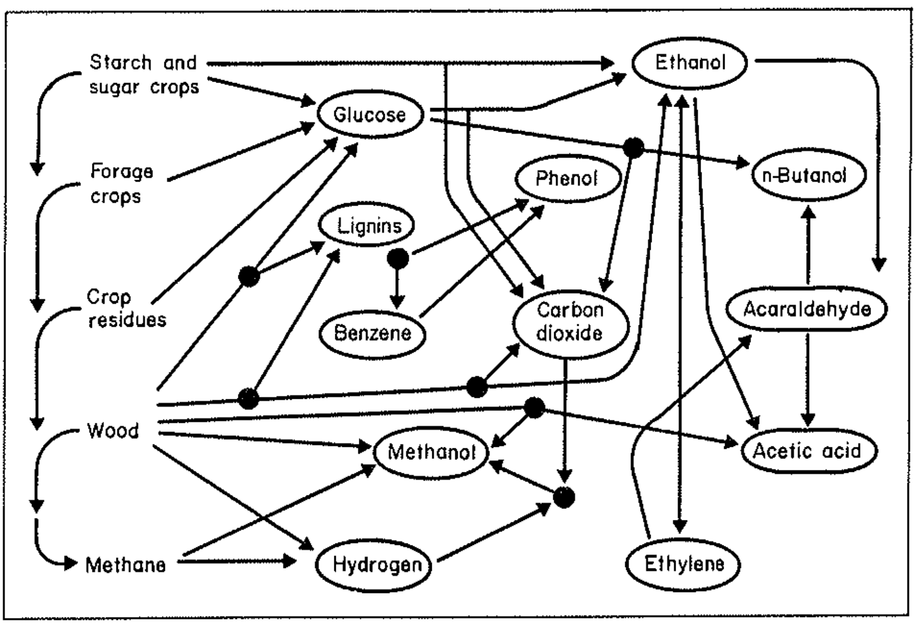

FIG. 3. Some of the many compounds and chemicals, most of them intermediates, produced from field crops and trees. ● = By-product. (*Source*: Rolfe G.L. & Moore K.J., 1984; Okigbo, 1988).

TABLE 11 - *Benefits of Alternative Strategies of Grassland Management.*

Management Strategies	Potential Benefits **									
	Meat Supply	Damage Control	Animal Export.	Trophies & Skins	Tourism	Econ. Dev.	Conservation Research	Research	Disease Control	Employ- ment
NONE *	(C)	C	(C)	(C)	I	I	I	I	C	I
LIVESTOCK RANCHING	N	C	I	I	I	N	N	I	C	N
GAME PRESERVES	N	C	C	N	C	C	C	C	I	C
NATIONAL PARKS	N	C	C	N	C	C	N	C	I	C
GAME RANCHING	C	C	C	C	N	N	N	C	C	N

* Allow traditional hunting, agriculture, and pastoralism to continue development in grassland areas.

** C = Compatible (C) = Compatible but for limited duration in grassland areas
N = Natural I = Incompatible

project is executed on the environment that is most favorable for the production of the commodities to be produced (Figure 4). Large-scale development projects for arable crops, such as maize, are sometimes sited in the humid tropics, where these crops have the least potential. Similarly, maize has sometimes replaced sorghum in areas subject to drought.

Related to this is the development of land use capability classification and surveys that provide information for use by foresters, agriculturalists, engineers, and so on. In agricultural development projects, sustainability can be attained in the most costeffective manner where soils of the highest potential are developed first (Figure 4). This minimizes the cost of imports needed to create a favorable environment for the crop or animal.

3. In order to minimize soil degradation and damage to the landscape in agricultural production projects with minimum adverse effects to the environment, integrated watershed development principles should be used so that each toposequence is used for production of the commodities and activities most adapted to conditions in each toposequence (Figure 5). With this approach, it is possible to use the flooded valleys for agriculture and rice production, followed, as one ascends the slope, by cocoyams, yams, cassava, and other upland crops, with the highest part of the slope used for pasture or tree crops (Figure 5). Integrated farming systems that must be given due consideration for suitable parts of the landscape include:

— agroforestry systems, such as valley cropping, that combine food crops with the crops on sloped land,
— integrated crops and animal production systems,
— integrated crops, livestock, and agricultural systems in which animal waste and crop residue are used to feed fish.

4. The potentials of highly productive valley bottoms of hydromorphic soils, about 20 million of which are under-utilized in tropical Africa, especially in the production of rice and off-season vegetables, have to be tapped with measures taken to combat river blindness and schistomiasis where they exist. One of the most sustainable production systems for the humid tropics is lowland rice. Its potential in Africa has not been tapped and needs to be given the priority it deserves so as to reduce reliance on rice imports to satisfy demand.

5. Tropical Africa currently relies on expansion of area to attain about 80% of annual increases in food production. In order to mini-

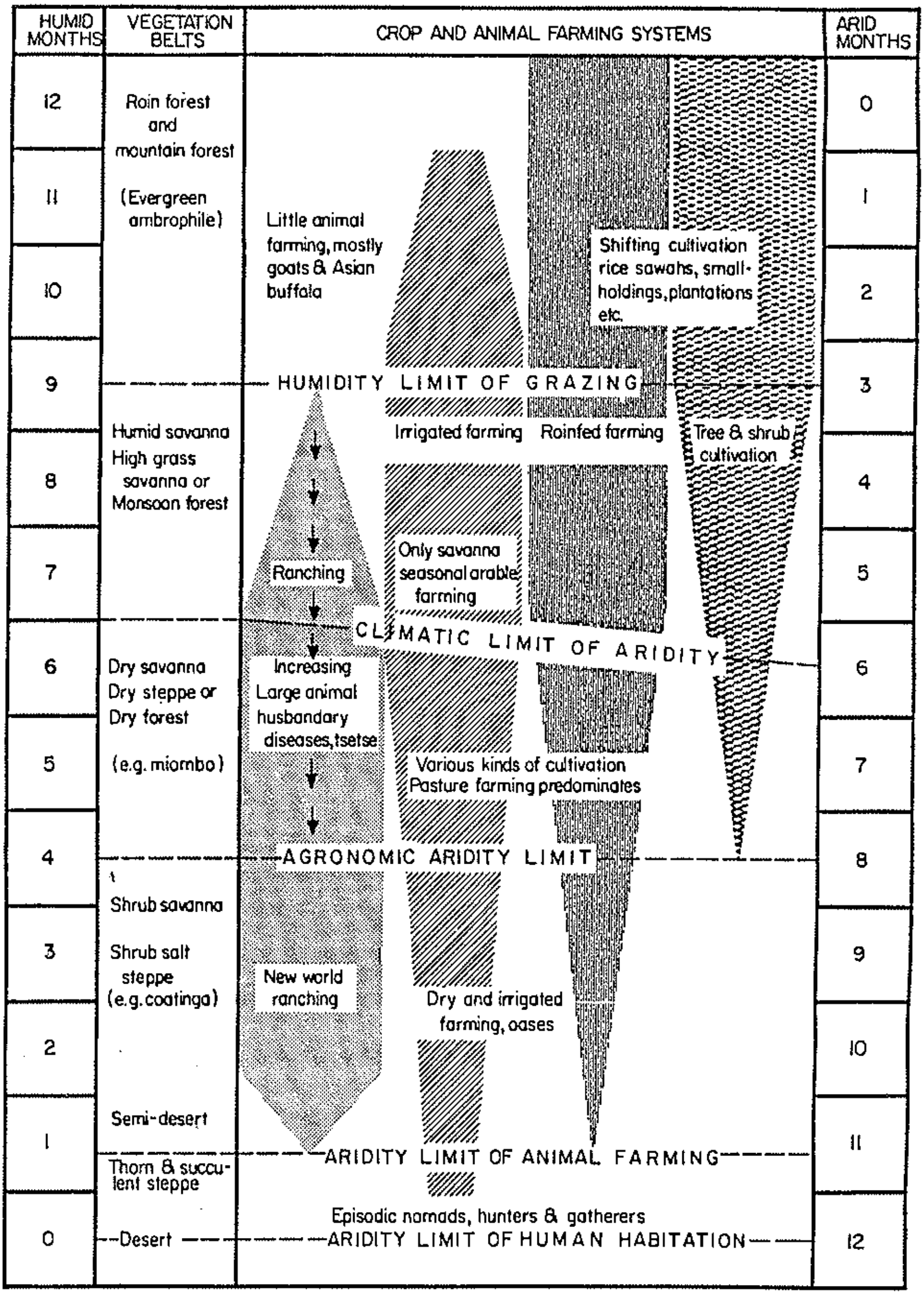

FIG. 4. Humid and arid months, vegetation belts and farming systems in the tropics. (Adapted from Uhlig, 1965 and Andreae, 1980); Okigbo, 1981 and 1984.

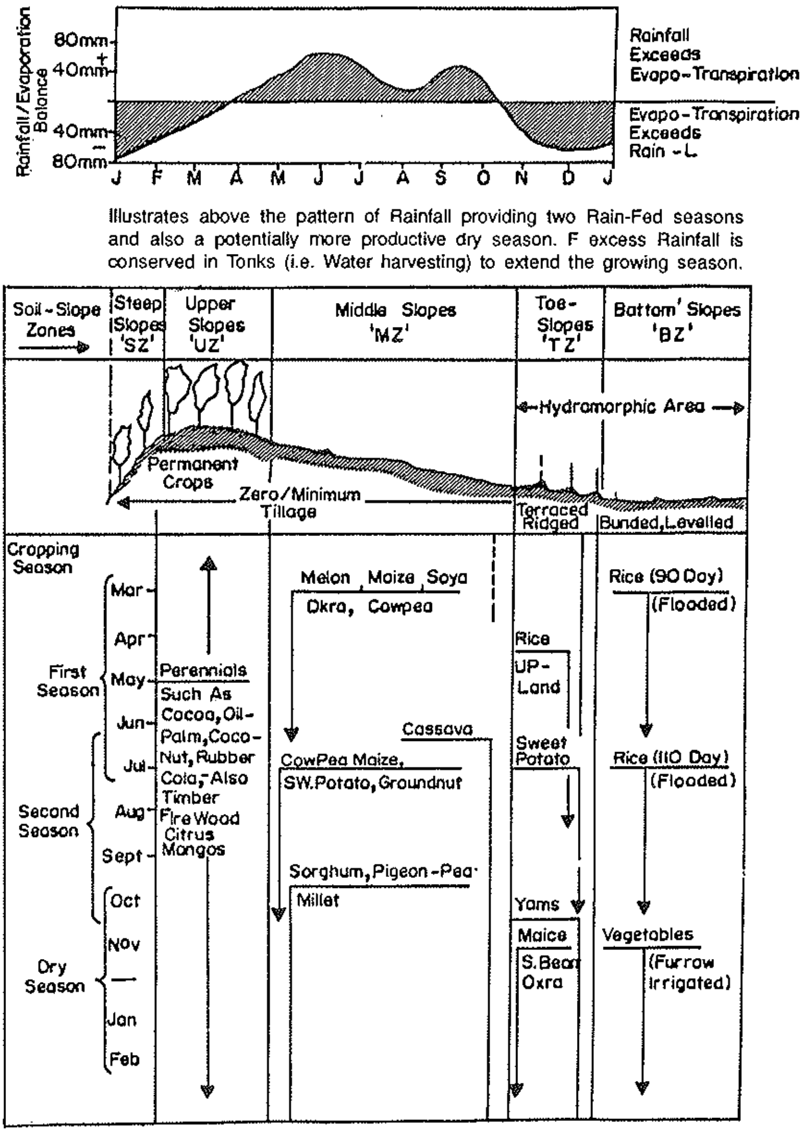

FIG. 5. Integrated watershed management (Okigbo, 1984).

mize deforestation and expansion into marginal land, FAO (1981) expects Africa to adopt a land-saving strategy aimed at increasing production 27% by expansion of area, 22% by cropping intensity and 51% by increased yield by the year 2000. Maintenance of soil fertility will be a major constraint to achieving this objective unless cost of fertilizers is reduced. There is no doubt that fertilizer use is imperative, but what is required is attainment of sustainability by maintaining soil fertility at reduced cost through the use of biological nitrogen fixation, mycorrhizal phosphate nutrition and other biological processes of reducing, the amount of fertilizer used. Associated with this should be research aimed at attaining increased efficiency of fertilizer use and reduction of amount of fertilizers lost through leaching, volatilization, etc.

6. As a result of high input costs and adverse effects of pesticides on living things and the pollution they cause, emphasis should be given to the development of integrated weed, pest, and disease management systems that compatibly combine physical, chemical, biological, and cultural methods, thereby minimizing the cost and amount of pesticides used and their adverse effects on the ecosystem.

7. Soil erosion and degradation is emerging and is probably one of the past most serious constraints to development of sustainable agriculture production systems on fragile soils of tropical Africa. Increasing emphasis should be given to research and measures aimed at improved soil management through such practices as reduced zero tillage, maintenance of as much cover of the soil as possible with adequate plant or crop residue management, various kinds of mulching, careful mechanization of clearing and other operations that damage soil structures and minimization of extent of or reliance on physical and engineering methods of soil conservation. Special attention should be given to the development of soil conservation systems in savanna and semi-arid areas where large animal populations make it difficult to maintain good crop cover of soil surface in the dry season.

8. Stability in production and sustainability is often associated with diversity of species as is encountered in the wild in the humid tropics. More efforts and resources should be allocated to research for improving cropping patterns and maintenance of diversity through different planting patterns in time and space. For this reason, more use should be made of knowledge of various aspects of plant competition, especially below the ground, such as allelopathy, by better understanding and manipulation of the rhizosphere of crops and weeds.

9. A special plant breeding agenda is needed for developing sustainable agricultural production systems for tropical Africa, that combine the advantages of photoperiod insensitive cultivars and the flexibility of traditional poly culture systems that is achieved with photoperiod sensitive cultivars.

10. Many indigenous African crops of high potential as sources of food, drugs, new materials for industry, timber, etc., have remained underexploited and are increasingly in danger of extinction. There is need for a special effort aimed at conserving, improving and utilizing them in different production systems. Emerging technologies, such as tissue culture and the manipulations it enhances in biotechnological research, should be exploited for the propagation, breeding and conservation of these indigenous plants. About 200 indigenous species are neglected in the humid and sub-humid tropical areas of Africa.

11. Agricultural productivity and sustainability cannot be readily achieved in Africa as long as there is labor shortage due to rural urban migration because of the drudgery and low incomes in agriculture. There is need for appropriate technologies for several operations ranging from land clearing to post-harvest technologies. Of major concern is the need to develop technologies that address the needs and problems of women, who in certain operations are more involved in farming than men.

12. In the development of sustainable agriculture in tropical Africa, more use should be made of irrigation since although about 56% of tbe area of Africa needs water for irrigation only 5% of irrigable land is irrigated.

13. The development of sustainable agricultural production systems in tropical Africa as a component of improved natural resources conservation, management, and utilization is a complex problem, requiring multidiscipline research and development, institutional and manpower capabilities and more political commitment on a long-term basis than many African countries can muster. There is a need for institutional linkage and collaboration of sufficient scope among developing countries and with developed countries, so as to take advantage of advances in such emerging technologies as biotechnology, and to develop local capabilities and exchange information and materials.

14. There is a need for periodic conferences to facilitate updating of information arising from research and development. In this regard, it

would be necessary for a special project to be launched on the collation and assessment of indigenous knowledge systems and technologies in sustainable agriculture.

15. With the rapid depletion in nonrenewable resources and the emerging of biomass technologies as a means of obtaining chemicals from plants, priority should be given to research in this aspect of agroforestry since the tropical environment, with its high primary productivity, has the potential for high yields of biomass and development of new industrial raw materials and sources of foreign exchange. Of course, more priority should be given to the attainment of food self-sufficiency and security, but research to satisfy both objectives can be carried out simultaneously.

Conclusion

In this review of the African dilemma in food and agricultural production, and of strategies for finding options for lasting solutions, it is necessary to emphasize that the problem will continue to be more or less intractable under prevailing high rates of population growth. As long as Africa adopts technologies to reduce death rates and child mortality, it must develop capabilities that can give higher returns from agricultural research and development than has been the case in Europe since the year 1900. During 1900 to 1980 mean annual growth rates in developed countries averaged 1.23%, while that of Africa was 2.4%. Unless Africa can marshal resources and wage a campaign against hunger through integrated development strategies, including curbing population growth, the crisis will always overtake all efforts aimed at finding effective solutions.

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II

SCIENCE AND THE FUTURE OF AGRICULTURE

AGRICULTURE IN A DESERT SALINE ENVIRONMENT — A CASE STUDY

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INTRODUCTION

Until the beginning of this century, it had been the general opinion in Israel that efforts to turn the Jewish people into farmers and the land into an agriculturally self-sufficient area depended on the redemption of the desert, and that desert agriculture, when possible, would be considered the best success. Making the desert bloom is a popular slogan in our country.

Nonetheless, until 1943 agricultural efforts were directed to the temperate northern part of the country, mostly arid, but also swampy in some places; the success in northern Israel is well known and documented [56, 54].

Desert agriculture presents a more difficult challenge to scientists and farmers. Only in 1943 were the first approaches made to the real desert when three Mizpim (observation points) were established in the Negev. This was mainly a result of the holocaust, followed by the hope that more space would be needed for those surviving after the war.

The triangle of the Negev occupies the southern part of Israel (60% of the total area) and should be considered a fringe of the Sahara desert. The climate varies from dry to very dry. Rain is scanty: 200 mm./year in the northern part near Beer Sheva, diminishing abruptly towards the south, where at the site of our Experimental Station, only 25 km south of that city there is an average of only 80 mm. rainfall. Near the Dead Sea and the Red Sea the precipitation is even lower (25 and 50 mm./year respectively). The total annual evaporation is 2300 mm./year.

The agricultural history of the Negev may be divided into three main periods: 1943-48, 1949-1970, and 1971 until today.

In the *first period* research began as a first approach to a *terra incognita*, in which only nomadic shepherds lived and where even the most rudimentary data were unavailable. The farmers were young and inexperienced, and extension services and professional advice were also inadequate. Efforts were directed to various systems of water harvesting, from very small ones, such as micro-catchments [58] to relatively large dams [57]. The results were poor and could not meet the needs of a population having even a modest standard of life. The main difficulty consisted in the sporadic nature of the rainfall regime: droughts were too frequent, and some years had practically no rain.

The conclusion was that even with modern agriculture for sedentary populations, only areas having at least 250-300 mm. rain per year, regularly distributed, would be capable of economic yields of cereals. Regions having between 150 and 250 mm./year can be used for pasturage of sheep and goats, while below the 150 mm./year isohyet in most conditions even water harvesting will not give encouraging results.

I know that these statements are to be taken "grano salis" and must be considered only as a general rule, with many exceptions in other areas due to the season of precipitation, the intensity and distribution of rain, the temperature, evaporation, local standard of living, social conditions and other factors. I only want to emphasize the actual practical conclusions in our country.

During our first period, making acquaintance with desert agriculture, during the forties, we tried also efforts to use some brackish water (EC = 3.8 dS/m) from small local wells from the Eocene horizon, which is present in many parts of the Negev. This also was a failure: the metal pipes rusted, leaf scalds almost killed many crops, and the yields were very poor. When furrow irrigation was used instead of sprinkler irrigation, the salts that rose between the furrows by capillarity action and subsequent evaporation were not easily leached, and soil salinity levels became very high.

Today we have returned to confronting the problem of salinity with relative success. The next part of this lecture will deal mostly with salinity problems and ways to overcome them. With the passage of time, we have had to change almost everything: crops, irrigation methods and equipment and agrotechniques, as I shall explain.

Due to the shortage of time and space, I will be brief on the *second period*: after many bitter disputes about the economic feasibility of the project, Israel's main National Water Carrier, which originates from the sources of the Jordan, was extended as far as the Central Negev desert, opening a new era of agriculture and settlement.

Efforts were then directed to the choice of the crops and trees with the best economic returns, and which were capable of taking full advantage of the local ecological conditions. Drought has a certain advantage for irrigated crops: it prevents diseases and ensures the possibility of harvesting independent of the weather. During the fifties, the cultivation of cotton, a very salt-resistant plant [3], was introduced into Israel and became one of our most important crops. Late autumn was found to be the most important season for fruit and vegetable cultivation.

During this period the agricultural plan achieved a permanent structure: extension of agriculture was seriously hampered by the limited quantity of water allotted by the government to the cooperative farms of the region in competition with industrial and urban consumers; the green area was still rather restricted.

The third period. At the beginning of the seventies the scene changed again: on the one hand, Israel was already utilizing all its known fresb water supplies. Out of about 1.8 billion m^3 of fresh water available, 1.2 were used for irrigation and the amount of fresh water still available for agriculture diminished each year due to competition with urban and industrial customers. On the other hand, drilling techniques had greatly improved and to depths of thousands of meters water could be attained. Almost everywhere one drills in the Negev saline water can be found. The water is contained in three main aquifers: tbe Nubian sandstone of the late Jurassic and early Cretaceous, in the Cenomanian and, in smaller quantities, in the more recent Plio-Pleistocene aquifer [1]. In the Negev today fresh water is scarce, but saline water is not. Energy costs today do not allow water desalination for commercial irrigation purposes, so we had to look after the best agricultural use of this water without any treatment.

The Ramath Negev Experimental Station

In 1971 we started to explore the possibilities of utilizing the saline water of the Cenomanian aquifer for irrigation in the Negev Highlands (Ramath Negev). The salt concentration in tbis water varies from place to place, the EC increasing from 3.2 dS/m. near Beer Sheva to 7.0 dS/m. at Nitzana, near the Egyptian border. A small experimental site (4 ha.) was first established and fresh and saline water lines were installed. In 1981 we moved to a new, larger (50 ha.) and well equipped saline water experimental station near Ashalim: the RNAES (Ramat Negev Agricultural Experimental Station).

The Negev desert is ideal for the practice of saline water irrigation, for the following reasons:

a) most of the soils are deep and leaching to below root level is relatively easy;

b) there are no significant fresh water aquifers that can be contaminated by saline drainage water;

c) the desert has a very good natural system of wadis that drain into the Mediterranean;

d) the soil is rich in calcium, which neutralizes to a great extent the damaging effects of excess sodium (a major cation in most saline waters) on soil structure;

e) and finally, the bulk of the saline water of the Negev has a relatively low sodium/calcium ratio (SAR less than 9) and therefore does not impose a potential sodium hazard on the soils.

Very soon after commencing the trials, we realized that available information on the practical use of saline water irrigation [2, 43, 37] was very limited and unsuitable for large scale commercial application, at least under our conditions. Therefore, over the past 17 years we have developed a comprehensive approach to saline water irrigation based on relatively large field experiments, scientific study of process in plants and soil, collecting also many empirical observations.

In the following I will try to summarize our experience, discuss the merits and the limitations of various aspects of the art of saline water irrigation and present new avenues for further development.

The soils at the RNAES are of two different types:

a) torrifluvent sandy loam to loam containing 60-70% sand, 15-20% loam and 10-15% silt. This soil is rich in calcium and generally also in phosphorus and potassium. It constitutes a redisposition of Eolian material from the adjacent hills and from the Northern Sinai mountains.

b) sandy soils containing 90-95% sand, 8-10% silt and only a few % clay, if any. This soil is the continuation of the seashore sandy belt and originates from the material brought up through the Nile to the Delta.

The water is also of two different sources: a) water of the Israel National Carrier, which is relatively fresh (1.2 dS/m.) and b) water from local wells. Its salinity at the experimental site is approximately 6 dS/m. and it is also rich in potassium and magnesium. This water gushes up at a temperature of 38-40 C° [7].

In the first years, experiments were conducted to compare only these two qualities of water. Later/we realized that different crops should be evaluated under different salinity levels according to their sensitivity, and now at our station we have equipment capable of producing mixtures of water of any possible salinity and even of shifting at will from one level of salinity to another [34].

Methods of Salinity Research

The methods of research and development on salinity at our station are as follows:

1) *Demonstration farm.*

A small demonstration farm was established to show farmers that this kind of water has at least some agricultural value. For this purpose, small plots were sown with the most tolerant crops.

This step was important for creating a favorable atmosphere among farmers, planners and extension officers and to encourage a re-evaluation of the potential of brackish water for irrigation.

2) *Crop selection.*

Based on a literature survey and previous experience, an initial screening of salt-tolerant crops was carried out. A preliminary trial usually with two different water salinities (fresh and brackish) was conducted to identify problems specific to each of the selected crops. This trial also served to confirm whether the results obtained in laboratories or under a range of different environmental conditions and agrotechniques will occur under real field conditions in the region to be developed.

3) *Field studies of salt resistance mechanisms.*

Salinity can affect plant growth and yield in a variety of ways [36]. It can reduce turgor pressure, which is associated with stomatal closure and associated lower rates of photosynthesis. It can have a toxic effect due to accumulation of excess ions or disturbance of plant nutrition. Additionally, salinity stress can change the partitioning of carbohydrates, resulting in an improved or reduced harvest index [ratio between the harvested and the total weight of vegetal matter in terms of dry weight].

Studying the parameters affected by salinity stress serves as a basis for devising specific management practices and/or yields criteria for varietal selection for salt resistance [14]. In practice, the main efforts for a better understanding of field salinity problems are directed as follows:

a. *Detection of salt sensitive stages* [Fig. 1]. The time course of dry matter production differs in the different plant species [25, 32]. Knowledge of growth rhythm of crops stressed by salinity is very important for detecting the physiological factors of salt resistance but has also important practical management implications, as will be discussed later.

b. *Osmotic adjustment to salinity.* Some crops increase their osmotic pressure in response to salinity, thus preventing tissue water loss. With modern techniques [25, 39] it is possible to distinguish between

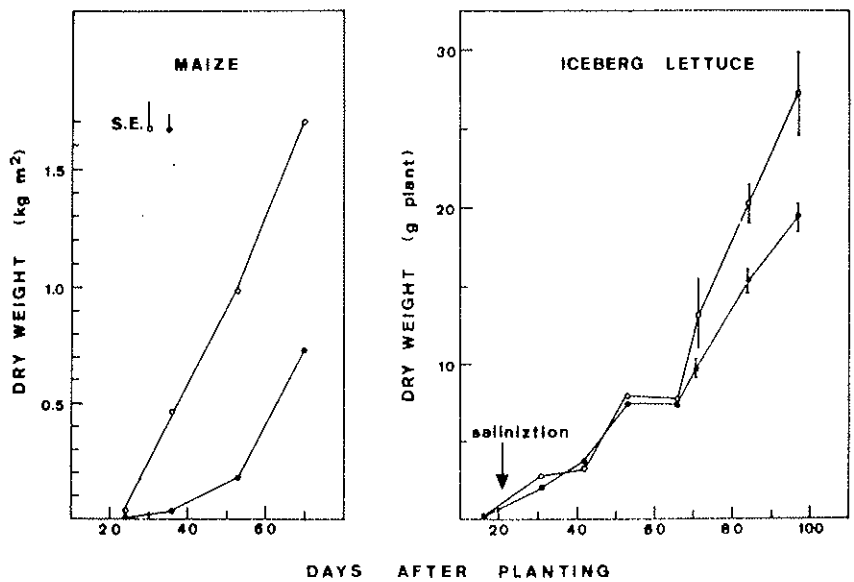

FIG. 1. *Dry matter production of maize and iceberg lettuce irrigated with fresh (open symbols, EC_i = 1.2 dS/m) and saline (closed symbols, EC_i = 10.5 dS/m) water.* Salinity affected maize growth at the young stage, while lettuce was affected only at a later growth stage. Data for maize from ref. 25 and for lettuce from ref. 32.

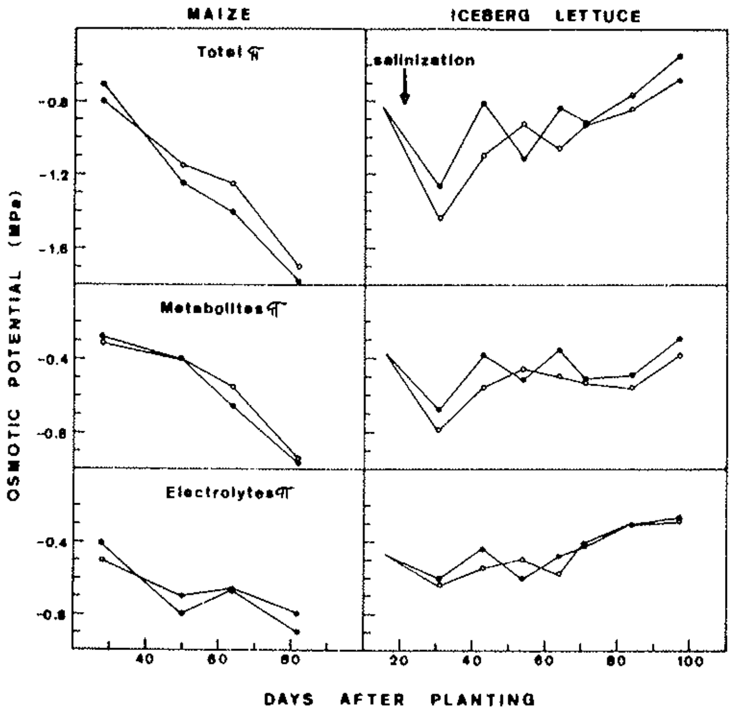

FIG. 2. *Change with time of osmotic potential in leaves of maize and iceberg lettuce irrigated with fresh (open symbols, EC_i = 1.2 dS/m) and saline (closed symbols, maize EC_i = 4.4 dS/m, lettuce EC_i = 10.5 dS/m) water.* Total osmotic potential (π) is separated into osmotic potential due to metabolites and that due to electrolytes (see text). Salinity did not affect π of the two crops. However, for maize the π declined with development, whereas in lettuce the π increased. Data for maize from ref. 19 and for lettuce from 32.

metabolic and electrolytic effects on osmotic potential. In fig. 2, the importance of this distinction is explained. Plants that cannot adjust osmotically to salinity are likely to suffer from water stress, especially under conditions of high summer radiation [Fig. 3].

c. *Salt toxicity.* Plants differ also with respect to their regulation of salt intake, and different crops accumulate various amounts of salts, especially chlorides, in their tissues [Fig. 4]. Large amounts of chlorides are associated often with severe leaf burn.

d. *Carbohydrate storage and photosynthate partitioning.* Analysis of yield components (fruit number and size) and partitioning of photosynthates between organs can often explain phenomena associated with salt stress, such as why cotton yields are higher under irrigation with 4.4

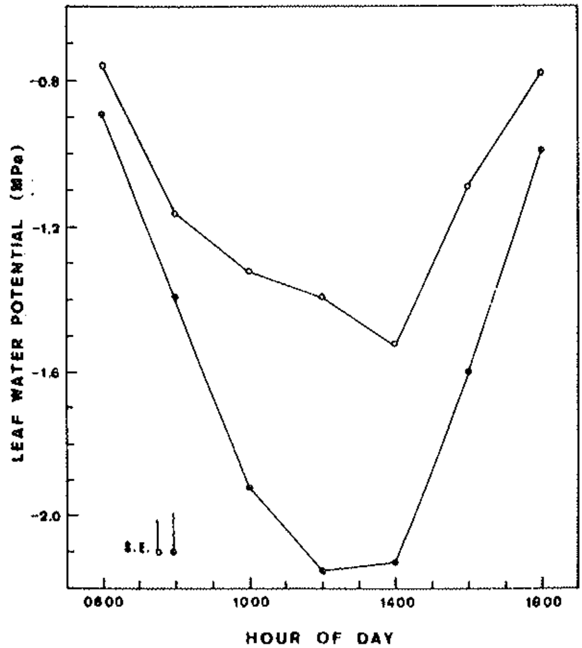

FIG. 3. *Daylight variation in leaf blade water potential of maize irrigated with 1.2 (open circles) and 10.5 dS/m (closed circles) water.* The differences in water potential reflected differences in leaf water status induced by salinity. From ref. 25.

dS/m. than with less saline water [14]. In most cases photosynthesis is limited by the diurnal rhythm of stomatal closure. The infrared thermometer is a quick and reliable method for estimating stomatal resistance.

e. *Morphological traits.* Sensitivity to salinity is not necessarily a physiological trait. It can often result from such morphological features as root depth [Fig. 8], stomata structure, etc. Thus, the structure of plant organs and their interactions must be understood in depth to ensure proper management in the field.

Integrating all these and other kinds of information leads to the development of management practices, some of them general, some of them appropriate for each crop, as seen in the following section.

4) *Management.*

The greatest advances that have been made in the use of saline

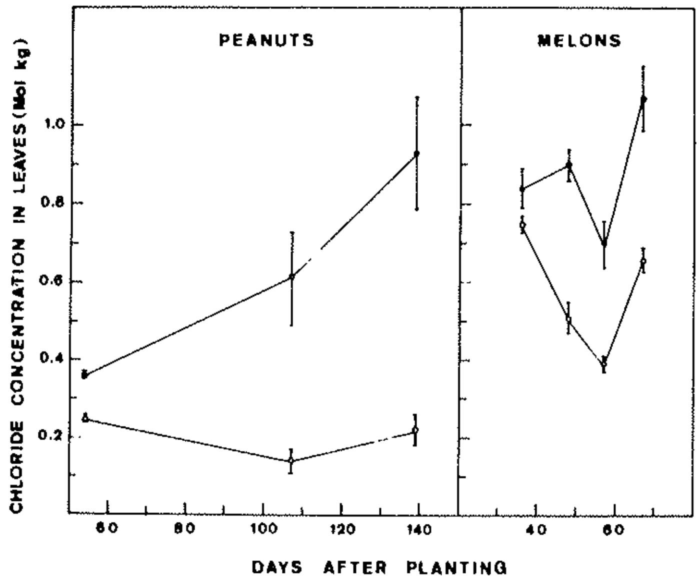

FIG. 4. *Changes with time in chloride concentration in leaves of peanuts and melons irrigated with fresh (open circles) and saline (closed circles) water.* Fresh water EC was 1.2 dS/m for both crops. Saline water EC for peanuts was 8.0 dS/m and for melons 12 dS/m. In melons the differences in chloride content between treatments remained relatively constant during the season, while in peanuts at the end of the season, leaf chloride concentration in saline water plants was five times that in fresh water plants. Unpublished data of D. Pasternak, Y. De Malach and S. Mendlinger.

water have been due to the development of specific agromanagement practices, especially drip irrigation.

a. *Irrigation systems.* Three irrigation systems are used in Israel: sprinkler, moving lines, and drip. A comparison between drip and sprinkler irrigation, with special emphasis on salinity problems, is presented in Fig. 5. The advantages of drip irrigation [9, 38] can be summarized as follows: i) maintaining the leaves dry; ii) avoiding wind drift; iii) increased frequency of irrigation; iv) better leaching; v) allowing start of irrigation at any time of day; vi) increased soil aeration; vii) improved uniformity of water distribution.

Leaching is facilitated under drip irrigation because only a limited volume of soil is wet and the quantity of water needed is thus reduced. Plant roots respond mainly to the lowest salt concentration to which they are exposed [Fig. 6]: thus, having a portion of the soil totally free from salts is of immediate relief and benefit to the plants. Fig. 7 shows typical salt profiles in soil under sprinkler and drip systems.

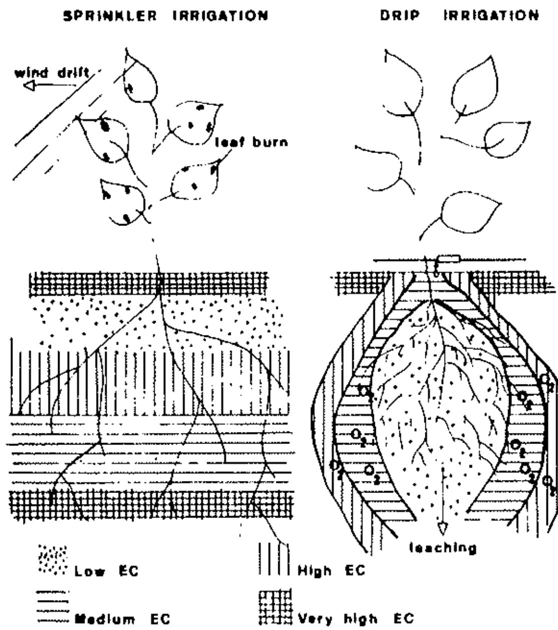

FIG. 5. *Schematic presentation of some advantages and disadvantages of drip and sprinkle irrigation with saline water.* a) Sprinkler-irrigated plants have leaf burns due to salt spray on leaves; b) wind may carry salt spray to adjacent salt spray-sensitive crops; c) roots are spread over the whole soil profile; d) position of salt profiles in the soil may change from time to time, depending on irrigation management; e) the whole soil volume is water-saturated after irrigation and therefore lacks oxygen. In contrast, a) drip-irrigated plants have no leaf burns induced by salt spray; b) the soil volume immediately under the emitter is always the place with the lowest salinity and roots concentrate there; c) irrigation water does not wet the whole soil volume allowing for 1) better salt leaching under the drippers and 2) better aeration of the root system; d) light rains can leach the salt at the upper layer into the leached zone, resulting in significant salt damage particulary to perennial plants. This can be prevented by irrigating during and after every rainfall.

b. *By-passing salt sensitive growth stages.* Shifting from saline to fresh water during the sensitive growth stages of each particular crop enables the use of water of a quality that, under normal circumstances, would be very harmful to yield. As an example, replacing saline by fresh water during only the first 21 days after germination of corn [Zea mays L.] eliminated the dry yield reduction due to irrigation with 7.0 dS/m. water. Continuous irrigations with saline water resulted in a yield decrease of 60%.

c. *Irrigation quantity.* Salinity reduces consumptive use of water [60]. This finding means that the term "leaching fraction" [42], which

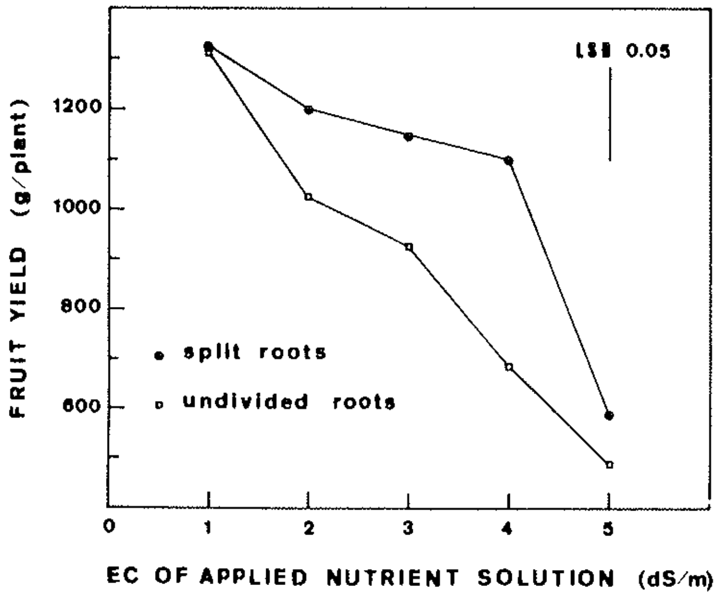

FIG. 6. *Fruit yield of tomato plants with split roots and with undivided roots. Five groups of plants had split root systems and five groups had "undivided" roots.* In each group of split root plants, the roots of individual plants were divided into four, each quarter immersed in a solution of different EC. The *mean* EC values of the four solutions were 1, 2, 3, 4 and 5 dS/m for the five corresponding plant groups. These five groups were compared with 5 groups of "undivided roots" plants in which all roots were immersed in solutions of 1, 2, 3, 4 and 5 dS/m, correspondingly (ref. 41).

refers to the amount of water in excess of consumptive use, needed for salt leaching from the root zone, must be related to the water consumptive requirement of each crop at a given salinity level. Since we do not yet have enough information on consumptive use by various crops at different levels of salinity, we currently recommend giving crops irrigated with saline water the same amount of water as they are given under fresh water irrigation. The extra water thus serves to leach excess salts to below root zone.

d. *Irrigation frequency.* Theoretically, very frequent irrigation should reduce "total soil moisture stress" [matric + osmotic potential] by keeping soil solution constantly diluted, but so far in our experiments, very frequent irrigations did not increase yields. This may have been due to interaction with the consequent decrease in rhyzospheric oxygen [35].

e. *Fertilization.* So far, most authors [43, 44] claim that since the

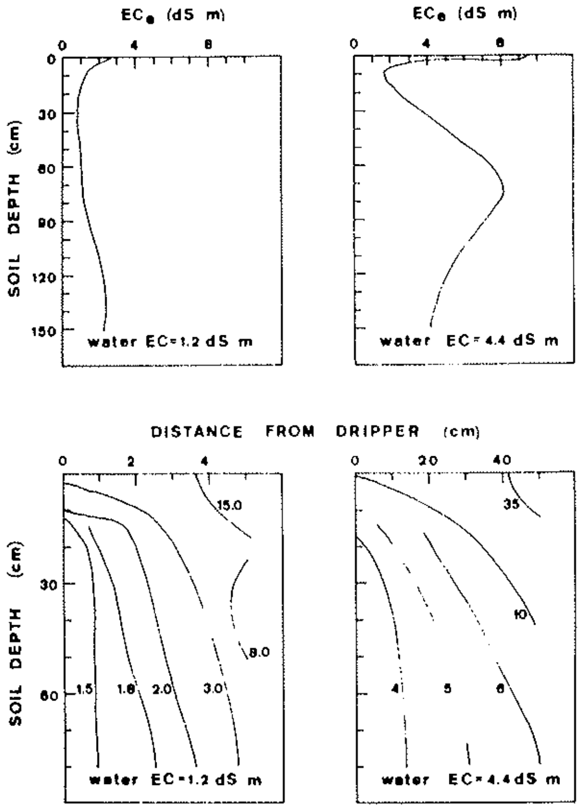

FIG. 7. *Typical end-of-season salinity profiles in the soil under irrigation with a sprinkler system (upper part) and a drip system (lower part).* Data for sprinkler from cotton trials (ref. 6) and for drip from maize trial (ref. 19).

osmotic potential is the predominant factor that affects plant growth under saline conditions, no beneficial effect can be achieved by changing the quality or increasing the quantity of fertilizers which are all electrolytes. Nevertheless, a group of scientists at our station is involved in experiments aimed at alleviating the damage to the plant by generous fertilization with potassium and nitrate to limit sodium and chlorine intake respectively.

We should emphasize that drip irrigation leaches both salts and nutrient ions from the soil very effectively. For this reason it is very important to apply fertilizers with every irrigation and to start fertilizing from the first day after sowing [33].

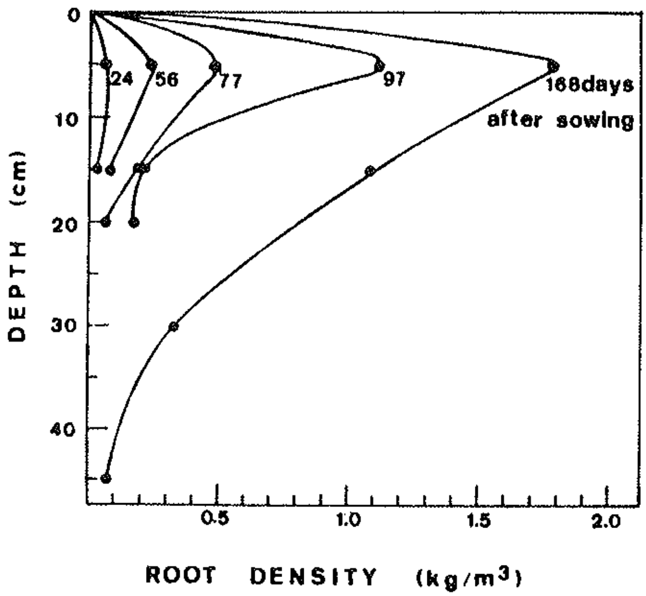

FIG. 8. *Onion root distribution in soil under sprinkler irrigation with 4.4 dS/m saline water* (from ref. 24).

f. *Germination.* The germination stage is the most critical for most crops. It appears that for many species, young seedlings are more sensitive to salinity than older plants [35, 45]; in addition, the germinating seeds are located in the upper 5 cm of soil, where the salt concentration is the highest, due to the continuous irrigation needed to ensure good emergence and to the associated evaporation. We recommend heavy application of water during the germination period and sowing within shallow furrows [30] to let maximum water concentrate near the seeds.

5. *Selection and breeding for salt resistance.*

The genetics of salinity is a relatively new science. There are two major approaches to selecting for salt tolerance: selecting to the cell or tissue level and selection at the plant level, which is the interesting one for us, as a field research station.

Selection and breeding at the plant level has recently been discussed by many authors [36] and various methods have been used: a) selecting and breeding for ion exclusion or harmless inclusion; b) selecting and breeding for high concentrations of organic solutes; c) introduction of polyploidy. At our place methods that are more suitable for the nature of a field station are used; d) selection of salt tolerant cvrs., and e) crosses with salt-tolerant cvrs. or related species.

d. *Selection of salt-tolerant varieties.* As an example are presented the yields obtained with seven tomato cvrs. irrigated with fresh and brackish water. The American cvr. Napoli was considerably more resistant to salinity than the others. Similar effects were obtained with some cvrs. of melons and lettuce. These cultivars may be used directly or, if they are not suitable for local demand, they may represent an important gene source for future crossing or breeding.

e. *Crosses with tolerant cvrs. and species.* The original parent lines for crossing and breeding are chosen from selected cultivars, or, what is even better in many cases from tolerant wild relatives. As an example, we may quote the genetic work done by our collaborator, Dr. Mendlinger, who started his breeding program with a wild Iranian melon, or the work by the late Prof. Rudich and Dr. Saranga at our station, which started from the wild, salinity-resistant, tomato relative from South America: *Lycopersicum pinellii.*

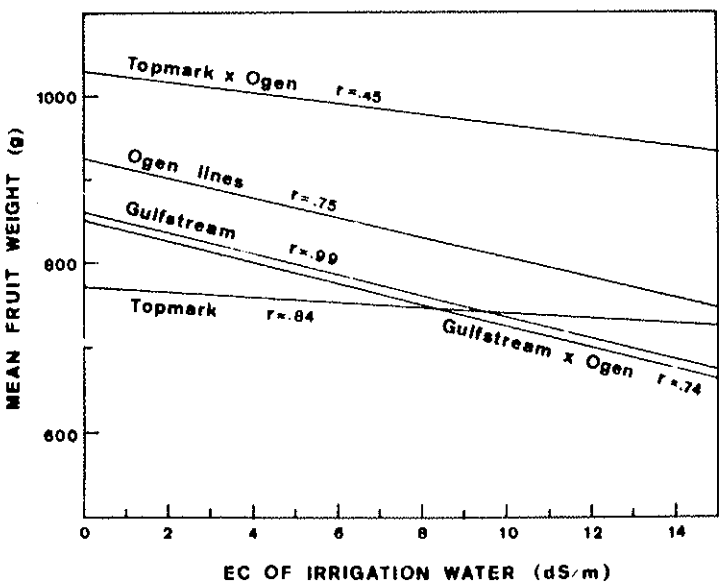

FIG. 9. *Relationship between irrigation water EC and fruit weight for Ogen, Gulfstream and Topmark melon cultivars and for hybrids of Ogen and the latter two cultivars.* Topmark was the most salt-tolerant of the three cultivars and transmitted salt tolerance to its hybrid with Ogen. In addition, the Ogen x Topmark hybrid displayed significant hybrid vigor. On the other hand, Gulfstream x Ogen was identical in weight and in salt tolerance to the salt-sensitive Gulfstream parent (S. Mendlinger, unpublished results).

6. *Salinity and hormonal balance.*

The problems related to the hormonal balance of crops under saline conditions have been until now almost completely relagated to laboratories and to glass house research. We plan to be joined soon by a plant hormone expert and to begin research in the open field.

SALINITY AND SAND DUNES

Sandy soils prevail in many Middle Eastern countries and deserts where saline water abounds. Although irrigation of sand dunes with saline water has been practiced in some places (for example in the Buseily area of Egypt) [29], not much has been written in the professional literature on this aspect. Our experiments are just beginning and, except for cotton and asparagus, they have not yet been successful. Surprisingly enough, saline water (6.2 dS/m.) reduced yields in the sand much more than in the heavier loess soils for most crops: tomatoes, corn, peanuts and others. We do not yet have any explanation for this effect.

SALINITY AS AN ADVANTAGE

Our work has shown that saline water irrigation can actually give significant economic advantages over fresh water and in some cases increas marketable yields by improving the harvest index. We have shown this for cotton [3, 6, 14], but we found that saline water can also improve the quality of certain fruits. Israel farmers are starting to exploit the economic advantages of saline water commercially for tomatoes and melons. Our collaborators [26] have shown that salinity in processing tomatoes improves color, reduces the occurrence of green shoulders and improves firmness, thereby doubling the yield suitable for peeling. The marked increase in Total Soluble Solids at the fruit compensates, and sometimes more than compensates, for the reduction in fresh yield (Table). Israeli canning factories have started to pay a bonus for high TSS. Similar effects have been found for other crops: sugar beets, melons, grapes and pomegranates. More vegetables and fruits are now under study.

RESULTS

A table presenting the yields of about 27 different crops tested over the years at the RNAES is included in the Appendix to this paper. Most of these results have been reported in detail in previous papers [3-6, 8, 10-12, 14-17, 19-26, 31]. In most cases, we found that both absolute and relative yields (i.e., considering fresh water yields as 100%) were higher than expected from the literature. In many cases, the encouraging results were obtained substituting saline by fresh water during the sensitive stages of growth. In almost 20 crops the yields were not significantly decreased under irrigation when adequate management procedures of were employed. Cotton, sugar beets, wheat and barley were the most important crops of this group. Asparagus was found to be the most resistant crop. Tomatoes, rye grass, brassicas, celery and onions fallow. More species are under study and the list of plants fit for salinity agriculture is increasing. Among orchard species, we succeeded in growing olives, pomegranates, grapes, and, surprisingly, enough, pears; but a final answer will be obtained only after the trees are maintained under saline conditions for a longer period.

Conclusions

This lecture has described the evolution of a complex R&D program aimed at the utilization of saline water to irrigate new desert areas. To succeed, we have considered not only the basic scientific aspects of applied salinity research, but also other complex aspects of agricultural production and regional development, such as state of technology, cost of water, type of existing cooperative settlements, and current economic trends. As our work progressed, we began to realize that to succeed in the development of saline water agriculture, one must take a very broad experimental approach, addressing and solving very many factors involved in plant production (such as water requirement, nutrition, genetics, post-harvest changes) [18, 28]. It is necessary to utilize all available technological knowledge (irrigation systems and automatization, computers, fertigation) and all scientific tools (plant physiology, plant nutrition, soil physics, genetics) to provide answers to an ever — increasing number of problems.

Today we can recommend crops and technologies that will allow agricultural production with water of up to 7 dS/m. (4000 p.p.m. TDS or 10% sea water). We are convinced that in the future, water of even higher salinity [13, 27] will be put in use, opening new horizons for salinity-based agriculture in deserts of the Middle East and throughout the world.

APPENDIX - Tables 1.-16.

TABLE 1 - *Chemical composition of Mashabei Sade well water and National Carrier water* (from ref. 24).

Water quality	Ion concentration (mol/cu. m)							EC (dS/m)	SAR
	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}		
National Carrier	4.7	0.15	3.6	4.0	6.1	2.6	2.2	1.2	3.4
Local well	20.7	0.40	12.0	12.0	28.4	4.7	12.8	4.4	8.5

TABLE 2 - *Mean monthly maximum and minimum temperatures, evaporation from screened USWB class A pan, and rainfall at the experimental site** (from ref. 24).

Paramater		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Temp. (°C):	max.	17.2	18.3	22.9	26.8	31.9	33.4	34.9	34.1	32.8	29.8	24.4	18.5
	min.	5.4	5.6	7.6	10.3	12.1	14.5	16.9	17.5	16.2	13.9	9.8	6.4
Evaporation (mm/day)		2.9	3.9	5.2	7.3	8.5	9.2	10.0	8.7	7.3	5.7	3.8	2.7
Rainfall (mm)		24.0	19.6	18.0	5.9	1.4	—	—	—	0.1	2.3	10.8	21.0

* Values are averages of 17 years.

TABLE 3 - *Crop yields in tons per hectare.*

Crop	Irrigation system	Ref. no.	Yield (ton/ha) at Electrical conductivity of irrigation water (dS/m)					Remarks
			1.2	4.5-5.5	6-8	8-10	10-15	
Forage crops (dry weight/year)								
Bermuda grass (Cynodon dactylon)	sprinkler	U.R.*	—	33.0	—	—	—	cv Suwannee, mean of two years
Rhodes grass (Chloris gayana)	sprinkler	U.R.	—	33.0	—	—	—	cv Katanbura, mean of two years
Grains (Yield of grain at 12% moisture)								
Wheat (Triticum vulgare)	sprinkler	4	6.77	6.68	—	—	—	cv Mivhor 1177
Sorghum (Sorghum vulgare)	sprinkler	5	10.0	8.4	—	—	—	cv RS 610
Maize (Zea mays)	drip	25	7.09	4.56	3.07	1.31	—	cv KWS 752, saline irrigation throughout season
Maize (Zea mays)	drip	25	6.98	6.73	6.98	5.17	—	cv KWS 752, saline irrigation from day 21 after germination
Field crops								
Sugarbeet (Beta vulgaris)	sprinkler	12	18.9	17.4	—	—	—	cv Depre, sucrose yield
Cotton (Gossypium hirsutum)	sprinkler	6	4.25	5.40	—	—	—	cv Acala SJ-1, lint yield mean of two years
Processing tomatoes (Lycopersicon esculentum)	drip	34	136	123	55	—	—	cv VFM 82-1-8, saline irrigation throughout
Processing tomatoes (Lycopersicon esculentum)	drip	35	136	120	127	—	—	cv VFM 82-1-8, saline irrigation from 4-leaf stage
Processing tomatoes (Lycopersicon esculentum)	sprinkler	10	107.7	73.5	—	—	—	cv Napoli, saline irrigation throughout
Sweet corn (Zea mays)	drip	25	19.5	12.6	11.7	1.0	—	cv Jubilee, ear yield, saline irrigation throughout
Sweet corn (Zea mays)	drip	25	18.1	18.2	15.7	15.0	—	cv Jubilee, ear yield, saline irrigation from day 21 after germination
Canning peas (Pisum sativum)	sprinkler	U.R.	19.0	17.0	—	—	—	
Peanuts (Arachis hypogaea)	drip	U.R.	9.01	4.83	1.72	0.68	—	cv Shulamit, EC values were 1, 4, 6 and 8 dS/m

(continued)

(Tab. 3 - *continued*)

Vegetables								
Asparagus (Asparagus officinalis)	drip	22	6.65	6.62	—	—	—	cv UC 711, four-year-old plot
Broccoli (Brassica oleracea)	drip	U.R. *	23.4	21.8	—	19.0	14.3	cv Green Duke, fresh weight
Beetroot (Beta vulgaris)	sprinkler	U.R.	55.5	52.7	—	—	—	cv Cylindra
Celery (Apium graveolens)	sprinkler	16	155.0	171.0	—	—	—	cv Early bell, fresh weight
Chinese cabbage (Brassica pekinensis)	drip	U.R.	135.0	118.0	108.0	109.0	—	cv Michili, fresh weight
Chinese cabbage (Brassica pekinensis)	sprinkler	16	135.0	109.0	—	—	—	cv Michili, fresh weight
Chinese cabbage (Brassica chinensis)	drip	U.R.	58.0	58.0	55.0	65.0	—	cv Spring A, fresh weight
Chinese cabbage (Brassica chinensis)	sprinkler	16	120.0	88.0	—	—	—	cv Spring A, fresh weight
Melons (Cucumis melo)	drip	U.R.	27.0	24.0	24.0	22.0	—	cv BG-83, a salt tolerant cultivar, autumn-grown
Lettuce (Lactuca sativa)	drip	32	67.7	65.5 a	52.8	58.3	—	Romaine lettuce, cv Roman-9, fresh weight heads, a: water EC = 3.5 dS/m
Tomatoes (Lycopersicon esculentum)	drip	U.R.	86.5	72.9	—	62.7	53.0	cv Faculty 19, summer-grown
Lettuce (Lactuca sativa)	drip	32	41.0	40.3 a	30.5	27.5	—	Iceberg lettuce, cv Vanmax, fresh weight heads, a: water EC = 3.5 dS/m
Lettuce (Lactuca sativa)	sprinkler	16	54.0	48.0	—	—	—	Iceberg lettuce, cv Vangard, fresh weight heads
Kohlrabi (Brassica caulorapa)	drip	U.R.	30.0	20.3 a	17.4	11.7	—	cv White Prague, a: water EC = 3.5 dS/m
Onion (Allium cepa)	drip	U.R.	50.1	28.4 a	4.12 b	0.44 c	—	cv Grano, a, b, c: water EC = 4.0, 6.0 and 8.0 dS/m, respectively, saline irrigation throughout
Onion (Allium cepa)	drip	U.R.	50.1	34.0 a	27.9 b	22.4 c	—	cv Grano, saline irrigation from day 64 after planting, a, b, c: water EC = 4.0, 6.0 and 8.0 dS/m, respectively
Onion (Allium cepa)	sprinkler	24	50.9	20.1	—	—	—	cv Riverside
Carrot (Daucus carota)	drip	U.R.	45.8	41.2 a	33.8 b	0 c	—	cv Denver, a, b, b: water EC = 2, 4, 6 dS/m respectively
French beans (Phaseolus vulgaris)	drip	U.R.	8.1	6.4 a	0 b	0 c	—	cv Arey, a, b, c: water EC = 2, 4, 6 dS/m, respectively

* Values are average of 17 years.
a, b, c, d - Values in rows with same letter do not differ at P = 5%.

TABLE 4 - *Effect of day of salinization on number of onion plants/10 sq. m at harvest* (Y. De Malach and D. Pasternak, unpublished results).

Time of salinization (days after sowing)	Irrigation water EC (dS/m)				
	1.2	4.0	6.0	8.0	mean
27	1135 a	767 b	180 c	29 d	527
64	1135 a	1092 a	1061 a	940 a	1057
104	1135 a	1156 a	1211 a	1173 a	1168
mean	1135	1005	817	714	

a, b, c, d - Values in rows with same letter do not differ at P = 5%

TABLE 5 - *Effect of day of salinization on yields (kg/10 sq. m) of onions irrigated with water of four salinity levels (days after sowing)* (De Malach and D. Pasternak, unpublished results).

Time of salinization (days after sowing)	Irrigation water EC (dS/m)			
	1.2	4.0	6.0	8.0
27	50.08 a	28.35 b	4.12 c	0.44 d
64	50.08 a	28.35 b	27.89 c	22.40 b
104	50.08 a	41.52 a	42.87 a	37.23 a
mean	50.08	34.61	24.96	20.02

a, b, c, d - Values in rows with same letters do not differ at P = 5%

TABLE 6 - *Interaction between irrigation water salinity and irrigation frequency on processing tomato yield** (D. Pasternak and Y. De Malach, unpublished results).

Irrigation frequency	Yield (ton/ha) at EC_i (dS/m)			
	1.2	5.5	10.0	mean
Every day	126.5 a	108.3 a	75.2 b	103.3
Every 2 days	118.6 a	100.8 a	89.4 a	102.9
Every 3 days	123.8 a	99.2 a	51.4 c	91.5
mean	123.0	102.7	72.0	

* All treatments received the same amount of water.
a, b, c - Values in columns with same letter do not differ at P = 5%.

TABLE 7 - *Effect of application of N fertilizer from Day 1 and from Day 14 of irrigation with fresh (1.2 dS/m) and brackish (4.4 dS/m) water on mean dry weight of tomato seedlings on three sampling occasions after sowing* (from ref. 33).

Fertilization	Type of water	Mean dry weight (mg)		
		Day 17	Day 26	Day 35
N from Day 1	Fresh	56.6 a	307.2 a	1515 a
	Brackish	33.5 b	207.0 a	952 a
N from Day 14	Fresh	11.4 c	78.0 b	462 b
	Brackish	9.0 c	47.8 b	250 b

a, b, c - Values in each column denoted by the same letters do not differ at P = 5%.

TABLE 8 - *Irrigation regime and quantities of water applied with sprinklers during germination in three primary treatments* (from ref. 30).

Days after sowing	Daily irrigation amount (mm) in each treatment		
	Fresh conventional	Brackish conventional	Brackish special
40 days before (pre-irrigation)	100	100	—
0	35	35	25
1, 3, 5, 7	5	5	30
2, 4, 6, 8	5	5	5
9	5	5	—
10	5	5	50
Total amount	185	185	215

TABLE 9 - *Electrical conductivity of saturated soil extract (EC_e in dS/m) over five soil depths, before and after the germination period in the three primary irrigation treatments* * (from ref. 30).

Treatment **	Soil depth									
	0-2 cm		2-5 cm		5-10 cm		10-60 cm		60-90 cm	
	Before	After	Before	After	Before	After	Before	After	Before	After
Fresh conventional	2.8	7.2	3.2	2.6	3.2	2.7	2.5	2.3	2.6	2.0
Brackish conventional	4.9	18.5	5.9	4.6	5.9	4.2	3.9	3.2	2.5	2.7
Brackish special	7.7	8.5	9.6	2.6	8.9	3.2	6.0	3.4	2.4	3.8

* Each Value is an average of twelve determinations. The standard errors were all 5-10% of the means.

** Defined in Table 8.

TABLE 10 - *Effect of irrigation regime and cultural practice on the number of tomato seedlings per meter row at the end of the germination period** (from ref. 30).

Primary treatment **	Secondary treatment			
	Flat sowing	Shallow furrow	Wood-chip mulch	Plastic mulch
Fresh conventional	13.3	13.6	20.0	10.8
Brackish conventional	2.0	7.1	9.1	12.2
Brackish special	11.0	17.0	12.8	7.8
Mean	8.8 B	12.6 AB	14.0 A	10.3 B

* Values of means with same letters do not differ at P = 5%.
** Defined in Table 8.

TABLE 11 - *Yields of seven tomato cultivars sprinkler irrigated with saline (4.4 dS/m) and fresh (1.2 dS/m) water* (from ref. 14). Values are means of 5 replications.

Cultivar	Yield (kg/10 sq. m)		
	Saline		Fresh
Napoli	73.5 a		107.7 a
VF 198[1]	59.1 b		86.5 b
Macheast-22	57.1 b		78.5 b
VF B17	49.6 bc		87.4 b
VF 145, B7879	43.6 c		75.6 bc
VF 145 FS	38.8 c		72.0 c
VF 134-1	37.6 c		65.9 c
Treatment mean	51.3		82.0
Treatment difference		30.7	
SE of difference		± 2.4	
% reduction		37.4	

* Parameters in colomns with same letters do not differ at P = 5%.
** Standard errors of difference are calculated from the residual variance after removing main irrigation and variety effects.

TABLE 12 - *Means of yields of seven iceberg lettuce cultivars and of three Romaine cultivars (in kg/10 sq. m) as affected by irrigation water salinity* (from ref. 32).

Cultivar group *	EC of water (dS/m)			
	1.2	3.5	8.2	10.5
Iceberg cultivars	38.8 a	38 a	28.3 b	23.7 b
Romaine cultivars	58.6 a	61.5 a	57.1 a	50.5 b

* The seven iceberg cultivars were Cal K-60 Vanmax, Morangold, Climax, Salinas, King Gordon and Great Lakes Mesa. The three Romaine cultivars were Roman-9, Cos and Roman yellow.

a, b - Values in rows with same letters do not differ at $P = 5\%$. Within each group of cultivars there were no interactions between water salinity and cultivar.

TABLE 13 - *Effect of water quality and irrigation interval on yield of tomatoes grown on sand dunes* (D. Pasternak, Y. De Malach and I. Borovic, unpublished results).

Irrigation interval	Yield (kg/10 sq. m) at	
	1.2 dS/m	6.2 dS/m
Twice a day	128.1	55.5
Every day	123.1	57.3
Every two days	92.4	37.4
Every three days	80.3	24.9

TABLE 14 - *Effect of water salinity on quality parameters (± standard error) of juice of processing tomatoes (cv M82-1-8)* (from ref. 26).

Electrical conductivity of irrigation water	Quality parameters			
	TSS (%)	pH	Acidity (% citric acid)	EC (dS/m)
1.2	4.76 ± 0.15	4.26 ± 0.02	0.36 ± 0.01	6.3 ± 0.2
4.5	5.11 ± 0.12	4.31 ± 0.03	0.37 ± 0.01	7.4 ± 0.3
7.5	5.76 ± 0.19	4.30 ± 0.02	0.40 ± 0.02	7.6 ± 0.3
10.0	6.10 ± 0.14	4.16 ± 0.03	0.53 ± 0.02	8.9 ± 0.6

TABLE 15 - *Effect of irrigation water salinity on dry matter yield (% total soluble solid x fresh yield) of tomatoes irrigated every two days* (D. Pasternak, Y. De Malach and I. Borovic, unpublished results).

Water salinity (EC dS/m)	Dry weight of fruit (kg/sq. m)
1.2	6.13
5.5	5.53
10.0	5.56

Yield values do not differ significantly at P = 5%.

TABLE 16 - *Effect of irrigation water salinity (EC = 1.2 and 4.4 dS/m) on taste of fruit of three melon cultivars* (from ref. 26)*

Cultivar	Irrigation water quality	Storage time, weeks: 0				3				4			
		Average taste score**	Frequency of preference score***			Average taste score	Frequency of preference score			Average taste score	Frequency of preference score		
			+	–	0		+	–	0		+	–	0
Honey dew	Fresh	1.58	17	5	7	1.90	14	11	0	2.06	11	15	0
	Saline	2.20				1.96				2.06			
Makdimon	Fresh	1.79	22	4	3	2.03	18	11	4	already deteri-orated			
	Saline	2.58				2.33							
Ogen	Fresh	1.96	21	4	4	already deteri-orated							
	Saline	2.55											

* For each test (same date, same cultivar), slices taken from at least 8 fruits were combined, in separate plates for each treatment.

** Taste score: best = 3, medium = 2, worst = 1.

*** Preference score: +, testers preferring fruits from the saline water treatment; –, testers preferring the fresh water fruits; 0, no preference.

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SOIL FERTILITY ALTERNATIVES IN TROPICAL AGRICULTURE

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Introduction

Among the various fields of soil fertility, soil biology offers the most alternatives for new technologies in replacement of traditional agricultural systems which are based on the ever-growing use of fertilizers and agrotoxics. Even though there is an unlimited reserve of nitrogen in the atmosphere, this element represents 75% of the fertilizer costs. It is therefore not surprising that biological N_2 fixation is one of the most studied aspects of soil biology and the many new developments in biotechnology have been responsible for the rapid advancements in this field in recent years. Tropical agriculture not only is less suitable for agricultural systems based on heavy fertilizer investments and is much more subject to erosion problems, it also offers almost optimal temperature and humidity conditions for microbial acitivity.

In the present paper we will review the most recent advances in soil biology research in Brazil and discuss their implications for the economy of tropical agriculture.

N_2 fixation in legumes

Legumes process the most sophisticated and efficient symbiotic association with N_2 fixing bacteria, and grain and forage legumes play important roles in tropical agriculture. Soybeans, after coffee, represent the most important export crop of Brazil and are rapidly advancing into the central highland savannas (cerrados). This was only possible due to plant breeding and to the development of new *Rhizobium* inoculants which had to be adapted to the specific microbial disequilibrium prevailing in these soils after they have been taken under culture. These *Rhizobium* strains, however, in generalized use now in the country, even though they produce large nodule masses and fix a lot of N_2, are rather inefficient in terms of transference of the fixed N_2 to the grains. Recently new strains were identified which produce fewer nodules but which fix similar amounts of N_2 which is almost completely incorporated into ureides producing increases in harvest indexes from 60 to 82% (Neves *et al.*, 1985). Grain yield increases in the field with these "super strains" can reach 45% (Table 1), if they can be established. In the cerrado soils however they can so far not be used due to competition problems with the already established less efficient strains. The incorporation of fixed N_2 into ureides first described by Matsumoto *et al.* (1976) has been shown to be related to the activity of an uptake hydrogenase (HUP) in the nodules, which recycles H_2 liberated by the nitrogenase enzyme (Table 2). This HUP activity can now be used for the identification of individual nodules in relation to their relative efficiency (RE) and for adaptation to adverse soil conditions. The interrelationship of the HUP phenotype with ureide N transport has now been confirmed with isogenic HUP mutants (Hungria and Döbereiner, in preparation).

TABLE 1 - Rhizobium *strain effects on nitrogen fixation and yields of field grown soybeans* (Neves *et al.*, 1985).

Strain	N_2 fixed[a] (kg N ha^{-1})	Nodule efficiency (mg N_2 fixed g^{-1} nodule)	Seed yield kg/ha	N harvest index[c]
29 W	343 b[c]	426 b	1863 c	60.1 b
DF 395	214 b	543 b	1768 cd	61.1 b
Sm_1b	204 c	491 b	1398 de	56.0 b
965	278 a	899 a	2898 a	86.5 a
CB 1809	239 b	1005 a	2682 a	82.2 a
DF 383	242 b	851 a	2284 b	82.0 a
Control	0	—	948 f	49.1 bc

[a] At maximum plant nitrogen content (109 d), calculated by the difference in total plant nitrogen between inoculated and control plants.

[b] At maximum nodule weight (74 d).

[c] $(\frac{\text{N seed}}{\text{total N}} \times 100)$.

TABLE 2 - *Effect of* Rhizobium *strain on nodulation, hydrogen evolution, nodule relative efficienty, ureide-N in xylem sap, seed yield and nitrogen harvest index of soybeans grown in pots (outside the glass-house during the day)* (Neves *et al.*, 1985).

Strain	Nodule dry Weight (mg per plant)	Relative efficiency $(1 - \frac{H_2}{C_2H_4})$	Ureide-N (µg N cm^{-3})	N harvest index $(\frac{N\ seed}{total\ N} \times 100)$
29 W	230 a[a]	0.17 b	323.3 b	58.9 b
DF 395	307 a	0.41 c	194.3 c	52.1 b
SM_1b	233 a	0.30 c	209.5 c	55.9 b
965	97 b	0.97 a	580.0 a	68.8 a
CB 1809	83 b	0.98 a	627.1 a	69.0 a
DF 383	92 b	0.94 a	439.5 b	67.7 a

[a] Values followed by the same letter are not different at P = 0.05 level (Duncan's multiple range test).

Similar relationships between nodule efficiency, HUP, ureide synthesis and harvest indexes have been obtained with beans (*Phaseolus vulgaris*) (Hungria and Neves, 1986; Neves and Hungria, 1987), where instead of two distinct groups of strains, more continuous differences were observed, which also were affected by the plant genotype (Fig. 1).

Nitrogen fixation in beans has an additional problem related to the genetic instability of the NOD and FIX genes in the traditional *Rhizobium phaseoli* strains related to the frequent rearrangement in these strains (Martinez *et al.*, 1988). These authors observed two groups (possibly two species) of *Rhizobium* capable of nodulating beans, group I being specific for *Phaseolus vulgaris* and genetically instable in relation to symbiotic performance, and group II which, besides beans, also nodulates *Leucaena leucocaephala* and other legumes. Strains of group II have the NOD and FIX genes localized on two large plasmids, show no or little rearrangement and are therefore much more stable.

In the tropics the instability of *Rhizobium* strains for beans is aggravated by excessive soil temperatures. Even one heat shock of 8h at 38°C turned well nodulated beans completely inefficent during 10 days (Hungria and Franco, 1988). However, nodulation and N_2 fixation of

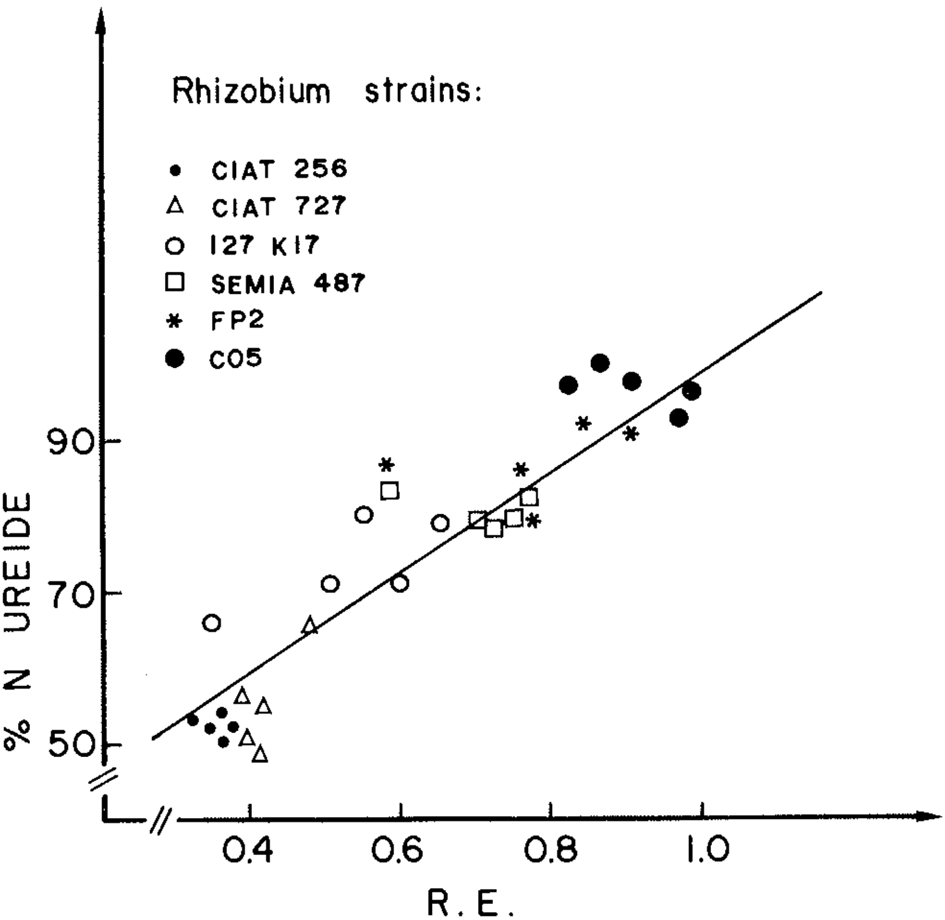

FIG. 1. Correlation of Relative efficiency (RE) of bean nodules with % N transported as ureides (c = 0.903). Points are means of 4 replicate jars and each point is from a different bean cultivar (Hungria and Neves, 1986).

certain legume tree species (e.g., *Leucaena* or *Prosopis*) was unaffected by an 8h/day regime of 38°C during the whole growth cycle (C.O. Cunha and A.A. Franco, personal communication). Selection among more than 100 *Rhizobium* strains isolated from 18 tree legume species yielded 14 strains (isolated from *Leucaena, Gliricidia* or *Lonchocarpus*) which were able to nodulate beans effectively and fix N_2. When these strains were used to inoculate beans grown at an 8h/day 40°C soil temperature regime, some of them were able to nodulate and fix N_2, yielding plants equal or superior to N fertilized ones (Table 3).

TABLE 3 - *Nodulation and N_2 fixation at high soil temperatures of beans inoculated with* Rhizobium *sp. strains isolated from tree legumes (plants were grown in Leonard jars in a water bath with an 8h/day 40°C regime. Values are means of 4 replicate jars)* (Hungria and Franco, 1988).

Origin of strains	Strain N°	Nodule N°/plant	Total N (mg/plant)
Gliricidia sp.	BR 8801	8 c	15 d
	8802	20 cd	22 cd
	8803	12 c	14 d
Leucaena sp.	BR 814	46 b	41 ab
	816	40 bc	41 ab
	817	68 a	52 a
Lonchocarpus sp.	BR 6009	14 de	28 c
	6010	60 ab	48 ab
	6011	20 cde	22 cd
Phaseolus vulgaris	CNPAF 146	2 c	12 d
P. vulgaris + 90 mg N/plant		0	35 bc

N_2 fixation in cereals and sugar cane

Major advances in this field have been achieved mainly through the identification of various new diazotrophs which associate with cereals and sugar cane (Table 4). Strain Sp 7 of *Azospirillum brasilense*, one of the first isolates obtained from soil samples collected under digit grass, does not multiply and establish in the rhizosphere (Albrecht *et al.*, 1983; Baldani *et al.*, 1986) and consistent inoculation effects were only observed in soils where few or no azospirilla occur as in Israel (Y. Okon personal communication). There, production of growth substances by the bacteria rather than N_2 fixation is regarded as responsible for the inoculation effects of this strain (Okon, 1985). Under tropical conditions, however, where high numbers of azospirilla and other diazotrophs occur in most fields, there is selective multiplication of these organisms

TABLE 4 - *Comparison of new N_2 fixing bacteria which occur in association with plant roots* (Baldani *et al.*, 1986b; Cavalcante and Döbereiner, 1988; Reinhold *et al.*, 1988; Seldin *et al.*, 1984; Tarrand *et al.*, 1978).

	Azospirillum brasilense, A. lipoferum	*A. amazonense*	*A. halopraeferans*	*Herbaspirillum seropedicae*	*Acetobacter diazotrophicus*	*Bacillus azotofixans*
Growth under air	+	+	+	+	+	+
Microaerobic N_2-fixation	+	+	+	+	+	−
Growth with N_2 as sole N source	+	+	+	+	+	+
N_2 fixation unaffected by 10 mM NO_3^-	−	−	−	−	+	+
Use of sucrose	−	−	−	−	+	±
Optimum	6,0-7,0	5,8-6,6	6,8-8,0	5,3-8,0	3,8-5,5	6,5-7,5
Optimum temperature (C)	35	35	41	35	30	32
Isolated from surface sterilized roots	+	+	−	+	+	+
Isolated from stems	+	+	−	−	+	−

on and in roots of many Gramineae (Baldani, 1984; Magalhães *et al.*, 1983; Pereira *et al.*, 1988). Selected strains of *Azospirillum* spp, isolated either from washed or surface sterilized roots and marked with antibiotic resistance, can be established on the root surface or within roots in the field and even in stems of the species they had been isolated from.

The most consistent results so far have been obtained with wheat in the southern region of Brazil (Baldani *et al.*, 1987). Table 5 gives an example of an experiment where strain Sp 7 established poorly, and *A. amazonense* YTr isolated from washed roots being intermediate and strain Sp 245 isolated from surface sterilized roots established best and was most effective. The effect of strain Sp 245, however, could not be attributed to N_2 fixation but rather to more efficient assimilation of $^{15}NO_3$ (Boddey *et al.*, 1986). This was confimed in monoxenic wheat cultures with nitrate reductase negative mutants of this strain and where

TABLE 5 - *Effect of inoculation with various strain of* Azospirillum *spp labelled with antibiotics resistance on field grown wheat in Southern Brazil (means of 4 replicate plots)* (Baldani *et al.*, 1986a; Boddey *et al.*, 1986).

Inoculant strain[c]	% inoculated strain[a]		Total N	Grain
	washed	steril.[b]	in tops	yield
			g/plot	
A. brasilense				
Sp 7	50	0	0.87 c	27.0 c
Sp 246	94	27	1.29 b	35.1 b
Sp 245	100	67	1.57 a	41.5 a
A. amazonense				
YTr	56	11	1.26 b	31.9 b
Autoclaved Sp 245	0	0	0.66 c	23.2 c

[a] % of the higest dilution vials in MPN counts containing the inoculated strain. The controls were tested against all antibiotics.
[b] Washed or surface sterilized roots (15 min. in 1% chloramine T).
[c] Strain Sp 7 was isolated from soil, Sp 246 and YTr from washed wheat roots and Sp 245 from surface sterilized wheat roots.

it was suggested that the bacterial nitrate reductase played an important role in NO_3^- assimilation by the plant (Ferreira *et al.*, 1987).

A. halopraeferans is common on the root surface (not root interior) of Kallar grass grown in salt affected soils in Pakistan (Reinhold *et. al.*, 1987). The organism shows a remarkable adaptation to this environment with a temperature optimum for growth and N_2 fixation at 41°C and a salt requirement of 0.25%. The species was not found in salt-affected soils in Rio de Janeiro or in the semiarid region of Northeast Brazil, but *A. brasilense* strains isolated from roots of grasses grown in these soils showed considerable increase in heat and salt tolerance as compared with the type strain Sp 7 (Reinhold *et al.*, 1988).

Bacillus azotofixans (Seldin *et al.*, 1984), a much more efficient N_2 fixing bacterium than other *Bacillus* spp, was isolated from surface sterilized roots of grasses, wheat and sugar cane. In contrast to other *Bacillus* spp, it is capable of N_2 dependent growth and also of N_2 fixation in the presence of NO_3^-. This most important characteristic for root association is shared so far by only two other diazotrophs, *Azotobacter paspali* (Döbereiner, 1966) and the most recently discovered diazotroph, *Acetobacter diazotrophicus*, isolated from sugar cane (Cavalcante and Döbereiner, 1988). This most extraordinary diazotroph was originally isolated from semi-solid sugar cane juice medium inoculated with dilutions of sugar cane roots and stems which showed ARA up do dilutions 10^{-6} or 10^{-7}. Improved counting and isolation procedures were obtained in N-free mineral medium containing 10% cane sugar and 1% cane juice, acidified with acetic acid to pH 4,5. The bacterium is a small Gram-negative aerobic rod showing pellicle formation (microaerobic chemotaxis) and ARA also in N-free semi-solid medium without cane juice, forming a thick surface pellicle after 5 days. Best growth occurs with high sucrose or glucose concentrations (10%), and strong acid production results in a final pH of 3.0 or below. Growth and N_2 fixation (more than 100 nmoles/h.ml) continue at this pH for several days (Teixeira *et al.*, 1987). Ethanol is used for growth and is oxidized to CO_2. Dark brown colonies form on potato agar with 10% sugar and dark orange colonies on N poor (0.005% yeast extract) mineral medium with 10% sugar and bromothymol blue. DNA and rRNA analyses showed that the bacterium belongs to the *Acetobacter* rRNA cystron (M. Gillis personal communication) and there it is most similar to *A. liquefaciens*. This species, however, does not fix N_2, does not form pigmented colonies on the above media and shows several other physiological differences (Stephan *et al.*, 1988). DNA/DNA binding experiments confirm it to be a new species (Gillis *et al.*, 1988). Therefore the name originally proposed as *Saccharobacter nitrocaptans*, (Cavalcante and Döbereiner, 1988) was changed to *Acetobacter diazotrophicus*.

The bacterium has been found in many sugar cane cultivars in several regions of Brazil, and numbers were in the range (all per g wet weight) of 10^3 to 10^5 in rhizosphere soil, 10^3 to 10^7 in washed roots, 10^3 to 10^5 in surface sterilized roots, 10^3 to 10^6 in basal and apical stems and 10^4 to 10^7 in sugar cane trash. It was not found in soil betwenn rows or roots from 12 different weed species growing there. It also was not found in grain or sugar sorghum but was isolated from washed roots and aerial parts of *Pennisetum purpureum* cv. Cameroon. This species as sugar cane is propagated by stem cuttings confirming earlier indications that this organism is propagated within the cuttings.

The potential for N_2 fixation in forage grasses as *Brachiaria* spp (Boddey and Victoria, 1986) and *Panicum* genotypes (Miranda and Boddey, 1987) has now been confirmed with the 15N isotope dilution

TABLE 6 - *Effect of sugar cane genotypes on N_2 fixation as evaluated in an 80 cm deep tank by total N accumulation and ^{15}N dilution in comparison with a non-fixing control* (Brachiaria radicans).

Sugar cane Cultivar	Total N accumulation $kg.ha^{-1}$ Yr^{-1}	^{15}N atom % excess	Contribution of BNF ($kg.ha^{-1}$ Yr^{-1})	
			^{15}N dil.	difference
Saccharum oficinalis				
CB 47-89	209 bc	0.108 bc	41	166
NA 56-79	188 cd	0.126 ab	11	145
Sp 70-1143	216 b	0.109 bc	40	173
Saccharum espontaneum				
Krakatau	452 a	0.097 c	125	409
Saccharum barberi				
Chunee	119 bcd	0.124 ab	9	76
Bracchiaria radicans				
Tanner	43 cd	0.134 a	0	0

method. Depending on the plant genotype, up to 40% of the total N incorporation can come from biological N_2 fixation and plant breeding with the objective of increased BNF has already started. The most impressive data on the scope of plant genotype effects on BNF been found with sugar cane cultivars (Table 6).

The recent advances in N_2 fixation research in the tropics indicate many new possibilities for replacement of nitrogen fertilizers and increasing crop yields. Biotechnology will play a major role in speeding up progress and helping to solve problems which with traditional selection or adaptation methods would take much longer to be solved. The development of HUP^+ competitive soybean rhizobia which transfer the fixed N as ureides directly to the grains, even if they proportion mean grain yield increases of only 10% in Brazil will mean yearly gains of more than one billion US$. Partial or complete replacement of N fertilizers in sugar cane will make the major difference for highly positive energy balances with this crop, which are the basis for any successive biofuel program.

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PEST AND DISEASE CONTROL ALTERNATIVES

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The grain weevil, *Sitophilus granarius* L., and the flour beetle, *Tribolium* sp., both ubiquitous pests of stored grain, have been found in Egyptian tombs dating from about 2300 B.C., and the flour moth was found in such tombs even earlier (about 3000 B.C.). What advances have we actually made in the control of agricultural pests over the last 5000 years since then of man-made agricultural production systems?

We have not in fact gone very far. Trypanosomiasis-carrying tsetse, and malaria-transmitting mosquitoes, and other disease-carrying insects and ticks have remained intractable to human technology to control them on a sustainable basis, and have consequently weighed substantially in circumscribing where tropical man may live. Indeed, a number of age-old insect pest problems, including swarming locusts of biblical proportions, have remained today just as devastating as during the times of the leader and law-giver of Israel, Moses, who in preparation for the Exodus of the Israelites from Egypt pleaded with the ruling Pharaoh in these pregnant words uttered in 1491 B.C.:

> "This is what the Lord, the God of the Hebrews, says: '... Let my people go, so that they may worship me. If you refuse to let them go, I will bring locusts into your country tomorrow. They will cover the face of the ground so that it cannot be seen. They will devour what little you have left after the hail, including every tree that is growing in your fields. They will fill your houses and those of all your officials and all the Egyptians ...' " (Exodus 10:3-6).

Seven hundred years later, at about 800 B.C., the Judaic prophet Joel described vividly what an invasion of locusts was capable of wrecking:

"What the locust swarm has
left
the great locusts have
eaten;
What the great locusts have
left
the young locusts have
eaten;
What the young locusts have
left
other locusts have eaten".
(Joel 1:4)

A new epoch for insect control dawned in 1939 with the discovery by the Swiss chemist, Paul Müller, that dichloro-diphenyl-trichloro-ethane (DDT, in short), which had been first synthesized 65 years previously in Germany, had biocidal properties. It was quickly put to use in delousing thousands of troops, prisoners and refugees during the Second World War; and it was only after the end of these hostilities that it was released for civilian use. The advent of DDT spawned an entirely new industry for the manufacture of whole classes of synthetic insecticides; and it seemed as if we had found the final solution to insect pests of crops and trees, and disease vectors of animal and human diseases.

But it has not been done without enormous cost to man and his environment, wherever these new chemicals have been used indiscriminately, or entirely mechanically on a fixed schedule without regard to the host-pest interrelations, or whenever we have not taken due care of their long-term effect on the health of non-target organisms. It is known that DDT (and analogous chemicals) are weakly carcinogenic to human beings, and its accumulation leads to the thinning of egg-shells of birds; some 10,000 human deaths result annually from poisoning by synthetic organic pesticides and a further 400,000 annually become acutely ill; and a number of pesticides (aldrin, dieldrin, chlordane, heptachlor, and mirex) have been banned from general use in many countries because of their long persistence in the environment and their propensities for causing cancer, tumours, reproductive disorders, birth defects and other long-term illnesses (Dover, 1985). In an impassioned communication to the world a quarter of a century ago, Carson (1962) pithily painted the dilemma of the insect control practitioner:

"The whole process of spraying seems caught up in an endless spiral ... This has happened because insects ... have evolved super races immune to the particular insecticide used, hence a deadlier one has always to be developed — and then a deadlier one than that. It has happened also because ... destructive insects often undergo a 'flareback', or resurgence, after spraying, in numbers greater than before. Thus the chemical war is never won, and all life is caught in its violent crossfire ... All this has been risked for what? Future historians may well be amazed by our distorted sense of proportion. How could intelligent beings seek to control a few unwanted species by a method that contaminated the entire environment and brought the threat of disease and death even to their own kind?"

Two things seemed to have happened with the dawning of the chemical insecticide epoch: first, we tended to ignore the tremendous body of natural history information that we had acquired during the pre-1940 period, and the subsequent ecological awakening of the last 40 years, in which it became clear that insect populations are kept in reasonable population balance by the natural defences that their own hosts have evolved over millenia, and a range of predators and pathogens that in turn prey on these insects. Man can enhance these population regulatory mechanisms by managing or manipulating these biological control components, as he has indeed succeeded in doing with some spectacular results ever since the Russian insect scientist, Metschnikoff, first mass-produced a fungal pathogen (*Metarhizium anisopliae*) for the control of the wheat cockchafer (Zimmermann, 1986).

Second, we have lured ourselves into thinking that we can indeed deal an emphatic final blow on insect pests, which would eradicate them from the face of the earth, by the massive use of chemical insecticides. Consequently, we have come to believe in the single-approach strategy for insect control, relying almost entirely on chemical treatment, as Dover (1985) reminds us:

"Most projections of future use of pest-management technologies are based on the assumption that chemical pesticides will be the principal pest-control method at least until the next century. But the need for chemicals may well be overstated. Do pesticide-use levels reflect the inherent superiority of chemical controls over other methods, or do they indicate the amount of research dedicated to developing chemicals instead of alternative control?"

We have no definitive answer to this last question. But we do know that there are serious concerns about the long-term efficacy of the present conventional pesticide approach to insect control, and its sustainability over time. We do know also that biological control approach to insect pest control is unattractive to the pest control industry because of a number of business disadvantages inherent in the approach (Van Lenteren, 1987):

— It is impossible to patent natural enemies, unless they produce chemical biocides such as *Bacillus thuringiensis* does;

— It subsumes a complicated mass production system;

— Most of the natural enemies have only short shelf-life;

— The approach may require a complex set of guidelines for farmers to implement the biological control approach, where repeated releases are necessary;

— Where a natural enemy is released only once, and mass production is therefore not a continuing necessity, such an approach will hold little industrial interest.

The alternative interest groups will, of necessity, comprise governmental bodies charged with pest control research and extension, farmers' cooperatives, and communal groups. Further, there is no question that the cost-benefit ratio for biological control is large (something in the region of 1:100), and that for pest control through plant-host, resistance is an enormous 1:300, while that for pesticide-control strategies is a mere 1:3 (Dover, 1985). For instance, the introduction of parasitoids to control sugarcane scale in Tanzania in 1974 cost a total of U.S. $11,975, but the benefit that Tanzania has derived ever since through increased sugarcane yields amounts to $67,830 annually. Again, up to 1976, 102 out of a total of 327 introductions of exotic parasitoids and predators to control insect pests have resulted in complete success, which have been sustained (Stehr, 1982).

Pest management through biological control and plant-host resistance is greatly demanding in terms of scientific information. Yet, very little support for research and development (R&D) is being given to this area. For instance, in the Federal Republic of Germany approximately DM200 million annually is devoted to pesticide R&D, while a mere 1% of that figure is devoted to biological control research (Van Lenteren, 1987). We need therefore to adopt a new intellectual environment for providing a larger and more sustained effort in this area.

New Intellectual Environment for Sustainable Pest Management R&D

The demand for food is growing in Africa, because of new requirements (such as easily prepared food requiring little energy for its processing and cooking, such as wheat, rice and maize) and the rapidly increasing population. However, this problem has become acute and almost persistent, because of a number of constraints that have been expressed by the African farmers, particularly the majority that produce African foodstocks, the resource-poor farming households:

— They have to contend with poor soils, with only a thin top-soil being agriculturally productive and which is easily eroded by wind and water;

— A climate which is uncertain and whose rainfall is largely unpredictable, while the cost of installing irrigation is comparatively high, amounting to approximately U.S. $5,000-15,000 per hectare, which is several times higher than the costs pertaining in Asia (Eicher, 1988);

— Much of the unused land in the continent is in the central humid region, which is very sparsely populated, has poor communication and is inaccessible by modern means, and where the incidence of plant and animal diseases is very high;

— Economic factors are unfavourable: domestic terms of trade are poor, marketing and delivery systems are rudimentary, industrial policies in support of agriculture are poorly articulated, and rural institutions for credit, seed multiplication, etc., are rudimentary;

— There are few on-shelf technologies, tested for specific agro-ecological situations, available to the resource-poor farming households.

Thus, given the current technology available to the majority of African farmers, the marginal lands into which food agriculture is now expanding, are unusable in a sustainable manner (FAO, 1986). The present technology for pest management is a case in point.

The central importance of technology is well brought out in the green revolution for rice in Asia, as highlighted so clearly by Schuh and Barghouti (1988):

> "Technological developments such as that experienced by the rice industry in Asia in the last 10 to 15 years are a powerful source of economic growth, in part because their benefits are so widely diffused in the economy and favor the poor ... Sustaining the capacity to develop new technology for rice is important because rice is still a major food staple in the region and thus a powerful source of economic growth. But the capacity for producing new technology needs to be broadened ... Such innovations require research".

Research capacity implies a human resources development of a high order of excellence. Africa is presently experiencing a crisis in its university education and postgraduate training, which is vividly summarized by Moock and Jamison (1988), based on a wide-ranging World Bank policy study on "Education in Sub-Saharan Africa: Policies for Adjustment, Revitalization, and Expansion", which was published in early 1988. First, Africa's higher education is threatened by the deteriorating quality of the graduates in many countries, characterized by over-enrollment in "less rigorous fields of study", the lack of spare-parts for laboratory equipment, and the dwindling stock of new textbooks, research journals and monographs. Second, the cost of higher education per student is exorbitant, at 60 times that of primary education, as compared to the situation in Asia and Latin America, where the unit cost of higher education is only 10 to 15 times that of primary education. Third, higher education, including the living expenses of students, is entirely met by the public budget. These threats to university education and training have made it difficult to create an enabling environment for R&D in African universities, which in fact comprise the largest portion of the African brain bank. The need for Africa to intensify its efforts to develop its own capacity to conduct research, as well as to provide high-quality postgraduate education and research training, is a high priority for technology-oriented development in Africa (Harbison and Habte, 1988).

This priority need could not be greater. It is not sustainable to consider that the necessary R&D for the long-term management of the insect pests for Africa's agriculture and health can be done elsewhere and then the results in the form of new technology be transferred to the continent in a completed form, or that expatriate scientists work in Africa to develop these technologies for the wide range of major pests and disease vectors bequeathed to Africa. Yet, as Eicher (1988) opines — perhaps with little justification other than quoting "the respected Africanist, Colin Legum":

> "After a third of a century of independence, there is a growing awareness in many circles that Africa may be generations, and perhaps centuries, behind Asia and Latin America in terms of its stage of scientific and human development and political and institutional maturity ... The level of development of the continent's nation-state was still roughly equivalent to that of Europe or China in the fourteenth and fifteenth centuries — and certainly no later than the seventeenth century".

Ultimately, in a world whose survival and production have progressively become more intensely knowledge-based, and particulary science-led, Africa must raise substantially its stock of human capital, and make the priority areas of its concern major attractions for its human resources development.

Such an area of plant protection priority concern is the desert locust (*Schistocerca gregaria*). Africa has been experiencing, since 1986, a major outbreak of swarming locusts in the northen half of the continent. The cost of emergency control measures was more than US $50 million during 1986 and 1987, and it threatens to top $150 million for the 1988 control campaigns. What should be our approach to this recurring, cyclical, major pest plague of Africa?

A New Approach to Locust Control

Widespread international concern has been expressed against the conventional use of broad-spectrum, persistent insecticides in the massive and wide-scale applications that have become traditional for the last 40 years or so. The potential for considerable damage to the fragile ecosystems of the semi-arid zones where the locusts normally breed, and the serious disruption of the food chains through the destruction of the natural enemies of these locusts and other major pests in the application zone, is real.

The desert locust is not a major pest when it occupies a large area, breeding there as solitary, dispersed individuals. It becomes a pest when three things take place in a time-continuum of short duration:

— When the gregarization pheromone gregarizes solitarius locust nymphs (the so-called hoppers), and potentiates them for population aggregation and swarming in the adult stage;

— When the maturation pheromone accelerates as well as synchronizes the sexual maturation of both sexes; and

— When the oviposition pheromone aggregates females to the same egg-laying site and stimulates egg-laying.

If we can effectively disrupt any of these pheromone-mediated behaviour systems, then we are likely to keep non-swarming locusts localized. The problem we face is that we know very little about these pheromones, in terms of their chemical characterization, their biological origin, and the full panoply of their impact on behaviour and development. We know even less about the locust kairomones, the plant volatile substances that are attractive to locusts, which could add significantly to the attractiveness of baits for locust hoppers.

Biological control seems to offer another approach to locust control — as it has done with other major pests. Many pathogenic organisms, occupying different classes of one-celled organisms, have been isolated from locusts and grasshoppers; and several appear to be good candidates for more intensive R&D. Among these is the protozoan, *Nosema locustae*, that infects a wide range of grasshoppers and locusts, including *S. gregaria*. It is already in use against the sedentary grasshoppers in the Great Plains of the U.S.A. with great efficacy (Henry and Onsager, 1982); and it could prove useful in desert locust control during their solitaria phase.

Whatever new technologies we develop in the near future for locust control and plant protection for the resource-poor farmers, they must conform to at least four characteristics:

— They must be technically effective, so as to ensure that pest damage is kept low and to an acceptable level;

— The pest management technologies must be cost-effective: they must be affordable and bring economic advantage to their practitioners;

— They must be sensitive to the human environment and the sustainability of the productive potential of the agro-ecology;

— They must be sustainable and answer to the long-term control of the pest population.

If we can do all this for the resource-poor farming households, then these selfsame technologies will serve the long-term needs of the commercial food farmers as well.

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III

DEVELOPMENT OF AGRICULTURE SYSTEMS FOR SPECIFIC ENVIRONMENTS

AGROFORESTRY

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Several definitions of agroforestry appear in the literature (ICRAF, 1979), but for the purpose of this paper the term agroforestry implies land management techniques involving the combination of forest trees with crops, or with domestic animals, or both. The combination may be either simultaneous or sequential in time or in space.

Over the last decade the techniques have received considerable publicity, particularly since the creation of the International Centre for Agroforestry, but they are not new and have been practiced in some form since the time when man first started to cultivate the soil. Indeed, when man was thrown out of the Garden of Eden it was not for taking grain or vegetables, but for taking the fruit of a tree crop.

The oldest form of agroforestry is that which is now commonly considered to be a major contributor to soil erosion: the practice of shifting cultivation, in which the farmers slash down the trees in an area of forest, burn the cut timber, and then plant their crops among the ashes. In two, three or four years' time, when the yields begin to decline, the plot is abandoned, the forest allowed to regenerate, and the whole process repeated elsewhere. Work in West Africa nearly thirty years ago showed that the soil under shifting cultivation was still well supplied with plant nutrients (Nye and Greenland, 1960). More recently in the Venezuelan Amazon (Jordan *et al.*, 1983) it has been shown that there was no decline in the nitrogen level during four years after felling.

The practice was not restricted to simple village communities and in the days when the Maya Empire occupied the Yucatan peninsula in eastern Mexico, the slasb and burn system was practiced with some precision, the farmers waiting until particular species in the regrowth had reached an appropriate stage before clearing the land again. More recent work at Xalapa (Delgado, 1988) has shown that the native flora of the Yucatan contained some forty species capable of fixing nitrogen, of which seven species were outstanding (*Psicidiacommunis*, *Gliricidia sepium*, *Enterologium cyclocarpum*, *Albitzia lebbecki*, *Inga brevipedicelata* and *Acacia pennatula*). It seems likely that the continued productivity of the Maya Empire during the 1000 years of its existence depended on the nitrogen-fixing capacity of these species.

For the system to be successful, the period between cultivations must be long enough to allow regeneration of the trees. Recent data from the Rift Valley, Nyanza and Western provinces of Kenya show that the farmers have on the average 6.7 per cent of their area under forest, compared to 38 per cent under temporary crops, while farmers with less than one hectare have 60 per cent of their land under crop (Hallsworth, 1987). With the frequency of cropping inherent in these figures, the trees would not have sufficient time to restore the fertility of the topsoil. The system is consequently valueless when the pressure of population is too great. In the hope of minimizing the effect of the short time for natural regeneration, attempts are being made in Nigeria to plant seedlings of suitable species, but it is yet too early to evaluate the results.

We are all of us to some extent the prisoners of our own upbringing. When we talk of land management, we think in terms of the balance of crops to pastures, the use of irrigation and drainage, of fertilisers or cultivation systems, or of forest operations designed to extract wood for use in the industrialized world. Yet as Webb (1982) has pointed out, forest management has been and still is undertaken in many parts of the world by local people without any academic training, people who have managed their forests for thousands of years, and for whom the forest may play a major role in the quality of their lives. Quite apart from the supply of food the farmers obtain from the plots in the forest, the forest itself provides other services to the people living in it. It supplies timbers for home building, birds and wild animals to supplement the protein level of the food supply, feathers and skins for festivals and religious purposes, most of which could be lost under systems of land management in which the forest is removed.

A second group of ancient systems of what would now be called agroforestry has examples both in western Africa and eastern Asia. In parts of Nigeria where slash and burn is still extensively practiced, a farmer will have two sorts of plots, one plot adjacent to his house and other plots distant from the house. The latter are cut from the forest under the slash and burn system described above, while the household plot will carry trees of species desired for particular purpose, either for poles or for fruit, with food crops grown underneath them. These are never burned, although their branches may be removed when they cast too much shade. It is noteworthy that while the distant plots, intermittently cut from the forest, are community land, the house plots are generally considered to belong to the farmer.

An analogous situation is found in the Philippines, where many of the peasant farmers rent land from the larger landholders, but the area planted to tree crops is always restricted to the farmer's own land.

Moving to more modern developments, leguminous trees have been successfully used over the last fifty years, both in the Caribbean and in West Africa to provide shade for the more delicate plantation crops such as cocoa and coffee. The trees help to prevent the shaded trees from being scorched, and at the same time add nitrogen by leaf fall and root decomposition. One variant of this system that is practiced in Costa Rica is to grow the laurel intermittently along the rows of coffee bushes. The effect on the production of coffee appears to be debatable, but the main function of the trees is to act as a financial reserve. The trees can be cut down, one at a time, and sold to provide cash to meet the needs of a family emergency, and in the eyes of the small farmer this is a much more reliable source of emergency cash than putting money in the bank.

Planting leguminous trees and shrubs, notably *Leucaena spp* 1/2 along the contour, is now being advocated as a means of controlling erosion, the land between being planted to other crops. This system has the advantage that the deeper roots of the trees not only allow them to grow on water stored in the subsoil and so provide additional grazing for the farmer's livestock, but also serve as nutrient pumps absorbing nutrients that had been washed down into the deeper layers of the soil or released there by weathering, and returning them to the surface by leaf fall. In areas where the rainfall is marginal for cultivation, the tree crop on the contour provides a valuable reserve of fodder in dry conditions, and if sufficiently extensive will also provide poles for house construction and wood for fuel.

Part of the success of the work of ICRAF will arise from its role in improving culture contact, in bringing to the notice of the farmers in one part of the world practices of which they were unaware but which could be of benefit in their area. One such practice is the use of the 'live' fence. This technique consists in planting pieces of live tree trunks in the line in which the fence is desired to run, and then nailing the fence wire on to them. The trunks grow into trees, which can in due course serve as reserve fodder or as a supply of fuelwood. This practice, which is being vigorously advocated in Central America, is a traditional practice in the southwest Pacific, particularly in Papua-New Guinea, and produces a result which does not differ greatly from the hedge rows of England.

Perhaps the most sophisticated development of agroforestry is alley cropping, in which the perennial tree or shrub crop is planted in rows several metres apart and the annual grain or vegetable crop is planted in rows between the rows of trees. There is clearly scope for tremendous variation within the framework of this technique. The tree crop may vary in normal growth height. It could be a nitrogen fixer, it could be being grown as a supplier of fuelwood, it could be a fruit or nut crop, or a commercial crop such as coffee, while rubber trees are being used in part of southwestern China.

The direction in which the lines of trees are oriented can also be varied. Where the technique is being practiced as a means of controlling water erosion, the line of trees will be laid out more or less along the contour, but where this restraint is not present the lines of trees can be laid out to run either north-south or east-west, being varied according to the crops being grown.

The distance between the rows of the tree crop varies not only with the tree species being used, but also with the types of annual crops and the method of cultivation, for with hand labour the rows of the tree crop can be placed closer than where machinery is used. In areas of low rainfall a drought-resistant tree or shrub can be used, such as saltbush (*Atriplex*) which, provided it is not overgrazed, will provide some protection against wind erosiom. The problem of this technique in low rainfall areas, or in a dry season, is that the roots of the perennial crop stretch laterally into the soil in which the annual crop is growing, and by reducing the water supply of the annual, will reduce the yield of the row of annuals immediately adjacent to the tree row.

One form of agroforestry that has received little attention is the practice of growing a tree crop along the bunds surrounding areas under irrigation. This has been practiced for centuries in Indonesia, where palm trees are planted along the banks between the rice paddies. As well as providing an extra crop, the trees probably give added stability to the banks. This technique has recently been extended to India, to the irrigated areas of Haryana State. Here, on the initiative of the Commissioner for Forests, seedlings of a cross-bred eucalyptus have been given to the farmers to plant on the banks between the irrigation bays, and have produced millable timber in eight years. The original idea was that the trees would provide fuelwood, and so allow the farmers to apply their cattle dung to the fields as manure rather than using it for fuel, but because of the increased income that could be obtained by selling the trees for timber or for wood-pulp the farmers are still burning the dung. This practice is being widely adopted, 3,500,000 trees were distributed in 1981, and 5,000,000 in 1982! The tree crop is an extra, and is being grown without any reduction in the yields of the traditional annual crops.

Agroforestry in Relation to Animal Husbandry

In most of the forms of agroforestry described above, the provision of additional fodder for the farmer's livestock has been an additional benefit rather than a major reason for adoption. One of the oldest examples of the use of trees to provide supplementary fodder for domestic stock has been described for the Himalayan and Siwalik regions of Uttar Pradesh (Gupta, 1982), where some 1,500,000 cattle and 600,000 buffaloes graze in the forests, fodder being provided during the dry period by lopping branches of the forest trees.

An analogous system has developed in various parts of Australia, where in the pastoral lands certain species are prized for their value as reserve fodder, while in the wheat-sheep country of northern New South Wales care is taken to avoid destroying the kurrajong trees in the areas that from time to time are sown to wheat.

Both of these cases have developed in a rather haphazard way in response to the needs of the moment, as indeed most early agricultural practices did. In Western Australia during the last decade, however, there has been a deliberate attempt to combine the growth of forest trees with pastoral activities. The system is to plant radiata pine in a sown legume-based pasture that is grazed by sheep. The trees receive nitrogen from the legumes, while during the early stages when the tree crop can provide no return for the growers' labours, the sheep can provide an income from the sale of fat lambs and wool.

Summary

The various land management practices that can be generally described under the term agroforestry have many advantages in different circumstances. Many of the practices developed independently in different parts of the world in response to the problems encountered.

The systematic study of the potentialities of the techniques, utilising the vast variety of plant species that can now be introduced into any one area from all over the world, seems likely to be able to reduce the risk of erosion, and thus to be able to enhance productivity in a sustainable manner, and to be able to improve the quality of life for many people.

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ALTERNATIVES IN AGRICULTURE IN THE TROPICS

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Introduction and Background

Throughout the world and ever since men embarked on settled agriculture, trees and agricultural crops have been grown together in some association with each other in a given ecosystem or on the same farm.

In the temperate climatic zone, trees were usually planted on land which was less suitable for crop production either because the land was too sandy, too poorly drained, too rocky or too acid, alkaline or saline. The trees constituted a form of land use which to some extent contributed to the income of the farming community. In a good many instances the trees during 40 to 50 years of growth had such a favorable impact on the land that it could subsequently be used for agricultural production purposes. To a very limited extent this is still happening today. Where such soil improvement is not taking place the land is permanently kept in wood lots or in forest plantations.

In the tropical zone of the world, especially in the humid and semi-humid tropics the association of trees with food crops has been of a very special nature in traditional agriculture. In different parts of the tropics different systems with a different degree of complexity have been used.

In Central America and in the humid and in semi-humid transitional zone of Africa, as well as in certain humid parts of Asia, farmers have all along tried to immitate forest conditions with the growing of food crops, in order to obtain the beneficial effect of the forest biosphere and the forest structure.

In the so-called "compound units" on an area of usually not more than 1/2 ha of land around the farmhouse, tree species and annual crops are grown in such a combination that the layered configuration of tropical forest is imitated. As many as 10-20 different species of plants are grown on this small area; coconut and papaya usually constitute the upper layer under which bananas, citrus and cacao are grown, with a next layer of tall annuals such as corn, yams and cassava, and finally a ground cover of ground nuts, pineapple, cowpeas, sweet potatoes, taro and cocoyam.

This system represents a very intimate combination of tree crops and agricultural crops which allows the farmer to practice continuous production on the same piece of land without the application of any modern technology, yet maintaining sufficient fertility to practice a subsistence type of agriculture. The beneficial effects of the residue of trees and plants combined with the excrements of humans and small animals maintain soil structure and fertility.

In the same tropical zone sometimes next to the compound farm the bush fallow and shifting cultivation system is widely practiced.

Under this system the bush is usually cleared by hand, leaving some scattered large economic trees such as palm trees and timber trees. After burning the felled trees and bush, the land is cultivated for 2 to 3 years, after which it is allowed to grow back to its natural vegetations for a period of 5-7 years. During the short cycle of cultivation, the fertility accumulated during the bush fallow period is being utilized.

In the semi-humid savannah zone the shifting cultivation system is widely practiced, which is similar to the bush fallow system except for a sparsc tree coverage but with an abundance of natural grasses and small bush plants.

Either under the bush fallow or shifting cultivation system, the land deteriorates during the cultivation period but the subsequently fallow period restores sufficient organic matter, structure and fertility so that the land can be used again for production of food crops for a short period. This land management practice provides the traditional farmers with an ecologically sound stable system for maintenance of soil fertility but, as a great drawback, necessitates the continuous use of a large amount of family labor to bring new land into production. Studies at the International Institute of Agriculture (IITA) at Ibadan, Nigeria, have shown that at least 50 percent of the family labor is used for this purpose. No more than 2 ha in the forest zone and 4 ha in the savannah zone can be cultivated by an average farm family at the present level of technology. Because of poor cultivation practices, use of low yield varieties, heavy land infestation and a certain amount of shading effect, the returns are generally low. Consequently, under this system a *subsistence type of agriculture* is the result, with very little produce going to the market.

As long as some 85-90 percent of the population of the tropical countries lived on the land, food supplies were adequate to feed the rural as well as the urban population. With the rapidly emerging urban centres and a decrease in the rural population to about 50 percent, neither the compound farmers nor the farms under bush fallow and shifting cultivation are capable to meet food requirements, and with a simultaneous 3-4 percent increase in population most African countries are forced to import large amounts of food.

A first answer to these changed conditions was the shortening of the traditional fallow period and the more intensive use of land, in most cases resulting in a sharp decline of soil productivity if not complete destruction of the arable land. The lack of a sufficiently long bush fallow period without other protective measures has acute consequences in the humid forest zones of Africa and Latin America, as the deeply weathered acidic soils lose fertility rapidly under repeated cultivation. In places where inappropriate land clearing and subsequent poor soil management methods have been used, some 50 tons or more of surface soils are removed annually per ha. This incidentally is 100 times the natural rate of soil formation (which is 0.5 Ton/Ha) in the tropics even under good soil formation conditions. It is estimated by Dr. Lal of IITA that some 2 million ha of land are destroyed each year in the humid and semi-humid tropics as a result of poor land management.

To maintain fertility in the low acidity clay soils (LAC), which are the dominant type in the humid and semi-humid tropics, a fallow period, or the growing of a special crop for the supply of organic matter must be included in the crop rotation. Humus and fertility need to be supplied on a sustained basis to these soils, which are characterized by a low cation exchange capacity and a low moisture holding capacity.

Parallel with the degratation of soils due to poor crop production practices on small farms, large areas of forest in the tropics are being cut for industrial wood production or for the setting up of western style large scale agricultural enterprises; in both cases with disastrous results for the soils and the enviroment. The World Commission on Environment and Development of the United Nations in its report of 1987 states that "every year six million ha. of arable land is turned into desert. In thirty years thus an area as large as the territory of the Kingdom of Saudi Arabia. Every year some 12 million ha. of forest in the humid tropics are exploited, thus leaving the land in a very precarious equilibrium. The report draws attention to the fact that it took nature in the tropics a period of 2000 to 3000 years to form 50 cm. of fertile soil, while it takes men from 10 to 20 years to destroy it.

Because of the soil characteristics and the extreme climatic conditions of tropical rainstorms and high temperatures, the tropical ecosystem is naturally very fragile. If the present rate of forest destruction continues without any other complementary offsetting measures, major changes in the micro climate but also in the hydrological cycle, the energy balance and the soil physical and biosphere will occur. In the not so long run it might also affect the world's microclimate and the capacity to sustain life.

Yet the developing countries with their lack of foreign exchange and their heavy debt repaying burden will have little choice but to sell exploitable wood resources in search of immediate returns wherever they have such supplies. The World Commission makes a number of recommendations for urgent action by the developed as well as the developing world to stop these destructive actions of the biosphere so that the human race may have durable development and progress.

I will not further elaborate on these actions other speakers in this study week (no doubt will do so), but I would like to concentrate in this paper on the possible alternatives in agriculture in the tropics to have *durable development and progress* so as to lift the rural people above the subsistence level and have them share more fully in the abundant resources of nature.

Alternatives to Present Traditional System

"Compound farming" and the system of bush fallow and shifting cultivation are ecologically sound and stable land management systems. However, in the traditional form they allow for little more than a subsistence standard of living and they certainly cannot bridge the gap of food imports in African countries.

Certain important changes will have to be made in the farming structure to allow modern technology, as it develops for the tropics, to be applied, giving full weight to the need for maintaining soil structure and fertility.

Some organizations have advocated large-scale mechanization to increase labor productivity along the same lines as happened in the Western World. Under present conditions tractorisation and large-scale mechanization cannot possibly be adopted, either by the individual small farmer or on a cooperative basis, on purely technical and economic grounds. Unfortunately, proponents of such schemes have usually little knowledge or regard for the basic soil conservation and soil fertility requirements of the tropical soils.

It was not until about 15 years ago that serious studies were made in Africa and Latin America by IITA and CIAT, the two International Agricultural Research Centers in these respective zones, which lead to solid information on the need for soil improvemenet and soil conservation through various measures, including the growing of trees. Such studies also threw more light on the wisdom of farmers in practicing the compound and the bush fallow system but also created a greater understanding of the economic weakness of this stable traditional farming system.

In 1977 a study commissioned by the International Development and Resource Centre (IDRC) gave a clear understanding and focus to the high priority to be given to a combined production system which would integrate forestry and agriculture, and if possible animal husbandry, in order to optimize tropical land use. The salient feature of this proposed agroforestry system is the combination of producing food and wood while at the same time conserving and rehabilitating soils and the related ecosystem. As a result of the need for more knowledge on this proposed system, the International Council for Research in Agroforestry (ICRAF) was established at Nairobi, Kenya. The Council had as objectives to encourage and support research in agroforestry, the dissemination of information on agroforestry systems, and the administration and promotion of a comprehensive programme leading to better land use in the developing countries.

During the ten years of ICRAF's existence great progress has been made in the systematic inventory of agroforestry systems (Nair, 1978) world-wide. It showed a great multitude of systems, from the relative simple one with two or three components to the complex one previous by mentioned compound or home gardens which may contain upwards of 20 species plus animals.

Because of the complexity of the systems and because of the fact that experimental designs for research in agriculture had generally been developed mostly for monocultures, ICRAF has been investigating different experimental designs which can cope with the serious gap in presently available knowledge in these multicrop systems.

Another difficulty is appropriate input/output measurements. With the agroforestry system there are multiple outputs. The agricultural output is usually rather easy to evaluate in quantitative terms, while the forestry component may give great difficulties. Especially hard to measure is its effect on the entire system, such as the recycling of nutrients from the subsoil, control of erosion, lowering of soil temperature, moisture-holding capacity and infiltration rates.

Furthermore ICRAF has tried to identify and make an inventory of the true species that are most likely to he useful for experimentation. Multipurpose tree research is still in a very primitive stage as compared to agricultural, except for a few species such as Leucaena sometimes referred to as the miracle tree.

While this basic work has started at ICRAF, the Nigeria hased International Institute of Tropical Agriculture (IITA) has concentrated a large part of its research on a better understanding of the physical and chemical characteristics of tropical soils and on solutions for solving the soil degradation process while at the same time increasing the lahor productivity of the African farmers.

It became abundantly clear that the compound farm system and the bush fallow and shifting cultivation system were poorly adapted to the introduction of conventional new technologies. At the same time it was recognized that tropical soils should be constantly supplied with organic matter, all factors which the traditional farming system has incorporated.

To meet these soil conservation requirements and at the same time increase productivity, IITA scientists during the 1970s opted for two alternatives:

1) A planted fallow dominated by the use of herbacious legumes for the production of green manure with special reference to crops such as *Mucuna utilis*, *Pueroria phaseolides*, *Centrosema pubescens* and *Psophocapes palustris*. These were found capable of producing in-situ mulch for minumum tillage production. The problem in this system is the loss of one year of production on each field every fourth or fifth year, yet the land requires considerable work and expenses. Although this planted fallow approach was taken by researchers since the 30s and positive results were obtained, farmers have never adopted it on a wide scale.

2) An agroforestry approach whereby woody species are planted and managed in an organized system, — something which had not been tried before — has led to the development of what is now known as the alley cropping system.

Under these systems arable crops are grown between hedge rows of leguminous, woody perennials, the prunings of which are regularly spread on the land, providing nitrogen for the associated crop and a source of mulch and green manure. The leguminous shrubs and trees grown in hedge, rows have the same functions of recycling nutrients, suppressing weeds and controlling erosion on sloping land as in the bush fallow system.

The alley cropping technique can be regarded as a greatly improved bush fallow system with the following advantages:

1. The same land can be continuously used, eliminating the need for using unproductive labor for bush clearing;

2. The possibility of using more effective new techniques such as crop varieties, fertilizers and cultural practices including small or large-scale mechanization thereby greatly increasing land use intensity;

3. Instead of the long years of natural bush fallow, a small part of the land (up to 20%) is now permanently in a selected species which has a high ability of nutrient recycling and soil fertility regeneration;

4. It reduces the requirements for external inputs and therefore fits well into a low input system of the peasant farmer yet obtaining higher productivity than in the traditional system;

5. The system can be used by small as well as large-scale farmers;

6. As the species used are very deeply rooted, they continue to produce succulent green material during the dry season. The International Livestock Centre for Africa (ILCA) has developed an alley farming concept, in which the prunings are used for high quality supplementary animal fodder;

7. The hedge rows can be left to grow during the dry season and thereby provide valuable stakes or fuel wood.

In spite of these apparent advantages, the system has not spread very rapidly in Africa. Over the past few years, however, alley cropping has been succesfully introduced in critical areas of Indonesia, in the southern Philippines and in Sri Lanka.

In Africa the acceptance is best in areas with pressure on the land. In Nigeria, through the ILCA activities, adoption has been high in some parts of the southern region, but in other parts land tenure systems have been a major constraint to its adoption. If a farmer has to change land every year or two, obviously the alley cropping system cannot be attractive. The system has no immediate benefits. It takes one year before the hedge rows can be cut and the prunings be used. It is a longer term investment leading to sustained productivity.

A farmer may well be reluctant to give up part of his cleared land for the cultivation of trees and shrubs, thereby having less production and income during the first year after clearing.

These drawbacks must be recognized, but possibly they can be overcome with the assistance of international or bilateral organizations.

Organizations like FAO/UNDP, WFP, IFAD and IBRD are well placed to assist countries through technical assistance, credit provisions, and food aid. Their programs should give much more attention to this new possibility for making alley farming an attractive alternative to the prevailing bush fallow and shifting cultivation system.

The Future Action Required

So far, two species of hedge row trees have been used in alley farming: *Leucaena leucocephala* and *Glericidia sepium.* Both species are leguminous, grow fast and have a deep rooting system. Leucaena has been most widely propagated and used in preference over Glericidia. Yet recent studies (1987/88 Annual Report of IITA) at IITA have shown that Glericidia may perform better than Leucaena under certain soil and climatic conditions. The symbiosis effect with indigenous Rhizobium is one factor in favor of Glericidia. It is therefore suggested that both species be used initially on a trial basis, after which the best is selected.

Generally on acid soils liming is required for Leucaena to have good results; however there is evidence that Leucaena because of its very deep root system is more suitable in the transition and savannah zone with rainfall of 800-1500 mm.

Present knowledge of the alley cropping system provides a solid basis to move ahead in the humid and semi-humid tropics.

The development of this system for large parts of Africa and in other humid and sub-humid regions will have the obviously beneficial effect of reducing the land area needed for food production but at the same time enlarging the productive farm unit with the same demand for labor. Expanded alley cropping will definitely accelerate the process of increasing agricultural development and increasing living standards. At the same time it will help to arrest deforestation. In fact, it may liberate large areas for rational reforestation with valuable wood species.

The system, as stated, has low input, low capital requirements with a heavy reliance on biological processes, thus counteracting the high input, high recurrent cost systems often promoted by the Western World. It has none of the negative aspects of wasteful exploitations of natural resources which encompasses great danger for the enviroment because of the excessive use of chemical fertilizers and pesticides.

More research is needed to select the most suitable multipurpose woody species for alley cropping, particularly for acid soils, higher elevations and drier areas. Also species most resistant to fires is another aspect to be considered as fires during the dry season are a common danger in all of the tropics.

Conclusion

In this paper I have heavily concentrated on a practical alternative to bush fallow and shifting cultivation by means of a special type of agroforestry system, namely alley cropping. I have done so because I consider that this alternative gives farmers the critical mass to move traditional subsistence farming into a new era of development. This system together with the enormous progress which has been made in finding new high-yielding varieties of all major food crops in the tropics could well trigger a much needed green revolution for the poorest part of the world, which so far has greatly lagged behind.

I realize that I have neglected other aspects of agroforestry such as the temporary or permanent intercropping of trees and cultivated crops, the grazing of animals under trees and the symbiosis of different tree species for wood, fruit, food and feed production. ICRAF with its multidisciplinary team of experts and scientists in collaboration with national and international organizations no doubt will tackle many of these problems in the future. It has already developed a network of international collaboration with national and regional bodies in Africa for work on the analysis of land use problems and on the design of research programs to solve the most urgent problems, including desertification in the Sahel countries.

Some progress has been made in the very short period of its existence. We should remember, however, that research involving trees by its very nature takes a long period of time before reliable results can be measured. It is indeed unfortunate that it took so long to recognize the important role trees are playing in the whole life cycle of plants, animals and human beings.

Let us make sure it is not too late!!!.

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COASTAL DESERTS — A CHALLENGE FOR A PROPOSED BIOLOGICAL RESOURCE DEVELOPMENT CORPORATION

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Biotechnology in Support of Agri- and Aquaculture

In my view any policy which is aimed at "growth with fairness", must give room for a level of regional self-reliance that can provide the necessary stability for socio-economic development. Historically, this development has always been characterized by cycles that reflect the interaction between social needs on the one hand, and on the other families of inventions that tend to emerge whenever the energy and resource-base changes.

The current global need to limit the mining of water, the burning of fossil fuels and the pollution of our environment heralds such a change, and it gives special significance to a class of technologies, which I like to call *equilibrium technologies*, since they will help us optimize the utilization of renewable resources, for instance by energy cascading, systems integration and recycling of materials.

As an expression of enlightened self-interest the industrial world — which is now tied to a flywheel of cheap energy and heavy investments both in capital and in traditional education — ought to regard the development of the equilibrium technologies as a high priority. They are certainly needed by the developing countries right now, but they will probably be extensively employed also by the rich countries in the early part of the next century.

Microelectronics and modern communication technologies will then play important synergistic roles, but I will here concentrate on the bio-resources, and specifically on the need for a long-range, intelligent use of that cluster of emerging technologies that we refer to as biotechnology and genetic engineering. Those fields of activity have a unique potential for upgrading many traditional practices based on photosynthesis (Heden, 1987), but their strategic significance needs to be highlighted by a dramatic demonstration case.

With this in mind the International Federation of Institutes for Advanced Study (IFIAS) early advanced "Greening of the Deserts" as a suitable area for a megaproject, and it later initiated a special programme aimed at studying the "International Diffusion of Biotechnology". With the author of this paper as the link, the World Academy of Art and Science (WAAS) therefore began to consider how its systematic networking efforts in biotechnology might best be utilized. This led to a suggestion that the "Biological Resource Development Corporation", which was a structure that one of the Academy's task-forces had suggested to stimulate diffusion, might be an interesting "guinea-pig" for the IFIAS' study, and that a suitable focus for a concentrated effort might be "coastal deserts".

Coastal desert is a dispersed 30.000 km long, largely neglected "resource", where energy cascading has already been practiced (OTEC), great opportunities for integrating plant - and marine biotechnology exist (Hedén, 1981) and various options for recycling organic waste can readily be tested.

It should also be noted that the development of integrated uses of salt-tolerant plants (Malik *et al.*, 1986; Rajoka and Malik, 1988), and particularly grasses that have the capacity to utilize symbiotic fixation of atmospheric nitrogen (Malik *et al.*, 1988), might find many uses very far from any ocean coast-line.

To appreciate the geo-political significance of such resources it might for instance be noted that the sea level in the Aral lake, which was once the world's largest inland sea (65,000 sq.km.), is dropping about 0,5 m per year, which means that the shoreline is now 50-60 km closer to the middle than it was at the beginning of the 60s. At the 1987 congress of the Author's union of the USSR, Tulenberger Kaipbergenov, noted that this for instance meant that the wind carried 75 million tons of salt out over the surrounding countryside each year. In the USSR irrigation also takes a severe toll of the Caspian Sea, but Pakistan and parts of India also face salination, and the loss of arable soil and a sinking water table in many parts of the US is another serious memento.

Obviously we should look to marine biology for ideas about salt-tolerant systems. Research on salt-tolerant methane-producers, nitrogen fixers and other beneficial soil microorganisms is for instance needed, and microbial strains that — under primitive conditions — could convert macroalgae or fish waste into a substrate for brine shrimps or other types of aquaculture fodder might offer interesting new approaches to food production.

Mariculture and Marine Biotechnology

In the face of growing population pressures and the threat of climatological disturbances, aquatic animals deserve special attention in view of their feed conversion efficiency. This is better than that of terrestrial animals, not only because those animals are cold-blooded, and consequently do not need to expend energy on thermoregulation. Also movement is not very demanding, partly because their density is about the same as that of the environment, and partly because the latter acts as a food conveyor. However, for maximum efficiency we should aim for microalgae like *Spirulina*, or at least harvest early in the food chain. This means that we should pay special attention to zooplankton, oysters, blue mussels, mullet and some species of the genus Tilapia, since they feed on the primary producers, the phytoplankton. If we want carnivores, that need about 40% protein in their diet, we should also give some thought to fermentative upgrading as a means to balance the composition of vegetable protein, before we settle for the standard fish-meal.

Aquaculture has a long history, particularly in China (Pritchard, 1980), where ducks in fish ponds, and the practice of using green manure and piggery waste as fertilizer constitute well-known examples of simple process integration. However, applied ecology can also be practiced in marine environments, as demonstrated by Woods Hole Oceanographic Institute in the US, where sewage from a secondary treatment plant was mixed with sea water to grow algae which then fed oysters, clams, scallops and mussels. Both those and a wide range of fish and shellfish can however now also be produced in controlled monocultures. Those are however often subject to infections that can cause great losses. In fact this is an area where inputs from biotechnology are badly needed, for instance in the form of Vibrio-vaccines made by excising the virulence genes from the pathogen.

Marine biotechnology is, however, in the process of introducing many more opportunities to developing countries (Colwell, 1986). Chinese workers have for instance used mutagenesis, inbreeding and selection to improve the yields and extend the geographic coverage of the important seaweed kelp.

Marine algae are not only an important food (nori in Japan, tsao in China, rimu in Tahiti, limu in Hawaii, etc.), but they are also the source of valuable substances like agar, carrageenan and alginate, which have many industrial uses. Their combined world market value is around $250 million year. Only the nori-farms in Japan cover more than 60,000 hectares and yield a product worth around $730 million year. Marine algae may in fact generate the first economically significant products for developing countries that enter the field of marine biotechnology (Klausner, 1986; Harvey, 1988).

In this connection however Colwell also stresses the significance of the improved stocks of fish and shellfish that are now being produced, and the importance of the tecniques for cloning, cell fusion, production of chimeras and other DNA techniques that are now being applied not only to fish and shellfish but also to oysters, clams, abalone and other molluscan species.

In abalone the spawning (regulated by prostaglandins) can easily be controlled with the addition of small amounts of hydrogen peroxide; the molecules needed to induce larval settlement and metamorphosis are known (derivatives of aminobutyric acid) and so are also the hormones that can be used to stimulate growth. In the case of another valuable product, the Eastern oyster, scientists at the University of Maryland have identified the bacterial products (neurotransmitter-related substances) that induce larvae settlement and metamorphosis.

With the development of gene-banks for abalone and oysters such knowledge, and the possibility to clone the genes which control the production of various attractants and inducers, will certainly pave the way for safe and homogeneous, and consequently also very valuable products.

Add to this the wide spectrum of pharmacologically active compounds that have been isolated from marine biota (antibacterial, antifungal, antiviral, anticarginogenic, antispasmodic, hypotensive, hypertensive, insecticidal, etc.), and it is obvious that developing countries should try to benefit from this resource.

Colwell (1986) has suggested that UNIDO should consider the establishment of an international center with this in mind. However, the difficulty of involving the major industrialized countries in the International Center for Biotechnology and Genetic Engineering (ICGEB) indicates that additional non-governmental initiatives, such as the one discusses in this paper, might be helpful.

Conceptual Integration

Even a very superficial review of the advances made in biotechnology and genetic engineering over the last few decades underlines its potential not only for supporting nutritional self-reliance but, sadly enough, also for undermining economic self-reliance by generating new types of dependencies, for istance by creating a need for novel genetic resources (Sans, 1988). This constitutes a challenge for international science policy, but it also underlines the need for an efficient international cooperation, a need that has been stressed repeatedly for the last 25 years by eight International Conferences on Global Impacts of Applied Microbiology (the GIAMs in Stockholm, Addis Ababa, Bombay, São Paulo, Bangkok, Lagos, Helsinki and Hong Kong).

Even if we are very far from seeing those needs met, growing efforts can fortunately be noted (Da Silva and Hedén, 1986). They are for instance illustrated by the gradual expansion of the UNEP/UNESCO/ICRO network of Microbiological Resource Centers (MIRCENs). Significant national (Japan and FRG) and international (WHO, UNU, IAEA) educational projects have been launched, and noteworthy is also UNIDO's efforts to establish a R&D-Center (Trieste/New Delhi) on genetic engineering and biotechnology (ICGEB) for developing countries. Since the International Council of Scientific Unions (ICSU) has established an inter-union coordinating committee for biotechnology (COBIOTECH) a needed structure for transdisciplinary initiatives now also exists.

In view of its special interest in creativity as a key resource for development, those various initiatives were closely followed by the World Academy of Art and Science (WAAS), ever since it actively participated in launching the first GIAM conference in 1963. Stimulated by a five-year study of the impact of enzyme engineering, initiated by the International Federation of Institutes for Advanced Study (Hedén, 1974), and its concluding volume: "Biological Paths to Self-reliance" (Andersson, 1979), the Academy in 1978 finally organized a major conference: "Bioresources for Development" (King and Cleveland, 1980).

This conference provided strong arguments for biotechnology as a strategic development factor, and it caused WAAS to initiate a series of feasibility studies aimed at evaluating the potential of electronic means of communication as a tool for focusing the creativity of bioengineers on the towering problems in developing countries.

MIRCEN/Stockholm acted as a work-horse in this connection,

1. for initiating an effort to evaluate the potential of computer conferencing as a means to stimulate interest in bioconversion of lignocellulose (Hedén, 1985a), 2. to build a biogas-network, and 3. to explore the potential of electronic communications as a means to extend the coverage of major goal-oriented meetings, like the 1988 International AIDS-conference (Foo, 1988).

By participating also in the granting activities of the International Foundation for Science (IFS) and in the International Inventor Award (IIA) - effort (see below), the author of this paper had developed a healthy respect for the problems of stimulating indigenous creativity. This consequently became an important topic for a one-year transdisciplinary computer conference on the "Impact of Biotechnology" (IBC), which the Academy last year initiated as a contribution to a major study called "Rethinking International Governance" (Cleveland, 1988). This conference used a major feasibility study on networking carried out for UNESCO as its starter (Hedén, 1987), and it was concluded in August this year by a round table discussion that took place in Hong Kong. Among other things (cf. Fig. 1) it expressed the view that.

> "Networking among concerned experts, advocacy groups, foundations and public (national and international) officials will be of the essence in achieving consensus and charting global strategies for biotechnology. It also suggests that those in the new network, above all the biotechnologists, need to develop for their own use an explicit code of ethics to guide the application to human needs and purposes of the new powers biological and genetic knowledge confers on humankind. An important role in the needed networking can be played by electronic teleconferencing".

It was the last point, where the possibility of a collective generation of inventions by small task-forces, and the unique potential of the technique for tracing the birth of an idea, that led to the discussion about the need for a defined code-of-conduct. It was felt that this ought to stimulate participation of young and dedicated scientists. However, it would also be required in order to define BRDC's relation to industries that would accept the operating principles (for instance a royalty based on the BNP/capita in the country where an invention would be practiced) and support the Corporation's activities without getting more than a first refusal right to any inventions generated.

Acting on the basics of the recommendations made in Hong Kong, an interim executive committee is now in the process of finding seed money to get a "Biological Resource Development Corporation" (BRDC), *Points highlighted at the Hong Kong workshop (Aug. 6th 1988)*

* The introduction of biotechnologies in the context of coastal desert development should emphasize that the systems approach to bio-productivity not only involves food, but also other products that can improve local buying power and stimulate entrepreneurship. A gradual upgrading of traditional practices by means of process integration and waste reduction might eventually generate a sound "biorefinery" approach. In this context, leasing arrangements might be helpful as a means to stimulate investments and franchising as a tool for information transfer.
* The use for multiple purposes (e.g., energy and aquaculture) of cold nutrient-rich water in tropical and semi-tropical environments.
* Utilization of lignocellulose from agricultural waste materials and halophyte straw for mushroom cultivation and for chemical feedstock.
* Biofertilizer systems, such as blue-green algae, for the cultivation of halophytes.
* Halophytes as a source of biogas, using the residue as fertilizer.

The Hong Kong workshop decided that the following steps needed to be taken.

1. A Bioresource Network should be developed and expanded, using the ibc conference as an initial nucleus (later referred to as BIXNET = Bioresources Information Exchange NETwork).
2. A nongovernmental Biological Resources Development Corporation (BRDC) should be incorporated, to promote "growth with fairness" through the actions of the biotechnological community.
3. The BRDC, its Board of Directors and its executive officer, should generate joint ventures with private or public organizations to conduct research, development and application of biotechnology for "growth with fairness". These ventures would be designed to make a profit, a portion of which would benefit a Trust Fund intended to promote basic and applied research in biotechnology for development.
4. The trust funds thus created would be allocated for development - related R&D by a Council. Since it would be operating primarily by electronic teleconferencing, it doesn't much matter where the secretariat is located.
5. BIXNET would be managed by the BRDC executive. It would operate primarily through task forces focused on particular applications of biotechnology for development.

FIG. 1

and an associated "Bioresources Information Exchange NETwork" (=BIXNET), off the ground.

Biotechnology Transfer

In its future efforts to stimulate creativity aimed at solving some of the problems faced by developing countries, BRDC must obviously spend a lot of effort on the selection of R&D targets that will be so well adapted to technology transfer that they will not end up as useless "technical fixes".

BRDC must consequently consider the fact that sucess in technology transfer depends on the establishment of a proper balance between three factors: a receptive infrastructure, "soft-ware" adapted to a new culture and finally "hard-ware" in the form of essential equipment and materials.

1. *Infrastructure.* Biotechnology has a great potential for upgrading nutrition in developing countries, but it can easily go astray if the benificiary does not realize that it is not itself a discipline but just a "cement" between disciplinary bricks like microbiology, immunology, biochemistry, fermentation technology, etc. To neglect education in those fields is like trying to build a staircase without a good supply of solid bricks and a proper set of drawings. It leads to dependencies on external inputs and on priorities that are governed by market forces that normally tend to favour labor-saving solutions and energy — intensive agri — and aquacultural practices.

The infrastructure which forms the basic of socio-economic development easily becomes unbalanced when the traditional trickle-down/seep-out principle of aid is permitted to dominate. This favours an urban setting, and approaches that tend to presuppose the existence of centralized services like electricity, water and sewerage. This directs the attention of many bioengineers towards the scale-factor advantages that can be attained in the urban environment, and away from technologies that have a potential for supporting rural self-reliance. This thus easily becomes the domain of enthusiasts who may lack the expert advice they might need to avoid becoming entangled in various unrealistic schemes.

Often the enthusiasts have a holistic view of the global situation (militarization, inflation, unemployment, environmental and social stresses), and they tend to regard "Big Government", "Big Labour" and "Big Business" as part of the problem rather than as its solution. This they claim can instead be found under the banners with the motto: "Small is Beautiful" (Schumacher, 1973).

The consequent polarization between big and small is unfortunate, because it obscures a fact which ought to be obvious, namely that *both* approaches are needed if we want to avoid traps like protectionism and bureaucraty. Sure enough those are "sweet traps" as long as we only aim for short-range solutions and believe in the merit of abstractions such as national sovereignty, GNP as a measure of development, and science and technology as secondary factors in the economy.

However, if we accept the "One World" — concept, and the fact that products of the mind cannot be contained by national borderlines as easily as the products of industry, we are inevitably led to take a long-range strategic look at the impact which "high technology" might have on the global matrix of resource endowments: the physical — and bioresources, the renewable energy base and the human resources. Among the latter probably women are our largest underutilized resource whenever it comes to applications of biotechnology to health and nutrition.

The gap between the experts in the industrialized world and the dedicated amateurs must obviously be bridged, which might perhaps be done if they jointly discuss the prerequisites for success in biotechnology transfer. Schemes such as the one given in fig. 2 (Hedén, 1985b, modified after Ackerfors, 1985) might then help to generate a realism that might also be helped by a frank discussion of some basic requirements, like the availablility of financial resources and the freedom from politics, and any bureaucratic inefficiency that might interfere with focused efforts (Zimmerman, 1988).

2. *"Software".* The need for a broad-based discussion in the selection of R&D targets brings the question of software into focus, and particularly the three areas where the developing countries have much to learn from the industrial parts of the world, feed-back control in project management, incentive systems used to stimulate entrepeneurship, and finally the use of social innovations to stimulate economic growth.

In my view, the failure of many development efforts can be traced to a combination of human weaknesses and a tendency to manage complexity with the aid of military command structures (Hedén, in press). The business world is well aware of the fact that this approach can interfere with both adaptability and creativity, so it uses efficient electronic means of communication to decentralize its activities, and

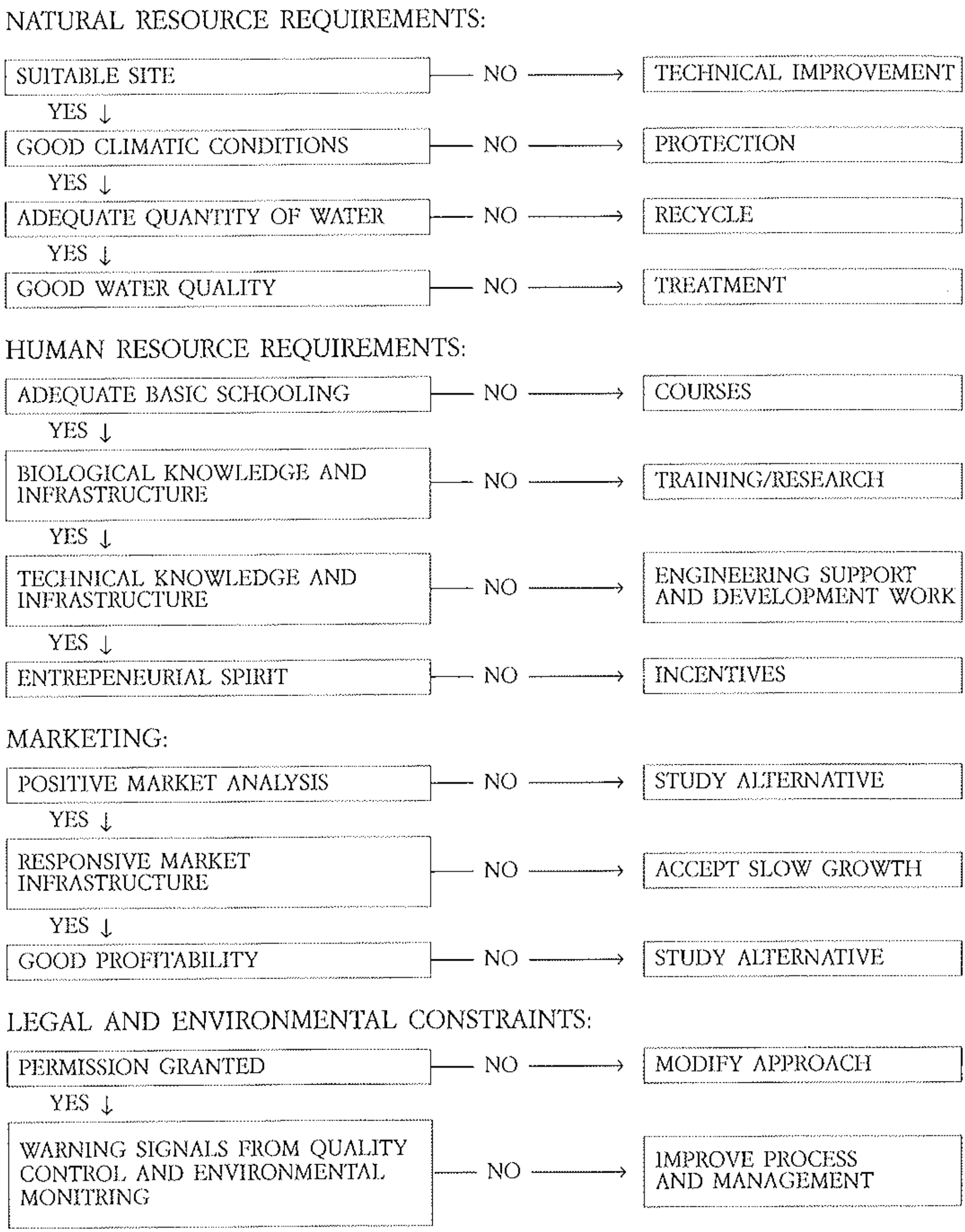
NATURAL RESOURCE REQUIREMENTS:
SUITABLE SITE
NO
TECHNICAL IMPROVEMENT
YES
GOOD CLIMATIC CONDITIONS
NO
PROTECTION
YES
ADEQUATE QUANTITY OF WATER
NO
RECYCLE
YES
GOOD WATER QUALITY
NO
TREATMENT
HUMAN RESOURCE REQUIREMENTS:
ADEQUATE BASIC SCHOOLING
NO
COURSES
YES
BIOLOGICAL KNOWLEDGE AND INFRASTRUCTURE
NO
TRAINING/RESEARCH
YES
TECHNICAL KNOWLEDGE AND INFRASTRUCTURE
NO
ENGINEERING SUPPORT AND DEVELOPMENT WORK
YES
ENTREPENEURIAL SPIRIT
NO
INCENTIVES
MARKETING:
POSITIVE MARKET ANALYSIS
NO
STUDY ALTERNATIVE
YES
RESPONSIVE MARKET INFRASTRUCTURE
NO
ACCEPT SLOW GROWTH
YES
GOOD PROFITABILITY
NO
STUDY ALTERNATIVE
LEGAL AND ENVIRONMENTAL CONSTRAINTS:
PERMISSION GRANTED
NO
MODIFY APPROACH
YES
WARNING SIGNALS FROM QUALITY CONTROL AND ENVIRONMENTAL MONITRING
NO
IMPROVE PROCESS AND MANAGEMENT

FIG. 2

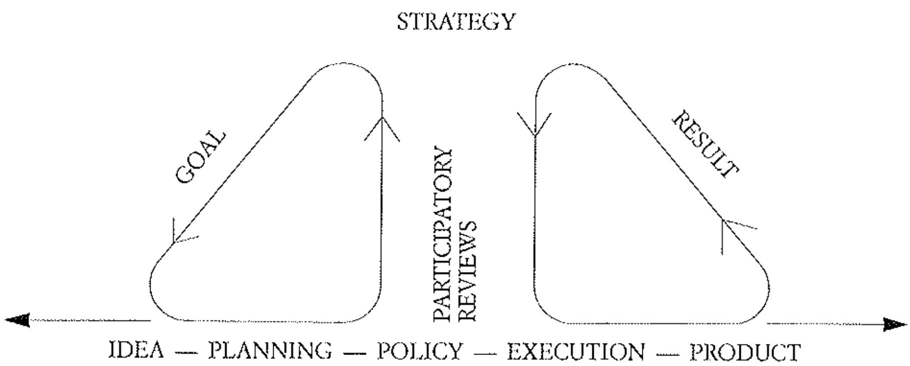

FIG. 3

various types of feedback-control in order to ensure a dynamic project management (cf. example in Fig. 3).

The urgent need for an orchestration of biotechnology and genetic engineering as major forces for the upgrading of life quality in developing countries calls for a similar approach. Such an approach also deserves attention as a test case for what Harlan Cleveland regards as the next phase in international governance: the move from decentralization, used to conserve centralized power, and towards "uncentralization" as a means to distribute power.

Developing countries also have a lot to learn from the galaxy of incentive mechanisms that help to mobilize individual creativity in the industrial parts of the world. Financial rewards are certainly important, but recognition of individual creativity by promotions, decorations and awards also plays important roles in many countries.

In a country like Sweden, with its long experience with the retrospective Nobel awards, I guess that it was natural to start thinking about the potential of prospective awards as a means to focus the attention of creative minds on innovations relevant to developing countries. Four major awards (a quarter of a million Swedish Crowns each) were consequently announced in 1976 for presentation in 1986. They were focused on inventions in the fields of water management, industrial activities based on appropriate technology, forestry, and energy systems suitable for poor countries. The experience gained (Een and Joste, 1988) underlined the significance of the "zooming" process in the selection of target areas, so this will certainly be an important feature of the next two rounds that aim for presentations in 1990 and 1993. The areas will then be the same, with the exception that agri- and aquaculture as well as fisheries will be added. Since the bioresource focus is so dominant, it can be presupposed that there will be a close cooperation between this effort and the BRDC initiative and especially with its BIXNET component.

Even if the stimulation of technical creativity is a very logical focus for efforts to upgrade agri- and aquaculture by means of modern biotechnology, the significance of social innovations that could pave the way for entrepreneurship must not be forgotten. Also in this regard the industrialized countries have devised methods that deverse attention in

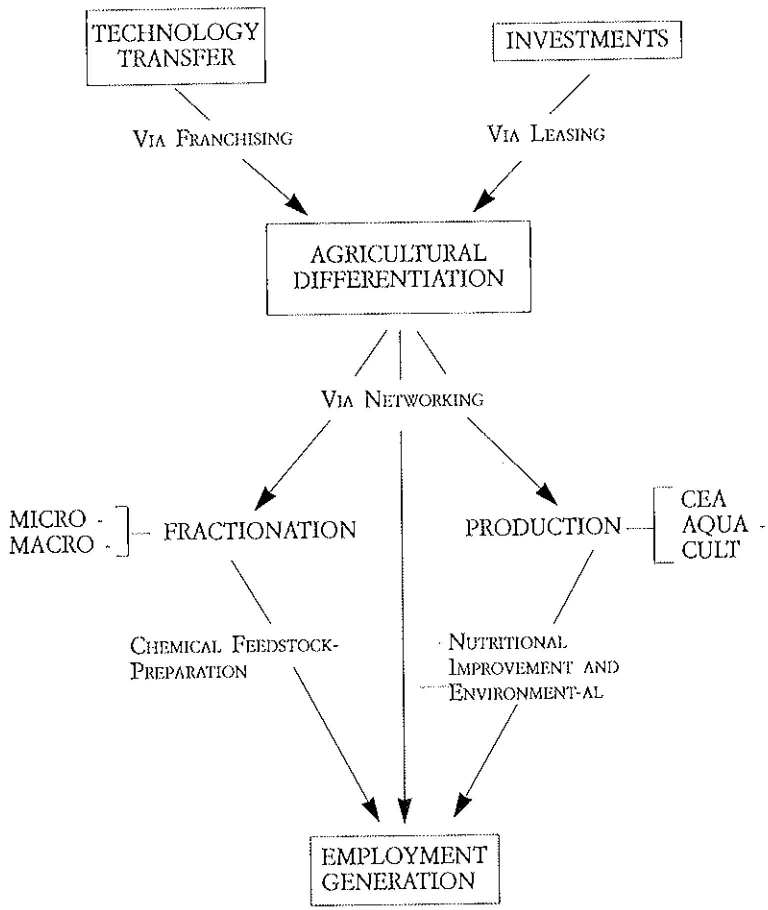

FIG. 4

the context of bringing the utilization of bioresources to bear on the socio-economic development in poor countries.

Two approaches (Fig. 4) deserve special attention as a means to generate employment (Hedén, 1987). One is leading as a means to provide the capital needed to inject the hardware necessary to generate a self-propelling activity, and the other is franchising as a method to couple education with product quality. In leasing, the gradual shift from dependence to ownership has an educational function and the same is true for franchising. The quick-food chains certainly would not have survived long if they had not spent as much effort on their human resources as on the raw material supply. Needless to say, such approaches however must be tailored to the culture in which they will be practiced. The experience with "putting out industries", for instance in the textile field, indicates that one will otherwise only see the middlemen prosper.

3. *Hardware.* Equipment for the utilization of lignocellulose as a chemical feed-stock (Hedén, 1986), facilities for Controlled Environment Agriculture (CEA), mobile refrigeration units as well as crushers for small-scale mineral leaching have all been suggested as objects for a hypothetical company (Develease) designed to adopt the leasing/franchising-approach to employment generation (Hedén, 1987). Under special circumstances they might all be relevant to a Coastal Desert programme, but I will here choose three examples that might more directly impinge on this focal area. They concern the production of seed inoculants to reduce fertilizer needs, the supply of shaft power to improve bioproductivity, and finally nutritional upgrading by means of fermentation techniques.

a. For almost 10 years one of the MIRCEN-laboratories ("NifTAL" = Nitrogen fixation by Tropical Agricultural Legumes), attached to the University of Hawaii, has received USAID-support to build up an impressive collection of nitrogen fixing microorganisms, carry out a number of training courses and develop a "package" for the production of seed inoculants. The latter consists of a simple fermentor, a fluorescent microscope and supporting laboratory equipmant matched to a special handbook. In relation to the potential of this technique for saving nitrogen fertilizer, the adoption has however been slow, and after a few years the product quality has occasionally been found to slide. A leasing arrangement, coupled to a franchising arrangement where the NifTAL seal would carry the same weight as "MacDonald" or "Burger King" might solve this problem. A successful operation might help to provide funds for an associated research programme concerned with soil microbiology in coastal deserts; The fact that one of the world's largest facilities for the production of microalgae (Cyanotech Ltd) is also located on Hawaii, makes it logical to consider the potential of cyanobacteria in such environments.

b. Some of the long-term research activities at the Environmental Research Laboratory in Tucson, Arizona, have concerned the evaluation of halophilic plants which can thrive under conditions of seawater irrigation. Prof. Carl Hodges and his colleagues have now carried out highly successful field studies with an oilseed producer (Salucornia) that is suitable for shore-line cultivation. It is of course tempting to speculate about its potential as raw material for a fish fodder production that might provide some fertilizer feedback to the plants. However, under all circumstances, there will be a need for shaft power for water pumping, threshing, milling and oil extraction and perhaps also for running the ammonia compressor of a refrigeration unit or for aerating an aquaculture pond. This brings the simple two-stroke crude oil engine, also called the ignition bulb motor or semidiesel, into focus (Thorén and Sporre, 1988).

This is a multifuel engine based on an 1897 American patent, and it is an excellent example of the type of technology that was left behind when cheap fossil fuels and electricity became available everywhere (except in developing countries!). However, it is simple to build and service, and it runs well on fuels like vegetable oils, wood tar and fish oil, and it is in fact without equal when operated with producer gas as the fuel. Its durability and reliability, which is caused by lower operating temperatures and speed (400-800 rpm) than used in diesels, was clearly demonstrated during the 1914-1918 period, when tar oils kept the engines running in the Swedish fishing boats, where it was actually the most common engine until the 1950s. This piece of hardware, suitable for bioenergy utilization, which could fill so many functions in the context of coastal desert development, is another object that might initiate certain leasing/franchising-arrangements. Some of the economic gains might then be directed towards research on agri-aquaculture integrations.

c. The third example concerns fodder production by means of protein enrichment with yeast grown on substrates such as molasses, sugar juices, fruit syrups, coconut milk, whey and starch. Such fermentations are normally regarded as economically infeasible, but this is largely because transport, sterilization and drying costs are standard elements in normal cost estimates. However, if solar drying can be used, for instance in the preparation of fish fodder, or if cattle, pigs and poultry can be fed the semisolid product as soon as the fermentation process is finished, the calculation gives a very different result. If fermentation processes are chosen that obviate sterilization (room for genetic engineering and ecological cross-protection!) and a fan is used for aeration rather than a compressor, the cost comes down even further. This approach has in fact been taken by the German firm Hoechst and UHDE (Pamphlet, 1984) in their design of a mobile and quite robust paddle-wheel fermentor for Single Cell Protein production in the 100-1000 Tons/annum range. Here again the leasing/franchising approch comes to mind as a means to make the entrepreneurs partners in goal-oriented research.

Concluding remarks.

In considering the bioproductivity potential of coastal deserts, the thoughts of course first go to fishing, and to the biotechnology involved in the processing, storage and transport of catches brought in from the sea, perhaps with the simplified boat designs developed by C. Seshadri and his colleagues outside Madras. Next one tends to consider the utilization of thrash fish and the management of the organic waste material that is derived from processing. However, as indicated above, both shoreline aquaculture, and the cultivation of selected halophytes, offer many new opportunities.

Wherever there is deep sea water (600 m. or so) available close to the shore, the temperature difference between the cold bottom water and the surface water might for instance be used either to run a turbine for generating electricity or a distillation process for producing fresh water. But, as demonstrated at the Natural Energy Laboratory of Hawaii, the cool and nutrient-rich bottom water is also a unique resource for sequential aquacultures. The cultivation of kelp (Macrocystis) in big tanks as a fodder for abalone, and the production of microalgae as a source of beta-carotin and fluorescent dyes can be cited as examples.

However, marine biotechnology has only just started to emerge as a new and dynamic field, so any concentrated activity aimed at coastal desert developments would be well poised to ride the crest of a new wave (Colwell, 1986). A concerted effort is however needed if developing countries are to reap some of the benifits. They should definitely regard their desert coastline as a resource for more than tourism and skin diving.

Let me end by saying that I am particularly pleased to give this talk in Italy, which has shown so much more foresight than most other industrial nations, when ICGEB was established in Trieste. The attention which was there recently given to women as a major development resource, and the Trieste Declaration of a network of Third World Organizations shows that mankind's race against time is not yet lost.

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AN AGRICULTURAL APPROACH FOR THE UPLIFTMENT OF THE QUALITY OF LIFE IN ARID LANDS

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Over half a billion people, about one-sixth of the world's population, live in dry lands, which comprise one-third of the world's land area. While most of the arid lands are in the less developed and poorest countries, the rate of increase of their populations is amongst the world's highest. A factor which intensifies the general stress and food shortage is the process of "desertification", which entails transformation — at a rate of some 50,000 km^2/yr in some areas (Schechter, 1985) — of productive land to desert of very low productivity. A vicious cycle is thus imposed: over-population coupled with occasional droughts results in excessive removal of land cover by wrong tillage practices, overgrazing and over-collection of firewood. The productive capacity of the available land plunges from bad to worse: resulting in an ever-increasing threat of malnutrition and famine. This situation raises a critical question: are deprivation and hunger unavoidable, a necessary evil, to which the inhabitants of the arid lands are fated?

The answer is clearly negative, for while the arid regions of our globe have definite and obvious disadvantages compared with the more humid regions which abound in primary productivity, the arid lands could be made much more productive. Thus malnutrition and hunger are in essence man-made, caused by general ignorance and a dismal lack of incentive on the part of the local population to create a social organization that will facilitate both higher production of food, and even more important, efficient and just distribution of food and supplies (Garcia, 1981).

Indeed, it is commonly agreed that the correct solution to eradicate food scarcity is by augmenting local production — either to make more food or, at worst, produce a marketable commodity to be exchanged for food. What is truly needed is assistance in a form that will enable those assisted to aid themselves and guide them to independent self-reliance. Such as ingenious aid may be possible by honest information-transfer. Indeed, much useful information is published and available through university and government-sponsored research throughout the world. It must be stressed, however, that transfer of technology from developed countries has quite a few pitfalls and is in itself no panacea for the myriad problems faced by the inhabitants of many dry lands. The bitter experience which is now generally recognized is that technology in itself, when simply imported from the developed countries, has a small chance to better life. Science provides a promising course that gives hope, not instant progress. In the societies to be uplifted through information transfer, very much depends on the way social justice is perceived, on the extent birth control is exercised, as well as on political unity and resolve.

Much progress has nevertheless been achieved in the past few decades in various aspects of arid-land development, providing ample evidence to demonstrate that guided by science and technology it is possible to take the unique features of many arid lands — which, untapped, spell low productivity and little hope — and exploit them in such a way as to make desert areas support a satisfactory standard of living. This "adaptive agriculture" encompases a useful approach for increasing productivity in arid lands. It calls for the development of production systems and strategies with which, on the one hand, the unique environmental conditions of the dry lands may be skillfully exploited, and which, on the other hand, do not harm the fragile ecological equilibrium.

In what follows, three basic themes will be considered: (a) exploitation and management of local water resources; (b) introduction, selection and genetic improvements of plant crops with high tolerance to drought and salinity, and of animal species well adapted to the environment; and (c) new biotechnologies to grow plants and animals, based on sophisticated exploitation of both saline or sea water as well as the unique environmental features characteristic of many dry lands:

(a) *Local Water*: runoff represents a local water resource which is usually wasted at the present. That was not always the case in the past: innumerable remains in the highlands of the Negev desert in Israel, for example, indicate the existence of extensive agriculture, from the Israelite period, 950 to 700 B.C. to the Nabatean and Roman-Byzantine period, which lasted up to 630 A.D. Each farm consisted of two parts, the farm proper (i.e., the cultivated area) and the catchment basin. Runoff was collected in channels that led it to the various terraces of the farm proper. The terrace walls kept part of the water standing on the field, where it slowly soaked into the ground. The surplus went through drop-structures in the terrace walls to the next, lower terrace, each hectare of cultivated land receiving about 3,000 to 6,000 cubic meters of runoff water per year. One to five floods could be expected annually, producing enough runoff to soak the loose soil of the cultivated farm area (Evenari *et al.*, 1971).

Another usually untapped, rich source of water in many of the world's deserts is ground water, aquifers containing fresh and brackish water having been found underneath many arid regions the world over. One well-researched example is the Nubian Sandstone, a thick, predominantly sandy sequence composed mainly of fine to coarse-grained sandstones (Issar *et al.*, 1972). This sandstone aquifer extends all along the northern margin of Africa, from Egypt through Libya to the western Sahara, and the water stored in this aquifer is estimated at a few hundred billion cubic meters under the Sinai and Negev deserts alone. Although only a small fraction of this water has pumpage potential today, this aquifer may develop to become of great economic importance. In Libya, such water is already well exploited.

Some of these desert aquifers are brackish, with salinities reaching up to 10 times and more of that present in normal irrigation water. In the USA, where non-saline ground water is being rapidly depleted, it is estimated that the quantity of readily pumpable brackish ground water amounts to the water holding of Lake Michigan, six times over (Myers, 1984). This water is not suitable for all conventional crops, but much of this water could be well used to grow salt-resistant crops in well drained soils, or in the future in closed systems and in algal and fish ponds. It is well to remember that although the resources of sweet water are dwindling the world over, there are large rivers in many arid lands, e.g., the Nile, the Indus, and the Tigris-Euphrates, which flow through large desert areas, being used only to a limited extent (Schechter, 1985). Indeed, in many dry lands the world over, sweet water flows away unused, while deprived populations nearby are helpless in using this water to produce food.

A method that rapidly expands efficient usage of water, including marginal water, and that has already substantially increased production in arid lands around the world, is based on the concept of applying water in small amounts over a long period of time. The concept, which is now called "trickle" or "drip" irrigation, has proved to be particularly useful in arid areas (Kobe, 1977), particularly if used to supplement chemical fertilizers. The method has beneficial effects on crop growth, overcoming most of the limiting factors for plant growth in hot arid lands and resulting in a substantial saving of irrigation water.

(b) *Introduction of new crops*: selection of crops tolerant to drought and soil salinity for cultivation in arid regions is still in the early stages, but research has already singled out some species of seemingly great potential for the arid lands, one of which is the Jojoba (*Simondsia sinensis*), native to the southwestern United States and northern Mexico. Its seeds contain a liquid wax that seems to have an impressive industrial potential. The plant tolerates extreme desert temperatures and thrives under relatively low soil moisture conditions which are not suitable for most agricultural crops.

Another example of a promising desert shrub of seeming industrial potential is the Guayule shrub (*Parthenium argentatum* Gray), which grows in desert regions of north-central Mexico and southwestern United States. All parts of the shrub contain rubber similar to that collected from Hevea trees. A potential source of rubber for arid lands, it may grow in poor desert soils.

Much progress has been made in the development of drought-resistant fodder crops into commercial entities. The Australian salt bush (*Atriplex nummularia*), in particular, merits special attention, being very useful in areas in which rainfall is about 250 mm. The spineless cactus (*Opuntia spp.*) is another fodder crop of great potential for the 100 to 200 mm rainfall areas. Spineless cactus possesses the exceptional characteristic of being able to store large quantities of water in the succulent parts. Aptly called "camels of the plant world", these cacti can benefit from a shower of only a few mm, which would ordinarily be of no value to conventional fodder crops (Forti, 1971).

The jojoba, buffalo gourd, salt bush, spineless cactus, and guayule illustrate the great potential in systematic plant-introduction, which involves import of plants from many arid lands around the world and testing their performance in a particular arid region. The most physiologically-adept species would then be further selected for economic performance. This promising field is yet greatly unexplored, and Norman Myers (Myers, 1984) mentioned the aborigines in Australia who have been gathering a great many drought-adaptable plants, favouring certain yams, well adapted to dry conditions. Likewise, the yeheb nut bush from Somalia (*Cordeauxia edulis*), as well as a marine plant from the west coast of Mexico (*Zostera marina*) may be other species of promising potential for dry lands (Myers, 1984).

Afforestation is most important for many arid lands, where wood is collected for energy and where extensive deforestation has been causing soil erosion and desertification. Wood growth in such lands is limited to drought-and-salt-tolerant tree species, planted in riverbeds and in especially constructed terraces (Richmond, 1985) in which water accumulates following a flush of rain. Thus, there is to date ample tested information concerning strategies and tactics by which to augment the food production potential of many arid lands, and the future seems even brighter.

(c) *Recent developments*: concern agricultural biotechnologies of outstanding possibilities for great enhancement of agricultural production on our planet. Many arid regions, which are albeit devoid of sweet water, abound in solar irradiance and high daily temperature throughout most of the year, and this holds special advantages for some of the novel approaches to food production. Plant geneticists and plant breeders have been using, at an ever-increasing momentum, techniques which are commonly regarded as "bioengineering". Plant tissue culture has become, in particular, an essential complement to plant selection and breeding, replacing tedious and time-consuming field work (Heden, 1985).

An altogether different mode of bioengineering which is advancing rapidly and opens new frontiers in animal husbandry concerns fertilization in vitro and freezing and transplantations of embryos. Sex can be determined in cattle embryos six days after fertilization, increasing the efficiency of dairy and meat production (Buttel, 1984). These techniques may greatly aid animal husbandry in arid lands of harsh environments.

A particularly interesting biotechnology for arid regions involves specially designed enclosures for the production of plants which will benefit from the intensive solar irradiance, particularly in winter, and in which water will be conserved and only a limited and controlled exchange of the gaseous environment inside with the outside air will take place. Therein lies the challenge to optimize the environment of plant-growth at an acceptable cost. Saving in water use represents one obvious advantage in this closed-system agriculture. Other advantages include the possibility of adding CO_2 to enhance growth and of heating the plants at night using the heat accumulated and stored during the day, as well as the increased resistance of many plant species to saline water. Consequently, locally available brackish water may be well used for closed systems, especially if diluted with solar-distilled water (Gale, 1979).

Still another interesting tactic for optimal use of water resources in warm deserts is intensified fish growth in controlled systems. This may be acomplished by raising a high concentration of fast-growing warm-water fish in relatively small volume tanks. The fish tank waste water would in turn be treated, recycled and reused. The local water for many species of warm-water fish could be brackish, of low alternative usages.

An innovative approach to agricultural production in arid lands entails production of warm-water salt-tolerant microalgae (Richmond, 1983). The general concept calls for the use of the high rate of solar irradiance and the high temperatures prevalent in many deserts throughout the year, coupled with locally available saline or even sea water, i.e., water not suitable for the production of most useful land plants, to grow algae. Conditions and resources which are in effect limiting to growth and development of conventional agricultural crops are conducive to the growth of many algal species, conferring a specific advantage on algaculture in arid zones.

In conclusion, it is evident that misery and low quality of life which so often are the lot of people in the arid lands are not simply necessary evils imposed by the harshness of the environment but are man-made and may thus be resolved in principle (Garcia and Spitz, 1986). Considerable knowledge exists concerning arid land management, which is related to the utilization of water, plant and animal introduction, and the development of new biotechnologies. Information transfer, however, will be fruitless unless an educational process — involving at least some change in social patterns — takes place. It is essential to realize that the obstacles to be overcome in order to improve the quality of life in arid lands rest just as much on the social and political structure of the society which needs assistance, as with the harsh environment or the callousness of the affluent societies (Richmond, 1987).

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SMALL, MEDIUM, AND LARGE FARMING SYSTEMS: IMPROVING PRODUCTIVITY AND ENSURING SUSTAINABILITY

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Traditional farming systems have been based on low input practices responsive to prevailing agroecological conditions. While productivity may not be great, practices such as slash-and-burn cultivation and transhumant grazing are not inherently deleterious to the sustainability of natural resource base. Unfortunately, pressures from the rapidly growing human population have so modified traditional practices that they often become instruments for environmental degradation through deforestation and desertification. Replacing traditional low input practices with high input practices is not necessarily the answer. Too often, increases in productivity are at the expense of eroded soils, agrochemical pollution and exhaustion of ground water supplies. Neither size of farming system nor level of inputs guarantees that the twin goals of increased productivity and sustainability will be achieved.

Strategies for improving productivity and ensuring sustainability must take into account the agroecological and socioeconomic factors and their interactions which affect the system. What is appropriate for capital-intensive, high-input farming systems in temperate regions is not likely to suit needs of small-scale, low-input farming systems in the tropics. In this paper, we discuss how classifying farming systems according to both agroecological and socioeconomic environments can lead to more effective agricultural development strategies. To be effective, these strategies should aim to feed today's generation without depriving tomorrow's generations.

Balancing food Supply and Demand

Today's global population of five billion is expected to double by the middle of the next century (Brown, 1987). Continuing increases in human population leads to continuing expansion in the demand for food production from available agricultural resources. These population increases are disproportionately skewed toward less developed regions of the world. While annual growth rates for many developed countries have fallen below 1%, growth rates for less developed countries exceed 2% annually, even 3% for many African nations. As we enter the next century, meeting the food needs from local resources will become increasingly difficult in South Asia and Africa.

Shifting Attention from High to low Productivity Environments

Attaining self-sufficiency in basic food production throughout the less developed regions of the world continues to be a goal for many in the international development community. A solution seemed at hand during the "Green Revolution" of the 1960's. Adoption of high yielding varieties and complementary agronomic management technologies have increased rice and wheat yields several fold in many countries. However, these advances in food production tended to be best suited to hightly productive, irrigated areas and tended to disproportionately favor larger scale farmers, who could more readily obtain information and credit, risk venture capital, and exploit commercial markets.

Small-scale commercial and subsistence farmers in less favorable production environments were slow or unable to benefit from the Green Revolution. They have often been negatively affected when the rapid increase in the supply of basic grains caused market prices to drop. Furthermore, the transfer of Green Revolution technologies and strategies from Asia to other food-deficit regions, such as Africa, has not had the same impact on food production. Green Revolution technologies are best suited to optimal growing conditions in countries with the necessary infrastructure of government services (i.e., agricultural extension, credit, input supply, etc.). It has become increasingly apparent that the development issue is not the "production potential" of the technologies, but rather their "appropriateness" for more marginal production conditions and for farmers with limited resources.

Sustainability for the longer term is a major concern. With the highly productive sites already in agricultural production, cultivation for food production progressively encroaches into the more marginal and fragile environments with less production potential. Policy makers and development managers are now faced with decisions on how to accelerate food, fiber, and fuelwood production in less developed countries without harming fragile environments. More than half of the arable land in Africa is considered marginal for cultivation and especially subject to degradation. Traditional practices, such as charcoal making and shifting cultivation, are no longer sustainable. Instead attention must be directed to pasture husbandry, tree farming, and watershed manage-ment.

Stratification of Production Units

Generalizations regarding agroecological and socioeconomic production potential are fundamental to the formulation of appropriate agricultural development strategies. Classification criteria for identifying producer groups include:

— Agroecological endowments,
— Resources distribution (i.e., size of landholding, access to production inputs and markets, arable land per capita, etc.),
— Degree of commercialization along a spectrum from subsistence to commercial farm management,
— Nature of the production systems (e.g., annual monoculture cropping, polyculture cropping, mixed crop/livestock/tree, or perennial livestock or tree systems),
— Type and extent of input utilization; e.g., ranging from labor intensive to capital intensive.

There is a general progression of farming systems from annual cropping to perennial tree and livestock production patterns as the agroecological endowment declines and size of land holding increases (Figure 1). Implicit in this typology of farming systems is the requirement that the farming systems must meet family needs for food and income. Otherwise the systems is unstable and not sustainable.

Polycultures are primarily in the tropics with monocultures more prevalent in temperate developed regions. Mixed crop/livestock/tree systems tended to be the norm for family farms in temperate regions until the middle of this century. Grazing livestock on ranches and communal lands in low rainfall, non-irrigated areas requires large expanses of land. At any one time, the land cultivated by a single household is small in the forest fallow system. However, for this system

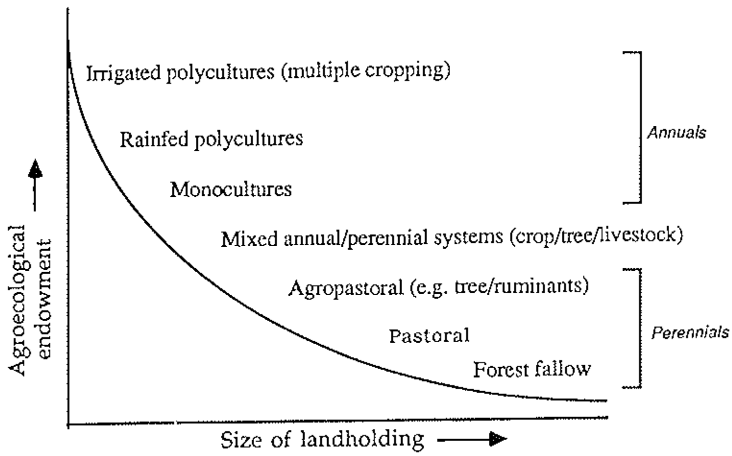

FIG. 1. Distribution of agricultural production systems by agroecological endowment and size of land holding.

to be sustainable, the household must have access to large land areas to allow lengthy fallow periods.

A second approach uses statistics based on arable land per capita to compare "man-land" ratios between regions. Figure 2 illustrates such a comparison, highlighting the much greater population density of Asia compared to sub-Saharan Africa. However, this graph approach ignores problems arising from current rapid population growth rates in Africa and the fact that over half of the arable land in Africa is of marginal production potential because of poor soil quality and low, erratic rainfall.

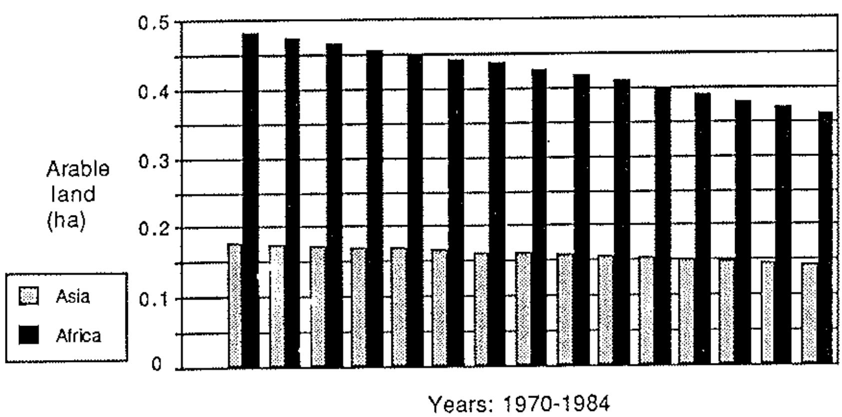

FIG. 2. Comparison of mean arable land per capita for Asia and Sub-Sahara Africa (1970-1984).

TABLE 1 - *Classification of Farms by Size of Landholding in Bangladesh and Zambia.*

Classification	Size of landholding (ha.)	
	Bangladesh[1]	Zambia[2]
Small	0.5-1.0	5.0
Medium	1.0-2.0	5.0-40.0
Large	> 2.0	> 40.0

[1] From On-farm Research Division, Bangladesh Agricultural Research Institute, Jamalpur, Bangladesh.
[2] From Adaptive Research Planning Team, Ministry of Agriculture and Water Development, Lusaka, Zambia.

Comparison of regions or subregions based on size of average landholding overlooks land use potential. For example, the agricultural resource base in Bangladesh supports much greater food production per ha than in Zambia. Consequently, it is not surprising that the definitions used to define "small landholding" vary between the two countries (Table 1). Furthermore, countries or regions within a country also differ greatly in terms of farmer access to credit, technical assistance, and markets.

Stratification that combines both agroecological and socioeconomic indicators can provide a better basis for development planning. The Food and Agriculture Organization (FAO) has established a stratification matrix to estimate the potential food production that can be sustained at low input, intermediate input, and high input levels of technology for agroecological cells within each country (Higgins *et al.*, 1982). While this approach is not a good indicator of future agricultural production, it does provide a standardized basic for comparing food production between countries.

The incorporation population density considerations allow an estimate of "agroclimatic population density" (Binswanger and Pingali, 1988). Table 2 illustrates the application of this technique to sub-Saharan Africa. The greatest portion of the sub-Saharan population is already in the intermediate climatic zone. Future population growth will therefore place increasing pressure on the less favorable humid and arid zones.

TABLE 2 - *Percentage Distribution of Sub-Saharan African Population by Agroclimatic Population Density.*

Climate	Low	Population Density Medium	High
Humid	8.9	0.9	0.3
Intermediate	12.8	22.1	46.3
Arid	0	1.8	7.1

Source: Derived from Binswanger and Pingali, 1988.

Agricultural Development Strategies

The three principal mechanisms for increasing agricultural food production include:

— expanding cropland (i.e., increase acreage),
— increasing yield (i.e., increase productivity/unit land area),
— intensifying land use (i.e., diversify).

The typical approach has been to expand land area under cultivation. Throughout history, the need for opening new land areas has stimulated major migrations, which have relieved pressure on land already under cultivation. There remain large expanses of untilled arable land. In Africa, less than 25% of the potentially arable land is cultivated. However, much of the remaining higher potential land is in the tsetse fly belt, where trypanosomiasis is a threat to man and his animals. Outside Africa, the expansion of cropland is limited by the availability of land. In 1975, 63% of the population of the Third World lived in countries in which more than 70% of the potentially arable land is already being cultivated (Brown, 1987).

The successes of the Green Revolution demonstrate the potentials for increasing yields. However, in spite of the introduction of agrochemicals and high-yielding varieties, the average cereal crop yields in Africa have actually declined over the last decade. Overall, the annual percentage growth in world grain output per capita has dropped from 1.2% during the period 1950-1973 to 0.4% during the period 1973-1986 (Brown, 1987).

The characteristics of several important farming systems classified according to level of primary input and agroecological endowment are shown in Table 3. In many developed regions, the high value of agricultural products combined with industrial demand for labor leads to capital-intensive, mechanized, high-input agriculture. The first quadrant is representative of temperate developed regions, where relatively few farmers produce food and fiber for the urban majority. Capital-intensive systems compensate for poor soil fertility and water with fertilizer and irrigation development. Where cropping is not practical or profitable, livestock ranching and industrial forestry predominate.

Labor generally has low opportunity cost relative to capital in most developing regions (Ruthenberg, 1985). In highly productive agroecological zones, small mixed farm systems utilize multiple cropping and intercropping to increase food production. Livestock is often an important but underrated source of draft power and manure, as well as food and income. Along with small farms, large estates producing export crops (coffee, tea, rubber, etc.) are important employers of agricultural labor. However, small landholders in resource-poor, capital-deficient regions have fewer development options. Under these conditions, subsistence agriculture and off-farm employment is the norm.

Potentials for improving productivity and ensuring sustainability of farming systems varies greatly among these classifications. Greatest progress has been made for farming systems in the resource-rich, capital-intensive situation. Biotechnology and other developments offer promise of further gains in productivity. Public awareness of environmental

TABLE 3 - *Characteristics of Principal Farming Systems.*

	Agroecological Endowment	
Input Level	Resource-Rich	Resource-Poor
Capital-intensive	Commercial, medim to large scale farms Mechanized, high input Intensive dairy, poultry swine	Commercial, large scale Agrochemical inputs Irrigation Ranching, industrial forests
Labor-intensive	Semi-commercial small to large farms Intercropping, export crops Mixed crop/livestock Agroforestry	Subsistence agriculture Stress tolerant crops Scavenger livestock Utilize communal lands for crazing, woodlots Multipurpose enterprises

problems is leading to effective political action to ensure sustainability. In resource-rich developing regions, there is excellent potential for improving agricultural productivity and quality of life. Unfortunately, rapid population growth and political instability often limit the achievement of potentials.

Resource-rich farmers have the ability to commercialize production by using capital-intensive technologies, whereas resource-poor farmers must focus on maximizing returns to labor invested in improving their productive resources (e.g., using lime, fertilizers, irrigation, mechanization, terracing, etc.). While farmers with ample land and labor focus on diversifying and intensifying production, the goal of "part-time" or "landless" farmers with limited land and capital resources should be to maximize returns to the scarce resources through multipurpose tree crops and livestock (e.g., dual-purpose goats convert crop residues and other low value feedstuffs to meat and milk).

Conclusions

The environmental dimension of agricultural development will be a central theme of policy makers in the next decade, especially in relation to development strategies for different strata of the farming sector and for fragile environments. While the major increases in food production may continue to come from the better soils in the higher rainfall zones or with supplemental irrigation, the challenge of sustainability is more critical on marginal lands with low productivity. The panacea of the Green Revolution fades under these conditions. Technologies are needed that recognize soil and water limitations, biomass dissipation, the role of livestock and wildlife, and the interrelationships between crops, livestock, and wood products.

Poor people and their agricultural systems should not be blamed for environmental degradation if they do not have access to other economically viable alternatives. In fact, the traditional farming systems which appear outdated actually use few expensive external inputs, accumulate and cycle natural nutrients effectively, and rely on genetic diversity to minimize production risk. The content of new technologies must consider these factors along with the social and economic costs and benefits associated with technological change in agriculture in marginal environments. The challenge of the next decade is to produce more food to meet increasing demand while maintaining the quality of the environment and, hence, the quality of life for future generations.

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TRADITIONAL SYSTEMS OF SOIL CONSERVATION

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In 1979 the International Federation of Institutes of Advanced Study asked me to initiate an enquiry into whether there were social or economic constraints that were preventing the use amongst the small farmers of the Tropics of the knowledge on soil conservation and on the maintenance of soil fertility that had come to light during the last 50 years. The enquiry extended over fifteen countries, with answers to detailed questionnaires being obtained in ten of them.

During the course of the study it was observed that in many parts of tropical and sub-tropical world, systems of soil conservation were being practiced that followed all the principles that had been discovered in modern research. The interest of these observations lay in two aspects, the systems had often been practiced for more than a thousand years, but in many parts they were falling into disuse.

The systems fall into five different categories, three of which provide physical barriers to the movement of soil downslope, while two provide some protection against the shattering action of raindrops. The first group, in which banks or walls are built to restrain soil movement have been found in Asia, Africa, Europe, North and South America and in Oceania. Their occurrences in Oceania, however, were restricted to the islands, and none were built in mainland Australia until the modern conservation developments of the mid-twentieth century.

It is not clear whether they were built first in eastern or in western Asia. The earliest account of a conservation practice is in a Chinese classic "The Book of Songs" (Fang, 1985), but Chinese farmers must have been using terraces long before then, for pottery models ecavated from the ancient tombs of the Han dynasty (2500 to 2240 B.C.) demonstrate the widespread existence of terraces in those times.

The oldest terraces in western Asia are about nine kilometres west of Jerusalem, and are associated with Iron Age artefacts. These terraces are particularly interesting in that they are built on successive layers of horizontally bedded sedimentary rocks which, with a bank built on the edge, formed natural terraces (Fig. 1). Similar levelled terraces, though not always on horizontally bedded rocks, and invariably irrigated with spring water, are associated with 87 out of the 101 springs in the Israel section of the Judean mountains. At least 88 springs in the Hebron mountains and the Bethlehem area are exploited in the same way. In the terraces themselves 8th Century B.C. ceramics have been discovered, but no earlier pottery, which suggests that the initial construction of the terraces was probably about that time. Similar irrigated terraces extend eastwards to the entrance of Petra, on the edge of the desert (Plate 1:A).

There is a difference between the two systems. The stone terraces in China were apparently built, and are still being used, for dryland crops and tea, orange and mulberry, as well as for rice, whilst those in western Asia are most commonly used for irrigation.

A very extensive system of irrigated terraces occurs in the Yemen,

FIG. 1. Ancient terraces on horizontally bedded rocks, nine km west of Jerusalem (Photo Edelstein).

in that part of the Arabian peninsula known to the Romans as *Arabia Felix*. Water is carried to the terraces, or carried away from those areas that may receive an excess, through a sophisticated canal system. The canals are lined with stones, and often run under the terraces. They vary in size, and where they run beneath the terraces only their outlets and inlets may be visible (Plate 1:B). The Yemen terraces are level bench terraces, with a small earthen bank on top of the stone wall, analogous to the Chinese terraces, which retain most of the rain that falls on them (Vogel, 1985). In the area from which these terraces have been described both irrigated and rain-fed terraces occur above 2200 m. above sea level the natural rainfall must be sufficient for some crops. At lower altitudes only the irrigated terraces are found, where presumably the smaller quantity of rainfall requires to be supplemented if adequate growth is to be obtained.

The most extensive areas of irrigated terraces are those of the central Andes, with a million hectares of such terraces in Peru alone, many of which have now fallen into disuse. They extend generally through the lands of the former Inca Empire, with extensions into pre-Columbian Mexico. These terraces, which are mostly pre-Inca in origin, are constructed on slopes of up to 60 degrees with some of the most remarkable examples, nine metres or more tall, occurring in the long lost city of Machu Pichu. At the time of the Spanish invasion the inhabitants referred to the terraces as "*andenes*", from which the name of the mountain range itself — the Andes — was probably derived. Although the irrigated terrace system is being used as it was originally planned to be used, for example in parts of the Urumamba valley near Cuzco, and quite widely in the Colca valley (Plate 2:A), in other parts the inhabitants have forgotten how to use the structures that their ancestors built (Cusichaca, 1984).

The irrigated terrace culture occurs in Central and North America, and its extent has been documented by Donkin (1979). It appears to have spread into what is now the southwestern United States between 100 B.C. and 1400 A.D. and is consequently entirely pre-Inca. The best examples still in use are around the Hopi setlement at First Mesa (Stewart, 1941), but the culture probably ended in Colorado by 1300 (Hewitt *et al.*, 1913).

In Africa stone terraces have been observed in Ethiopia (Hurni, 1985), Zimbabwe (Stocking, 1984), northern Cameroon (Nye, 1985), and Uganda (Odiambo, 1988). The Ethiopian terraces contain carbon dated 1350 and 2450 B.C.

It is interesting to speculate whether these similar systems spread

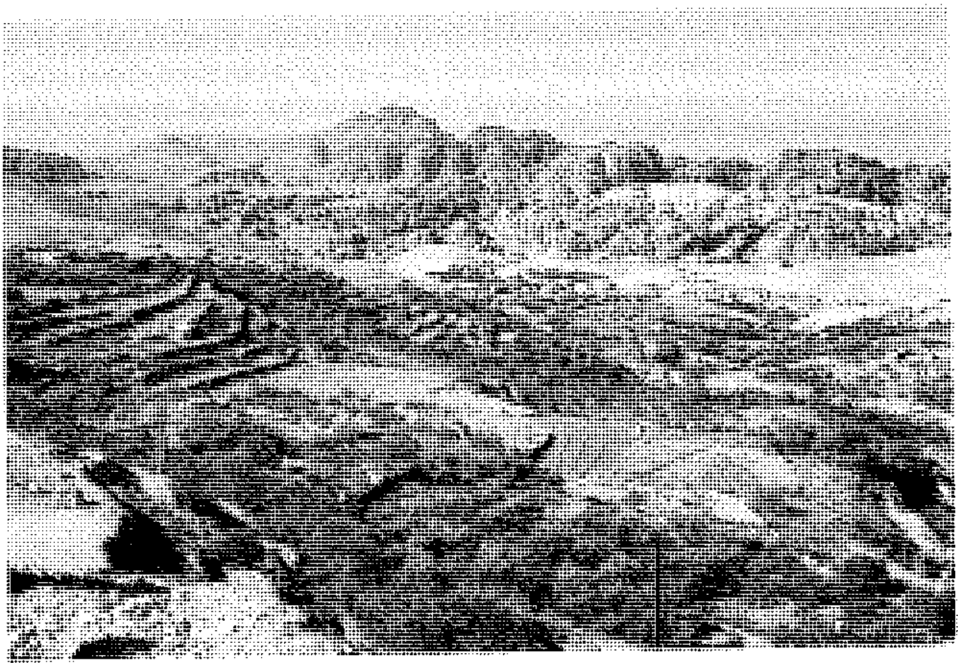
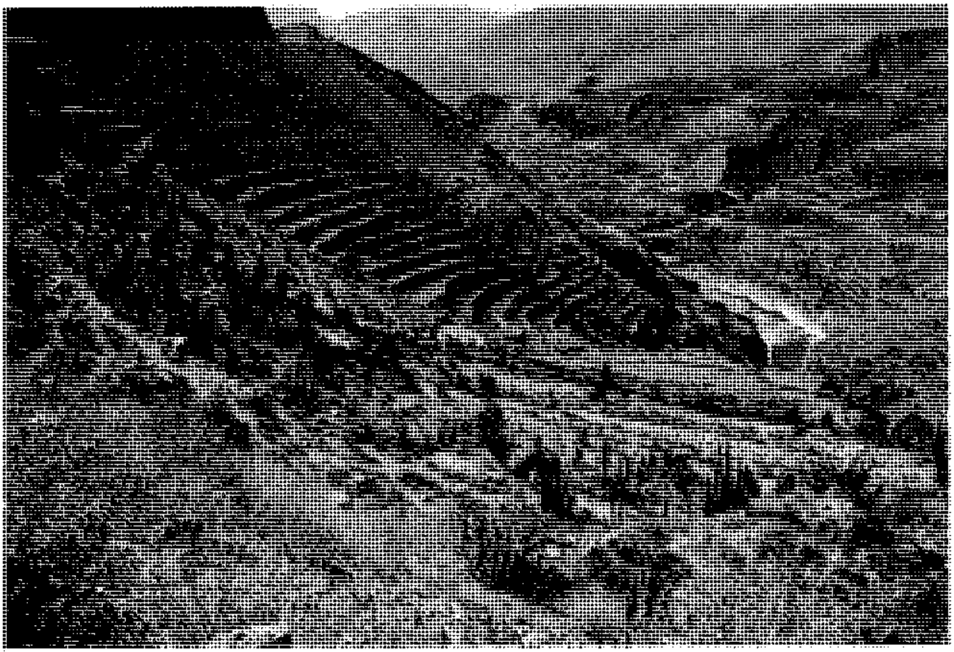


PLATE 1:A. Stone terraces at the entrance to Petra, Jordan (Photo E.G. Hallsworth).

PLATE 1:B. The entrance to an underground canal in the Yemen at Manakhah (Photo H. Vogel).



PALTE 2:A. Irrigated terraces in the Colca Valley, Peru, below the Condor National Park (Photo E.G. Hallsworth).

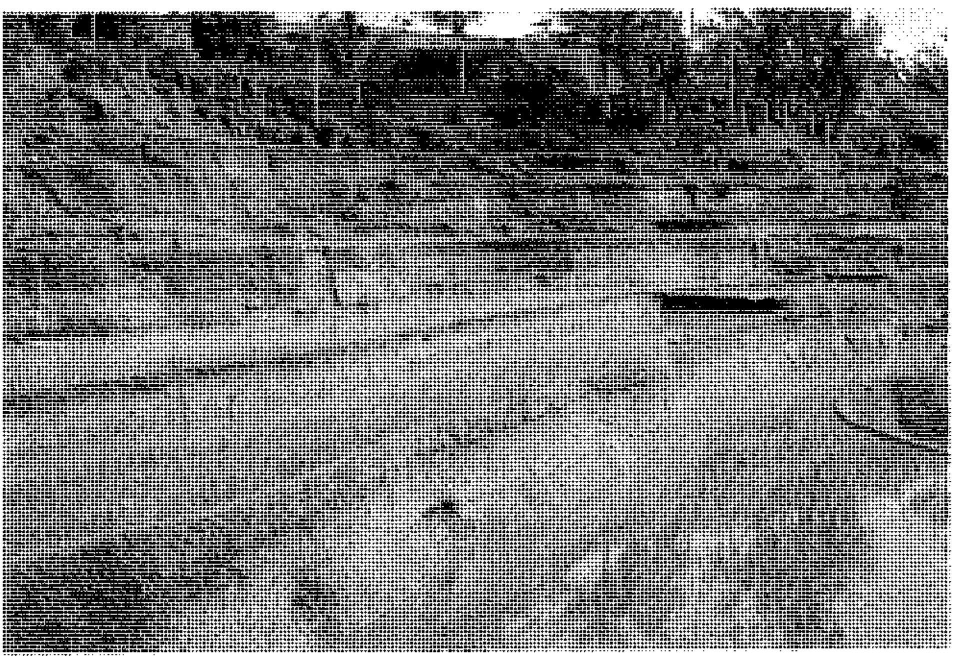


PLATE 2:B. Soil-built terraces in Bali, Indonesia, built on a slope of 30°, with rice in the bay and coconut trees on the banks (Photo E.G. Hallsworth).

from their earliest examples in western Asia, or whether they represent the spontaneous attempts of man in different parts of the world to overcome the problem that was facing him. Heyerdahl (1978) has pointed out the importance of the oceans (and of rivers) as means of communication and culture contact for early man. Assuming that the irrigated terrace culture had spread from its origin in Palestine along the shores of the Mediterranean, through the Straits of Gibraltar and down the Barbary coast, Heyerdahl's own voyages in *Ra I* and *Ra II* across the Atlantic have shown that the culture could have spread to Central America. The carriers of the culture could have crossed the Isthmus of Panama with no more difficulty than did the Spaniards of Pizarro's time, and on sailing south from Panama, they would have come across a desert coast crossed with rivers, and so capabable of being irrigated using the irrigation technique familiar in their Egyptian or Sumerian homelands. Beyond the desert coastal strip were the semi-arid mountains of the western Andes, only capable of cultivation using the irrigated bench terraces so exquisitely developed in *Arabia Felix*. From Peru, the culture could have been carried on rafts similar to Heyerdahl's *Kon-tiki* to Easter Island, for on Easter Island are found similar terraces, as well as pediments on which the great stone moies stand, in which the stones are cut with the same precision as is shown in the lower layers of the pre-Inca stonework at Cuzco. The only date available at the time of writing for the Peruvian terraces is 1400 yr B.P., which allows time enough for the culture to have spread from the Iron Age terraces of western Asia.

The voyagers from the Mediterranean probably landed, as the voyage of *Ra II* suggested, on the coast of what is now Guatemala, where stone terraces are also found. Northward lie the great irrigation systems of the Maya Empire in Yucatan, and from there too, the irrigated terrace culture extended along the semi-arid belts fringing the central basin of Mexico, and of the Sonora and Chihuahua deserts and into what are now Colorado and New Mexico.

In Ethiopia and Uganda, the culture could have spread up the Nile from Egypt, whilst for Zimbabwe the culture could have spread down the coast of East Africa and up the Zambesi river with the traders from Arabia. The culture could have spead easily along the coasts of south Asia. The builders of the great 1000-year-old terraces of the Philippines were the Ifugao people, who, legend has it, came in from the sea. But clearly, they could equally well have come south from China as east from Asia. It seems reasonably certain that the technique did not reach western Asia from Peru, for although Heyerdahl's voyage on the *Kon-tiki* showed that the pre-Inca culture reached Easter Island and the Marquesas, it does not seem to have reached Fiji and certainly not Papua-New Guinea.

The pattern of a possible spread around the world from western Asia does not accommodate the very extensive stone terraces of China. The Chinese records suggest that terrace building in China was at least contemporaneous with that in western Asia, and possible pre-dates it.

The Soil-Built Terraces

The second category of traditional terraces is that in which the terraces are built of soil. They occur widely throughout southeast Asia, from India and China, extending through the Indonesian island chain as far east as Bali. They also occur in Ethiopia and Burundi in eastern Africa, and in the sub-Sahelian areas of western Africa. In Bali they are used on slopes of up to 30 per cent (Plate 2:B), in Assam on slopes up to 10 per cent, whilst on the Deccan, with the increase in the availability of water for irrigation in the last thirty years, they have spread widely across the landscape. They are efficient in controlling erosion, and their use results in greater yields of rice. In the SOS enquiries in Assam, although 100 per cent of the farmers questioned used the technique, none of them used it as an anti-erosion measure. It was part of their tradition, and the technique of building the banks (or bunds) had been handed down from their forefathers.

In Assam the bunds are constructed by piling soil or clay to a height 30 to 45 centimetres. They are then strengthened by mixing them with soda, which makes the soil sodic, and gives a sufficiently strong structure to resist erosion due to flooding or heavy rainfall. The height of the bunds varies between 30 and 120 centimetres, depending on the slope and rainfall (Fig. 2). The bunds in Assam are not used for irrigation, but for the growth of rain-fed rice. Since the soil is puddled, and the area is divided into small fields, the bunded area can hold water for the period between successive rains. In southern India they are used for rice under irrigation as well as for dryland crops of maize, etc. In Bali the bunds are built in much the same way, but since the soil is lateritic in character no soda is required. Rice is grown on the terraces under irrigation, with water from a stream being fed into the highest terrace and them successively into the lower terraces through a series of spouts cut in the bunds.

FIG. 2. Earthen bunds being used for the growth of rain-fed rice, Assam (Photo A.K. Roy).

The Use of Contour Drains and Cultivation Across the Slope

On the andosols of the Alto Plano, north of Bogota in Colombia, the farmers use trenches cut across the slope to take excess water away. To improve the operation of these, small logs are placed at intervals across the drain, which act as small dams, holding up the flow of water and producing a system very similar to the cross-tied contour banks advocated for certain parts by the U.S.D.A. Conservation Service.

This practice is usually associated with the traditional practice of mixed cropping, rather than monoculture. This has the effect of never leaving the soil bare of vegetation, and consequently provides protection against the action of raindrops. In the Valle de Tenza, Colombia, a long isolated Indian community uses mixed cropping, and plants all the crops on the contour, with trenches cut as drains across the slope. As in Assam, the practice is traditional and was learned from their ancestors. Most of the farmers use the practices without realising that they are soil-conserving. One effect of the failure to appreciate this was illustrated when a new crop, tomatoes for the Bogota market, was introduced in

1980. They were grown in monoculture, planted up and down the slope, and in three years the beginnings of erosion had become evident!

The Use of Plants and Plant Debris

The use of plant debris, or of lines of plants, constitutes the third category of techniques that provide mechanical obstruction to overland flow. This is done very simply but very deliberately in Papua-New Guinea, where in the Milne Bay Province casuarina logs are laid on the contour to allow cropping on the steep slopes. As well as the use of tree trunks as terrace banks, the use of what in agro-forestry are termed "live fences" is quite common. These are allowed to grow into quite thick hedgerows which not only protect the soil but also supply timber for farm use (Fig. 3). This is an independently developed system of agro-forestry.

An analogous practice is found in the Batangas region of the Philippines. This is to grow a row of bananas across the field at right

FIG. 3. "Live" fences that have grown into hedgerows, Tari, Papua-New Guinea (Photo J. Powell).

angles to the slope. Soil and vegetable debris accumulate at the base of the banana plants and so provide a barrier to further soil movement. The fields in this part of the Philippines often run up-and-downhill. Where no banana strip has been planted, it is not unusual now to see gullies running the length of the field, whilst the field alongside, with banana strips reducing the length of the slope to two or three pieces, half to one-third of that in the neighbouring field, is almost without erosion. No advice is tendered by the extension service on the use of this practice, the technique has been handed down from father to son.

Over much of tropical Africa the pressure of populations has not been sufficiently great to prevent the traditional method of slash and burn from both holding the soil and maintaining its productivity, (see chapter by Dr. Hartmans). Sporadically across the contintent there are little patches of country in which quite highly effective practices have evolved. One of these is the Matengo pit system developed by the Wamatengo tribe in the highlands between the Ungoni plateau and Lake Nyassa.

In this system the Wamatengo men cut the grass and lay it in rows forming a grid, with one set of rows roughly along the contour. The rows are two to three metres apart, depending on the quantity of grass and the depth of the soil. Cultivation is done by the women. The soil in the squares is dug out and put on the grass, the cultivator working around each square in turn. Thus one-quarter of the work is done pulling the soil uphill, and half the work is done standing sideways to the hill slope. This prevents denudation of the hill slope. Digging continues until the subsoil is exposed at the centre of each square. Up to a square metre of subsoil is exposed in each pit.

Storm drains are not made if the hillside is cultivated to the top, but where the hilltop cannot be cultivated a storm drain is usually made above the cultivated land. The crops are planted on the raised beds, clean weeding is the rule, and the weeds are thrown into the pit where they form compost. At the end of the season the crop residues are also thrown into the pits, the old soil beds are split and new beds formed over the old pits, the new pits occupying the places where the beds intersected. The technique is simple, even heavy downpours are fully trapped, and the water sinks gradually into the subsoil (Stenhouse, 1944).

A slightly different system has been developed by the Erok tribe in the mountainous country between the Rift valley and the Yaida and Eyassi depressions (Hartley, 1938). The Erok are a small, not very warlike tribe, under pressure from the M'sai on their northern flank. Conservation starts with the construction of a storm drain across the upper side of the area, followed by pulling down soil from a face about a metre deep, and the provision of a Kikuyu grass verge. The land is deeply cultivated with a long digging lope, leaving a broken surface to weather during the cold period. With the advent of the rains and higher temperatures the land is contour planted with (say) maize, while a strip of pumpkins is established on the lower side of the terrace as additional protection. At hoeing time the ridges are commonly re-inforced. When that crop is harvested (in May), the cultivator chops up the maize stover and lays it evenly over the field, giving an almost complete mulch cover. When the next cultivation takes place, the maize stover is drawn into lines starting at the lower side of the terrace, then ridged over and the seed planted at once between the ridges. In the process of ridging, the soil is gradually pulled downhill, and slowly, season by season, a terrace is formed.

In Sierra Leone in West Africa, the scene is slightly different. The treatments which provide a mechanical impedance to water flow involve the construction of bunds made of sticks and/or stones. The stick bunds are made by collecting bundles of twigs, tied together by thongs of lianas or of wire, pegged into the ground on either side of the bank. The stone bunds are easier to construct and consist of low walls about one third of a metre high (Millington, 1982, 1984). This system, which has a relatively low labour input, is still being used, whereas those of the Erok and Wamatengo are falling into disuse now that the dangers from taiding tribes have been prevented by the central goverment.

The other ancient system, of growing trees in the compound plots and using slash and burn with a bush fallow, has already been described in the section on agro-forestry.

Summary

The accounts of the traditional systems given above show that the principles of soil conservation were well understood centuries ago by the farmers of the world. Their systems included three methods, in which stones, soil or vegetable matter are laid into banks more or less on the contour to provide some physical resistance to the movement of soil downslope. In most of the world the systems are falling into disuse, and the men are turning to practices which give a better return for their labour. The Erok and the Wamatengo moved out to the plains once the threat of raids from other tribes had subsided. In the Andes the young men move off to the bright light of the cities, and the old men no longer cultivate the most difficult parts of their land. In the Yemen the attraction of higher wages in the oilfields of the Gulf draws the young men off the land. If we are to convince the young men of the small farms of the tropics and sub-tropics of the value of life on the land, it seems to be neccary to find ways of reducing the burden of maintaining these high labour-demanding practices whilst at the same time providing alternative activities for their leisure hours.

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IV

TECHNOLOGIES AND INDUSTRIALIZATION

BIOTECHNOLOGY AND TECHNOLOGICAL INNOVATION IN AGROINDUSTRY

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Introduction

It is essential that new trends in the field of biotechnology be followed closely by those involved with agroindustrial issues worldwide. Motivations may vary from country to country, but in certain aspects either private sector or governmental agencies should be concerned about the likely impacts of biotechnology.

Looking back to the recommendations of the international meeting entitled "Towards a Second Green Revolution: from Chemical to New Biological Technologies in Agriculture in the Tropics", the basic considerations were: the capacity of emerging technologies to fight hunger adequately, a long-term view of self-sustained production conditions, substitution of chemical inputs and an evaluation of the actions of the three areas involved, namely: private sector, R&D institutes and non-profit international research organizations.

This paper intends to take these considerations as starting points and discuss more thoroughly the question of biotechnology and agro-industry from the point of view of a third world country immersed in a very competitive and internationalized environment represented by agroindustrial activity. The study is divided into four topics: the first examines the investment capability of LDC economies, focusing on R&D spending; the second considers the role of government in R&D activity; the third discusses the agroindustrial complex, stressing the ever-increasing ties between agricultural and industrial activities, and lastly the issue of quality of life.

Investments in R&D

There is a worldwide trend towards increasing the share of the private sector in total R&D spending, especially in promising new fields such as biotechnology and new materials. The reason is clear, since there are potential gains to be had, which make such investments attractive to the private sector.

If we consider the existence of potential returns on R&D investments in biotechnology, these economic returns will not be evenly distributed, benefitting some countries and some corporations more than others.

There are three major variables determining the effort directed to R&D activity, either public or private: the cost of the program (including its maturity), the expected benefit (social or private) and the risk associated with the specific activity. Different actors will behave differently depending on how they are affected by each of these variables, and this will shape the manner in which the benefits will be shared among those involved. One characteristic of the R&D activity is the lag between exploratory research and development and the point where returns start coming in. Therefore, costs come first and benefits later. The length of time to carry out R&D activity, the probability of success and the risk of market acceptability of the new product or process are all variables to be considered.

The question which arises is: what are the possibilities of LDCs having a share of the gains existing in the biotechnological markets?

Brazil invests less than one percent of its GNP in R&D, whereas USA, Germany and Japan invest more than 2.5%. In absolute terms the gap is very large, which is relevant when R&D activities are known to present returns to scale. Large corporations such as Dow Chemical, Du Pont and Monsanto invested more than US$ 500 million each in R&D in 1987, as shown in Table 1. Their biotechnology budgets are larger than the total amount of investments made in Brazil or in any other Latin American country.

Among the 54 companies operating in the U.S. market of biotechnology products, the total amount of R&D investment in 1987 was US$ 710 million, expressing a rising tendency, although at decreasing growth rates. In the same sample of companies, the sector still runs at a deficit of US$ 76 million dollars, although 20 companies are already showing profits. (Biotechnology News, 1988).

With such large differences in R&D investment capability, the LDCs may risk not being able to carry out their own development, nor even being prepared to absorb new technologies in the biological area. Some

TABLE 1 - *R&D expenses fro selected corporations.*

	Amount (US$ million)	% of sales	% of profits
Dow Chemical	605	5.4	48.9
Du Pont	1,156	4.3	38.7
Monsanto	523	7.6	82.2

Source: Business Week, June 22, 1987.

Latin American countries have made an effort towards industrialization, which culminated with the installation of modern industrial capacity. Other countries in Asia have been raising their income steadily by enabling the domestic sector to absorb new technologies and foreign capital, thus turning traditional sectors into modern sectors, integrated into the trend towards worldwide technological development.

Even with limited capability to generate new technologies, LDCs expecting to have the opportunity to increase their national income must engage in a strategy which enables them to at least follow the pace of technological change, by expanding their ability to absorb these changes into their productive structure. Even for this purpose, resources must be allocated for coordinated R&D investments as well as for education.

Countries with economies strongly dependent on agroindustrial activity have been facing worldwide protectionism especially imposed by developed countries (Valdes and Zietz, 1980; OECD, 1987). The trend, however, is towards developed societies being increasingly more critical in accepting the costs of supporting their own agricultural activities (Hardy, 1985). The expected results of this change are, as a first stage effect, that agriculture-based economies will gain a share of the international market. An expected second-stage effect is greater investment in the transformation of agricultural raw materials into high-valued end-products.

In this scenario of rapid technological change together with a worldwide oversupply of food, there are gains to be sought by agriculture-based economies, if they make investments in agroindustry and increase the value of raw products before they enter the international market. Again R&D must be developed to be able to compete in those markets with good quality products produced efficiently, in the near future.

Government and Private sectors: R&D Arrangements

Worldwide arrangements for R&D advances are strongly affected by multinational corporations. Those corporations usually have, among their objectives, broader aspects that do not necessarily meet the domestic needs of LDCs. Some of these aspects are pointed out by Dembo and Morehouse (1987).

The impact of new technologies on developing countries will depend on several aspects, such as:

— Access to technology depends on property rights arrangements, generally in the form of agreements entered into between transnational corporations and universities. In general these agreements, associated with the high expectations held by scientists of gaining the private economic benefits of their work, are limiting the access of third world scientists to research results in biotechnology.

— The inflow of resources from large corporations into universities, especially in developed countries, is affecting the process of setting research goals for their laboratories. These goals are naturally directed at projects with favorable expected market results, not always meant to meet the needs of LDCs, especially in respect to human health.

In addition to these concerns we can add the usual problems developing countries face in obtaining inputs for biotechnological research and production, since almost all the equipment is imported from developed countries, and also in training and maintaining the human capital needed to perform the task. It is important to have strategies to give underdeveloped economies the opportunity to close the gap to a more equitable standard of living. New technologies are playing an important role and will affect the ways that economies find to deal with the issue of development. Given the aspects mentioned above, it is unlikely that LDCs will be able to jump onto the bandwagon of development unless local governments give priority to the goals of education, R&D instruments and integration with the private sector.

Domestic private sectors, especially in Latin American economies, are unable to meet the need for competitive R&D developments. New creative arrangements for R&D, such as pre-competitive associations, are not being established in countries like Brazil. Important actions are being implemented, such as the recent Brazilian National Research Council, creating mechanisms to supply funds for R&D in the private sector, given that the project or program is jointly developed by private and public institutions.

Local governments must also play the important role of controlling the environment as well as other socially important conditions affected by the biotechnological industry. This fact is becoming increasingly important as new products developed worldwide are reaching the markets.

The basic conclusion of this part is that underveloped economies must engage in long-term R&D-oriented programs fitted to their needs, and this has to be done under a budget constraint that makes it impossible just to imitate strategies adopted by developed economies. Keeping the doors open for foreign capital should be a basic condition, however this must be done in such a way as to provide the possibility of redirecting their transnational corporate goals to attack locally significant problems. International research centers may help local countries in designing adequate R&D policies in biotechnology.

Agroindustry and Biotechnology

Agroindustry represents a sizeable share of the national income of many nations. A study conducted by BNDES, 1988, shows that in Brazil it accounts for about 40% of total GNP.

The agricultural activity itself is increasingly tied to industry, either through the buying of industrialized inputs, or by the selling of production to a considerably larger agroindustry. The agricultural sectors of developing countries are experiencing the transfer of a share of the income generated to other sectors. In Brazil different studies have focused on this process, some evaluating the effects of industrial protectionism (Zylbersztajn, 1983), others looking at exchange rate policies (Alves and Pastore, 1974), and others still evaluating the different effects of price policies (Lopes, 1977).

The agroindustrial activity brings into the traditional agricultural production new needs that range from new management techniques to contracts where the farmer can negotiate the price and the risks he is willing to assume. The three segments of agroindustry: inputs industry, food and processing industry, and agricultural production are interrelated in the modern world. Any technical change that happens to occur in one segment may have effects on the others.

Biotechnology promises to affect each one of the three segments, with new biotechnological inputs such as bio-defensives, new inoculants, newly engineered varieties and transformed plants and the food industry with the possibility of advances in the traditional fermentation processes and in the infant industry of phytochemical products.

Technological changes affecting the food industry will affect especially the consumer, with new products reaching the markets at lower costs. The backward effects those technological changes may have, will strongly depend on the special characteristics of the raw material that the food industry demands from the agricultural producers.

In terms of the effects on the agricultural segment of the agroindustrial complex, the main concern today has to do with the phytochemical industry, which has the capacity to be completely independent from the traditional agricultural production. In that sense, large agroindustrial activities carried out by LDCs today may rapidly become inefficient, running the risk of losing markets with subsequent effects on the employment resources and the level of income of these countries.

The impact of biotechnological developments on agricultural production itself is a more complex question to be evaluated ex-ante. The first aspect to be considered is the question of the development of a new product replacing other similar inputs traditionally existing in the market. This advancement may be represented by bio-defensives replacing chemical ones. The second aspect is related to new developments to be incorporated into inputs already adopted, such as seeds for engineered plants. In this case the farmer will have no costs of adoption since the input is already in use.

Whether the biotechnological advances will be adopted or not rapidly or whether they will be scale neutral is a matter that depends on a complex evaluation concerning the adoption of agricultural innovations in general. There are no general answers but only answers to specific technologies which must be individually evaluated.

Feder, Just and Zilberman (1982) pointed out the complexity of relations between the pattern of adoption of new technologies and elements such as risks associated with technological change and the existence of fixed adoption costs, which will shape the pattern of adoption, thus explaining the relationship between farm size and adoption. Whether or not biotechnological advances are scale neutral will depend on the specific type of technical change, as well as on the characteristics of the farming system in use.

Focusing on the issue of impacts of biotechnology on low-income farmers, Ahmed (1988) concludes that the so-called biotechnological revolution contains both pro-and anti-poor elements: "Despite immense scope for exploiting the pro-poor potential, the corporate sector is vigorously pursuing strategies, both technological and institutional, whose outcome is totally anti-poor".

The same author considers that when compared to the green revolution technological advances, biotechnology promises to be more neutral than the first, as well as environmentally more sound. The question of being environmentally clean or not is one that cannot be generalized in biotechnology as easily as in other technologies. Controls must be continuous as are being employed by many countries. LDCs must be very careful with respect to the registration of products not yet approved by environmental agencies at the countries of origin.

Biotechnology and Quality of Life

The question of technological change and quality of life must consider some basic questions related to welfare economics. First, standard measures of quality of life are basically associated with the standard of living or, in other words, to the income as well as to its distribution in the economy. There are other issues also indirectly related to income, that must also be considered when evaluating quality of life. One special topic in this case is the environmental question, clearly a point usually not taken very seriously in many LDC economies. Is a clean environment a luxury that poor countries cannot afford?

The impact of technological advances on agroindustrial income promises to be positive. Still unsettled is the question of income distribution, especially as applied to the agricultural sector, by evaluating the characteristics of new technologies in terms of capital and labor intensity.

On the international level, there is a likely impact of new biotechnological advances on the economies strongly dependent on agricultural raw materials. This impact is possible through the replacement of agricultural products by other protein sources obtained through industrial production. Other products such as natural food additives are being displaced by phytochemical production. These changes are important in that they modify the comparative advantages related to agricultural production, following the pattern of substitution of traditional raw materials by new materials (copper and optical fiber, for example).

The panaceic view of the wonders of biotechnology is not acceptable. There are very important expected impacts that will emerge along with new products or through the decrease in the cost of food as a result of more efficient production processes. Consumers will benefit from the advances; however, on the production side there is not a clear view about the distributive impacts of the expected new technologies.

What biotechnology can and what it cannot do is a question of special interest. New biotechnologies cannot, in any case, replace measures at the socio-economic level, responsible for the basic problems of the LDC economies.

However, as in the case of other technical advances, it can represent an important source of opportunities for individuals, companies and societies. How to better benefit from those advances is a challenge to be faced by academic institutions, private companies and governmental agencies.

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SEED PRODUCTION AND COMMERCIALIZATION: AN ANALYSIS OF BRAZIL

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I salute the distinguished participants in this Workshop and thank the Pontifical Academy of Sciences for the honour conferred upon me to participate in it.

In concentrating on the Brazilian example for the development of my subject — "Seed Production and Commercialization" — I do not do so simply because I have a much better understanding of the seed sector of my country than that of any other, but because I consider Brazil a good paradigm for analysis.

Brazil's area of 850 million hectares, akin to a continent, and principally its profound regional differences which make the country an archipelago of different ecological, political, economic and social realities, make it possible for us to encounter in this enormous country nearly all the problems and many of the solutions which characterize the nations of the Third World. The fact that within our frontiers we have developed regions, regions undergoing transition and others with various levels of subdevelopment, makes it possible for an analysis of the situation of the Brazilian improved seed, which I intend to develop here superficially, to be valid in discussions of the overall tendencies of agriculture in the Third World, which is the main objective of this workshop.

I would like to begin my considerations with a few preliminary remarks. Firstly, it is important to bear in mind that agricultural development is not a process dissociated from economic and social development. Agriculture is an integral and inseparable part of social life as a whole. It is therefore affected by endogenous and exogenous factors, which include the overall structure of the society, the socio-economic changes, the demographic pressures, the cultural transformations and the environmental conditions. Agricultural behaviour is therefore defined by the result of the complex interaction of these factors. As an agent and reagent of the overall development process of society, agriculture cannot be analysed separately, since it reflects the social, political and economic structure, the culture, the religion, the administration of the country and the natural conditions which exist therein.

It should also be remembered — and history has shown us that this is so — that mankind's development process is the history of changes in farming practices. Industrialization and urbanization in developed countries or regions were only made possible because, in most cases, the improvement of farming methods for producing foodstuffs and fibers allowed agriculture to finance its industrialization through the transfer of income and exportable surpluses, and to generate excess labour which made it feasihle, thus populating the cities. In order not to lose the real perspective of the process, we must never fail to look at agricultural development from the angle of city-country relationships.

The beginning of the process is always an increase in agricultural production and/or productivity. Nowadays, the principal motivator of agricultural development lies in an increase in productivity via the transformation of traditional farming into modern farming, which involves modern techniques and inputs.

The improved seed is undoubtedly the most important productivity factor of the so-called modern inputs. Firstly, because the genetic improvement applied to it conditions it to take full advantage of the fertilizer, which is the second critical factor. Secondly, because at very low cost it promotes the highest gains in yield. This combination of relative low cost and high impact in yield makes the improved seed a valuable instrument towards rural extension of the transformation process from traditional farming to modern farming. The advent of hybrid corn in the 30s was the most important agent in the dramatic transformation of American farming. The increase in levels of production of that cereal, through genetic improvement, made it possible, already at that time, to show the American farmer the economic efficiency of modern farming and the importance of "technological packages" in the increase in productivity.

Since the improved seed is of dramatic importance to the transformation process from traditional to modern farming, one is curious to know how Brazil finds itself in this sector. But to analyze an agricultural problem singly, especially with Brazil's complex and diverse agriculture, brings the risk of half-truths being stated, if we do not have a wide understanding of the Brazilian agricultural problem, which cannot possibly be visualized as a whole.

Brazil is a country characterized by marked regional differences. If we look at its immense regions — North, Northeast, Midwest, Southeast and South — we have five countries with totally dissimilar characteristics, at different levels of educational and socio-economic development, aside from differences in climate, topography and soil.

Its farming meethods include all the stages of development known to man, from "squat" farming before the hoe, which is carried on in the low grasslands of the Amazon, to the most modern and sophisticated farming which is practiced in the advanced southeastern and southern regions of Brazil.

The southeastern, southern and part of the midwestern regions, which account for around 30% of the country's area, absorb more than 90% of all the modern inputs and agricultural machines in the country.

But the extreme regional differences are not the only ones which hinder Brazilian farming from being considered as a whole. The other big difference lies in the technological duality, characteristic of countries in the process of development, which presents the phenomenon of coexistence of traditional farming with modern farming in the same area or region. Thus, in a homogeneous area, we can see farming organization being divided into "castes", in which *commercialized farming*, that is, that in which the product is destined to the *domestic market*, to *industry* or for *export* becomes the rich cousin of *subsistence farming*. The first, non-traditional, enjoys the benefits of modernization, the use of modern inputs, of rural credit, of the cooperative structure and is practiced by the larger and more professionalized farmers. The second, traditional in its methods and objectives, is concentrated amongst small farmers or in the marginal areas of the large landed estates. In the first case, the nobility of the soybean, wheat, cotton, irrigated rice and sugar-cane shows agronomical results which are similar to those reached by developed countries. In the second case, products such as beans and cassava follow their primitive cultivation routine. There are crops, such as corn, in which the smaller portion is already being cultivated as a market crop under non-traditional standards, but the greater area still survives as subsistence farming or secondary cultivation, which exemplifies traditional farming. This same difference is also noticed in animal husbandry: a typically modern poultry farm, a cattle farm is in general traditional, a hog farm in process of transition.

One comes to the conclusion that not even a regional view is sufficient. The question should be analyzed per agricultural product, as each region and each product within the region have different characteristics, diverse prerequisites and distinct limitations.

It is only from this point of view that we will be able to understand how the level of utilization of improved soybean seeds has already surpassed 90% (wheat has practically reached 100%), why beans have not reached 8% and why the utilization of improved corn seed, a transition crop, partly traditional (subsistence), partly modern, despite the dramatic difference in productivity offered by hybrid corn in comparison with common corn, is only 60%.

The reason for these tremendous distortions has a lot to do with the recent economic development model adopted by Brazil. The Brazilian industrialization and urbanization process was disorganized and too fast: the haste to grow inverted the urban-rural profile in less than fifty years, the population going from 30% urban to 70%. And as the industrial urban concentration was concentrated in the mid-south of the country, the process was highly heterogenous: São Paulo, our most developed state, has only 18% of its population in the country. All this rapid urban-industrial development was financed by perverse agricultural income transfer mechanisms. Brazil is a country where the agricultural sector represents 11% of the gross domestic product and participates, on an average, with half the value of its exports. The necessity for agro-dollars, added to the fundamental requirement for cheap food in the cities to maintain low salaries, resulted in the prices of products for domestic supply being manipulated downwards more than those of export products. Consequently the modernization of the latter was very much more accelerated.

Brazil's seed industry history is recent. With the exception of isolated activities by state governments and private enterprise in hybrid corn, which began in the 40s, the seed boom began at the beginning of the 60s, witb the speeding up of the Brazilian industrialization model, with the development of the fertilizer, machinery and agricultural defensives industries. It also coincided with the dramatic expansion of our highway network — in spite of the country being dependent on foreign petroleum — and with the no less dramatic growth of our hydroelectric power generation. Since all this development was mostly concentrated in Brazil's mid-south, the modernization of farming was also concentrated there, which confirms the idea of interdependence between city and field.

Our first Seed Law dates from 1965, when the first National Seeds Plan was established. A package of incentives for the establishment of companies dealing in seeds was introduced, and great advantage was taken of this in the area of soybeans (for export) and of wheat (to substitute imports).

Despite mistakes, the seed industry in Brazil has already reached the critical stage of self-sufficiency. According to the Brazilian Association of Seed Producers, there are already 828 member companies, with 25,000 growers, generating 100,000 direct jobs. Technical activities in research, production and support involve 19,500 persons. The "Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)" alone, which is an organ of the Federal Government, has 12,500 employees. This year the system will produce 2.8 million metric tons of seeds and invoice US$ 1 billion. The attached table gives some statistics for the sector.

Brazil's seed production, 1981-88 ('000 tons)

Varieties	1981	1982	1983	1984	1985	1986	1987	1988
Soybean	818	804	592	899	847	867	860	953
Wheat	335	383	313	376	352	585	745	698
Rice	163	209	156	154	141	169	202	215
Maize	158	145	107	142	138	173	184	179
Forrage	—	—	—	13	14	44	89	101
Potato	40	89	59	88	75	76	88	85
Cotton	37	22	20	51	40	57	44	52
Beans	22	15	20	15	24	27	19	23
Barley	—	—	—	—	—	—	—	16
Peanuts *	7	5	5	6	15	23	6	6

* Only State of São Paulo.

To sommarize, we can see that the same distortions which exist in the agricultural sector are present in the seed sector: high utilization of improved seeds in modern export crops, or to substitute imports, such as soybeans and wheat, and low utilization in the crops for domestic supply. There are other equally serious regional differences: a high concentration of utilization in the developed regions of the Southeast, South and part of the Midwest, and an almost negligible presence of improved seeds in the Northeast and North. Statistics also show that in Brazil the increase in productivity is directly related to the use of improved seeds: whereas in the State of São Paulo, which surpasses the 90% utilization index for hybrid corn seeds, there has been an average annual increase of 2% in corn productivity in recent years, the productivity of this cereal has been decreasing in the northeastern regions.

To finalize, I would like to list a few items which I consider relevant to the improved seed development process in Brazil, or in any other country in process of development:

Research - there is an absence or dispersal of research. There are only a few introducers of improvements and there is a lack of research in the area of farming practices and in the integrated use of modern inputs. There is an absence or lack of basic seeds qualitatively and quantitatively sufficient for the requirements of seed production. Furthermore, the absence of a Law to Protect Breeder's Rights hinders participation by private enterprise in the genetic improvement of autogamous plants.

Interaction of production factors - the absence of integrated programs concerning modern production factors prevents the crops from expressing their full genetic potential. This is especially critical in relation to fertilizers.

Commercialization - in those areas in which the warehousing and commercialization processes are unreliable, the instability of prices for agricultural products often frustrates the farmer's expectations, since the difference in productivity generated by the improved seed is absorbed by the drop in prices.

Prices for agricultural products - there seems to be no doubt concerning the effect of prices for agricultural products on the technological development process in farming. A good example can be seen here in the European Economic Community. The artificially high prices made it possible for the nine original member countries of the block to rise from a situation of inferiority and, in a period of twenty years, to surpass the American grain production by twenty percent. What happens in the Third World countries is the opposite: the maintenance of artificially low prices for products for domestic supply inhibts the adoption of new technologies, including the adoption of the improved seed.

On the other hand, products for export have to face an international commodities market which is distorted and perverse, thanks to the rich countries' subsidies policy. I shall digress a moment from my subject to state that the protectionist mechanisms adopted by the United States, the European Economic Community and Japan are, in themselves, the biggest agricultural problem of the Third World countries, which would justify a chapter in this Workshop.

Government intervention - the government often inhibits private enterprise, especially in the less developed areas, by producing and subsidizing improved seed to the farmers. It is not surprising to observe that it is in those regions or crops that the process of adoption of improved seed is most incipient.

Agricultural policy - the urban-industrial development model attempted by Brazil and by many other countries in the Third World, through a predatory process of transfer of revenue from the primary sector to the secondary and tertiary sectors of economy, has petered out.

And now, more than ever, the agriculture of countries such as ours requires long term policies, dependable commitments, with explicit objectives, goals and strategies. The agricultural complex has been treated as a yo-yo of short term monetary policies, making agricultural economy a less important branch of government accounting. This is not a favourable atmosphere for technological development and modernization.

We shall conclude by recalling that any analysis of the regional problem concerning improved seeds must take into consideration the stage of development. It is not uncommon to see well-intentioned efforts to establish programmes of advanced stages in regions where the structural conditions of agricultural research and development are only prepared to deal with the earlier, more modest stages. Such efforts have almost always failed all over the world and, worst of all, with a waste of talent, material and financial resources, all of which are generally lacking in the less developed regions. Not to mention the frustration of many dedicated and competent technicians, who often feel like Don Quixote facing the windmills.

INTERCONNEXION ENERGY-NOURRITURE: L'AFRIQUE PEUT-ELLE ATTEINDRE L'AUTO-SUFFISANCE ALIMENTAIRE?

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Introduction

La situation alimentaire générale de l'Afrique est à tous égards préoccupante.

Les programmes visant l'auto-suffisance alimentaire dans le cadre d'un plus grand développement des zones rurales sont ainsi reconnus par tous les gouvernements africains comme des priorités absolues.

Encore faut-il que ces programmes soient efficaces. A cet égard l'Afrique est malheureusement notée pour les piètres résultats de ses efforts de développement. Ainsi par exemple sur 17 projets agricoles récemment revus par la Banque mondiale 5 à 10 ans après leur mise en place, 13 n'ont pas répondus aux attentes initiales [1].

Les raisons qui expliquent cet état de chose sont en règle générale un environnement socio-politique inhospitalier, une mauvaise conception des projets ne tenant généralement pas compte des vues des bénéficiaires, la faiblesse de l'appui logistique, un contexte socio-culturel inadapté ou peu souple, et un bas niveau technologique.

Pour réussir les programmes d'auto-suffisance alimentaire et de développement des zones rurales, il importe donc de cerner de très près les contraintes de tous ordres qui affectent les programmes de développement socio-économique en Afrique.

Parmi ces contraintes se trouvent les contraintes énergétiques. On rencontre ici une problématique particulièrement difficile, dont deux volets sont intéressants.

Le premier volet est lié à la recherche du meilleur moyen pour assurer, à l'échelle nationale comme à l'échelle du village, la "sécurité énergétique» sans induire une "vulnérabilité économique". Ce volet de la problématique de l'énergie est bien entendu caractéristique de la situation énergétique et économique de bien de pays, dans tous les continents, depuis les chocs pétroliers des années soixante dix [2].

Le second volet de la problématique de l'énergie en Afrique est lié à la gestion de la ferme à biomasse, y compris les forêts naturelles [3]. On rencontre dans ce volet le problème crucial, pour nombre de pays du Tiers Monde, de la compétition entre le système de production alimentaire et le système de production énergétique pour l'utilisation des ressources de base: terre de culture, besoin en eau, besoin en capitaux, besoin en main d'oeuvre, recyclage des matières nutritives ...

On se propose dans ce qui suit de s'étendre sur ce problème de la compétition entre les deux systèmes de production alimentaire et énergétique.

La competition "nourriture-énergie"

La production auto-suffisante de nourriture et d'énergie est devenue, par le jeu de la croissance démographique explosive et des effets dévastateurs de calamités naturelles et de politiques économiques mal inspirées, le problème majeur du continent africain.

La perception de l'importance de ce problème pour l'avenir du continent se mesure aux nombres de colloques, journées d'étude, initiatives diverses qui lui sont consacrés.

Si on n'est pas plus avancé dans la recherche d'une solution satisfaisante à ce problème, c'est peut-être parce que l'on tend à considérer de façon isolée le système de production énergétique et le système de production alimentaire alors qu'ils sont indissociables en zones rurales africaines par le jeu de contraintes communes et incontournables imposées par le bas niveau de développement des infrastructures et des technologies en Afrique.

L'une des contraintes est constituée par l'amenuisement accéléré de la base des ressources disponibles en milieu rural du fait de la dégradation de l'environnement bio-physique. L'objectif de production auto-suffisante de nourriture et d'énergie doit donc être poursuivi dans le cadre d'une approche qui fasse pleinement droit aux préoccupations de protection de l'environnement bio-physique et aux préoccupations de satisfaction durable et soutenue de la demande existante et future.

La formulation précédente laisse entrevoir que l'entreprise se heurte à deux difficultés majeures. La première concerne l'appréciation correcte de la demande future en nourriture et en énergie dans un contexte où la maîtrise de la croissance de la population est loin d'être assurée. La seconde concerne la nature exacte et les caracteristiques de l'interconnexion entre le secteur énergie et le secteur agricole, dès lors que ces deux secteurs s'influencent mutuellement de façon souvent négative entraînant des perturbations socio-économiques et écologiques graves.

Le problème de l'appréciation de la demande

S'agissant du premier problème celui de l'appréciation de la demande, on peut régler facilement, quoique de façon assez fruste, la demande future de nourriture en faisant référence aux normes de la FAO relatives aux besoins individuels en calorie, et à la dimension de la population.

Plus complexe est le problème de l'appréciation de la demande d'énergie.

Les énergéticiens sont venus, assez tardivement, à considérer que par la coordination correcte d'instruments de politique énergétique il était possible de traiter la demande d'énergie comme une variable active, c'est-à-dire comme une solution aux problèmes énergétiques, au même titre que l'offre d'énergie ou les avancées technologiques.

Cette perception de l'importance de la demande d'énergie est de grand intérêt pour les pays du Tiers-Monde, eu égard à leurs capacités réduites en investissements et aux contraintes qui affectent leurs balances des paiements. Dans ce cas, en effet, il est moins coûteux, mais pas nécessairement plus facile, de rétablir l'équilibre entre la demande et l'offre énergétique par des encouragements à la conservation de l'énergie plutôt que par l'accroissement de la capacité de l'offre d'énergie.

Sur le plan purement conceptuel il est évidemment plus facile d'opérer du côté fourniture de l'équation énergétique que du côté demande. Dans le premier cas on opère rationnellement sur une grande échelle et de manière concentrée alors que dans le dernier cas les actions reposent sur la contribution d'un grand nombre de consommateurs agissant de façon plus ou moins aléatoire, et motivés par des intérêts qui ne sont pas toujours strictement rationnels [2].

L'évaluation de la demande d'énergie est de ce fait une tâche difficile et pleine de risques, qui demande l'intervention de plusieurs disciplines scientifiques, et qui nécessite très souvent des investissements importants dans la collecte et le traitment des données.

Plusieurs modèles ont été conçus au fil des ans, de la simple relation entre "énergie et PIB" à des études micro-économiques diverses adaptées à une large gamme de variables, de formes fonctionnelles et de techniques d'estimation [2].

Malgré le caractère parfois sophistiqué de ces modèles, l'appréciation de la demande d'énergie reste un exercice périlleux. Il est difficile, en effet, voire impossible, de concevoir un modèle détaillé de l'économie qui soit à même de saisir l'effet du changement des activités économiques sur la consommation d'énergie et l'effet du changement des prix ou de la disponibilité énergétique sur les activités économiques. Le comportement erratique des économies et les discontinuités induites par divers chocs, dont les chocs pétroliers "forward" et "backward", rendent plus malaisé encore l'exercice d'appréciation de la demande d'énergie par le formalisme mathématique classique [2, 4].

A cause de toutes ces difficultés, la prévision de la demande d'énergie tend à devenir un exercice qui consiste non pas tellement à prévoir l'avenir qu'à le créer. Les méthodes de prévision basées sur ce principe ressortent d'une approche "téléologique". On commence par définir dans le futur des buts socio-économiques jugés viables. On met ensuite en oeuvre dans le présent les changements structurels, les arrangements institutionnels et les engagements politiques nécessaires pour atteindre ces buts. Pour rendre l'approche téléologique pratique et fonctionnelle il est nécessaire de décontracter la demande d'énergie en éléments de consommation finale [2, 4].

L'interconnexion énergie-nourriture

L'objectif d'une production auto-suffisante de nourriture et d'énergie qui soit durable et soutenue se heurte à une deuxième difficulté, qui concerne la nature exacte de l'interconnexion entre le secteur énergie et le secteur de la production alimentaire.

Cette seconde difficulté peut surprendre. On sait, en effet, que dans les pays du Tiers Monde de 30 à 70 % du coût des intrants agricoles sont directement ou indirectement liées à l'énergie; tandis que de 20 à 90 % de la production agricole constituent des intrants pour la production d'énergie non commerciale [3, 5].

Ces précisions, par ailleurs peu fiables, n'enlèvent rien au fait que peu de recherches approfondies s'orientent vers une exploration systématique de la nature et des caractéristiques de l'interconnexion "nourriture-énergie" dans les régions rurales du Tiers Monde. Or il importe d'entre-prendre de telles recherches approfondies car le caractère souvent négatif de l'interconnexion "noirriture-énergie" introduit des cercles vicieux de grande conséquence, spécialement pour les économies fragiles africaines. Le cercle vicieux des prix est assez caractéristique: le renchérissement de l'énergie entraîne celui des produits vivriers; marginalisée, la frange la plus pauvre de la population est forcée, pour survivre, de s'adonner à des pratiques prédatoires de l'environnement bio-physique; surchargé l'éco-système se dégrade et perd, en particulier, le caractère renouvelable qu'il pouvait encore avoir; la plus grande rareté des ressources de base qui en résulte pèse sur les prix des intrants agricoles dont l'énergie ...

Le couplage de plus en plus serré de l'interconnexion "nourriture-énergie" dans les zones rurales africaines, fait que l'Afrique ne peut espérer résoudre son probleme alimentaire sans résoudre simultanément son problème énergétique.

Pour réussir cette double entreprise il est nécessaire de transcender l'approche traditionnelle de gestion de la crise pour s'attacher à définir, dans une approche prospective et forcément téléologique, eu égard aux lacunes africaines en données fiables, un plan d'utilization plus rationnel et moins conflictuel des ressources de base communes aux deux secteurs de production envisagés: ressources en eau, en terre, en capitaux, en main d'oeuvre ...

Mais les contraintes ici ne sont pas uniquement matérielles. Elles sont aussi culturelles et socio-politiques. Les superstructures mentales et sociétales jouent, en effet, en Afrique un rôle pré-éminent. Elles laissent entrevoir qu'il n'y a pas à proprement parlér de solutions toutes faites, reconnaissables à partir de l'expérience historique des autres pays, et singulièrément des pays industrialisés.

L'Afrique est ainsi contraint d'innover. Il lui revient de définir une approche novatrice au problème de l'optimisation conjointe du secteur de la production alimentaire et du secteur de la production énergétique, tenant dûment compte du couplage de plus en plus serré de l'interconnexion, de caractère souvent négatif, entre ces deux secteurs. Tenant compte aussi des contraintes matérielles, économiques, socio-politiques et culturelles souvent dirimantes en Afrique. Le critère d'optimisation de l'entreprise est, bien entendu, la réalisation dans chaque secteur d'un niveau de production auto-suffisante, durable et soutenue au regard de la croissance explosive de la population africaine.

UN DEVELOPPEMENT ECO-DURABLE

Il paraît assez évident que dans un contexte de croissance explosive de la population, et donc d'amenuisement de la surface arable par habitant, il faille suppléer aux carences de l'agriculture traditionnelle en adoptant de façon massive les méthodes modernes de production alimentaire plus performantes. Cette agriculture moderne est cependant à grande intensité de capital et d'énergie.

La grande intensité énergétique de l'agriculture moderne est liée principalement à l'utilisation massive de fertilisants et de pesticides chimiques, et à la mécanisation de tous les étapes de la production agricole, et notamment des labours.

Tant que le pétrole était un intrant abondant et peu coûteux, le secteur énergétique fut à même de subsidier sans peine le secteur agricole. La croissance de l'intensité énergétique de la production agricole ne posait aucun problème particulier, aussi bien dans les économies des pays industrialisés que dans celles moins avancées et plus fragiles des pays africains, hormis celui de la mobilisation des capitaux, par ailleurs assez bon marché, pour la production énergétique.

Mais le renchérissement de l'énergie commerciale suite aux chocs pétroliers des années soixante-dix encouragea partout, et singulièrement dans de nombreux pays d'Afrique déjà fortement tributaires des formes d'énergie non commerciales, les pratiques de substitution intercombustibles.

Les résidus agricoles et des animaux furent utilisés de façon intensive et systématique pour faire l'appoint énergétique là où le déficit en combustibles commerciales, et même non commerciales, devenait aigu. Le secteur énergétique entrait, dès lors, en compétition avec le secteur agricole pour l'utilisation des intrants agricoles et d'autres ressources de base. Le processus de "subsidiation" s'inversait même avec l'utilisation des produits alimentaires, comme les céréales, pour la production de l'éthanol utilisé comme additif à l'essence dans certains pays.

Comme dans toute compétition l'opérateur économique tend à privilégier la production qui lui est la plus profitable, il est prévisible que si les tendances actuelles perdurent ce sera le prix de l'énergie qui servira demain de référence aux prix agricoles. Les tensions permanentes sur les marchés pétroliers mondiaux et la pénurie chronique des produits pétroliers sur les marchés africains auront pour conséquence d'exacerber davantage encore la pénurie de nourriture et d'énergie dans nombre de pays africains, induisant ce faisant une nouvelle spirale des prix énergétiques et agricoles.

Pour sortir de ce cercle vicieux, il faut s'attacher à optimiser simultanément les secteurs de production alimentaire et énergétique dans le cadre d'une stratégie qui vise à desserrer le couplage "nourriture-énergie" en réduisant:

— l'intensité énergétique de la production agricole, entendu comme l'enchaînement de toutes les étapes qui conduisent de la ferme au consommateur final;
— l'intensité agricole de la production énergétique en milieu rurale.

Pour réaliser le premier objectif, il faut identifier tous les intrants et sorties énergétiques de la chaîne de production alimentaire de façon à mettre en évidence et en oeuvre les technologies et les processus les plus efficaces sur le plan énergétique.

Plusieurs acquis de la science et de la technologie autorisent le succès de cette entreprise.

C'est par exemple la fixation biologique de l'azote atmosphérique au moyen d'associations spécifiques ryzobium-plantes, et l'utilisation de prédateurs naturels de divers parasites animaux et végétaux des cultures. Ces deux techniques permettent de réduire les quantités de fertilisants et de pesticides chimique nécessaires à la production alimentaire. On peut également mettre à contribution les phosphates naturels qui abondent dans de nombreux pays africains [6].

Il s'agit aussi de mettre en oeuvre en Afrique des techniques culturales qui se passe de l'exigence d'une mécanisation intensive de l'agriculture. Cette recomandation résulte d'un constat: la technique ancestrale africaine d'un minimum de labour est celle qui semble la mieux adaptée au caractère fragile des sols africains [7].

Pour réaliser le second objectif il faut privilégier en milieu villageois les formes d'énergies renouvelables non organiques et singulièrement l'énergie solaire, l'énergie hydraulique et l'énergie éolienne. Cet objectif est aujourd'hui activement poursuivi par plusieurs sociétés d'énergéticiens, dont le "Global Energy Society", qui a lancé en 1988 le projet AFRICA 1000, visant à créer 1000 villages africains entièrement alimentés en énergie nouvelle et renouvelable, et totalement pris en charge par les villageois eux-mêmes à toutes les étapes du projet, de sa conception à sa mise en oeuvre et à sa gestion [8].

Conclusion

Evoquant le problème de l'insécurité alimentaire, la Banque Mondiale constate dans un rapport récent que plus de 100 millions d'Africains souffrent de façon plus ou moins chronique de la faim, et que la situation risque de se détériorer si aucun programme d'action n'est entrepris [9].

Elle annonce un programme de prêts sans intérêt pour aider des pays africains à faire face à ce problème.

Le problème de l'insuffisance alimentaire et énergétique en Afrique est un problème complexe. Ce n'est pas un simple problème technique qui peut être résolu par des injections plus ou moins massives de capitaux et de techniques. C'est un problème qui présente, en effet, à la fois des aspects techniques, sociaux, politiques, économiques et culturels qu'il importe de cerner de très près pour espérer obtenir à terme des résultats concrets et durables.

Toute solution qui se veut durable du problème alimentaire et énergétique doit obligatoirement partir de l'impérieuse nécessité de passer en Afrique de la "dépendance à l'indépendance, du contrôle extérieur au contrôle interne, des sources non renouvelables aux sources renouvelables". C'est dire que l'approche à adopter doit faire droit à la pleine participation des bénéficiaires eux-mêmes à toutes les phases du projet, depuis sa conception jusqu'à sa mise en oeuvre et à sa gestion, avec comme critère d'optimisation le bien-être durable des bénéficiaires.

Cette exigence est fondamentale. Elle a des implications sur le développement même de la science et de la technologie au service du développement. Une science et une technologie pour le développement sont, en effet, d'une certaine manière une "science et une technologie du peuple pour le peuple". On entend par là une science et une technologie pour lesquelles le progrès de l'humanité ne se réduit pas au seul progrès des connaissances pour la connaissance [10].

Dans cette optique la science agronomique serait par exemple une science qui s'attacherait plus généralement à l'amélioration du bien-être global de ceux qui travaillent dans les champs et les fermes et non pas uniquement à l'amélioration de la productivité agricole. En matière de technologie cette conception revient en somme à adapter les techniques aux besoins et aux possibilités des bénéficiaires plutôt que le contraire.

Une telle vision de la science et de la technologie s'accomode mieux de la petite échelle et d'une approche de développement "bottom-up". Elle requière un système politique qui s'accomode de larges espaces de liberté, seul moyen d'encourager la participation effective de tous les opérateurs dans la prise en main de leur devenir.

En conclusion l'Afrique peut-elle s'auto-suffire alimentairement?

Oui si elle s'accommode des exigences précédentes.

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V

PROSPECTS FOR A NEW WORLD AGRICULTURE WHICH IMPROVES THE QUALITY OF LIFE

ENERGY FOR AGRICULTURE IN AFRICA

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I. *Agriculture in a State of Transition*

In global terms, there is an abundance of food stocks, as there is with energy, to meet the needs of the world population. Total world food production now stands at 4.2 billion tons, including 1.8 billion tons of cereals, more than enough, if it is equally distributed, to provide everyone with an adequate diet. However, for various reasons, be they political, institutional or economical, there are pockets of plenty and of scarcity co-existing in this world. African developing countries are typical examples of food deficit countries. Per capita food production has been declining at a rate close to 10% during the last decade. The overall result has been that most of these countries continue to rely increasingly on food imports, and food aid has become a necessity after natural disasters such as prolonged drought, to reduce human sufferings. Food import bills increased by almost 10 fold between 1972 and 1983. The 1984-85 African Food Emergency Programme estimated that 21 severely affected countries would need cereal imports of 12.2 million tons during 1985.

Obviously, such a state of affairs needs a halt to reduce more human sufferings in the future. African agriculture is entering a phase of transition, and several factors will have fundamental impact and therefore shape the future of agricultural development in these countries. The most important ones are the population growth rate, rural-urban migration rate, and arable land availability.

Africa is witnessing a very rapid population growth. There is no continent with such an explosive growth rate as Africa. Africa's annual

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population growth rate between 1980 and 1986 was of at least 3% (FAO, 1987), and if this rate is maintained there will be a doubling of its population in 24 years, reaching one billion, double its 1982 level, some time between 2000 and 2005. Africa is thus expected to emerge as the second most populous region of the world.

The second consideration is that the urban population in Africa is growing at an even faster rate, faster than any continent in recent history. Rapid urbanisation has been the major social change of recent decades with consequent changes in food consumption. During the period 1980-2000, it is projected (U.N., 1982) that the total net additions to African urban population will be of the order of 226 million inhabitants, representing a spectacular percentage change of 166%, one of the highest to occur. Urban population by 2000 is therefore expected to rise from 136 to 362 million inhabitants. As a result, while nearly 29% of the population of Africa lived in urban areas in 1980, in 2000 this figure will rise to nearly 40%. These two factors will have important bearings on agricultural production systems in rural areas, where rural population of working age are food producers, and almost all urban residents will be consumers not producing their own food. Rapid population growth will be a major element in boosting food production at a rate of 3.6% annually. Past trends, such as that between 1961 and 1980, where production of basic staples grew at only 1.7% per year, being outstripped by population growth by more than two full percentage points (Paulino, 1980), cannot continue. Food production in this decade has been falling by above 1% a year.

Rapid urbanisation will also have considerable changes in food consumption and implications for nutrition both in rural and urban areas. Urban growth will influence agricultural production in several ways. It will accentuate the need to increase food production per agricultural worker because it will increase the proportion of population not producing its own food. One estimate (FAO, 1985) of the additional food production per rural agricultural worker in 2000 to feed the additional urban population in Africa will be of the order of 330 kg. of wheat equivalents, and as such, Africa becomes the region where the proportion of production per agricultural worker will be the greatest (Table 1). Also, urbanisation causes the emergence of urban diets, and hence the changing pattern of food demand, which require similar adjustments in food production patterns. One already notable trend in Africa has been a declining demand for traditional cereals, roots and tubers grown locally, with a rise in popularity of rice and wheat. Consumption surveys, for example in Tunisia, have found that the tradi-

TABLE 1 - *Estimate of production measured in wheat equivalents per agricultural worker required to meet consumption needs of net additions to urban areas in developing countries, 1980-2000.*

Region	Additional production per agricultural worker	
	(kg)	(% total production)
Africa	330	24
Asia	244	16
Latin America	1268	17
Total	340	17

Source: FAO, 1985.

tional staples of hard wheat and barley are yielding place in urban diets to industrially processed cereals, livestock products and vegetables. The implication for the future is clear — if food import is not to be further increased, more staples must be produced by relatively fewer people in rural areas, and more marketable surplus is to be generated from rural land and other scarce rural resources to meet urban demand.

In the past, Africa witnessed a gradual evolution of its rural food-producing system in response to growing population pressures. While isolated areas of the "slash-and-burn" system, (the earliest type of farming system) still persist, pockets of intensive cropping have also evolved in many countries which raise staples and export crops. In between these, "bush-fallow", "grass-fallow", or annual cropping systems exist. In future, a change in the farming system is gradually expected to accelerate in many parts of Africa to enter into a phase of more intensive production.

The potential of urban agriculture is an area very little explored in Africa. In future, urban agriculture could very well be developed for food production. By using intensive gardening practices, American gardeners can produce several times more vegetables per square metre of land than commercial farms. The success story of urban agriculture in Shanghai, China, in Lae, Papua New Guinea and in metropolitan Manila, and the Philippines is well known. In future, it can be expected that such practices reach the cities of Africa.

These changes will take place because the concept that Africa, as a region with abundant land and possibilities of extensive cultivation, is now overdrawn. The longer term capacity of resources within given political boundaries to sustain present or potential population has been studied. One approach linking population with the local natural resource base is the concept of carrying capacity, borrowing from the work of biologists on a maximum population of a species that a habitat can sustain.

One such study by FAO/IISA divided Africa into six climatic zones, and estimated population-carrying capacity of each zone at various levels of input use and technology adoption. It is reported that four of the six ecological zones have already reached the stage where further expansion of agricultural land would mean encroachment on some very fragile ecosystems. The only major reserves of carrying capacity for human population lie in the hot, humid rain forests of the central and southern zones. However, even there, extension can only take place after massive investment in rural infrastructure and in reconditioning leached, acidic and infertile soils and at the expense of the destruction of rain forests, which is likely to cause ecological damage of significant magnitude.

The overall contribution of this analysis leads to the indication that shifting cultivation will gradually be phased out in many African countries and African agriculture will enter a phase of more intensive cultivation to meet the demand of its growing rural and urban population. A recently revised FAO survey (FAO, 1987) in effect suggests that African developing nations will have to depend on higher yields and multiple cropping from the same land to achieve the goal of higher food production. Even African export crops (sugarcane, coffee, cocoa, palm-oil, cotton, etc.) have to be further intensified. This is because world demand for these crops is stagnant while prices are declining. As such, it means that producers have to cultivate these crops at a level of efficiency that would enable them to compete with other major producers.

II. *The Role of Energy in the Intensification of Agriculture*

Throughout the history of mankind, man has attempted to increase food supply by investing increasing amounts of energy. In traditional agriculture, sun energy is supplemented by human and animal power. In the transition to more intensive agriculture, fewer farmers produce food, but both the reduced input of human labour and the impressive increases in yields are made possible through the use of energy inputs derived from non-renewable energy sources.

More intensive production generally implies greater input use such as fertilisers, pesticides, machanical tools, etc. Every activity and every input, whether it is the use of animal or mechanical traction, the preparation and delivery of agro-chemicals to the farmer, the drying and other post-harvest treatments of crops for safe storage and use, requires the dissipation of energy. For example, 1 kg of nitrogenous fertiliser requires about 1.85 kg. of oil equivalent for its manufacture, packaging, transport, and distribution, 2.3 kg for 1 kg of pesticides and 2 kg of oil equivalent to manufacture 1 kg of farm machinery.

The analysis of energy use in intensive agriculture grew rapidly ever since the 1973 energy crisis. This is because such analysis put in evidence how energy is being used in the production process both directly as fuel and electricity and indirectly as fertilisers, pesticides and machineries and, as a result, allows a better understanding of energy flows, highlights the relationship between energy input and yield and identifies areas for energy savings or substitution possibilities, otherwise where additional energy input can result in a significant increase in yield.

Analysis of energy use in crop production during the process of intensification has been carried out in several countries where agriculture consumes large quantities of energy. German agriculture has been studied for a period covering 1880 to 1976 by Weber (1979), French agriculture from 1945 to 1975 by Deleage *et al.* (1979), and corn production in the United States from 1700 to 1983 by Pimental (1987). Figure 1 depicts the change in German agriculture from 1800 to 1975. This is typical of developed countries' intensified agriculture. There had been a steady rise in the use of fertilisers till by 1975 they represented the equivalent of 9 GJ/ha or some 1.4 barrels of oil equivalent per hectare per year. A rapid substitution of traction animals by machines took

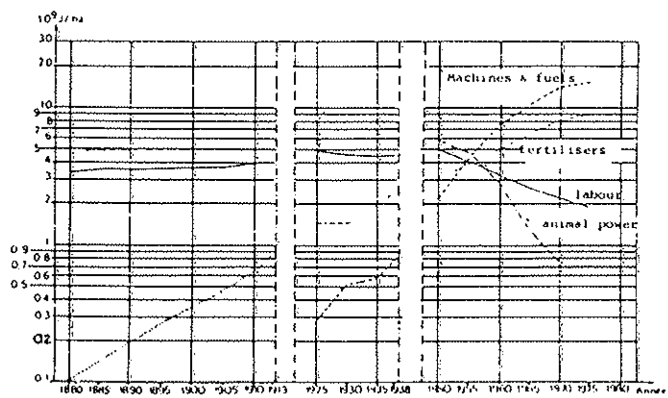

FIG. 1. Consumption of energy in German agriculture, 1880-1976 (*Source*: Weber, 1979).

place in the fifties so that by 1975 traction animals had virtually disappeared and fuel for mechanical farming had risen to an average 16 GJ/ha. The history of corn production in the United States shows a similar trend (Figure 2).

That there is an increase in yield with more energy input during the process of intensification has been established in many studies. In the United States, for example, corn yields rose from 1.88 t/ha in 1920 to 3.39 in 1959 and 6.5 in 1983 (Table 2). A graphical relationship better

TABLE 2 - *Energy inputs for various items in U.S. corn production* (1,000 Kcal per ha.).

Years	1920	1945	1959	1975	1983
Labour	65	31	19	10	6
Machinery	278	407	777	925	1018
Draft animals	886	0	0	0	0
Gasolene	0	1200	1550	600	400
Diesel	0	228	399	912	855
Nitrogen	0	118	676	1734	3192
Phosphorus	0	24	54	195	473
Potassium	0	13	54	120	240
Lime	3	46	50	69	134
Seeds	44	161	470	520	520
Insecticides	0	0	54	200	200
Herbicides	0	0	20	400	400
Irrigation	—	125	375	2000	2250
Drying	0	9	54	458	660
Electricity	1	8	36	90	100
Transport	25	44	79	82	89
Total	1302	2414	4667	8315	10537
Yield (kg/ha.)	1,88	2,132	3,387	5,143	6,5
Yield (1000 Kcal/ha.)	7520	8528	13548	20575	26000

Source: Pimentel, 1987.

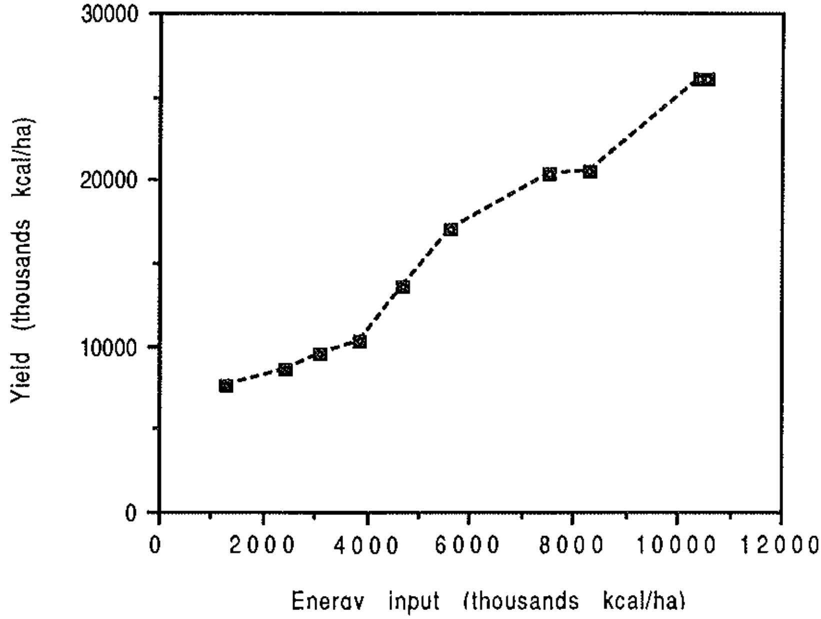

FIG. 2. Energy and corn production in USA (based on data from Pimental, 1987).

illustrates the trend (Fig. 2). When data from 350 food-producing systems were assembled, comparing output intensity of the farming system with the energy requirement of the system, a similar response was observed (Fig. 3). That agricultural yields respond positively to energy inputs is also the case of progressive farms in developing countries. Recent analysis of advanced farms in India and elsewhere proved that large increases in crop yield were a result of substantial investment of energy input in farms. One such relationship is shown in Figure 4.

Crops vary in their requirements of energy input to achieve good yields. A study in Italy showed that dietary energy output per hectare per unit of energy input for the major crops grown varies from 0.22 for almond to 2.9 for rice and corn. The energy input/output relationship is shown in Figure 5. Some crops are therefore more energy-intensive than others. The second point is that diminishing return per unit of input in energy terms also holds true during the process of intensification. Table 3 shows how protein output is related to the energy intensity of different farming systems, but calculation from these figures provides evidence that for each additional increment in energy input, less and less additional yield is obtained (Fig. 6). Adoption of energy-dependent tech-

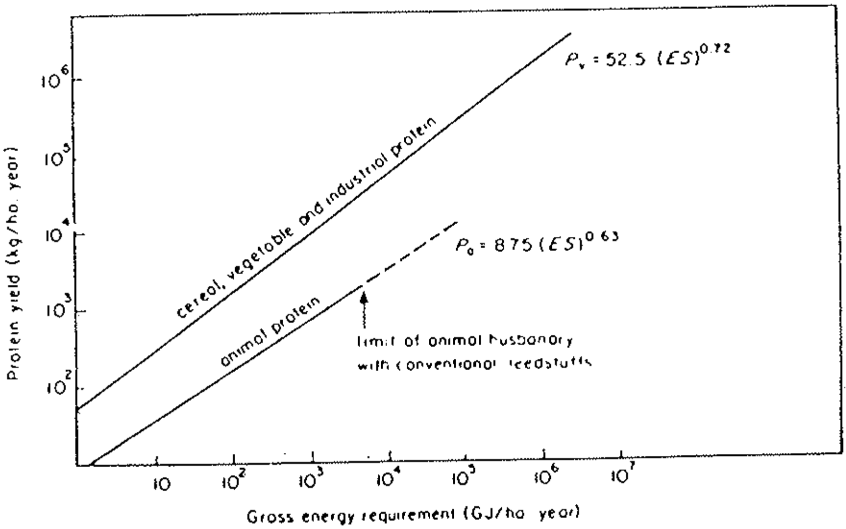

FIG. 3. Global relation between gross energy requirement for protein production and intensity of protein production (*Source*: Edwardson *et al.*, 1977).

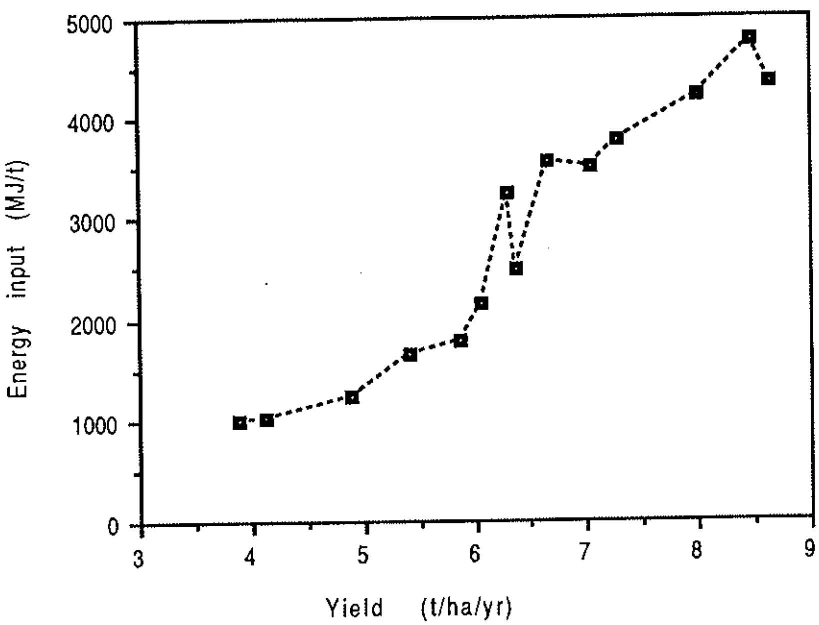

FIG. 4. Energy and land productivity in Punjab (based on data from Pathak, 1985).

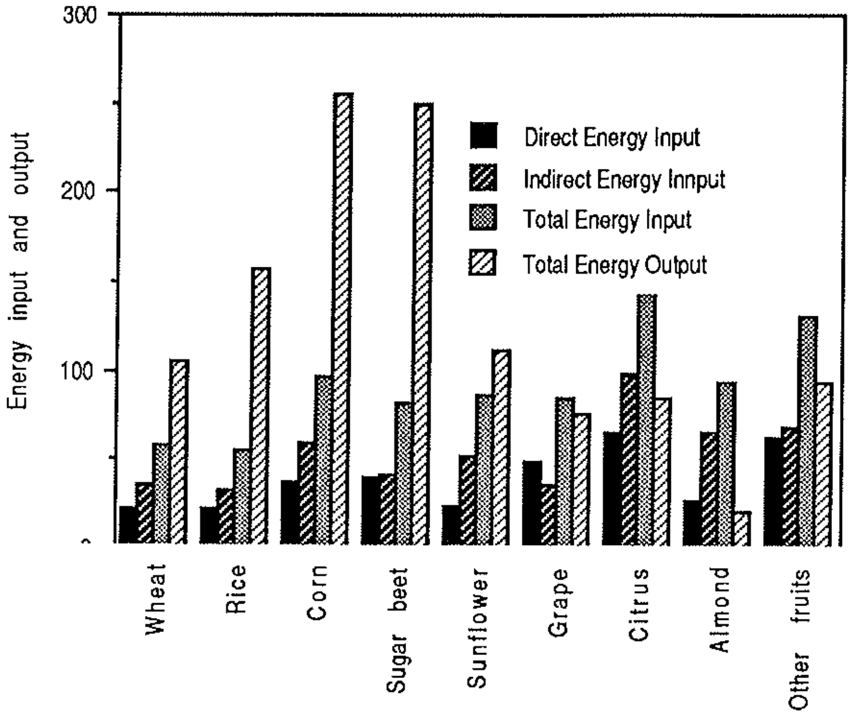

FIG. 5. Per hectare energy relations of major crops in Italy (x 10.000 Kcal) (based on data from Triolo and Unmole, 1986).

TABLE 3 - *Energy intensity of inputs and protein output in different types of enterprise.*

Types	Protein Output (kg/ha./yr.)	Energy intensity (GJ/ha. yr.)
Undeveloped agriculture	37	0,4
Low intensity agriculture	82	1,2
Upland farm Europe	137	2,4
Modern intensive farm, UK	328	8
Corn, USA	618	20

Source: Slesser, 1982.

nological advances in European and other industrialised countries' agriculture has, in fact, been the major driving force for large increases in yield both per unit of land and per agricultural worker.

The lesson is clear for developing countries. Energy inputs will raise yield of food crops significantly, but there is no point in intensifying agriculture to the extent to which developed countries have done so far. The analysis also suggests that the least intensive way to produce food globally would be to first intensify those parts of the world still comparatively unintensive such as Africa, rather than to further intensify advanced agriculture.

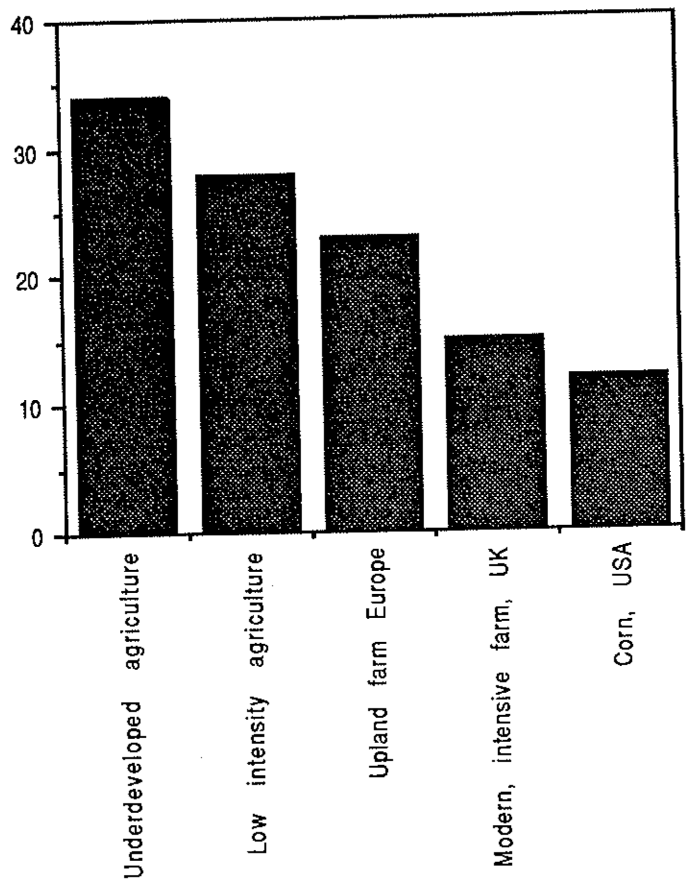

FIG. 6. Increment in protein output per 0.6 GJ/ha .y increase in input.

III. *The Role of Non-Renewable Energy Sources in African Agriculture*

An FAO assessment of commercial non-renewable energy sources in agriculture has revealed that energy use per agricultural worker and per hectare of arable land and permanent crop in Africa is one of the lowest of the major world regions. Total commercial energy use in 1972 and 1982 was only 2 and 3 million tons of oil equivalent respectively (Table 4). Such low figures of commercial energy consumption in Africa stem from the fact that the majority of farmers depend on family labour and natural soil fertility in raising food crops. Of the 3 million tons of oil equivalent consumed in 1982, the largest fractions were used in a few pockets of energy-intensive production systems geared towards export crops and a few highly productive farms which supply crops to urban markets.

African agriculture has to be revitalised with some commercial energy inputs if the level of yield and cropping intensity required to meet actual requirements and future demand is to be achieved. These will include both indirect and direct energy inputs.

Present consumption of fertiliser and pesticides on a per hectare basis reveals that Africa as a region takes little advantage of these yield-augmenting energy inputs. The average consumption of fertilisers is only about 19 kg of plant nutrients per hectare of arable land against a world average of 78 kg. If the high consumption of fertilisers in Egypt,

TABLE 4 - *Commercial energy use in Agriculture - Africa and other regions.*

Regions	Energy used in agricultural Production (million t.o.e)		Energy used per agricultural worker (kg.o.e)		Energy used per hectare (kg.o.e)	
	1972	1982	1972	1982	1972	1982
Africa	2	3	20	26	16	18
Far East	9	21	33	72	34	76
Latin America	7	11	193	186	48	63
Near East	4	10	123	235	47	120
Developed countries	169	210	2006	3294	253	312

Source: FAO, 1986.

Mauritius, Zimbabwe and the Republic of South Africa is excluded, the average scarcely reaches 8 kg per hectare of arable land while in Zaire, Somalia and Niger, the figure is less than 1 kg per hectare. Clearly, considerable potential exists to increase yield with fertiliser energy in the future. If the agronomically recommended rates of fertiliser application were to be applied only for nitrogen, the total requirements for Sub-Saharan Africa would have been about 15 million tons in 1980 against the 600,000 tons used. In energy terms, this would have been equivalent to 30 million tons of crude petroleum, and if distribution costs were included the figure rose to 40 million tons of oil equivalent. There is no evidence yet that this is likely to occur in the near future. The annual fertiliser consumption growth rate between 1980/81 and 1984/85 was only of the order of 0,5%, growing from 1.33 million tons to 1.47 million tons (FAO, 1987).

The geomorphology and climatic fluctuations of Africa make it the driest continent after Australia. However, in Europe, with less than a quarter of the potential arable land that Africa possesses, and with a much smaller natural water deficit, two and a half times as much land as in Africa is irrigated. At present, only 5% of the land area is irrigated. If the area under irrigation in Egypt is excluded, this figure of 5% is reduced by nearly half. FAO estimated the irrigation potential of Sub-Saharan Africa at 33.6 million hectares while the World Bank came up with a figure of 15 to 20 million hectares. There is now a growing awareness of the need for assured water supply for agricultural development in many African States. The development of irrigation will have to go hand in hand with energy supply in most of those cases where pumping will be required. Estimates of annual fuel requirements for irrigation vary from 160 kg per hectare in developed countries to about 200 kg in Africa.

As a means of increasing both land and labour productivity, selective mechanisation will be gaining popularity in the future. In many cases, there is already a shortage of labour at peak demand. Population and migration trends indicate that fewer people will be engaged in agriculture in the future and these rural people will need to produce more food than at present. In this process, human power will have to be supplemented with other power sources. Animal power has good potential in those areas of Africa where tsetse infestation does not exist. However, two-thirds of Sub-Saharan Africa are infested so that additional power can be met only through mechanisation. Given that farm size is small in Africa, there are several types of machinery which are eminently suitable there. These include motors and pumps for small tube wells, two-wheeled tractors, small motor driven hoes, ultra-low volume sprayers, etc. In situations where farm sizes are reasonable, there may be economic justification for the use of medium to large size tractors. Obviously, other factors will have to be considered before introducing such machineries. In 1980, the number of tractors in use in the whole of Africa (FAO, 1982) was only 443,000, with only about 27% of them in Sub-Saharan Africa. For comparative purposes, India alone had 418,000 tractors in that year.

Energy-related constraints as a factor hampering food production in Africa is very slowly gaining support. For example, in Nigeria, Mkpadi (1987) in an analysis of the agricultural energy situation concluded that the current poor level of the country's performance in agriculture is associated with a negligible investment of energy in this sector. Similarly, Nkonuki and Lushiky (1988) noted that there can be no major transformation in agricultural production in Tanzania unless energy inputs are increased substantially. Fairly detailed analysis for an 18 year period (1960-1978) by Weber (1981) has provided evidence that increased energy use in Kenya reflected very well in the rise of land productivity. That more energy is needed in African agriculture is also the stand of the African Development Bank. In 1983, the Bank stressed that the current methods of food production offer little scope for substantially raising the level of productivity and that achievement of the goal of food self-sufficiency will necessarily mean increased application of energy. The Club of Sahel also made a similar analysis and estimated that the total energy requirements in the region for food self-sufficiency by the year 2000 would be of the order 1 million tons of oil equivalent to feed 30 million inhabitants, or 33 kg per person. For Africa as a whole, as FAO estimate shows that a nearly fourfold increase in energy subsidy per hectare, from 12 kg oil equivalent to 46 kg in the year 2000, is required to double food production (Fig. 7).

There is however a serious paucity of data at national levels of the present energy flow in agriculture and requirements to achieve reasonable crop yields. Unmole (1983, 1986) demonstrated the positive role of energy use in Mauritian agriculture and examined future relations. Similar analysis is required for the major crops and cropping systems in African countries. Once such analyses are performed, it will become more precise to understand the exact role of energy in food production and to develop balanced development strategy to give priority treatment for agriculture's limited energy requirement.

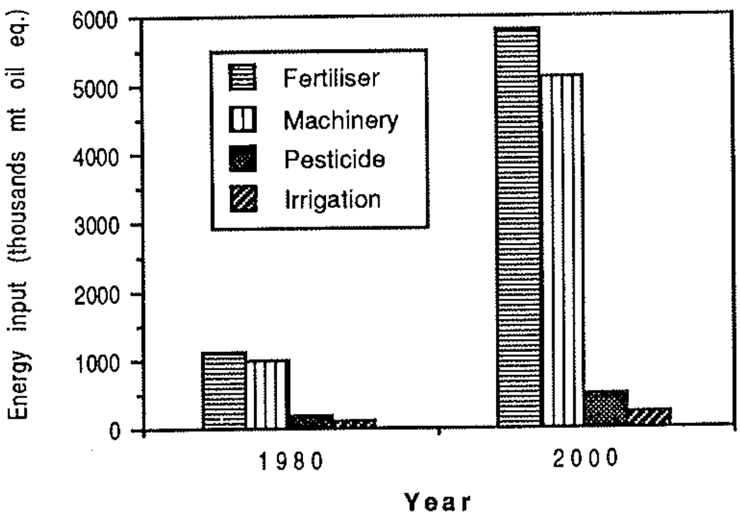

FIG. 7. Projection of Agricultural energy use in African developing countries, 1980-2000 (*Source*: FAO, 1981).

IV. *The Contribution of Renewable Energies and New Energy-Saving Practices and Technologies in African Agriculture*

Agriculture and food production in African developing countries is still highly labour-intensive, relying on simple tools and traditional practices. Human energy supplies 80% of agricultural power needs in Africa, one of the highest in developing regions (Figure 8) and in this, the contribution of women is very high (Unmole and Triolo, 1988). Women have traditionally been responsible to handle most of the family food production, processing and preparation, using outdated methods and practices. It is presently estimated that nearly 60% of Africa's agricultural output is produced by female labour.

Dependence on the traditional way of using renewable human energy has limited the size of farm holding and the intensity of cultivation. For example, hand digging consumes human energy at the rate of about 750 Kcal per hour. Therefore, active digging cannot be carried out for more than two hours a day. Also, the size of holding that can be prepared for planting by one man is about 0.5 hectare, a figure that has been found to be remarkably consistent across the continent of Africa. Obviously, unimproved hand tool technology cannot alone provide more food than for subsistence level with high risk of failures

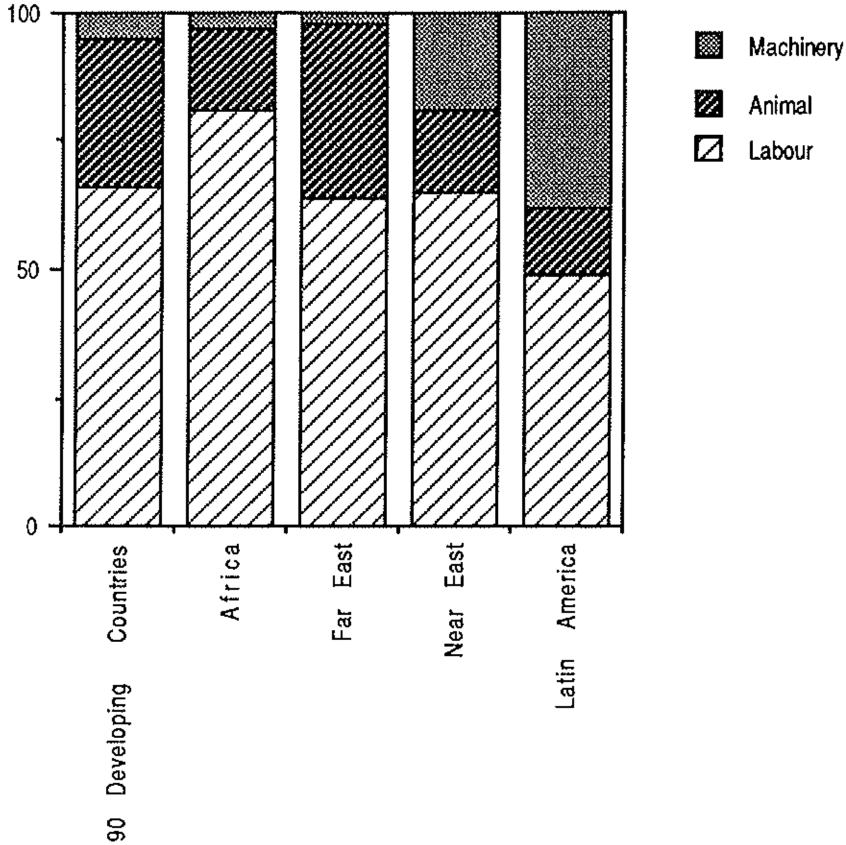

FIG. 8. Percentage share of total power in developing countries' agriculture.

during adverse weather conditions. Africa, in effect, has the least power investment — human, animal and mechanical — in agriculture (Fig. 9).

In the immediate future, there are therefore good possibilities to tap more efficiently this large input of human energy and this can be achieved if use is made of new hand tools and implements in combination with improved agronomic practices. Okigbo (1987) pointed out that one of the reasons for low yield and low cropping intensity is the use of unimproved hand tools such as hoes and machetes for food production. Simple but improved hand tools have heen developed in various research institutes worldwide which can be effectively put to use in African conditions. How yield has been increased by more than twice and labour productivity by several fold when the traditional way of producing crops

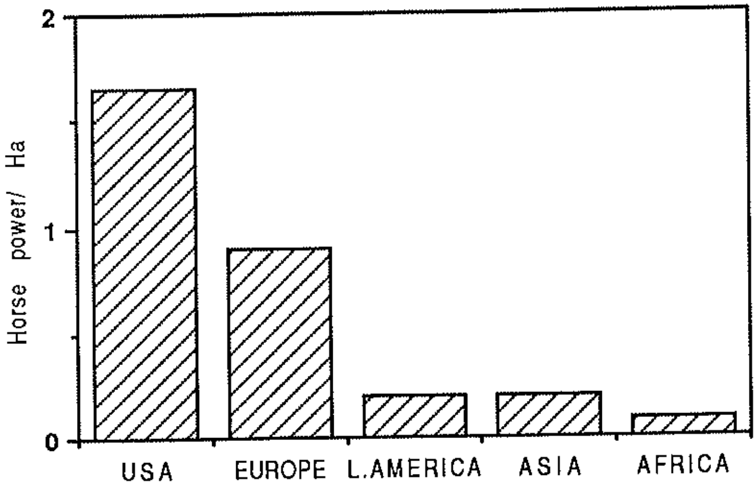

FIG. 9. Horsepower/ha for Agricultural operations in different regions.

was supplemented with improved hand tools such as rotary injection planter for sowing, rotary band applicator for fertilisation and battery or solar-operated light-weight controlled droplet application sprayers for weed and pest control combined with no-till system, has been demonstrated at the International Institute of Tropical Agriculture based in Ibadan, Nigeria. The success story of "bushbarrows", a prototype based on the concept of the wheelbarrow, using cycle wheels, carrying loads on the wheel shaft, and used in the bush (Soltner, 1988) is another example of how better use can be made of human energy in the African context. There is a need to promote such devices in Africa, especially, pedal-powered devices, to better utilise human energy. Examples include water pumps, winches, winnowers, corn grinders, hydraulic pumps, bicycle drawn trailers, pedal rovers, wheel barrows, etc. Most of these simple technologies are also well adapted to African women. Their use on a much wider scale than at present can reduce women's work load significantly and could lead to more productive activities.

There is considerable scope to increase animal power on farm holdings in many parts of Africa, especially in the tropical uplands and the zones of transition between rain forest and dry savannas. At present, the use of animals varies from country to country with Botswana, Ethiopia, Egypt, Madagascar and Tanzania all having long histories of animal power, whereas Ghana, Kenya, Nigeria and Zambia use animals relatively little. In Francophone African countries, the use of animal power has only been introduced relatively recently. In the Ivory Coast, for example, the number of oxen increased from 250 in 1972 to 29,000 in 1981 following a policy decision to promote animal power.

Of all developing countries, African countries require the most support in increasing their use of animal power as a renewable source of energy in agriculture. Reports from Senegal and Sierra Leone indicate that ox-ploughing and weeding using improved equipment cost considerably less than the same tasks by tractor or manual labour (FAO, 1984). The semi-arid tropics cover a large part of Africa where the results of research at ICRISAT (Bansal *et al.*, 1988) can be transferred. The authors have developed very efficient animal-drawn devices which in combination with improved agricultural practices (graded broad beds and furrows) have brought about substantially higher yields. Some African states such as Gambia and Tanzania have already witnessed farmers' ability to expand the area under cultivation by 20 to 80% with ox power.

Other renewable sources of energy of particular interest to promote agricultural development in Africa include direct solar radiation intercepted by solar-flat-plate collectors and photovoltaic cells as well as "indirect" solar energy such as biomass, small hydro power and wind energy. Much has been written on each one of these. What is needed is their applications in the field of agriculture. These energy systems are capable of meeting many of the power and fuel needs on farms and homesteads. Solar PV pumps and windmills can be used for lifting irrigation water. Minihydel systems, wind generators, community biogas plants and biomass gasifiers can produce agricultural power needs. There are also good candidates for supplying the energy needs for post-harvest treatments of crops. Africa's potential for decentralised energy oil crops has yet to be demonstrated. Several crops are being screened. One with good potential seems to be the physic nut tree (*Jatropha curcas*), a crop that had already been cultivated in Benin, Madagascar and the Cape Verde Islands during the Second World War for the manufacture of soap and the extraction of fuel oil.

Biotechnology is expected to combat the high energy costs of conventional intensive agriculture in the future. To some extent this is already taking place in developed countries. One important contribution for developing countries will come from the inclusion of genes for specific traits such as disease and pest tolerance, drought tolerance, and vigour in crops. Some achievable targets for Africa include stalk borer-resistant maize (Klein *et al.*, 1987), cutworm resistant potato (Dodds, 1987) and pink-bollworm-resistant cotton (Umbeck, 1987). The use of biotechnology for the improvement of cassava, yams, and plantains were recently discussed at IITA. Recent breakthrough in the identification of genes which can be incorporated to provide good resistance against drought for rice and maize shows the bright prospect of biotechnology in the future (Mundy and Chua, 1988; Gomez *et al.*, 1988). Biological nitrogen fixation is another area where important applications and breakthrough will reduce the need for energy-expensive industrial nitrogen fertilisers. The paper of Döbereiner in this meeting illustrates that non-legumes will soon benefit significantly from R and D in this area. Apart from a few, legumes have received very little attention in Africa (Vietmeyer, 1988). This is one way of quickly increasing food production with little or no fertiliser. The bambara ground nut (*Voandzeia subterranea*) is grown by villagers throughout most of sub-Saharan Africa, yet it has received very little research attention. Another good potential for increasing food production with less fertiliser includes green manuring with legumes. The paper of Hartmans discusses the case of alley cropping developed at IITA. Another crop with very good future is *Sesbania rostrata*, a Sahelian wild legume. This crop fixes large quantities of nitrogen and as green manure in sorghum and rice fields has produced good results at the ORSTOM research center in Dakar, Senegal. Rice yield was 5.9 tons per hectare as against 3.8 on plots fertilised with chemical nitrogen fertiliser (60 kg/ha) and 2.1 tons for unfertilised plots (Anon, 1988).

V. *To Conclude*

The sound use of renewable energies and simple devices along with improved agronomic practices can raise productivity of African farms and therefore pave the way for more commercial energy-intensive farming systems for the future. Much remains to be done to bring these technologies, devices and practices to the farmer in appropriate minimum cost packages. Priority treatment for agriculture's limited energy requirements is an essential component of a balanced development strategy and in this, external support is urgently needed to demonstrate the feasibility of integrated energy systems.

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"MODERNIZATION" AND SOCIO-ENVIRONMENTAL DETERIORATION

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1. *The Constant Catastrophe*

The world is periodically struck by news about catastrophic events involving famines, widespread malnutrition and massive migrations, in one part or another of the earth. The international concern fades away after the crisis is assumed to be finished.

However, the news reaching the public through the mass media refers only to culminating moments of a drama that constitutes the "normal" life for hundreds of millions of people. We have referred to it elsewhere as "the constant catastrophe".[1]

The prevailing situation in large regions of the Third World includes one thousand million undernourished human beings. On the other hand, the magnitude of the environmental problems affecting extensive regions of the world is reaching alarming proportions. UNEP figures of desertification trends in Third World countries are impressive. In 1977 at the United Nations Conference on Desertification, the halting of desertification was thought to be an attainable goal by the end of the century. It is now evident that such a view was over-optimistic. Near by half of the period is gone and desertification has accelerated in large-areas, whereas in others the measures taken have done nothing but slow down the process. The prospects are that the future will be more worrisome than the present. Not only local areas which are already bad are becoming worse, but environmental deterioration is reaching regions so far untouched, including "First World" countries. In addition, new

[1] Such is the title of Volume 2, [3].

threatening factors are on the horizon: gradual increase in carbon dioxide and dramatic decrease in ozone may change the picture in a yet unknown fashion.

We are not saying anything new. The deterioration of ecosystems and of the living conditions in increasingly large regions of the World has been discussed in an abundant literature. Why do we need more research projects, reports, books, conferences? What can be added to what has already been said?

There are several answers to be given to these questions. In the first place, during recent years one could detect signs of an increasing uneasiness in international organizations, both governmental and non-governmental, with reference to the frustrating experience of aid programmes, technical assistance, development decades, international conferences and other efforts "to help" the countries in distress. It seems that there is a growing awareness that far too little has been done to avoid the repetition of such catastrophes, and that not much progress has been made in the more modest task of gaining some consensus about the deep roots of the crises.

The last assertion leads us to our second answer to the above posed questions. Within the abundant literature already referred to, we find all sorts of analyses about soil deterioration, ecological alterations, peasant poverty, malnutrition and famines. What do they account for? Do they in fact "explain" what is happening?

2. *Misleading Analyses, Partial Truths and Pseudo-Explanations*

The great majority of the "explanations" referred to above fall into one or another of three categories.[2]

The first category contains the authors who sustain the position which I have called "the official version".[3] With a greater or lesser degree of rigidity, these publications resort to well known stereotypes: explosive demographic growth, peasant ignorance, technological backwardness, resistance to modernization.

The adherents to the official version seek *the* cause of the trouble in well localized factors, usually associated with problems of culture,

[2] We have referred to these "kinds of explanations" in [7] which contains a synthesis of case studies carried out in Mexico and Argentina.

[3] We introduced this expression in Volume 1 of [2] with reference to the "accepted view" of the Sahelian drama during the 1968-72 drought. It has, however, general application.

education, adaptability, and even race. In the final instance, leaving aside natural disasters, guilt is placed on the shoulders of the protagonists of the drama themselves. When they change, when they have less children, when they get an education, when they let themselves "be developed", when they decide to take the road of the highly industrialized countries, in synthesis, when they modernize — so the official version asserts — their problems will dissapear. The champions of an acritical modernization make a transmutation, transforming effects into causes and the victims of a fate they cannot control into the source of their own misfortune. In this way, consciously or unconsciously, the social "system" within which the drama takes place, remains untouched.

This position is the target of the authors belonging to the second of the two categories we have mentioned and who sustain a position I will call "the denouncing version". In their opinion, the guilty parties are different, their analysis boils down to a single cause that is found at the root of all the evils: the political and economic system. Its ways of action and its agents are numerous: capitalist exploitation, dependency, transnational corporations and a subservient national bourgeoisie. A large numher of Latin American publications have been devoted to identifying the villains of the drama and exposing them. Among the "accusers" one may find ecologists, social reformers, active revolutionaries and honest and conscientious researchers. We may agree with them in the identification of some of the devils, but we submit that the "denouncing version", by itself, lacks explanatory power. Our contention is that between the tactics of the transnational corporations and the physical process that leads to the degradation of an ecological system, or between the theory of imperialism and the forms acquired by the deterioration of the living conditions of the peasantry, there is a distance that we cannot jump over so easily. To say that in both cases there are casual relationships has no explanatory value. In concrete situations, such an affirmation has to be qualified and in some instances it may be considered, strictly speaking, as erroneous. An analogy may clarify our assertion.

The origin of the general circulation of the atmosphere, with its cyclones, anticyclones, waves and fronts, is the energy of the sun. However, if a student of meteorology is asked how a tropical cyclone affecting the islands of the Caribbean is formed, the answer "it derives from the sun's energy" is not acceptable. His answer will be considered as trivial, if it refers to the "first cause". And it will be considered wrong, if the student means that he can establish a direct causal relationship between the amount of solar energy arriving at the atmosphere and the dynamic and thermodynamic structure of the cyclones. In order to pass the test, the student should explain how the peculiar structure of a tropical cyclone with its accelerated vertical movements, its characteristic central "eye" and its violent transformations of energy is generated. The answer should be given in terms of the *mechanisms* which determine the dynamics of the processes involved. And the student should be able to show the difference between such processes and those governing the dynamics of a peaceful anticyclone that also derives its energy from the solar radiation.

The third category of studies is of a purely technical nature. They do not enter into the problem of "who is going to be blamed for that». They confine their task to the analysis of the physical environment (kind of soil, climate, water resources) and of the crops that could be best adapted to obtain high yields under those conditions. Without underestimating their value, such contributions fall short of the target. They take into account just *one* of the elements to be considered in the search for solutions to problems that are far more complex than the simple relation soil-plant-amount of production.

A well known historical example may illustrate our assertion. The Green Revolution was thought to be a universal panacea for food scarcity. In some instances it was so. But the net results of its application in many other cases, as illustrated by a large number of very serious studies, [4] made it evident that increasing productivity, no matter how, was not the final solution to the food problems, nor was it always a step in the right direction. This point requires, however, some more detailed discussion.

3. *Environmental Deterioration and Poverty in the Midst of Productive Abundance*

The experience we have repeatedly found in numerous case studies carried out within the context of international programmes, as well as the lessons learned from the history of many countries, have led us to consider that the three categories of studies referred to in the preceding section provide just pseudo-explanations to the problems we are concerned with. Let us briefly indicate why we are propounding a different approach.

[4] Among the large number of publications on critical appraisals of the Green Revolution we should mention the UNRISD Series on this subject, and in particular [1] and [13].

Food problems in developing countries are generally based on a linear pattern of linkages: production-processing-distribution-consumption. The proposal of a study that is not centered on the production and distribution of food may sound scandalous. Is it not absolutely obvious that malnutrition and famines are produced by shortages? Our answer is that the problems of malnutrition, and especially the great famines, cannot be reduced to the ambiguous formula "food shortages". In the case of Mexico, with growing malnutrition indices, we have shown [5] that there has never been insufficient food in the country to satisfy the needs of a rapidly growing population. When national production was insufficient, the deficit was covered by imports. In fact, food *availability* in the market grew faster than population. Food has been available but not to everyone. The real problem is that *access to food* has become increasingly difficult for large sectors of the population.

It is the accessibility of food to the poorer sectors which determines the nutritional levels in a country, and not the amount of food produced or its market availability (although in extreme critical conditions the absolute lack of food at a *local* level is *the* problem to be solved at once, without searching *at that moment* the reasons behind it). Frequently, however, this formulation of the problem, albeit correct, has only displaced the problem. It is often said that "It is true that the problem is not the shortage of food, but the poverty". In fact, one does not have access to food because one does not have the means. This is perfectly obvious! But, what causes poverty? This question finds the already mentioned traditional answers: ignorance, backwardness, low productivity. A Malthusian answer is not lacking: "They produce little and reproduce too much".

A typical counter-example has been provided by our studies in the Mexican region called "La Laguna". [6] From the strictly productive point of view this region appeared, only a decade ago, as an example of the achievements of modern agricultural practices. The economic variables that are currently used as "indicators" clearly justified this point of view. The "ejido" sector (peasants) took care of almost all cotton production of the region, using the best available technology and reaching the highest physical yields registered in the history of the country. They managed to produce the same amount of cotton as 20 years before with only 42% of the areas harvested in 1955. Indeed a great success of

[5] Cf. the introductory chapter of [8].
[6] Cf. [9].

modern technology. This appreciation becomes drastically modified when other factors are taken into account. The depredating effects of the technologies (in a broad sense) applied to production have become evident, announcing the collapse of agricultural production. Experts in the region consider that such a moment is very close and that the trend towards desertification already visible will increase in speed. At the same time, researchers began to realize that the expansion of the population and the maintenance of a low standard of living, which have been the caracteristics of the evolution of a large part of the peasantry, are not *generated* by population explosion, but are the inevitable consequences — the social cost! — of a productive system with methods and technologies imposed *contra-natura*. Population boom is just an aggravating factor but not the primary cause of emigration.

This corroborates the working hypothesis that guided our research under several international programmes: the problems of accessibility to food are the result of structural mechanisms that lead to the marginalization of large sectors of the rural population. Moreover, the degradation of the biosphere and the decline of living standards are not independent processes. They are closely related to each other and cannot be explained with reference to simple linear causal chains of events. They are concomitant effects of structural problems of complex systems that include not only the environmental system in which production occurs, the productive system itself and the social groups carrying out production, but also the economic regime they are subject to and the external factors that condition their activity.

4. *What do we Explain when we "Explain" Rural Problems?*

In section 1 we referred to the fact that not much agreement has been made in the task of obtaining some consensus about the deep roots of the crises affecting vast rural sectors of the Third World. And we asked ourselves whether we are in need of still further studies on the subject.

It should be obvious that a verification of the existence of poor peasants or of the overexploitation of resources here or there, could not by itself justify further "case studies". At a more sophisticated level, the verification of the existence of certain kinds of soils in various parts of the world that could be made more productive (or just productive, if now they are not) would be extremely valuable but will not take us very far in the diagnosis of the drama.

On the other hand, it seems that we now have enough evidence about regions having quite different environmental characteristics or that differ from each other in their socio-economic and cultural history and yet are suffering similar processes of deterioration. The working hypothesis stated in the preceding section provides, in our opinion, a clue to find a comprehensive explanation of such extensive and increasing deterioration. We may reformulate it as follows. We have to deal, not with productivity problems, but with problems that are the result of structural properties of complex systems. The productive system (as a *subsystem* of such a complex system) is the mediator in the interactions between the physical environment and the society. The technological package (in a wide sense) is the hinge of the articulation between both. Only a systemic approach can reveal the mechanisms behind the processes that are involved.

This is not the place to describe the kind of system analysis we are propounding.[7] We shall assume familiarity with the basic concepts of structure and function, as well as with the distinctions among levels of processes and levels of analysis. There are, however, a few remarks to be added.

System analyses applied to individual case studies need to be complemented with comparative studies between different systems. It is not easy to decide what one has to "compare" to carry out meaningful comparative studies concerning complex systems.

One of the distrinctions made in the theory of complex systems may serve as a guidance to establish criteria for such purpose: the distinction between structure and function. Complex systems behave as "totalities" composed of subsystems. Following the terminology introduced elsewhere, we use the expression "*functioning* of the system" to designate the activities of the system as a whole; and we call "*function*" the contribution of each element or subsystem to the functioning of the system. It should be clear that both expressions are relative to the level of the analysis. What we call "the whole system", for a certain level of analysis, is also a subsystem of larger systems, where they may perform one or more functions.

[7] The kind of system analysis we have applied in our own programmes owes very much to the theory of dissipative systems developed by Prigogine's School. The main references could be [11] and [12]. However we have tried to extend the theory to the studies of more complex systems such as those dealing with the interactions between physical environment and society. We maintain that these latter studies require a reformulation of the epistemological basis of interdisciplinary research. A synthesis of this view is given in [5] and [6].

The usefulness of the basic systemic concepts referred to above becomes clear in comparative studies. The lessons to be learned from a comparison of case studies go far beyond what can be obtained from the study of each case taken in isolation. It is, in fact, the only way to get results that may claim a certain degree of *generality* and have *explanatory value*. However, the notion of "comparing" is related to the concept of *similarity*, the meaning of which within the context of complex system analyses is not obvious.

Direct comparisons that look for similarities in the structures seldom provide solid grounds for useful generalizations. The reason is that comparative cases studies tend to focus on one or another of the subsystems. Similarities found in their structure may hide profound differences in the role they play in the functioning of their own sustems. Likewise, quite different structures of corresponding subsystems may perform similar functions in each one of the systems they belong to.

In our experience, meaningful comparisons of complex systems, as well as the very possibility of non-trivial and practical generalizations, require *shifting* the comparative analyses *from structures to functions, processes and mechanisms*.

Our emphasis on the functional aspects (processes and mechanisms) in comparative studies carried out in several countries has helped us a great deal in the search for "explanations" of the rural problems we are dealing with. [8] They have provided actual examples of rural situations very dissimilar in structure but being the setting of common processes or of activities where common mechanisms are in action. From the analysis of those cases we may draw general conclusions that may help to clarify the way to go in the search for alternative policies to halt and reverse deterioration of the environmental and the impoverishment of rural sectors.

5. *Epilogue*

The above comments all point in the same direction: the dramatic living conditions of large sectors of the rural population in Third World countries is by no means a problem that can be expressed just in terms of "productivity". They will not be solved on the basis of technological

[8] Cf. [10].

developments that, as a sort of *Deus-ex-machina*, will provide a happy end to the drama.

This point cannot be overemphasized. Once again, as happened at the start of the Green Revolution, a new wave of optimism is expanding in agricultural circles and in the world at large. It would seem that not everything looks dark in the future. An unprecedented technological revolution is already under way. It has the potential of changing the means of production and the production relations so drastically that many of the present problems may, in principle, disappear. Agricultural production may, for instance, cease to be a problem anywhere in the world. But other, and perhaps deeper, problems would come, unless both scientists and politicians realize that such technological revolution requires profound socioeconomic changes well in advance of its massive implementation.

The Third World cannot go on accepting the prevalent practices today. We have described them elsewhere: "Agricultural research priorities are shaped by the effective social demand of the minority. Affluent groups, internationally and nationally, shape agricultural strategies, including technological choice, to their advantage, not in accordance with the interests of the most deprived groups who live in permanent insecurity with respect to food" [1, 13]. The danger of deepening the gap between both groups may increase in the future in proportion to the magnitude of the technological jumps.

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SOME OBSERVATIONS ON ENERGY AND AGRICULTURE

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The relationship between energy and agriculture operates in three areas:

— Energy input to agricultural processes is both direct (electricity, fuel oil, solar energy, etc., absorbed on the farm) and indirect (consumption of agrochemical products and the use of machinery).
— Agriculture may itself produce energy sources: wood for fuel, the products of the transformation of biomass (biogas, alcohol, etc.).
— Particularly as a result of the combustion of fossil fuels, energy production and consumption releases pollutants into the atmosphere, water table and soil, damaging agricultural ecosystems and altering chemical and physical equilibria.

Figure 1 shows the complexity of these relationships.

Of the major pollutants generated by combustion processes — sulphur and nitrogen oxides, particulate matter, carbon monoxide, hydrocarbons and carbon dioxide — those most damaging to plant life are the sulphur oxides (especially sulphur dioxide) and particulate matter, plus ozone, which is not formed directly in combustion processes but is a product of reactions between nitrogen oxides and hydrocarbons in the presence of ultraviolet radiation. Ozone is formed in the presence of NO_2. In rural atmospheres, under normal conditions of pressure and temperature, NO_2 represents between 80% and 100% of all the nitrogen oxides produced by combustion.

Sulphur dioxide and ozone have a direct detrimental effect on plant life. The effect of carbon dioxide on agriculture is indirect. The clima-

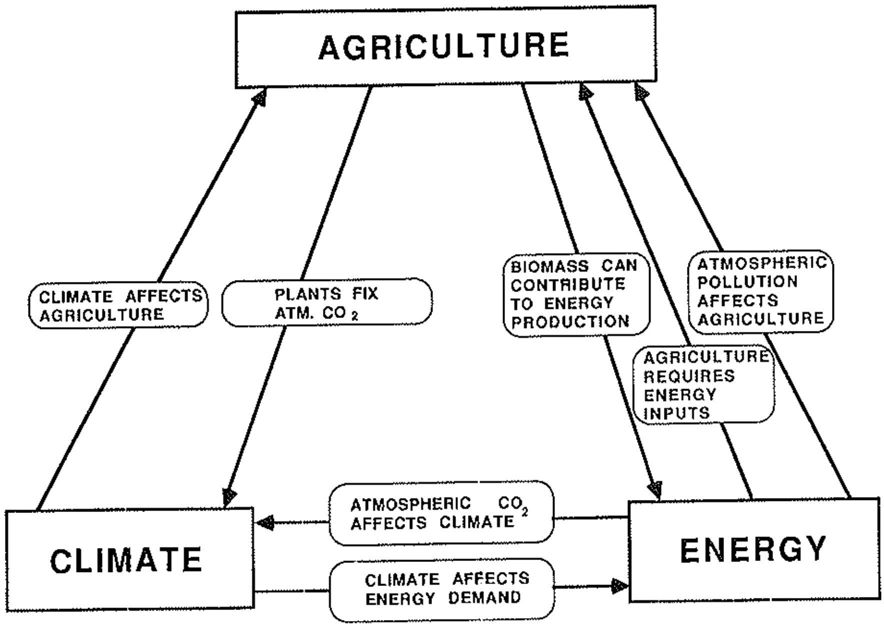

FIG. 1. The links between agriculture, energy and climate.

tic changes it causes affect the physiological behaviour of plants, changing crop productivity and harvesting dates. With regard to the direct response of plants to CO_2 concentration, the rate of photosynthesis increases, "coeteribus paribus", in proportion to the amount of CO_2 present in the atmosphere.

Particulate matter contains trace elements in the form of oxides, nitrates and sulphates which reach plants through the soil. These compounds, being soluble in water, cause a substantial decrease in the pH of atmospheric precipitation or of fog. As in the case of CO_2, the damaging effect on plants is indirect, through the soil, and depends on their biological, chemical and physical micro-environments.

Carbon monoxide has a very low water solubility compared to carbon dioxide, so that absorption of carbon monoxide through leaf stomata, which would have caused toxicity, is practically negligible. Hydrocarbons are insoluble in water. They are therefore not toxic to plants. However, hydrocarbons condense in particulate matter and, when deposited on leaves, they are carried along in the food chain and give rise to toxic effects at higher trophic levels.

The Effect of Air Pollution on Plants

Pollution affects plant development to a very considerable extent. Even if no visible symptoms such as lesions or chlorosis appear, airborne contaminants slow down photosynthesis and growth, thereby decreasing biomass yields. Where the impact of pollutants on plants is not actually lethal, effects may be classified as either acute or chronic.

Acute effects almost always show up in the form of necrotic lesions produced by high doses of contaminants absorbed over short spans of time. Since the leaves are the organs in which gaseous exchange with the surrounding atmosphere takes place, they are the parts of the plant most vulnerable to such lesions. Pollutants also directly damage flowers and fruit, but the leaves are their chief target.

Exposure to a pollutant that is toxic for plants hampers a plant's physiological functions and causes generally invisible chronic effects to develop. The normal pace of the plant's biological functions is usually altered as the pollutant impairs certain of its enzyme systems and specific metabolic functions. The extent of the damage depends on the concentration of the pollutant and on the type of metabolic process taking place within the plant cells.

Attention has been focused in recent years on the invisible, generally chronic effects of pollution on plants, which are of specific interest in estimating the damage caused to farming. The concentration of pollutants involved are generally not so high as to cause acute effects, but they are nonetheless present in rural areas, often for periods of time long enough to cover the entire life cycles of the crops grown in those regions. These effects may be summarised as follows (Triolo, 1983):

— decrease in the rate of plant growth caused by impairment of the photosynthesis process;
— decrease in leaf surface, with negative consequences for the overall amount of carbon dioxide assimilated by photosynthesis;
— decrease in plant height;
— decrease in the weight of the root system, which has a negative effect on the nutritional process;
— decrease in the number of flowers and delay in flowering;
— lower resistance to pathogenic factors and insects;
— lower resistance to physical and chemical stress (temperature, humidity, salinity);
— accumulation of trace elements in plant tissue and their transfer into the food chain.

The most important trace elements released in burning fuel oil and coal are vanadium, nickel, lead, chromium, cadmium, selenium and arsenic (Bocola, 1984). These are generally absorbed through the plant's roots. A number of factors influence the process of absorption: the concentration of trace elements in ground water solutions, the presence and the relative concentration of other ions, the chemical and physical properties of the soil, its acidity and its content of organic matter.

The penetration and accumulation of trace elements in plant tissue produce the following negative effects (Lamir *et al.*, 1984):

— reduction in the quality of the edible parts of the plant;
— bioamplification of the concentration of these elements along food chains;
— reduction of plant productivity.

Taken together, these factors obviously have a decisive effect on crop yields and on the quality of farm produce. The effects of each pollutant on the various plant species depend on a number of factors:

— extent to which plant biochemical processes are altered by gaseous pollutants, which in turn depends on species and variety and varies according to its stage of development;
— climatic factors: light intensity, temperature, humidity, wind speed;
— the time span and the conditions of exposure to pollutants, which influence the intensity of the effects.

One way of assessing the quantitative impact of air pollution on crop yields is to compute the numerical relationship between mean annual concentrations of airborne pollutants and falls in productivity. An example is given in Table 1, which shows relationships between ozone concentrations and crop yields, calculated by analysis of experimental field data. These relationships have been obtained from experimental results carried out in various regions of the U.S. by the National Crop Loss Assessment Network (NCLAN). Field crops were subjected to increasing concentration of ozone in open top chamber experiments. These equations allow a preliminary estimate of crop loss due to an increase in O_3 concentration to be made. Thus, in developed countries the O_3 concentration in agricultural areas can easily attain a value of 50 ppb. Based on these relationships, yield reductions are expected to be of the order of 6.9% for wheat, 1.7% for field tomatoes and 1.5% for maize (Camposano *et al.*, 1986).

As far as acid precipitation is concerned, the results of experimental research conducted in the United States do not prove that the highest winter and summer acidity levels registered in that country (i.e., pH

TABLE 1 - *Dose-response functions relative to crop yield loss from ozone.*

Species **	Model *	b		a	
WHEAT	$Y = \exp(-(X/b)^a)$	0.174	(0.01)	2.90	(0.78)
BARLEY	$Y = \exp(-(X/b)^a)$	0.205	(0.069)	1.988	(0.049)
CORN	$Y = \exp(-(X/b)^a)$	0.159	(0.004)	3.517	(0.568)
BEAN	$Y = \exp(-(X/b)^a)$	0.120	(0.013)	1.171	(0.489)
BEAN	$Y = \exp(-(X/b)^a)$	0.108	(0.007)	3.942	(1.733)
TOMATO	$Y = \exp(-(X/b)^a)$	0.142	(0.026)	3.607	(1.938)
TOMATO	$Y = \exp(-(X/b)^a)$	0.082	(0.025)	3.050	(1.871)

* Y is the yield response at concentration X as a proportion of the yield at zero concentration.
X is the pollutant air concentration, expressed in ppm (parts per million).
** The standard error is shown in parentheses for all data.

Source: Heck *et al.* (1984).

values of around 4), with various concentrations of nitrates and sulphates, have any substantial effect on crop yields. The species studied were the major cereals, vegetables and fruit crops grown in the United States (NAPAP, 1987). Effects on forests, where acidity acts through the soil, seem, however, to be demonstrably greater, and entail:

— decreased productivity of the micro-organisms that metabolise wastes;
— leaching of essential nutrients, such as potassium, calcium and magnesium;
— release of aluminium into surface water;
— mobilisation of trace elements, some of which toxic (Cr, Cd, As, etc.).

The Greenhouse Effect in Agriculture

Increasing the concentration of atmospheric trace gases such as carbon dioxide, methane and nitrous oxides in the atmosphere causes the earth's surface and lower atmosphere to warm like a greenhouse. This is because these gases are transparent to short wave radiation from the sun but absorb long-wave radiation from the earth, thus trapping heat. Per se, the greenhouse effect has positive aspects. It has been calculated that if the earth's atmosphere did not contain any of these greenhouse gases at all, the surface temperature of the planet would be around 33° Centigrade lower than the current mean annual +15°. In effect this rise in earth surface temperature has brought about the actual optimal equilibrium between living organisms in our biosphere. However, if current trends in the increase of CO_2 concentration in the atmosphere continues, the greenhouse effect could have negative consequences.

Carbon dioxide and methane emissions have been largely responsible for potential changes in climate. Since 1860, the concentration of CO_2 into the earth's atmosphere has risen some 25%, largely as a result of the burning of fossil fuels. Consumption of fossil fuel has reached the level where today mankind is emitting over 20 billion tons of CO_2 into the air every year (Fig. 2). There is an indisputable increase in concentration of CO_2 from 315 ppm (parts per million by volume) in 1958 to 346 ppm in 1985 (Fig. 3). Atmospheric methane concentrations have increased considerably in the past, and this correlates with the large increase in worldwide population and derives largely from anaerobic processes associated with increasing numbers of livestock and expanded rice paddy production (MacDonald, 1988). Atmospheric concentrations of nitrous oxide are also increasing and most of this increase is believed to be related to fossil fuel combustion, biomass burning, land conversion for agriculture and fertilizer use.

In addition, other greenhouse gases such as water vapour, chlorofluorocarbons and ozone contribute to the greenhouse effect.

The greenhouse effect causes the earth surface lower atmosphere to warm. Figure 4 shows the trend of earth's mean annual temperature since 1860. During the period under study, the mean annual surface temperature of the earth rose by 0.5 to 0.6° C. During the same period, the CO_2 concentration in the atmosphere increased by 25% for the reasons mentioned earlier, the major factor being the combustion of fossil fuels. It has been calculated that, at the projected rate of world fuel consumption, temperature will further rise by more than 1° C over the next 40 to 50 years, perhaps by as much as 2°.

According to the computer models available today, in the next 40 years the Earth's mean temperature may exceed all peak levels of the past million years (Fig. 5). The temperature is expected to increase more at higher latitudes (near the Poles) and less toward the Equator as a consequence of increased evaporation and precipitations and of enhanced air circulation.

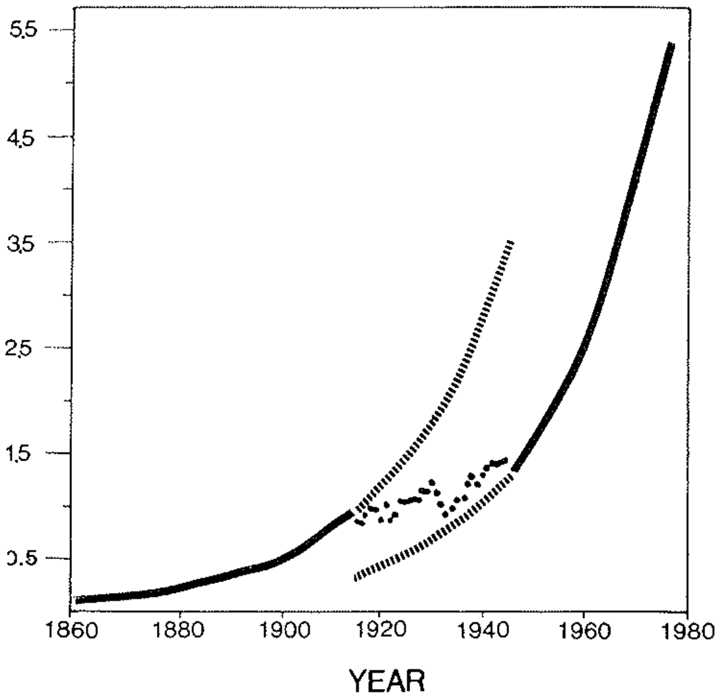

FIG. 2. The rate of production of carbon dioxide by man's activities (10^9 Tons/year). (*Source*: From and Keeling, 1986).

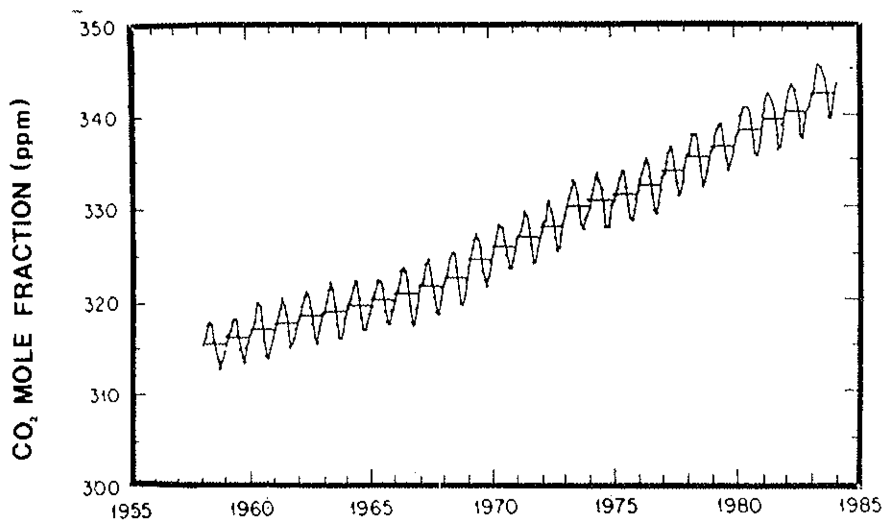

FIG. 3. Atmospheric carbon dioxide concentration. (*Source*: Keeling, 1986).

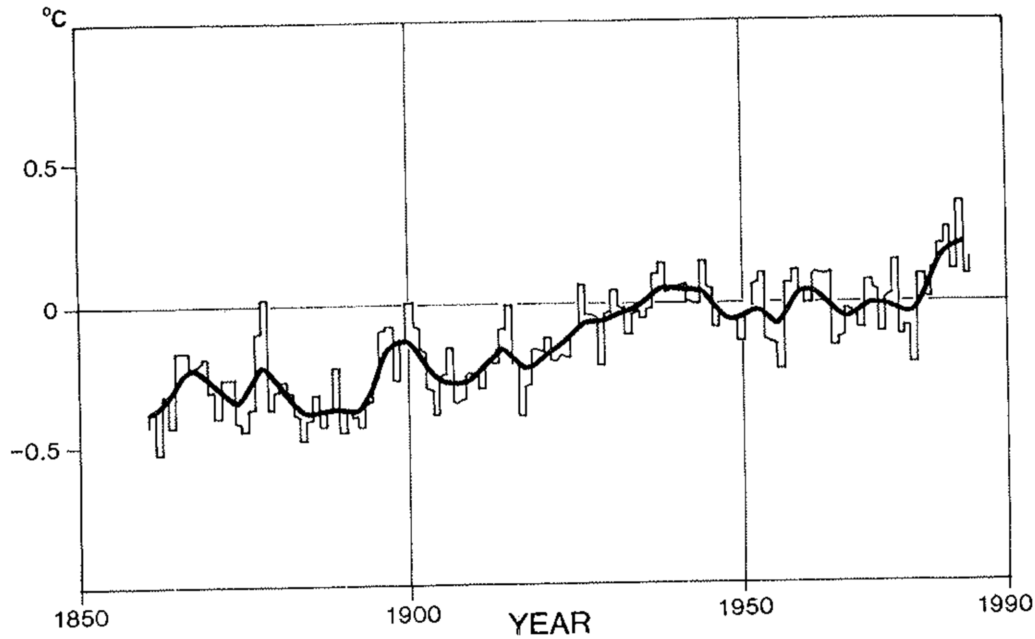

FIG. 4. Annual mean temperature variations since 1861. (*Source*: Jones *et al.*, 1986).

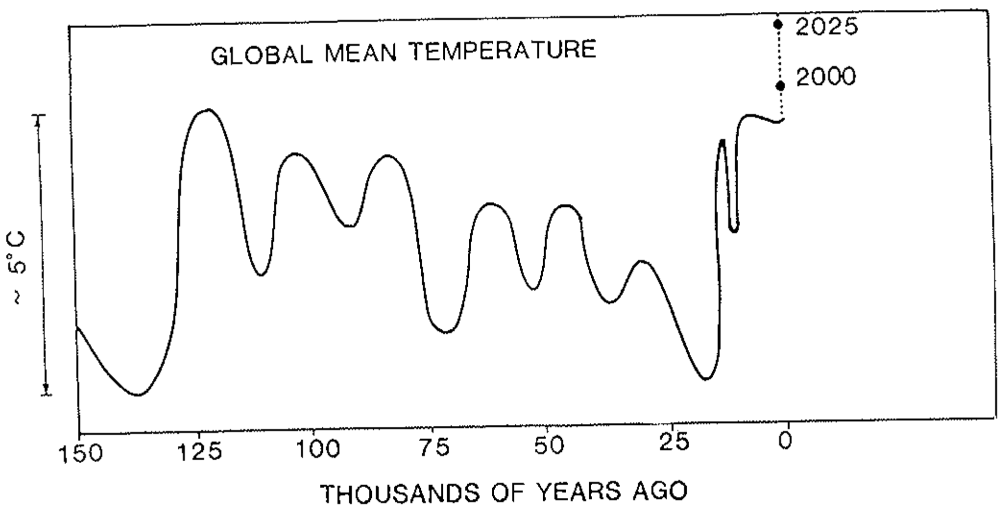

FIG. 5. Smoothed global mean temperature trend during the past 150,000 years and the simulated future temperature trend. (*Source*: EPA, 1986).

At the global and regional levels, the effects of the Earth's overheating on climate, ecosystems and seawater levels are manifold and complex (Colombo, 1988). Climatologists agree in predicting greater instability in the various regional climates as temperature goes up at a relatively high rate. As far as agriculture is concerned, the effect of such rise in temperature would result in converting the highly fertile areas in North America and Europe into arid and unproductive areas, while productivity is expected to increase in other regions such as the high plains of central and northern Asia. Increase in productivity will be also due to faster plant metabolism in the presence of higher concentrations of carbon dioxide. Higher mean temperatures will also increase the number of pests such as insects and fungi that farmers will have to cope with. The damage will be increased by the fact that the crop species which are grown today are limited in number, this making the system highly vulnerable to parasites. Moreover, variations in wind patterns will also cause changes in ocean currents, altering the amount of fish nutrients and consequently affecting fisheries to a considerable extent.

The increased concentration of carbon dioxide in the Earth's atmosphere has been brought about not only by the burning fossil fuels, but also by the disappearance of organic matter from the soil and the reduction of world vegetation due to deforestation. The worst effect of the deforestation across vast tracts of the Earth — around 11 million hectares of trees are disappearing per year — is the accelerated rate at which carbon dioxide, absorbed by trees in enormous quantities through photosynthesis, is accumulating in the atmosphere.

In the developing countries, the process of deforestation involves not only the use of deforested territory for non-farming purposes and a significantly high consumption of wood for fuel, but also the conversion of forest land to cropland and pasture. Agriculture in the developing countries is therefore to some extent contributing to the climatic changes that are affecting the stability of agro-ecosystems and increasing risks of desertification. Deforestation makes the land more vulnerable to erosion under the impact of rain and wind. By these, thousands of tons of fertile soil per square kilometer of land may be carried away every year.

Climatic effects, especially those connected with the increasing amounts of CO_2 in the atmosphere and the resulting greenhouse effect, have already stirred public opinion in many countries, and discussion has started on possible countermeasures. Such countermeasures include increased efficiencies of energy production, conversion and use; shift from fossil fuels to other forms of energies, notably renewables and nuclear; strict measures to reduce the depletion of tropical forests and a vigorous programme of reforestation wherever possible. Although all these measures are potentially very useful, it is recognized that it will not at all be easy to reach a worldwide consensus on their implementation.

The agro-ecosystems of the developed countries, where manufacturing exists alongside farming, are subject to types of stress different from those that cause desertification in developing countries. These agro-ecosystems are exposed not only to the pollutants emitted by energy production and consumption systems, but also to the contaminants released into the air, water and soil of rural environments by agricultural processes themselves: chemical products, fertilisers, pesticides, the particulates and gases generated by burning fuel oil to heat greenhouses, and the use of farm machinery.

We can thus say that the high rates of energy and raw materials consumption to which these agricultural systems are bound today is a factor of deterioration both of the environment and of the food products themselves. In addition, a good part of the environmental changes and the health risks that are entailed are absolutely unwarranted, being associated with the production of increasing food surpluses. This is true in North America and in Europe. The phenomenon has become more serious in the last decades also as a consequence of the agricultural policy adopted by the European Community, in the attempt to safeguard the income generation capacity of the agricultural sector.

I believe this necessarily sketchy review has confirmed that strict inter-relationships exist between agriculture, energy and the environment. Energy production and utilization, as well as agriculture, both as practiced today in industrial countries and, for different reasons, as prevailing in developing countries, adversely affect the environment. Agriculture requires increasing quantities of energy and thus further contributes indirectly to the degradation of the environment. The changes in the environment, in turn, are reflected, mostly in a negative way, on agriculture. Is there a way out of this vicious circle?

Other contributions to this conference have indicated ways in which new technologies, and the biotechnologies in particular, can reduce both the environmental impact and the energy requirements of agriculture. In other fields, increased efficiency of energy use and the development of alternative sources of energy, in particularly renewable sources, could substantially reduce environmental pollution and man-made climatic changes. All these trends are likely to be pursued in the future, as public opinion and policy makers realize the risks mankind will face if it continues along its present path of development.

There is, however, a more direct and, in a certain sense, endogenous way out of the impasse. If a sizable part of agriculture could be directed towards the production of energy and energy products, the consumption of fossil fuels would be reduced and the environment preserved.

In launching as a proposal in this direction before the European Parliament at the end of 1986 the IDEA project (IDEA stands for Innovative Dimensions in Energy and Agriculture) (Colombo, 1987), I referred primarily to western Europe and other industrialised countries where agriculture is facing problems of increasing overproduction, with unsold stocks building up at increasing rates at huge storage and conservation costs and, at the same time, it is heavily subsidized, at a cost that is becoming unbearable for the community as a whole. By devoting the land that is producing agricultural surpluses to the cultivation of energy crops, three goals can be simultaneously attained:

1. the elimination of excess food production and related costs;
2. the reduction of energy dependence on imported fossil fuels, hence improving energy security;
3. the reduction of the pressure on the environment and, in particular, the greenhouse effect (carbon dioxide being ultimately recycled between the atmosphere and plants in the energy uses of biomass).

A programme of research, development and demonstration is well under way in Italy and elsewhere in Europe, examining possible alternative crops for various regions, plant improvement, appropriate agronomical practices and conversion technologies, the utilization of by-products and environmental and social aspects, etc.

The same overall strategy is at least as interesting for developing countries as it is for industrialised countries; only motivations do not have the same priority. Starting conditions are very different, times and pathways for the implementation must necessarily be tuned with local situations. Many developing countries have only just reached the level of self-sufficiency in the production of food, and a major effort is required to keep production abreast of a rapidly increasing population and to make it more adequate, both quantitatively and qualitatively, to the actual needs of the population. Other countries, especially in Africa, are still far from producing enough food. It may be argued that it is necessary to reach a sufficient level of food production, including a margin for fluctuations in weather conditions, before turning to the cultivation of energy crops, which may compete with food crops in terms of land use and resources.

However, there are good reasons that would favour early consideration of advanced energy uses for biomass. It has been noted that, in many cases, scarcity of food production is not due to an insufficient level of agricultural technologies but to the limitations of the market, the poorer sections of the population not having enough money to purchase all the food they require. Most notably, this may be the case in Brazil, the only country where a very large programme of energy from agriculture (ProAlcool) has been set up. Reducing external dependence for energy products, especially oil, and making scarce foreign currency available for the import of key technologies necessary for development may be a good reason to put in place an energy biomass programme, even before all food requirements are fully satisfied. Adequate food production will no doubt follow as economic conditions improve in consequence of general development.

Another aspect that should not be forgotten is that in many developing countries much energy already comes from biomass, especially from fuel-wood and agricultural wastes. The very low overall efficiency of energy use is, however, one of the causes of deforestation and eventually of desertification. This trend must be inverted, by making the whole agricultural-energy cycle much more efficient: less energy use for agriculture, by substituting biotechnology for chemicals and other energy inputs; more energy from agriculture, by selecting and improving plants, by adopting more appropriate agronomical practices and by improving the efficiency of use of energy products and of energy itself.

Even before the large-scale investment and the far-reaching political decisions that will eventually be needed, this requires new scientific and technological research. Not all the solutions to the various problems are yet known, and those that are need to be adapted to very different local conditions. No recipe or technology can be transplanted in any sector without substantial adaptation, let alone in the most traditional one of all: agriculture. Much of the research and most of the adaptation work must be carried out in the countries involved, in particular in developing countries.

With this in mind, at a meeting of high level experts organized for the United Nations a year ago at Castel Gandolfo, outside Rome, we adopted a basic recommendation (UNO, 1987) that research and development in renewable energies, and particularly in biomass, should be carried out by a network of international research centres located mostly in developing countries, in a scheme drawing on the positive experience of CGIAR, the network that did so much for the first Green Revolution, learning from the difficulties the latter encountered as well. This proposal has been favourably received by the United Nations General Assembly and approved by the representatives of governments.

It is now being studied in detail by a joint effort of ENEA and the United Nations University prior to implementation.

Another recent development in this area comes from the International Foundation for the Survival and Development of Humanity (IFSDH). The IFSDH Workshop on Energy Programmes which met in Leningrad last June considered among its top priorities the development and diffusion of modern technologies for biomass energy conversion. In the words of one of the participants (Haile Lul Tebicke), "It is ... imperative that the widespread introduction of modern biomass energy supplies be designed to enhance tha access (of the poor) to energy for survival and development ...".

It is important that the present situation of low oil prices should not discourage efforts in terms of research and demonstration in this field. We must hope that initiatives such as ProAlcool will not be discouraged by cheap oil. Short-term financial considerations often overlook the relevance of the basic changes in our world, and the environment and the global climate are among its fundamental components.

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EDUCATION WITH RESPONSIBILITY TOWARDS THE ENVIRONMENT AND THE VALUE OF LIFE ON THE LAND

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Introduction

To look at this topic with the seriousness that is justified by the title requires us to analyse the implications somewhat further. There would seem to be three distinct components in the title:

Education for whom and at what level?
The Value of life on the land
Responsibility towardds the environment.

The Environment

The most definite area to which attention can be directed is the environment, but this in itself is not simple, for it has three components:

a. The biophysical environment
b. The economic environment
c. The psychological environments.

The first of these, the biophysical environment, is the most readily specified. It is the land around us, the land on which we walk, the water which we drink, fish in or swim in. It is the air we breathe. This is the component of the total environment that is most easy for man to change, and all of his activities result in some change to some part of the biophysical environment. But included in the conspectus of the biophysical environment are the plants and animals, which with man are the joint inhabitants of the earth. These again fall into two categories: the synthesiser species: the green plants, and the decomposer species, which includes all the animals, all the insects and fishes, some of the plant species including the moulds, the fungi, most of the bacteria, all of which live on the synthetate of organic materials produced by the synthesiser species, and, most importantly, man himself. Whilst the physical components are less readily altered by man's activities, the biological component can be widely altered, or almost totally changed, by man's activities even in a single season.

The economic environment is strictly a derivation from the first. It depends partly on the store of organic materials that the synthesiser species have manufactured from air and water by the use of the energy of the sun's rays, mediated in the main by the chlorophyll that is reponsible for their green colour; partly on the use of the organic material made by the synthesiser species in previous eras and now utilised as fossil fuels; partly on the use of solar energy that has been transformed into wind energy by the differential heating of the earth's surface or into water power by converting the potential energy of water that has been lifted away from the surface of the earth by the evaporative power of the sun. Each of these stores of energy can be released into the environment, and may cause striking changes in the heat balance of any area of the earth's surface on which they may be released. In the ultimate, we could grow strawberries in the Sahara and pineapples at the Pole, if only one chose to commit sufficient of the stored energy to the project. The use of fossil fuels can also supply the power for more effective cultivation, better drainage, better water supply and of course better housing and transport. All the consumer goods that are present in such abundance today are based on the increased efficiency of the primary worker on the land who now can feed many people by the skill of his hand, whereas 300 to 400 years ago all the average worker could do was to keep his wife and family alive. All the increased productivity is due to the controlled use by some of the human population of the energy of fossil fuels.

The psychological environment is the most difficult to define and hance to preserve, because it exists in the minds of the people and is seen differently by different people. A person's understanding and appreciation of the environment in which he or she happens to find themselves varies with their own past experience, with their present emotional situation, with their state of health and with the level of the funds they have at their disposal. These varied views of what constitutes a desirable environment are constant sources of strife between different sectors of the community, each combative group being certain that the environment that they wish to preserve is of course the only environment worth preserving. The conflict of desires is particularly difficult to resolve when it arises between two groups of people of widely differing cultures or views.

It is not possible to discuss the biophysical environment, and hence to know for what we are being responsible, unless one recognises that there are three different biophysical environments:

a. the "natural" environment
b. the agricultural environment
c. the built environment, which will not be considered further in this article.

The "natural" environment in the eyes of many is an environment exactly as it was before man arrived on the scene, an environment in which trees, herbaceous plants and animals lived together without strife. This is a difficult concept to sustain. One cannot proceed far with a biological education without realising that any ecological situation one investigates is a situation of constant competition — between the plants for light, for nutrients, for water — between the animal or microbiological components for part of the organic matter that has been produced by the synthesiser species. In any area of land new species arrive either by speciation or by migration from another area. If the invaders are more vigourous than some of the members of the existing population they will persist, and slowly occupy more of the land area, to the detriment of the earlier occupants. Whereas until perhaps 400 years ago the spread of species from one part of the world to another was relatively slow, in more recent times the process has been greatly accelerated. The seeds of plants were carried in air streams or by moving waters, or by adhering to the coats of man or animal and so being moved to wherever their carriers moved. Animals moved only on their own legs, and their movements were consequently restricted largely to the land masses of the world, although they could move across the land bridges that developed from time to time during periods of low sea level. All that began to change as man developed his ability to travel, and the last 400 years have seen massive movements of several species at a much greater rate than has ever occurred in the past, sometimes accidentally, but frequently deliberately — the movement of European species into Australia, the movement of Australian species, notably eucalyptus, into Africa, Latin America, North America and southern Asia. The eucalyptus have been planted over broad areas, sufficient in size to alter markedly the biophysical environment. This had led to objections from environmentalist groups, for example in India, that their environment is being spoiled by the introduction of this "foreign" tree. Exactly the same argument is put forward in Australia against the plantations of softwoods, notably radiata pine, again an objection to the "foreign" species, and an emotional desire to cling to what people remembered from their youth. The objection is, of course, simply to the change in the pattern of vegetation to which people have been accustomed. Such objections are rarely heard in England, because the population is accustomed to a vegetative cover of the land that has a large number of "foreign" species, thanks to the tremendous areas of woodlands planted 200 years ago by the great landowners, desirous of decorating their holdings with exotic trees, a pattern that was enhanced by the work of such great landscape gardeners as Capability Brown. So for the average English lover of the countryside a beautiful environment is one dotted with groves and spinneys of trees that have come from he knows not where, but which make a beautiful picture! This serves to illustrate the point that for the psychological environment, the experiences one has had in the past, and which are imprinted in the mind, alter the appreciation of what is seen by the eye in the present.

This produces some strange contradictions in environmental arguments. In many countries of the western world there are lobbies protesting against logging the tropical forests, using as one basis for their protests that forests function as the "lungs" of the earth. Yet these same people will be found protesting against plantations of trees in their own countries, which, if their arguments were true, would equally well serve as "lungs of the earth".

Education with Responsibility to the Environment

The first aspect that needs to be built into the education of everyone — town dweller or countryman alike — is to appreciate the point that the population of species which constitute the ecology at any one point in time is in a metastable equilibrium, and is liable to change in response to changes in the factors responsible for its development. Unfortunateltg much botanical teaching enshrines the doctrine of the climax vegetation, a concept which needs to be challenged.

It is generally accepted that the nature of the vegetative cover on each different locality is related primarily to the climate and soil that occur at that locality. Assuming constancy of the biotic component, i.e., that no migration or speciation is occurring, a climax vegetation will consequently only occur on a "mature" soil, that is, one that is undergoing no further change.

However, soil is not an independent factor but is the result of the interplay of the climate, the rock or rock debris on which it is formed, the topography, the biotic component and, above all, the length of time during which these same factors have been in operation. It is nearly 50 years since Jenny (1941) pointed out that the system is not static. The quantities of nutrients found in the soil at any one time will change, for in any area in which the rainfall exceeds the evaporation, even for part of the year, some of the nutrients will be washed out of the system, and in time the level of one or other of the nutrients will become low enough to restrict the growth of some of the plant species that were present earlier. This pattern of change of vegetation with change in nutrient level, and particularly change in acidity, has been documented on numerous occasions (in England by Salisbury, 1925; in Holland by Hissink, 1938; and in Australia by Burges and Drover, 1953). Analogous situations exist where there is a change in one or other of the biotic components. The effect of the exclusion of grazing animals on the subsequent development of a tree vegetation can be seen in many parts of Europe, the effect of netting to exclude rabbits is even more striking, for these are components of the biota that can be easily excluded, but for many components exclusion is difficult if not impossible. Insects and the seeds of many plants can pass through any fence and, if conditions are suitable to them, will colonise the other side.

What is found in any "natural" situation is the result of a balance between the different components of the biota, mediated by any change in nutrients, etc., that may occur over time. This aspect of what might be termed inter-biota competition needs to form an integral part of the education of all people. It is often understood almost intuitively by the small farmers of the tropics, but its incorporation into the general education of the urban masses whose votes dominate political decisions would appear to be essential.

Where man is part of the "natural" environment he plays no different a role from that of the other decomposer species of the biota, and lives by gathering from the plant communities present, and hunting and consuming some components of the animal species and, where great carnivores are present, being himself consumed. This hunter/gatherer lifestyle appears to have been the pattern in the early stages of man's existence on this planet. Indeed the hunting and gathering system was the only one operative in the long isolated land mass of Australia until the end of the eighteenth century, when immigration from Europe occurred, and it has persisted in parts of Australia into the twentieth century. Even in this system, man had an effect on the vegetative cover by his use of the firestick to clear away the undergrowth to help him hunt the emus and kangaroos (Harrington *et al.*, 1984). As soon as man began to alter the vegetative pattern by clearing part of the vegetation and deliberately attempting to aid in the growth of certain plant species, or began to protect certain animal species from attack by other predators, the age of agriculture had begum.

The agricultural environment, consequently, is an environment in which one component of the biota, man, has deliberately altered the other biotic components, either by removing one set of plants and aiding the growth of another, or by modifying the pressure of the decomposer species by changing the pattern and number of the grazing animals and by controlling the number of carnivorous predators. In the earliest form of agriculture, the slash and burn system described in another chapter and which is still the principal system of the small farms of the tropics, the change in the vegetative cover of the land surface is minimal, with only small areas of soil being exposed to the action of rain and wind and going back into scrub or forest after three or four years. This practice has been shown to have negligible effect on the nitrogen content of the soil, or on the ability of the soil to allow the forest to regenerate (Jordan, 1983). As the size of the holdings has grown larger, and the cropping system has moved from the mixed cropping, which gave an almost continuous vegetative cover, to monoculture, which exposes the soil surface to the action of wind and rain for large periods of the year, the danger od soil erosion and subsequent deterioration becomes greater, with a concomitant reduction in the area of the habitat available to other components of the biota such as wildflowers, small birds and mammals.

The "live fences" described elsewhere for Papua New Guinea, or the hedgerows of Britain, surrounding small areas of cultivated land, are a stage in between the tiny patches of the slash and burn farmer and the vast treeless plains of the Ukraine, Kazakhstan, U.S.A. and Canada, where enormous areas are under monoculture, in which the environment becomes progressively less attractive to the non-economic components of the biota, and the "agricultural" environment becomes progressively less attractive to a large population that is no longer dependent on agriculture for its livelihood. From the tacit support given by much of the urban populations of the industrialised countries to the environmental lobbyists, it seems that the urban populations prefer a country environment of fields, hedgerows and patches of trees to the larger expanses of monoculture cropland or plantation forestry, which demands for cheap food and cheap timber may make inevitable. An attempt to resolve these conflicting aspirations will require an education that will allow the different sectors of the population to appreciate the factors involved, and to evaluate the limits to which the environment can be manipulated if a sustainable system of agriculture is to be developed in the various biophysical environments of the world. There seems little point in concentrating only on a system of education for the man on the land when the major decisions that determine what can be done are made by urban masses, which may be largely ignorant of the issues involved.

If it is to be possible to have a dialogue that will lead to responsibility to the environment, and at the same time to improve the quality of life on the land, it is necessary that the education of the whole population should lead to an understanding of two concepts, those of capital accumulation and of catastrophe theory, for both are implicit in the development and management of a sustainable agriculture.

An old but very effective definition of capital is simply "enjoyment deferred" — the animal, plant or system that is accumulating the products of its endeavours for use on another ocasion rather than spending them immediately is developing a store or bank of capital. The pattern is obvious in agricultural practice. If the primitive farmer consumes all of the grain he has harvested, nothing will be left to produce the next year's crop. The development of agriculture began when man saved enough of the seed grains he had collected in the wild, to grow the next year in his own patch of land. In seasons of bounteous crops there would be plenty of grain to store for seed corn, in bad seasons, as the quantity required to feed the family would still be the same, the amount saved for the next year would be much less, and the area he could plant to grain would be reduced accordingly. So the "enjoyment" he could obtain by eating that last part of the grain would be deferred until it produced another harvest in the following year.

Precisely the same pattern holds in the pastoral areas, either ancient or modern. After the rains arrive, the plants grow and build up a store of synthetate. Some of it goes into the roots, where as it sloughs off it provides nutrients for the fungi and bacteria whose presence constitutes the living soil. Part of the synthetate is removed by the grazing animals. The rest remains with the plant, where it is stored either in the herbaceous tissues, in rhizomes or other storage organs, or in the seeds. From these various stores the plant resumes growth when the next rains arrive. Where only a little vegetation is removed, not only is there a larger capital of stored nutrients available for plant growth in the next season, but the vegetative cover protects the soil surface against the action of rain and wind, and so prevents erosion, and there is plenty of organic detritus falling into the soil which provides food for the microbial population, which improves the soil structure and enables the soil to absorb more of the water that falls on it, thus making more available for the subsequent year's growth. However, as the numbers of cattle, sheep (or rabbits!) consuming the vegetative cover which constitutes the pasture increase the quantity of synthetate that the plant community can store is reduced. With this reduction the protection that the vegetation can afford to the soil surface is also reduced, and the likelihood of erosion increases. With further increase in grazing pressure, the plant community — the synthesising species — will have its capital of synthetate further reduced.

It is at this point that a knowledge of catastrophe theory provides an understanding of what will happen. Any natural system can be considered to be in equilibrium with the factors responsable for its development. Within the constraints imposed by these factors, the system has a certain amount of elasticity, allowing change on one side or the other of its equilibrium position. In the pastoral situation the area of elasticity is that in which the quantity of synthetate removed by the grazing animals still leaves available to the plant community sufficient synthetate to provide the capital for growth in tbe next season, either from herbaceous tissues or from the seed store, to provide a vegetative cover over the entire soil surface. If the plant capital carried through from one growing period to the next is not sufficient to allow this cover to develop, not only will production of synthetate in that growing period be reduced relative to what it was in the previous season, but the unprotected patches of soil may begin to erode. May because where the area of bare soil does not exceed ten percent of the total area, the soil surface is commonly able to maintain its integrity for one or two seasons, whilst some soils will start to erode straight away.

Where, during the year, there has been lower rainfall and consequent lower production of synthetate, the result is a lower capital of synthetate in the plant community. If the number of animals grazing the pasture is kept at the same level, they will eat more drastically into the quantity of synthetate that the smaller area of plant community can produce, and the process will be repeated in subsequent years until the point of catastrophe is reached where the soil begins to erode and plant production to fall so markedly that the land is no longer able to carry the same number of livestock as it did earlier, before overgrazing of the plant community occurred. At this point the system has moved out of its area of elasticity, and major changes need to he made if the productive capacity of the land surface is to be maintained, albeit perhaps at a reduced level, or at the best restored to what it was originally. This is an over-simplified picture of what happens, for the various components of the land community do not react in an identical manner to the stresses that are being imposed on it and some species may disappear from the community, and the ecology of the resulting pasture will have changed.

To restore the system to the productivity of its original equilibrium position will require a change in the ecology, in the first place by a reduction in the numbers of the decomposer species. Where the species mainly responsible is a domesticated animal, such as sheep or cattle, this reduction can be readily achieved where the farmer, grazier or herdsman has alternative areas on which to graze his stock without loss of livelihood; but if no alternative grazing area is available, the required reduction in stock numbers means also a reduction in total numbers of people that the area can sustain. Where, as in Australia, the government of the country has the resources to move people out of a deteriorating area and provide them with the means of obtaining a livelihood elsewhere, the solution of destocking can be applied, as it was in the Gascoyne region of Western Australia. It could hardly be applied in the Sudan or the Ogaden.

Where the decomposer species responsible for the excessive consumption of synthetate is not a domesticated species, as occurs where there is an invasion by locusts, destocking alone may be insufficient, and international measures may be needed to control the invasion.

Catastrophe not infrequently occurs when one component of the system changes outside the limits expected or encountered in the equilibrium system. This is the situation when the rainfall is sufficiently lower than normal to lead to a lower production of synthetate, whilst at the same time the numbers of decomposer species remain the same. Even one year of low rainfall can initiate changes in the system that are irreversible without the introduction of other changes to counter their effects. When the low rainfall becomes a cycle of two or three years, the catastrophe becomes more obvious.

Unfortunately, the measures taken by national or international communities to alleviate the distress caused by the catastrophe are on occasion counterproductive. Thus in the droughts in northern New South Wales, Australia, in the early nineteen eighties, the government provided funds to the farmers for "drought relief" to prevent the loss of pedigree livestock. As the provision of funds was intended, farmers brought in food from outside the drought stricken area, and the figures shows that the numbers of stock maintained in the area showed little reduction. As the drought persisted for three years the numbers of stock — the main decomposer species present — remained effectively the same, whilst the productivity of the synthesiser species was considerably reduced, the damage to the vegetative cover was more extensive and liability to erosion was enhanced.

An analogous situation exists with the international efforts to alleviate the sufferings of the people of the drought-stricken areas of Africa. Food is supplied from outside the droughted areas, in order to keep alive the people who have lived there in the past. This procedure maintains the pressure of the decomposer species, without at the same time taking any steps to rectify the factors that are responsible for the disequilibrium between the synthesiser and the decomposer species. Catastrophe in these areas is becoming a not infrequent occurrence as the system swings more frequently outside its area of equilibrium. An appreciation of catastrophe theory and its implication in the marginal lands of the world might produce measures that would lead to the development of a sustainable agricultural/pastoral system, and thus to the maintainance of a pleasant environment, and a real improvement in the lot of the people of the land. The supply of food to the starving population is merely the provision of "enjoyment for today". It does nothing to improve the productive capital of the system. To keep up the numbers of the main decomposer species, man and his animals, without at the same time maintaining or increasing the productive capacity of the synthesizer species, is a prescription for continuing catastrophe and continuing disaster.

The answers to the questions posed by the title of this paper are in part answered by what has been said above, but only in part, for these are the general principles that should be part of everybody's education, countryman, town weller, environmental lobbyist, and decision maker alike. Unfortunately there is evidence that the education being given to the small farmers is not always taking into account the factors required for sustainable agriculture. The importance of maintaining the health of the soil by ensuring that the balance between synthesiser and decomposer species allows the return of sufficient synthetate to the soil to maintain its organic matter, and hence the continued operation of the microbial population is too frequently being overlooked. Evidence obtained recently in western Kenya shows that the younger and more literate of the small farmer population are not using the methods of maintain the organic matter of the soil that are used by their older and less literate fathers (Hallsworth, 1986), presumably because they are learning, either in farm school or from the extension workers, of the increased production that can be obtained by the use of fertilisers, in a system which makes less demands on their labour. Indeed the evidence reported (*ibid.*) shows that in this poorest and worst educated section of the agricultural community of the world literacy plays very little part in determining their acceptance of the soil-saving techniques that would lead to the development of sustainable agriculture. Provided they can see for themselves the benefits of the crops and practices which will enhance their incomes, in the first year of their use, sufficiently to allow the accumulation of capital by the "deferment of enjoyment", they will adopt them. There is no value in pointing out to the people on the lowest standard of life, that they need to conserve the land for their grandchildren. If they cannot feed their families this year, there will be no grandchildren!

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FORMATION AND RESEARCH: THE ROLE OF FAO

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I. INTRODUCTION

The United Nations Agency for Education, including formal agricultural training, is UNESCO. For international research, the organization mainly devoted to agricultural research in developing countries is the Consultative Group for International Agricultural Research (CGIAR) with its international centres disseminated mainly in the tropical areas. Finally, the international U.N. Agency mainly devoted to agricultural development is FAO. At national level in developing countries the institutions dealing with agricultural education, research and development, respectively, are normally: Universities, Ministries of Agriculture and Universities and Ministries of Agriculture and Rural Development.

After their formal educational training, agricultural technicians are often involved with "in service training", normally performed by specialized research institutions, universities and extension services (if existing). In this training phase, FAO plays an important role, providing specialized staff in support of post-graduate training in specialized courses or during the execution of FAO-operated field projects.

According to FAO's definition, "training is a specifically designed and structured learning activity utilizing prepared instructional programmes and/or learning materials aimed at improving knowledge or skill of a well identified group of trainees". It seems rather clear that in this case training is something different from education, since it is limited in scope, time, subject and objectives, with a well defined goal aiming at a specific result. Since the beginning of its activity, in 1946, FAO has performed this type of activity at various levels.

II. The Present Extent of FAO's Involvement in Training

1. *Sectoral Distribution*

In 1986, half (50 percent) of all FAO projects which reported to have conducted at least one training activity were in the agriculture sector (Figure 1), although 2 percent of them were in a combination of agriculture and other sectors (e.g., socio-economic and other sectors).

The second largest sector whose projects reported in 1986 to have conducted at least one training activity (and hereafter will be referred to as training projects) was the socio-economic sector, which accounted for 31 percent. Forestry and fisheries training projects accounted for 7 percent each. The information sector has about 3 percent.

More specifically, the breakdown of the specific subject matter contents of FAO training activities in 1986 is shown in Figure 2. Since the agricultural sector has the highest proportion (52 percent) of training activities, it is not surprising that the training subject matter on crops (42 percent) and livestock (10 percent) together constitutes the largest proportion. A multi-disciplinary approach to solve the complex and

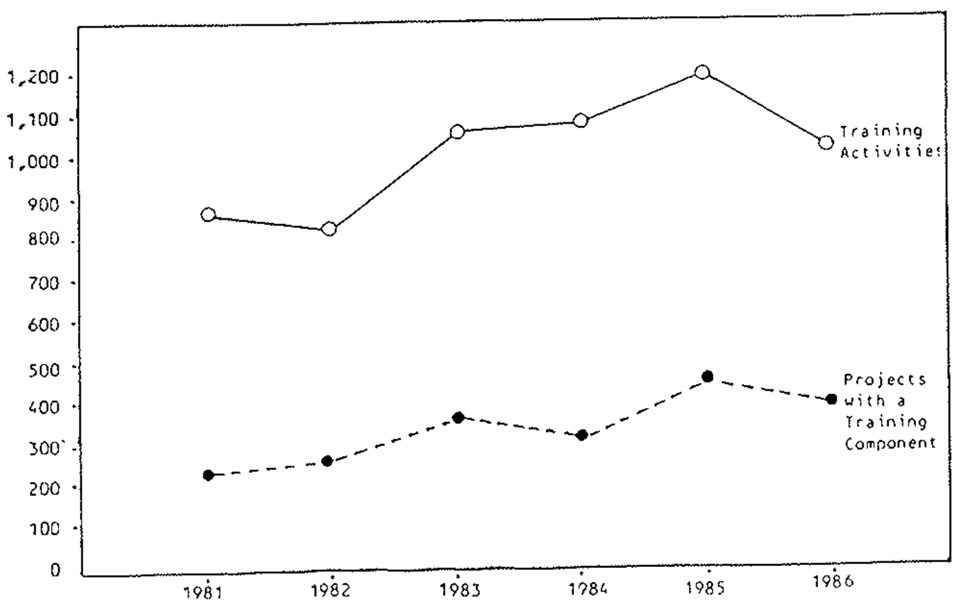

Fig. 1. Number of Reported FAO Projects with a Training Component and Number of Reported FAO Training Activities (1981-1986).

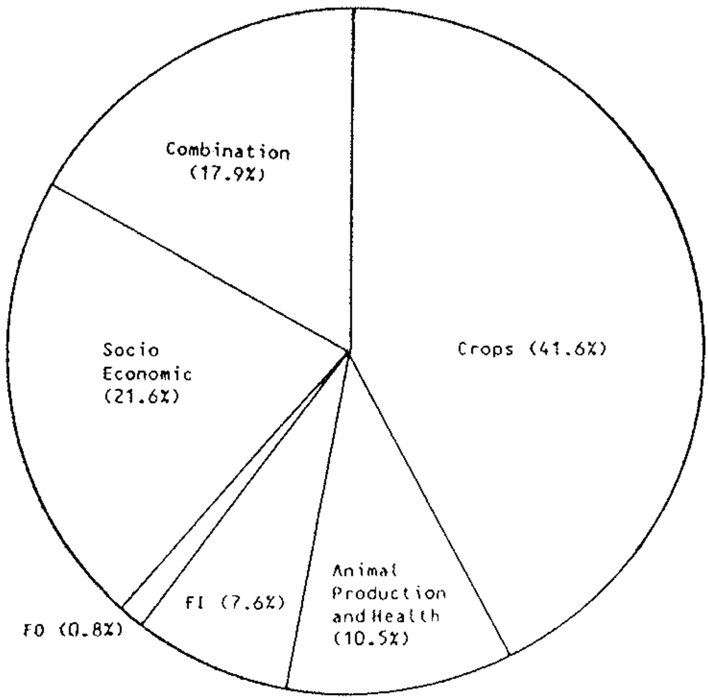

FIG. 2. Distribution of Reported Training Activities According to General Subjects in 1986.

interrelated problems of agricultural and rural development is also reflected in some FAO training activities. In 1986, FAO's training activities which offered a combination of subject matters (e.g., agriculture and socio-economics, or forestry with socio-economics, etc.) accounted for 18 percent.

The significant proportion (22 percent) of socio-economic subject matter focused in FAO's training activities suggests that the socio-economic aspects of agricultural and rural development are an important and integral part of the technology transfer processes advocated by FAO. Such an approach or direction is consistent with the principles and concepts recommended by the 1979 World Conference on Agrarian Reform and Rural Development (WCARRD), such as the need for more concern in the socio-economic and human resource development aspects in order to achieve a more equitable agricultural and rural development.

2. *Geographical Distribution*

In 1986, about four out of ten reported FAO training projects were in Africa (Figure 3). Asia accounted for about one-fourth of such training projects. As can be seen in Figure 3, the Near East and Latin American regions' proportions of training projects show a slight decrease in 1986. In Asia, the proportion of training projects shows a substantial increase.

Figure 4 shows the overall trend, during the 1981-1986 period, of the proportion of FAO's training activities conducted by FAO projects in the different regions. This trend seems to be similar to that of FAO's training projects as discussed earlier, the only exception being Latin America, where the number of projects has slightly decreased while the number of training activities is proportionally increasing since 1982.

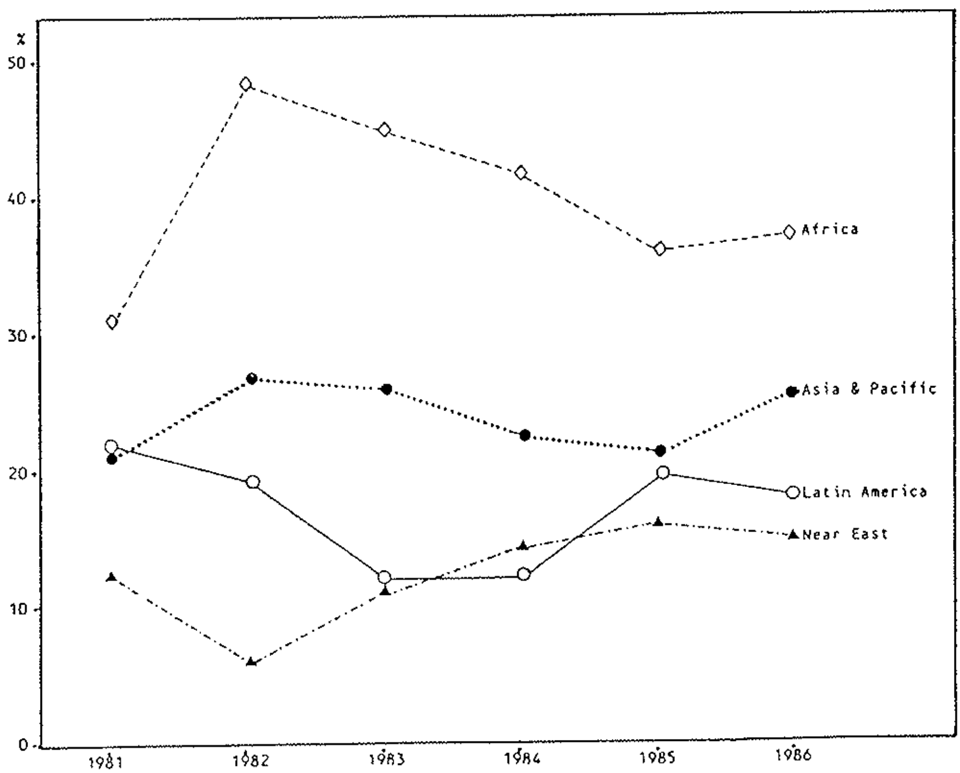

Fig. 3. Proportion of Reported Projects with a Training Component in Selected FAO Regions (1981-1986).

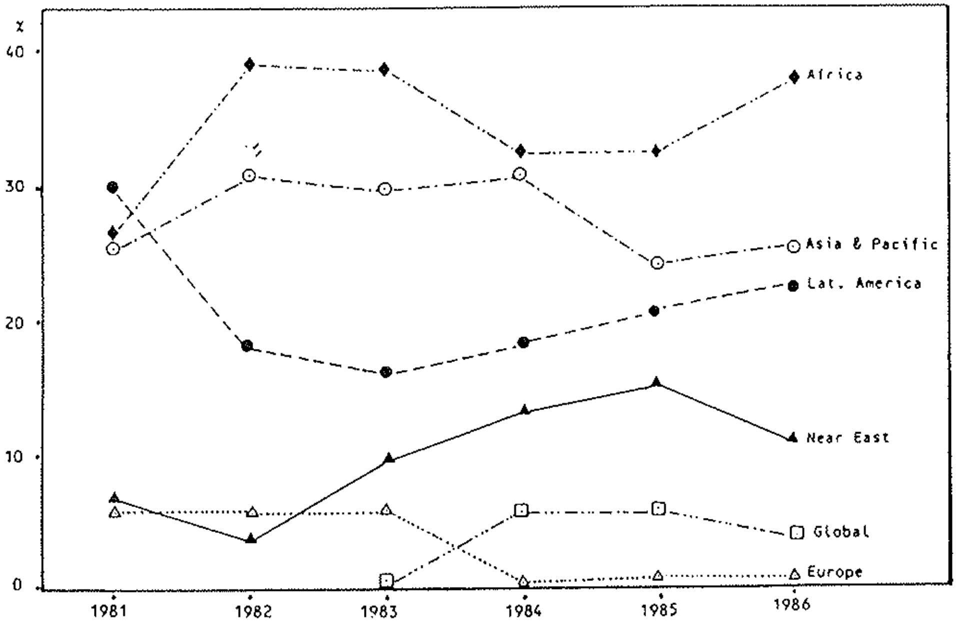

FIG. 4. Proportion of Reported Training Activities in Selected FAO Regions (1981-1986).

It should be noted that while Africa in 1986 acounted for the highest number of training projects and training activities (Figure 3), it conducted fewer training activities per project (average of 2.7), as compared to Latin America (average 3.6) or Asia (average 3). One of reasons might be the relatively higher cost of conducting training activities in Africa, where fewer training resources (e.g., expertise, learning materials, facilities, equipment, etc.) are available as compared to other regions such as Asia or Latin America.

3. *Number and Types of Trainees*

A total of 65,368 persons were reported to have completed FAO's training activities in 1986 (Figure 3). Of this total, 13,993 (21 percent) were women. Asia accounted for about 50 percent of all reported FAO trainees, although its proportion in terms of the number of training activities was only 26 percent.

It should also be mentioned that in addition to training activities conducted by FAO field projects, there are also those organized and implemented by FAO Headquarters' technical divisions and Regional

Offices. The *Review of Regular Programme of 1986-1987* mentioned that in 1986 a total of 8,231 persons participated in non-field project-related training activities. However, only 6,924 participants of such training activities were reported during the 1986 data collection of the FAO training activities. Therefore, in terms of the total number of FAO trainees, 1,307 persons could be added to the 65,368 trainees reported through the training activity questionnaire forms of 1986. This brings the total number of FAO trainees to at least 66,675. However, the discussions and analysis in this report will be based on the total number of trainees who had been reported through the questionnaire forms.

The total number of reported trainees in 1986 has increased compared to 1985 (Figure 5). However, it was noted that while the number of trainees in Asia had increased considerably, such was not the case in Africa. In addition the Near East reported an increase in the number of trainees in 1986 (Figure 6), while Latin America and Europe remained almost the same as in 1985.

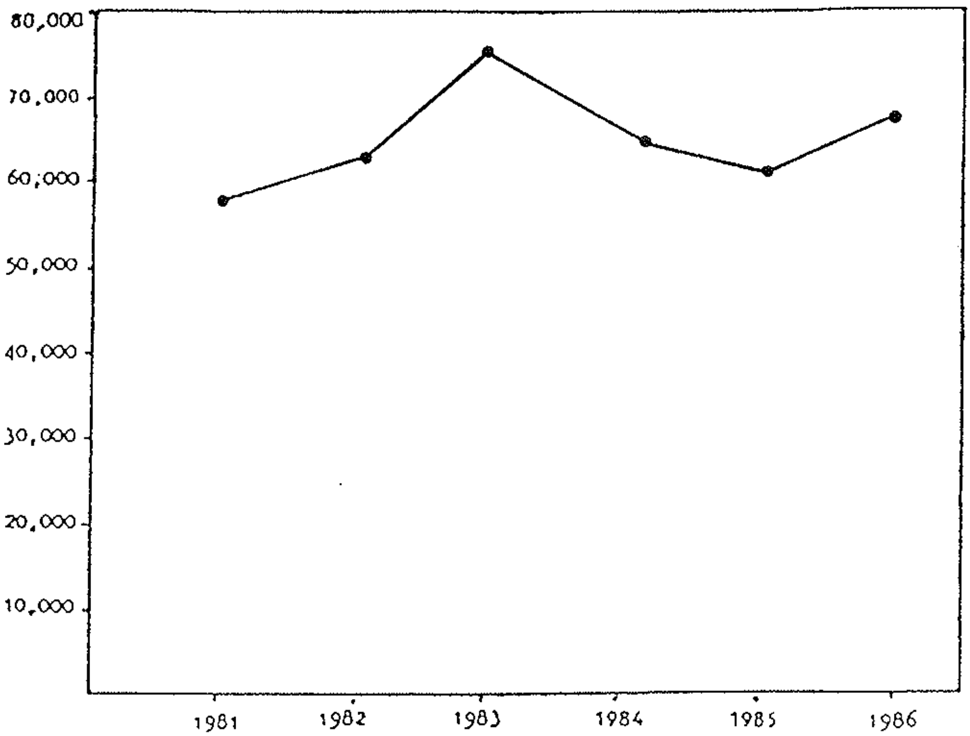

FIG. 5. Reported Number of Total Trainees (1981-1986).

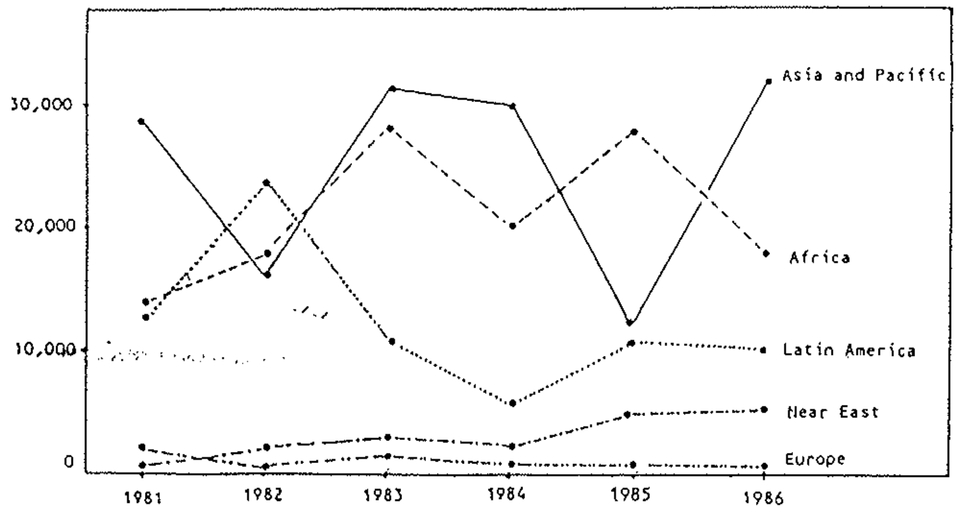

FIG. 6. Regional Distribution of Reported Number of Trainees (1981-1986).

While the number of trainees in Africa has decreased in 1986, the number of training activities in that region has increased. The average number of trainees per training activity has thus become smaller, and this trend could be seen as a good step toward training quality improvement, because the ratio of trainer to trainees has improved. The trend also seems to suggest that the variety of training courses offered for African trainees has increased, thus providing more opportunities for different levels and subjects to African trainees.

In Asia and the Pacific, due to a fairly large number of farmers trained (in a very short duration of one to two days) in 1986 as reported by several projects, but which did not report during 1985, there was a sharp increase in the total number of trainees in 1986 as compared to 1985. With the exception of 1985, the total number of trainees in Asia has not changed drastically since 1983: about 32,200 in 1983, 30,100 in 1984, 32,800 in 1986.

It is to be noted that while the proportion of reported trainees in Latin America has decreased (3 percent), the proportion of training activities has increased by 2 percent; this due to the fact the average number of participants per training activity in Latin America is the lowest (46).

The same trend as last year was observed in the Near East, whose training activities were principally (83 percent) for professionals and technical level specialists, whereas primary producers and vocational level personnel only accounted for 17 percent.

Three quarters of Asia's training activities were also for professionals and technicians, while in Africa at least 32 percent of the training activities were at the vocational and producer levels (Figure 6).

Almost one-third (31 percent) of FAO participants attended short training sessions (field days) (Figure 4). These training activities were mainly for primary producers, who accounted for 35 percent of all FAO trainees (Figure 5). Primary producers constituted the largest group of FAO participants in 1986. The second largest number in 1986 was artisans/operators, with 28 percent of the total number.

While 40 percent of the training activities in 1986 was for technical specialists, these trainees only accounted for 18 percent of the total number (Figure 5). This suggests that on the average the number of persons trained in each training activity for technical specialists is fewer than that of other training activities. Twenty-one percent of the total number of participants reported in 1986 were female trainees. Figure 7 shows that the proportion of female participants continues to increase since 1982, when it was only 10 percent.

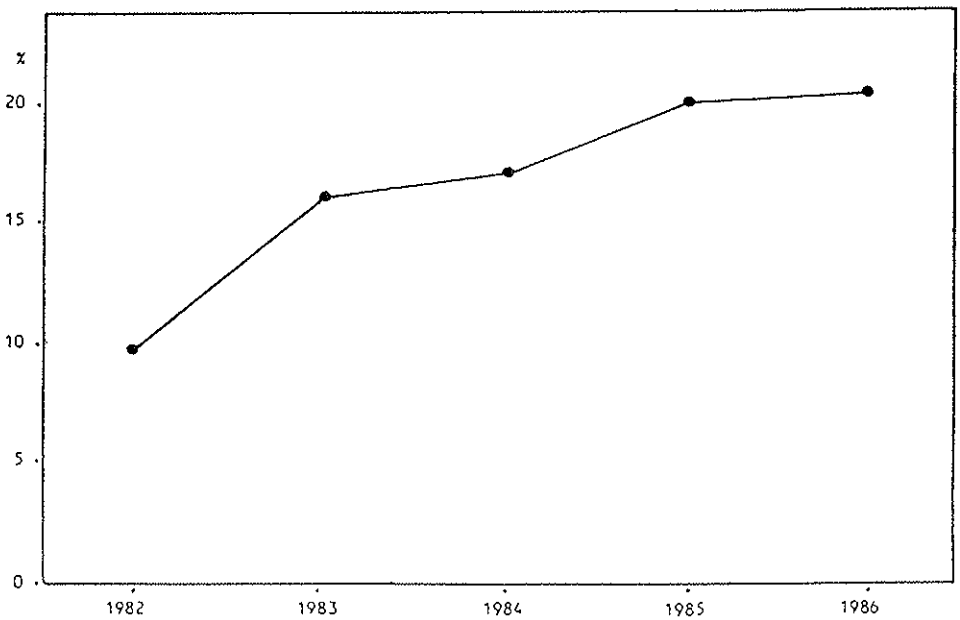

FIG. 7. Proportion of Reported Female Trainees in FAO Training Activities (1982-1986).

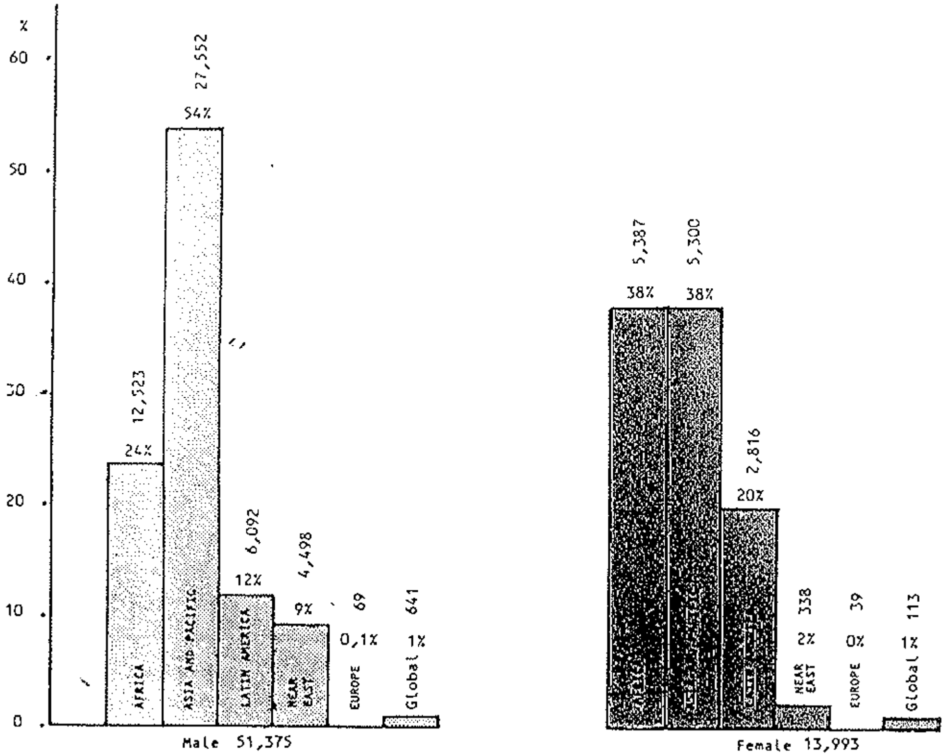

FIG. 8. Number and Proportion of Reported Male and Female Trainees in Selected FAO Regions in 1986.

As far as the regional distribution of female trainees is concerned, Africa and Asia trained the highest proportion of women (38 percent each). Latin America increased its proportion from 18 percent in 1985 to 20 percent in 1986, while the Near East proportion dropped compared to 1985, from 7 to 2 percent in 1986 (Figure 8). The proportion of reported trainees by sex (Figure 9) shows that in Latin America there is less discrepancy (68 percent males, 32 percent females) while in the Near East only 7 percent of reported trainees in 1986 were women.

4. *Level of Training*

Technical level training has been the most dominant type of FAO training since 1979, and it accounted for 40 percent of all FAO training activities in 1986 (Figure 10). Figure 6 also shows that this type of train-

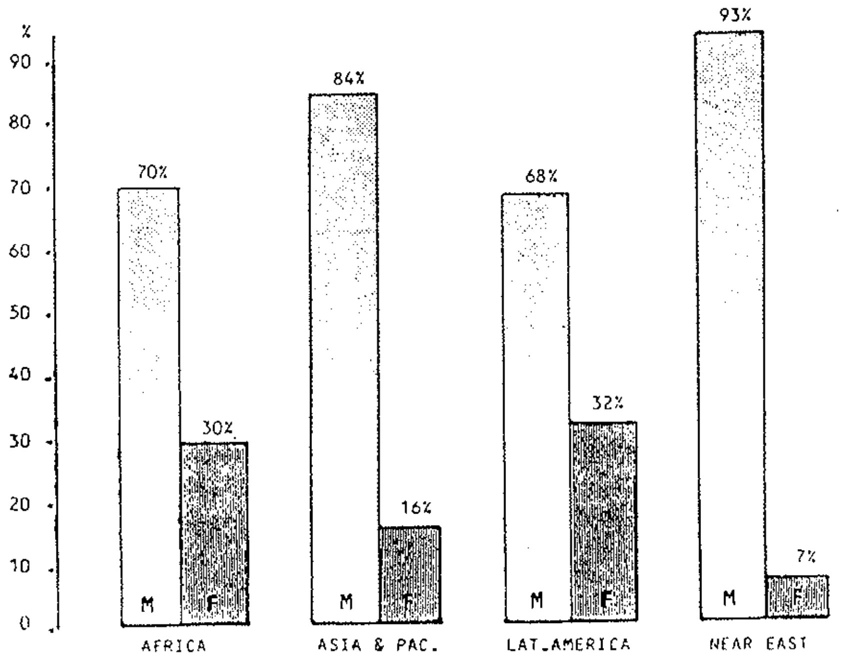

FIG. 9. Regional Proportion of Reported FAO Trainees by Sex, 1986.

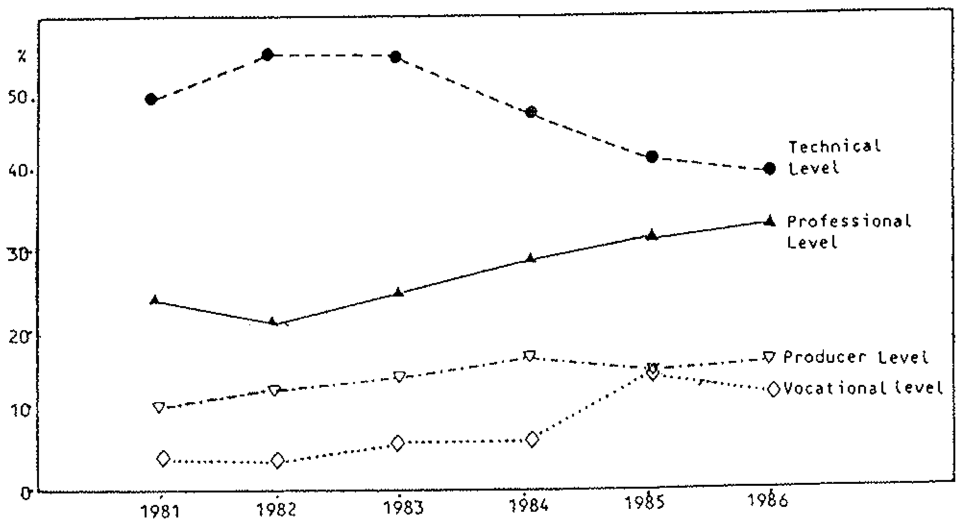

FIG. 10. Proportion of Reported FAO Training Activities in All Regions by Different Levels of Training (1981-1986).

ing was offered most frequently in Asia (32 percent), followed by Africa (31 percent). However, it should be noted that the number of training activities at the professional level in the last 5 years has continuously increased, while at the same time the reverse trend has appeared for technical level training. One possible explanation is that in many countries there seems to be an adequate number of trained agricultural technicians and the priority has now shifted to training of agricultural managers, planners, administrators, scientists, researchers, specialists, etc., who in the past have not been given high priority because of the importance of strengthening the field agricultural work force. With increased importance of the need for programme quality and management efficiency improvement in the field of agricultural development, agricultural training at the professional/management level appears to have been given more attention in the last 5 years.

5. *Duration of Training*

In 1986, three out of four (77 percent) reported FAO training activities were of short duration (two weeks or less). An additional 12 percent of all FAO training activities conducted training of between two weeks and one month duration (Figure 7). All training activities conducted in Europe in 1986 were of two weeks or less duration, and those conducted in Latin America in 1986 had a very high proportion (80 percent) of short duration training programmes as compared to Latin America and Asia (80 percent) and the Near East (85 percent).

Comparison of FAO training data from the previous years also indicated that the proportion of short duration training activities (two weeks or less), has been increasing constantly since 1980. For instance, in 1986 about 77 percent of all FAO's training activities were of such short duration. In 1985 it was 75 percent, in 1984 it was 65 percent, in 1983 it was 64 percent and about 57 percent in 1981 and 1982, while the lowest, 52 percent was in 1980.

Figure 11 shows the trend of the increasing proportion of FAO's short-term (one month or less) training activities, while the proportion of the longer duration (more than one month) training activities has been on the decrease in the past couple of years.

The increasing proportion of FAO training activities which conducted relatively short-duration training (one month or less) might be explained by the relatively high proportion of professional level training activities. As we already discussed earlier, there has been an increasing number of training activities for professional level in the last 5 years.

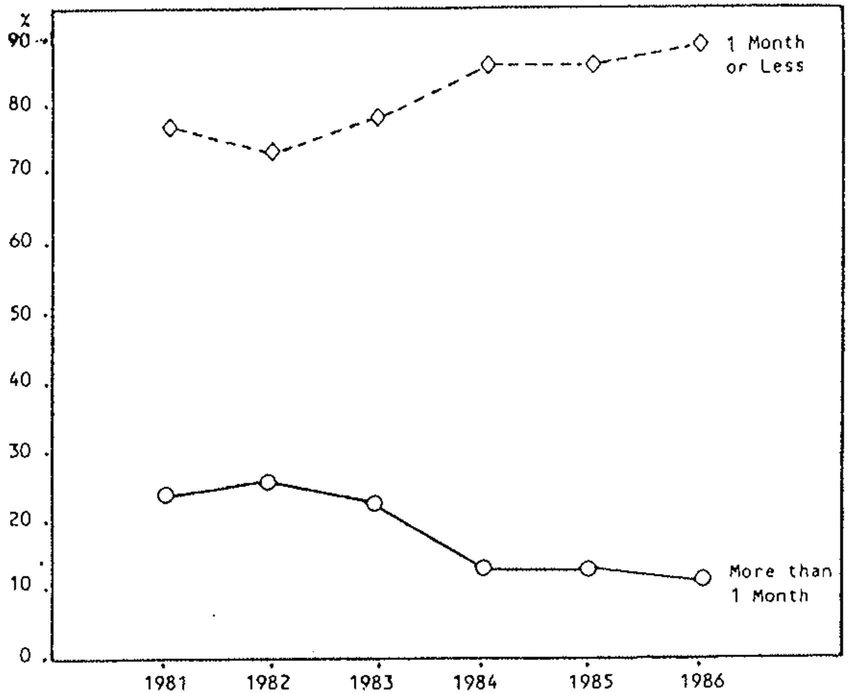

FIG. 11. Proportion of Reported Training Activities of 1 Month or Less, and More than 1 Month Duration (1981-1986).

Such a type of training, as can be seen in Figure 8, accounted for about one-third of the training activities whose duration was relatively short. For instance, 32 percent of all training activities of two weeks or less in 1986, were aimed at professionals. In many countries, due to the shortage of staff at the professional level, and also due to the relative importance of their jobs, these types of personnel could rarely be allowed to leave their jobs for more than one or two weeks even if the purpose was for training.

In addition, the number of training activities at the primary producers' level (which are usually conducted for a very short duration) has also been increasing and in 1986 accounted for almost one-fifth of all FAO training activities.

6. *Types of Trainers*

In 1986, few (15 percent) FAO training activities utilized international experts as the only trainers (without national experts). Thirty-one percent of FAO training activities used national experts (without international experts) as trainers. The majority (54 percent), however, utilized both international and national experts as trainers in their training activities (Figure 9).

It should also be noted that international experts were mainly used to train professionals and technical specialists, and this accounted for 95 percent of such training activities (Figure 10). If such a trend is to continue in the future, it will be quite likely that international experts would be needed more in highly technical and specialized areas, especially for training of managers, decision makers, agricultural scientists and researchers.

7. *Language*

The English language was still the most frequently used language in the reported FAO training activities in 1986 (Figure 11). One of four training activities in 1986 used English as the sole medium of instruction.

The use of the Spanish language had only increased slightly from 16 percent in 1985 to 17 percent in 1986, although a considerable increase (from 16 percent in 1983 to 22 percent in 1986) was noted in the proportion of training activities in Latin America, where almost all the Spanish language training activities took place.

The use of Arabic had decreased considerably from 8 percent in 1985 to 4 percent in 1986 (the same percentage of 1983) (Figure 12). This trend might be explained by the fact that the proportion of training activities in the Near East during the period also decreased significantly from 16.5 percent to 11.4 percent.

The French language has been used quite steadily in the last 5 years, with an average of about 13 percent, but its use in the Near East increased in 1986, whereas in Africa it shows a decrease in usage for the last 3 years.

Portuguese has been used as a language of instruction in only 3 percent of all FAO training activities in 1986. Almost all the training activities which used Portuguese were conducted in Africa.

8. *Operational and Technical Backstopping*

In 1986, 39 percent of FAO projects which reported to have conducted at least one training activity, were operated by AGO Division (Figure 12). The diminishing trend of training projects operated by the AGO continues, although it still ranks first as regards the Division/Unit

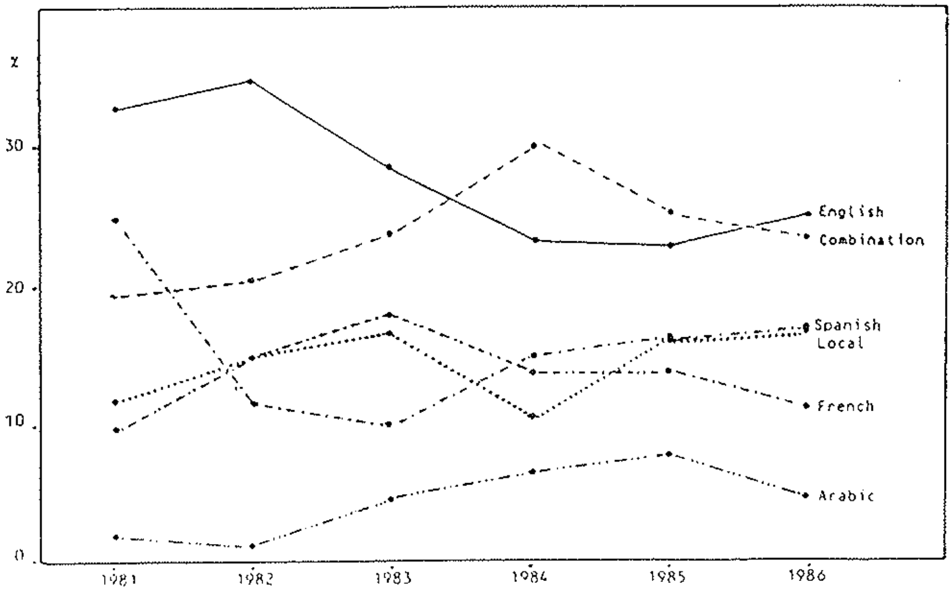

FIG. 12. Trends in the Main Languages Used in Reported FAO Training Activities (1981-1986).

that operates training projects. In 1983 the AGO Division operated 70 percent; in 1984 50 percent, in 1985, 44 percent. The FAO Regional Office for Latin America operated in 1986 about 8 percent of all the training projects, ESP accounted for 7.7 percent, AGP accounted for 7.4 percent, and the FAO Regional Office for Asia and the Pacific accounted for 6.3 percent.

As regards technical backstopping, in 1986 the Division which backstopped the highest number of projects which conducted at least one training activity, was AGP (21 percent), followed by ESH (13 percent), AGS (10 percent) and ESP (9 percent).

9. *Source of Funding*

Since 1982, the proportion of all FAO training projects which were funded by UNDP has declined continuously from 61 percent in 1982 to 23 percent in 1986, as shown in Figure 13. However, in 1986 UNDP still provided the funding for the majority of FAO training projects in Asia (37 percent) and in Africa 39 percent (Figure 13). The proportion of UNDP-funded training projects increased significantly in Asia, from

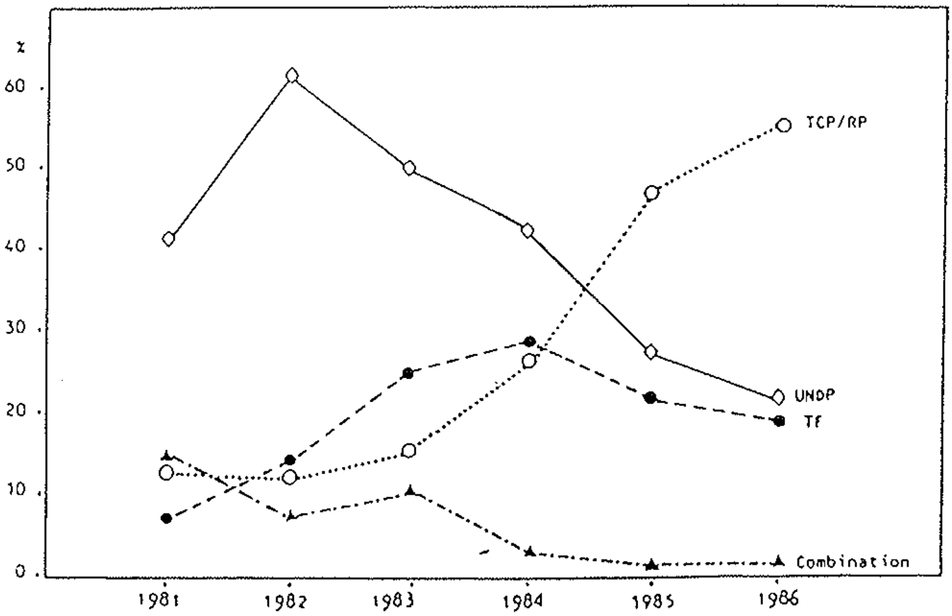

FIG. 13. Funding Sources and the Proportion of the Reported Number of FAO Projects with a Training Activity it Supported (1981-1986).

17 percent in 1985 to 37 percent in 1986, but decreased considerably in the Near East, from 20 percent in 1985 to 11 percent in 1986.

The proportion of FAO training projects which were funded by the Regular Programme/TCP had increased significantly since 1982, when it accounted for only 12 percent, to 55 percent in 1986. This trend seems to indicate the special importance given to training by FAO's Regular Programme/TCP activities.

The proportion of Trust Fund assisted training projects (GCP and UTF projects) declined in 1986 but it still accounted for a fairly significant proportion (19 percent).

As can be seen in Figure 13, several trends have emerged since 1982. While the proportion of UNDP-funded training projects seems to be on the decline, there has been an increasing proportion of Regular Programme/TCP-assisted training projects. In addition, the proportion of Trust Fund-assisted projects almost equalled that of UNDP-assisted training projects. In 1986, these two types of funding (Trust Fund and Regular Programme/TCP) were the main source(s) for more than two-thirds (70 percent) of all FAO training projects.

Of all the Regular Programme — and TCP — assisted training projects, Africa had in 1986 the highest proportion (31 percent). In terms of TCP-funded training projects, Africa accounted for 48 percent. This situation might be due to the special attention given to African rehabilitation programme follow-ups. For Regular Programme-funded training projects, Latin America's proportion was the highest, with 27 percent.

In Asia, it appeared that, in 1986 the highest proportion (48 percent) of FAO training projects conducted in that region were funded by Regular Programme/TCP. Similarly, in Latin America and the Near East 75 percent and 72 percent, respectively, of all its training projects were funded by Regular Programme/TCP (Figure 13).

III. Agricultural Research: the Role of FAO.

FAO has never established independent International Research Centres like those developed by the CGIAR during the seventies. The FAO choice has been technical and financial support to the establishment or promotion and reinforcement of national research institutions. However, FAO is one of the international organizations of the U.N. (together with UNDP) which has fostered and established the CGIAR, thus demonstrating support for any initiative promoting agriculture and rural development in developing countries. Support to national institutions is provided through a series of initiatives, among which the most relevant are: (1) support to the development of managerial capabilities and scientific level of research staff; (2) support, both financial and technical to the establishment of research structures; (3) support to the definition of research programmes and priorities.

During recent years, 24 national agricultural research reviews have been conducted by FAO, followed by national research follow-up, in order to keep the momentum for the development and orientation of research at a national integrated level.

In this perspective, together with Technical Divisions and Regional Offices, FAO has been conducting promotion and management of research networks, involving both developing and developed countries.

Another important component of the FAO-applied research activity is related to the operation of field projects. In each project there is nearly always a more or less important research component, even if the type of research involved is often referred to as adaptive research: transfer and adaptation of knowledge developed in other areas.

Adaptation and transfer of knowledge is in fact another important component of FAO research involvement.

Technical meetings are very often organized by FAO with this purpose. Every year a number of conferences, meetings, and workshops, disseminate information and research results among member countries, upgrading the level of knowledge of scientists and technicians involved in agriculture, forestry and fishery development.

Finally, FAO disseminates updated information through a very high number of technical publications. Some FAO publications have become classical reference texts, fundamental for establishishing methodologies and standards valid all over the world.

FAO disseminates pubblications among official institutions of all member countries and among scientific organizations and national or international development agencies. Technical reports of meetings organized by FAO in a very large area of technical subjects also have a very wide distribution and consideration, particularly in developing countries, where information is costly and often difficult to obtain.

IV. Knowledge Must be Shared — A Proposal for the Establishement of "an International Agriculture Universities Network"

This meeting is considered a good occasion for advancing a proposal rather simple conceptually, but with possible large effects for improving human brotherhood, reciprocal understanding and progress in agricultural development.

It would be nowadays timely to propose the establishment of an international agreement for voluntary circulation of the academic staff of agricultural universities all over the world. The visiting professors could be hosted for 4-12 months in another parallel university, where they could provide training to the university students for this period and participate in the local agricultural research activities. The exchange of teachers should possibly be in all directions: from developed to developing countries and vice-versa, among developed or among developing countries. Universities agreeing to this international network should partially finance such exchanges, while an international rotation training fund could be established with support from UNESCO, FAO, UNDP and other donor Institutions interested in the programme.

This initiative would specifically enable professors from developed countries to understand the problems and realities of developing countries, becoming involved personally and directly for some time, and, on the other hand, professors of developing countries could have opportunities to upgrade their information and express their potential in a more favorable and technically more advanced environment. Students of all countries could profit directly and indirectly from the experience gained by their teachers, being exposed to different approaches and perspectives. I am confident that the Pontificial Academy of Sciences could represent the organization that the world over can promote this idea and initiative, as a contribution to the development of knowledge and common understanding.

AGRICULTURE AND QUALITY OF LIFE: NEW GLOBAL TRENDS

CONCLUSIONS (*)

Humankind and its quality of life are in danger. Both in the developed and in the developing world, alarming signals of the danger are becoming evermore clear. Even agriculture, the "primary" sector of humankind's activity, has been accused during the last few decades of contributing to this danger. It has been blamed for its deleterious effect on the environment, diminishing and altering the quality of life.

This Study Week focussed its attention on the interaction between agriculture and quality of life. While mindful of the planetary dimensions of the quality of life and attentive to the effects on them of scientific innovations and new technologies in agriculture, the participants were particularly concerned for the quality of life in the underdeveloping world.

It is undeniable that progress in agriculture has marked the development of humankind and has made possible the existence of past and present societies. It is recognized that, even after ten thousand years of the continuous evolution of human activities on earth, agriculture still represents the fundamental effort whereby humans can provide food for an ever-growing world population, create conditions for housing and clothing, and even protect the environment in its almost natural equilibrium. Indeed, agriculture is the most important complex mastered by man for the production of renewable resources through the transformation of solar energy into more manageable forms of chemical energy found in commodity crops, firewood, agricultural wastes, and in other organic raw materials.

(*) These conclusions were drafted, on the basis of the papers presented and of the subsequent discussions, by G.T. Scarascia Mugnozza assisted by Johanna Döbereiner, G.B. Marini-Bettòlo and Father Bernard Przewozny.

Agriculture, which includes crop production, animal husbandry, fishing, and forest management, is a complex system, formed by a number of subsystems, each of which may assume particular characteristics in different environments. These environments are determined by such factors as meteorology, geology flora and fauna, and may be modified by different inputs of materials, such as fertilizers, pesticides, herbicides, and so on.

Indeed, agriculture has been and still is the primary link between humankind and its environment. It makes possible not only survival but lays the conditions for humankind's quality of life in the biosphere.

The phrase "quality of life" is understood here to refer to every human being's accessibility to means and resources according to availability in space and time. "Quality of life" points to a dynamic reality which takes into consideration the capacity to satisfy the fundamental needs of food, health, housing and water supply, as well as access to education and to the means of the transmission of traditional or inherited wisdom, all of which imply the consciousness of the cultural identity of persons and communities and their ability to contribute to the solution of political, economical and social problems at the national, regional and global levels. The phrase also indicates a standard of dignified life for every human being, a standard which foresees peaceful competition and the common development of other human beings, in harmony with the biosphere and natural resources and in respect for the quality of life of future generations.

An overview of the history of agricultural development indicates that different populations produced different agricultural systems because they satisfied particular needs by using indigenous plants and animals and by taking advantage of other locally available opportunities.

Traditional civilization and agriculture in Asia developed in alluvial plains in close association with big rivers, which induced for millennia the utilization of irrigation as the basic input for increasing and stabilizing production. In Latin America civilization flourished in highlands, based on maize, potato and beans, again often associated with sophisticated irrigation systems. Africa, south of Sahara, has been rather recently involved in massive agriculture. Game and the gathering of plant resources were able to support relatively low population pressures, mainly concentrated in semi arid savannas, where human and livestock diseases and parasites were absent or only scarcely present. Some very humid areas and river basins are still open to agricultural exploitation in Africa, where the world's highest population rate increase is now occuring. Still much larger areas of highland savanna are available in South America where rural agriculture is rapidly expanding.

If science and technology provide better means of controlling plant and animal pests and diseases, then large areas will become available to agriculture in Africa and other continents where food shortages and the quality of life need quick improvement. Present knowledge should permit the development of appropriate technologies for rational agricultural use of those areas, a use which can even safeguard the environment in a sustainable manner.

Growth in developing countries is a process which is inevitably linked to technological and institutional development, but, above all, it depends on the enhancement of human capital. Only if these interdependent factors develop together and quickly can agricultural productivity be increased rapidly. Countries are poor because the productivity of their resources is low. Basic engines of growth are those processes which increase productivity. Since agriculture is the technology which uses in the simplest way elementary natural resources — land, water, and sun energy — to satisfy an ever-growing demand for basic human commodities, it deserves highest attention from persons and institutions interested in increasing productivity and in improving humankind's quality of life.

The increase of agricultural production in the last twenty years was directed toward coping with the global increase of population. Technologies developed during this period demonstrated that sustainable production is possible and feasible. Population growth, however, is highest where poverty is highest. International solidarity should therefore concentrate efforts in those areas. Food surpluses from developed countries can be used effectively to pay a major part of the cost of building infrastructures in rural areas, providing especially in emergency situations an important link between short-term alleviation of poverty through relief and the long-term effort to achieve self-reliant growth.

As long as surpluses of labor in developing countries are not better integrated into their economic systems, efforts to eliminate hunger and poverty will be seriously limited. For this reason, to state the hunger problem simply in terms of "food production and availability" will not help to find the correct solutions to the problems of hunger and poverty. The latter should be formulated in terms of "job opportunity" or as livelihood security for the poor.

In order to achieve the above stated goals, full use should be made of science and technology, especially of the most advanced sciences and technologies such as genetics, microbiology, biotechnology, microelectronics, computer science, remote sensing, system analysis, etc. On the other hand, every effort must be made to integrate in an appropriate manner traditional and modern technologies.

Finally, a complete understanding of agriculture should include its increasing role in the protection of the environment and its importance for the improvement of humankind's quality of life.

1. *Science for Innovation in Agricultural Systems*

Growth is a process of human, institutional, technological and capital investment and development. All these factors increase the productivity of resources and the efficiency and effectiveness of every effort to promote humankind's quality of life. It should be clear that these and similar factors are so intimately interrelated that the development of one, without proper consideration for the development of the others, can cause distortions and intolerance, and, consequently, impede real development.

1.1. *Human Capital.* Decades of experience indicate that foreign assistance must be attentive to the environmental characteristics in which it operates. If the human and institutional capital — understood in terms of expertise, education and leadership qualities — is underdeveloped in recipient countries, then these countries do not use foreign assistance any more effectively than their own natural resources. Some of the factors which limit the success of such programs are the absence of coordinating ability, the inadequate setting of priorities, and the insufficient understanding of how to combine innovative and traditional technologies. This is why internationally aided projects very often collapse when the external inputs are withdrawn.

1.2. *Biotechnology.* Newly acquired knowledge in biological sciences and its rapid transformation into biotechnology are changing the way in which problems in agriculture can be addressed. They are not changing the purpose of agriculture, which remains that of producing and processing food, fiber, timber and chemical feedstocks, but they are promising to offer new techniques to complement the traditional methods used to enhance crop productivity and commodity processing, to obtain more fruitful and predictable results, and to increase the latitude and range of cost-effective products. Undeniably, then, the latter goals are possible today with the application of biotechnologies to the same resources.

Biotechnologies are promising to design and develop a number of agricultural inputs, such as bacterial insecticides, which show little or no toxicity to mammals and impede the buildup of resistance on the part of insects. Almost the same can be said for viruses and fungi as pest control agents, for mycoherbicides in weed control, and especially for the utilization of modern ways of replacing nitrogenous fertilizers by biological dinitrogen-fixation.

Weed control has long been and will continue to be an agricultural practice. By eliminating weeds that compete with crops for nutrients and water, herbicides help farmers to raise their yields substantially. On the other land, herbicides can cause serious environmental problems, as indicated by the detection of certain products in surface and ground waters. New and highly effective herbicides, which control vegetation by inhibiting the action of specificity plant enzymes so that these do not harm fish, insects and mammals which lack them, may represent an additional contribution to environmental quality. Moreover, enzymes are broken down rapidly and, therefore, do not spread appreciably in the environment or leach into water.

The lack of persistance of some of these inputs, especially in certain field situations, and their high specific activity and selectivity often make their use less attractive to farmers, but the very same characteristics make them ecologically sound.

Soil biology and, above all, mycorrhizae and N_2-fixing bacteria offer very promising alternatives as new biotechnologies seek to replace or integrate fertilization systems, especially in tropical areas where optimal temperature and humidity conditions allow for enhanced microbiological activity.

While under temperature climatic conditions ectomycorrhizae are essential to forest trees, endomycorrhizae play a major role in supplying phosphates to most agricultural crops in the acid, extremely phosphate-deficient, soils of the humid tropics. There, rock phosphates, made available to crops through mycorrhizae, can replace imported soluhle phosphates, offering economic advantages and possibilities for integrated cropping systems which are less aggressive to the environment.

Nitrogen represents the major limiting factor to crop yields and about 70% of fertilizers costs. Chemical nitrogenous fertilizers are very soluble and more than half ot those applied lixiviate into ground waters. Biological dinitrogen fixation represents the most economic and ecological alternative because, as long as there is not enough nitrogen available in the soil, nitrogen-fixing microorganisms fix only N_2, thus self-regulating the system.

Grain, fodder and green manure legumes, and, more recently, tree legumes, are playing an ever-growing role in cropping systems and are therefore beginning to contribute to a readjustment of many billions of dollars worth of nitrogenous fertilizer expenditures in tropical countries. Several, recently isolated, nitrogen-fixing bacteria offer rapidly growing opportunities of expanding biological N_2-fixation to cereals, grasses and sugarcane. The latter crops have become the only potential biomass alternative to fossil fuels. Their highly positive energy balance — a decisive factor in making any biomass energy project viable — is largely dependent on the replacement of nitrogen fertilizers and the availability of water. An even greater role will be played by biotechnology in the production of plants which require lower inputs, thus reducing environmental problems and costs.

Moving genes from different sources directly into the appropriate background is a new tool for speeding up breeding activities and to allow new varieties to be brought into cultivation more quickly, thus making agriculture more diverse and less vulnerable to harmful factors. The selection of plants for resistance to disease and pests has been one of the main aims of plant breeding since its very beginning. In the past, genes were derived from resistant land races and from wild relatives. Today, expression in plants of toxin-coding genes can provide a novel form of protection against defoliating larvae and those which bore into plant tissue, thus ensuring, for example, long timber life after processing.

Molecular techniques are becoming powerful tools for determining linkage maps and for recognizing chromosome segments, thus allowing the early detection of sets of enzyme-coding genes which act in a concerted fashion. This is the case of complex traits, such as those governing drought resistance, cold tolerance or improved nutritional values. The latter deserves special attention since seed proteins satisfy the basic dietary protein needs of large populations in developing countries, even if these needs are seldom satisfied in a nutritionally balanced manner. The transfer of gene sets which code for a specific protein fraction may be a valuable way to improve that nutritional balance. The same scope may be pursued in oil crops to modify properly both oil content and quality, not only for nutritional properties but also for industrial purposes. Since a great demand for oil products on the part of industry is expected, the closer collaboration in this area between agriculture and the chemical industry could be of mutual benefit.

In addition to better tools and new inputs, biotechnologies are also providing new opportunities for employment. This has been demonstrated especially in tissue culture and micropropagation activities, in fermentation technologies which provide specific nutrients, in the cosmetic and pharmaceutical industries, and in the production of feedstuffs from lignocellulose or from products of agroindustry. The same can be said of marine biology, which has only begun to emerge as a new field, or of the more experienced production of fodder by means of protein enrichment with yeasts or fungi grown on substrates such as molasses, sugar juice, fruit syrups, coconut milk, wheat and starch.

In providing these opportunities, biotechnologies cooperate not only to create a more sustainable form of agriculture and to protect the environment but also to allow people to find employment where they live, thus helping to strengthen their cultural and social bonds and to check the displacement of people to the concentrated and restricted spaces of urban areas, which so often become centers of famine, disease and human alienation. It can be said that biotechnologies contribute to the humanizing role that agriculture has always played in society.

1.3. *Aquaculture.* In developing countries, annual fish production — aquaculture and fishery combined — amounts to almost 40 million metric tons. Of this total, aquaculture production alone accounts for approximately 5,2 million metric tons.

By aquaculture is intended the husbandry of aquatic animals and plants at densities greater than those found under natural conditions. The main aquatic organisms of interest are finfish, molluscs, crustaceans and aquatic plants. These can be cultivated in stagnant water or with water exchange.

Asia can be considered to be the most important aquacultural region in the world: it represents almost 80% of the world's aquacultural fish production and its annual growth rate is about 8%. Although Latin American production represents only 4% of the world's total, its annual growth rate is the same order of magnitude as the Asian. African aquaculture, on the other hand, is not as widely distributed and its production rate has even decreased in the last decades.

Research priorities must differ in the three continents, keeping in mind their respective situations. In Asia and Latin America, intensive research should be pursued and production oriented toward the satisfaction of growing needs.

Inasmuch as aquaculture is quite well established in Asia, research should develop new techniques which can be adapted to local conditions in order to improve yields. Furthermore, since most farmers engaged in aquaculture possess small holdings and utilize integrated land-water production systems, it would be useful to support the market, improve transportation networks, and develop other infrastructures.

Aquaculture in Latin America and in the Caribbean is of quite recent origin. Moreover, the characteristics of South American markets are such that it is unreasonable to expect aquaculture to solve the nutritional needs of low-income people: meat, for example, can still be purchased at a low price. Nevertheless, the growth rate of this industry is positive and it would be economically advantageous for the region to support productivity in order to increase exports.

Although aquaculture is far less developed in Africa than in the other two continents, much effort has been directed toward its introduction there. Especially the development of tilapia and carp cultivation, in either extensive or intensive pond systems, has been undertaken because, despite relatively small amounts of fish harvested, the costs of production are low and can be absorbed by other activities. Fish cultivation in small or medium size ponds can undergo intense development provided that producers are carefully selected and that an integrated farming approach is implemented. Since aquaculture is a novel technique, commercialization and long-term financial and marketing assistance should be made available.

Finally, as sources of high quality protein, finfish products can contribute to the nutritional level of communities, increase the rural farmer's income, and provide employment opportunities.

1.4. *Agroforestry.* Forests, as vegetational cover, are multipurpose systems which perform various functions: assimilation of atmospheric carbon dioxide through photosynthesis, regulation of climatic conditions and water circulation, filtration and purification of water and soil, potential sources of alternative energy especially in developing areas, renewable supply of timber, etc.

Throughout the world and ever since mankind embarked on settled agriculture, trees and crops have been grown together in some form of interdependence, thus characterizing different agricultural systems.

Agroforestry systems, which combine forests with pastoral or arable practices, aim at producing more than one crop simultaneously from the same area of land and are, therefore, less offensive to the environment. Land, cultivated in this manner, produces different food, feed, fiber, etc., whereas the forest areas provide timber, firewood, and shade for flocks and herds during hot months, and act as windbreakers, purifying the air, preventing soil erosion, reducing evapotranspiration, stabilizing slopes, etc.

In the tropical zones of the world, the association of trees with farm crops is or has been of a very special nature in traditional agriculture. There, agroforestry systems are characterized by an understory of shade-tolerant fruit crops and an overstory of fruit, timber and firewood trees, thus optimizing the use of the environment (light, water and nutrients) with plants which do not compete with, but rather complement, one another. In limited areas around the farm house, from as many as ten to twenty different species of trees and annual crops usually are or were grown, thus continuously supplying unstorable food to human beings. This system represents a very close interdependence which protects against the great fragility of the soil in tropical ecosystems, where humans can destroy fertile soil in a brief period from three to five years, whereas nature requires thousands of years to form an arable layer of fertile soil. The predominant presence of legume trees in tropical agroforestry systems and the use of other multipurpose N_2-fixing trees play an important role in recycling nitrogen from the atmosphere and in restoring soil fertility.

Throughout the world, the salient features of an agroforestry system are its combination of food, timber and fuelwood production and, at the same time, its conservation and rehabilitation of soils and related ecosystems through the recycling of nutrients from the subsoil, fixing atmospheric dinitrogens and carbon dioxide, controlling erosion, preventing carbon dioxide, high soil temperatures, and so on.

Clearly, forest and agroforestry systems protect the environment. Since their vegetation cover constitutes an essential component of the biosphere, whatever damage is inflicted on it depletes resources important to humankind's survival. More specialized research into the characteristics and functions of these vital systems is definitely needed.

1.5. *Agroindustry.* Since nonrenewable sources of energy and raw materials are thought to have a short future and food production is becoming easier, agriculture and industry are rediscovering their interconnections. As in any change, this tendency has certain positive aspects which ought be developed and some negative problems which have to be solved.

It is possible for agriculture to be modern and at the same time self-sustainable and environmentally sound. The presence of industry in rural areas can be a new source of work and consequently of income for developing nations.

There are many activities that may provide a first transformation of the agricultural product at the farm site or near it. Simple preprocessing activities may help reduce the costs of final processing as well as losses due to the transportation of the product from the farm or the village to urban centers.

Agroindustry in general may become an important means of stabilizing populations in rural areas, generating new opportunities for low income populations, introducing new elements of management and organization, and, in general, improving the standard of living.

Contracts of production may decrease risks associated with the fluctuations of prices. Governments, on the other hand, should monitor situations and take action to prevent monopolistic forces which could lower prices paid to farmers. Governmental action is also required in providing education and training, a fundamental necessity if modern technologies are to be introduced and used, and in stimulating the organization of farmers' cooperatives, which could increase their participation, negotiating power and technology transfer.

Agroindustry may work as a powerful force to affect the pattern of adoption of technological innovations and their diffusion throughout the territory. It may also be a further source of employment and income, increasing the diversification of the job market and reducing labor displacement to urban agglomerates.

1.6. *Specific Environments.* It is commonly agreed that in arid and semi-arid environments malnutrition and hunger may be solved by using knowledge concerning arid land management, and selection and genetic improvement of plant crops with high tolerance to salinity and drought.

Experiences in different parts of the world indicate the possibility of using saline water to irrigate desert areas, provided specific management procedures are followed. Yield and quality of fruits can even be improved by the practice.

The principles of soil conservation in the tropics and subtropics were known to farmers already centuries ago. Only now, as extensive cultivation is introduced or when farmers move into cities, are these principles no longer applied. Traditional systems provided physical barriers to the downslope movement of soil or protected against the shattering action of raindrops. By cultivating mixed and/or multiple crops, rather than relying on monoculture, such systems never left the soil bare. Research should provide scientific content to these practices, improve them, and prevent their falling into disuse. Nutrients in the soil are not static, but they can be enriched or washed out of the system, according to the various types of human intervention.

Although considerable progress was made in arid and tropical land development in the past, a very broad experimental approach is necessary today, an approach which will utilize all available scientific knowledge and technological tools to overcome deprivation and hunger, conditions that are not unavoidable, and to produce a satisfactory standard of living even in areas unfavorable to agriculture.

2. *Opportunities for Africa*

Population in Africa increases annually by 3%, whereas agricultural production only by 1% or 2%. The importation of food amounted to 19 million tons in 1988. General nutrition levels in Africa are therefore declining.

Although vast areas of Africa can be farmed to feed the approximately 900 million people who live on the continent, a number of constraints limit production: vagaries of rainfall and temperature, low soil fertility, incidence of weed expansion, and plant and livestock pests and diseases. Other limiting factors are represented by socioeconomic constraints: labor division according to sex, illiteracy and educational deficiencies, inadequate political commitments to the agricultural sector, small farm size, poor marketing and trade facilities, etc.

Since about 80% of the population in most African countries earns a living from agriculture, the continued importation of food amounts to an importation of unemployment. Strong initiatives are urgently needed both at national and international levels to stimulate agricultural production. In addition to food self-reliance, increased agricultural production could contribute to the preservation of social balance.

Many factors — for example, the vastness of territoties, diversity of climate and soil types, environmental specificities, differences of agricultural systems and dietary habits — render difficult and almost questionable the adoption of technologies, varieties and cultivation practices developed in and for other regions of the world. Indeed, many introduced technologies — for example, the plowing of large areas — have been shown to generate additional problems, such as deforestation and soil erosion. Consequently, an effort to stimulate and/or strengthen the local generation and diffusion of new technologies, suited to local agricultural conditions, is urgently needed.

Some of the possible options to increase food production are the following: expansion of agricultural areas, intensification of land use, better use of improved varieties and inputs, more advantageous management of livestock, utilization of local genetic plant, animal and aquatic resources. Moreover, reforestation and, whenever possible, irrigation can represent natural complements to rainfed production.

Cultivation practices are normally improved in step with a farmer's realization of possibilities offered by additional opportunities. Technological innovation immediately follows to foster agricultural productivity, utilizing improved plant varieties and animal races which were previously made available and adapted to specific environmental conditions.

Agricultural system approaches should have high priority. They should possess a regenerative capacity which ensures land rehabilitation and longterm sustainable production. Past experiences should be studied to help establish a broader conceptual understanding of relations among environmental factors, natural resources, agricultural systems, and farmers' aptitudes.

Cooperation within African countries and with countries and institutions of the developed world should foster the education of people, agricultural training, elaboration of improved technologies, and the integration of traditional and modern forms of agriculture into sustainable systems of production.

3. *Energy*

Technological development in agriculture is coupled with a continual decrease in the output/input ratio of energy and with the continual shift from human and animal muscular energy to its mechanical and fossil forms.

Agricultural activities at the farm level represent subsystems within a larger system which includes the provisioning of energy and technology at one end and the processing of agricultural outputs at the other. Again, no matter how sophisticated the technology at the farm level, the mandriven system is oversimplified and even little changes in input can cause great inconveniences because useful resources are very easily destroyed by excessive use of inputs.

In the agricultural systems of industrialized countries, production constraints are overcome by the increased utilization of the cheapest resource per unit of product: nonrenewable energy and high level technology. But these advanced systems do not function in equilibrium over the long term or on a global scale. For this reason, extended trade, acquisition, and consumption of nonrenewable resources in order to assure the food supply create a divergence between the economic optimization of agricultural technology and the optimization of resource use in ecosystem exploitation.

In the developing world, the trend to provide commodities to evergrowing urban populations with western types of agriculture, without a proper analysis of the environmental impact of the technologies introduced and without due consideration of their consequences for the labor market, may have tremendous negative effects on local resources and promote unemployment and famine. Research can combat this dangerous trend by generating the appropriate and environmentally sound technologies which can increase and/or extend the use of renewable sources of energy and promote human employment. In addition, to combat this trend, the productivity of agriculture and farm incomes should be increased and, as far as possible, technologies for the transformation, distribution and marketing of agricultural products of local origin should be developed. The goal should be the creation of integrated and interdependent production/consumption systems, involving both developed and developing countries.

It is well known that in some cases the production of fossil energy by developing countries exceeds their real consumption needs. The reason for the overproduction is essentially economic: by marketing this high value energy, developing countries are able to obtain foreign exchange to buy technologies, food and other commodities. It is imperative that part of this earned income be utilized in the generation, testing and diffusion of agricultural technologies, the adoption of which may promote the improvement of commodity yields and farm incomes, and, consequently, the quality of life of about 60% of the present world's population.

Rural areas need more consistent energy investment. Technologies should be based on an optimum combination of energy and energy-dependent and substitutable techniques which improve farm yields and incomes. The first step toward this goal is to create an awareness of the problem. Renewable energy sources and techniques of agricultural production which maximize yield with minimum nonrenewable energy input and sustain adequate yield to meet the basic needs of the rural poor should be packaged and convincingly demonstrated in villages with the participation of the beneficiaries. Such an approach holds very good promise for the future.

4. *Education*

Education is a key to the solution of the multiple problems that agriculture must face within its own sector and in acquitting its tasks vis-à-vis humankind's demand for an improved quality of life. The development of human resources through education is an urgent imperative as we face the year 2000. Every year 60 million additional people in developing countries must be offered the possibility to earn a livelihood, most frequently in agricultural work or in related activities. Education in the expanding rural population of developing countries is essential to an increase of agricultural productivity in a manner that ought to be ecologically sound, economically viable, socially acceptable and politically feasible. Most certainly, new models of agricultural education are necessary if this is to be achieved.

Inasmuch as self-development is not possible in isolation, then education for the immediate enhancement of agricultural productivity must be centered on personal values rather than on individualistic principles, on cooperation rather than on isolationism and protectionism. Joint programs between research centers, universities and industries must be encouraged and facilitated. The flow of information and ideas must expand knowledge, produce appropriate technology and generate self-reliance and interdependence among scholars of developing and developed countries.

Innovative trends in education must foster the values of agricultural societies. They will be able to do this only if new models of education, rooted in a profoundly humanistic vision of life, are introduced. It is important to incorporate into any effort in favor of increasing productivity the immense wealth of traditional knowledge and of its particular forms of transmission from one generation to another. Indeed, to increase productivity for sustainable development, education must be primarily concerned with the empowerment of local land systems, traditional technologies, and indigenous cultural values.

Although the introduction of high technologies is necessary and, at times, essential, if productivity is to be increased, it must also be recognized that vital changes can be brought about through the knowledgeable application of simple agricultural techniques. If development is synonymous with agriculture, then the potentiation of simple technologies is of prime importance for sustainable agricultural growth. Educational policies should therefore be reoriented and learning institutions restructured so that researchers and extension workers can interact more effectively with farming households. Only through a realistic combination of traditional practices and new technologies can one hope to identify what is immediately practicable and what has yet to be done. Furthermore, such interaction can ensure that research will produce technologies with a "human face", technologies which will enhance self-identity and dignity. This approach can also trim or eliminate unnecessary programs of training and education, thus avoiding needless repetition, economic waste, and, most of all, the frustration of human abilities and creativity. Finally, it should be noted that, although education is essential, illiteracy is not a major impediment to learning techniques. Traditional farmers are capable managers who frequently need only understand ideas and concepts and not detailed prescriptions for what they should do.

The solution to recurrent problems in Africa is not vertically specialized agricultural education, although it is also necessary, but more extensive education in simple technologies. Schools should teach what touches farmers immediately and directly. Extension services should be reinforced in this sense. Even the more efficient use of energy can and must be taught at an early age. With this in mind, the mass media, and particularly television, must be used in innovative ways to instill such education. Lunch programs, even at the earliest levels of schooling, should be potentiated as an incentive to acquire a broad agricultural education.

Since women constitute the majority of the population involved in agricultural activities of developing African countries, their education in farming and processing techniques, both traditional and new, requires special attention. Their rights, interest in farming and in its associated professions, and their particular technological needs and income should be part of agricultural education.

A new model of agricultural education will instill a sense of social responsibility in those who acquire scientific expertise outside their countries or regions. Developing countries cannot afford the cultural, social and economic loss of their scientists and research experts to developed countries. Thus, agricultural education, understood as formation in values and not simply as the acquisition of highly technological information, should overcome the negative practices of the past. The creation of institutional infrastructures — for example, regional and transnational research centers — would offset some this brain drain. A special effort must be made to neutralize the negative effects that the international debt might have on educational programs. Cultural, social and economic incentives must be such as to foster human capital development at the local level.

Missionaries are very capable in building and conducting educational, medical, agricultural and cultural facilities in developing countries. Not all, however, are versed even in simple agricultural practices and techniques. Since they exercise in many areas of developing countries a socially significant influence, their professional formation should include basic agricultural principles, practices and techniques, all of which they should communicate to the populations in which they work in total respect for local needs and values.

Finally, a new model of agricultural education will be based on a fully humanistic worldview and on right answers to right questions. Only then can one hope that tight methodologies will be developed and appropriately applied to increase agricultural productivity for quality of life.

5. *Ethics*

Innovation to increase agricultural productivity for quality of life must be compatible with human rights and with cultural values. Furthermore, since agricultural impact on the environment is to be evaluated within the interdependence of the biosphere, an interdipendence which is also an ethical issue in the light of limited resources and humankind's right to the environment, then innovation in agriculture is also an ethical and moral issue; it is not merely a question of economic, scientific, technological, or political expertise. The choices to be made at all levels must respect the principles of social justice and authentic human development.

The perception of economic inequalities on the part of persons and communities is not always erroneous. The international debt and the subsidization policies of major producers of agricultural commodities impede the equitable transfer of labor forces, the acquisition of development capital, and the just exchange of goods. In addition, since the consumption of energy and resources by populations in industrial countries immensely exceeds consumption in developing countries, access to energy and resources for needed agricultural development becomes even more inequitable. In such an economic system, cash crops become a well-night irresistible practice, but one which again impedes agricultural productivity for balanced nutritional values, security, self-reliance and quality of life.

Economic imbalances disturb integrated systems which seek to maintain equilibria between agroindustries and small, often family, farms. The high costs of research, development and marketing of biotechnologies lead to further pressures on accessibility to innovations. On the other hand, the environmental consequences of harmful technologies are often ignored.

Although women are numerically the major human resource in agricultural activities in African countries, their personal and property rights are frequently disregarded.

Finally, prices of agricultural commodities seldom reflect the input expended in producing them. In some countries, such as Brazil, the urban population has increased in the last forty years from 30% to 70%. Unfortunately the cost of labor in the agricultural sector has not kept pace with the cost of labor in urban centers. Equity between rural and urban labor prices can help not only to stop environmentally damaging migration to urban centers but also to improve the quality of life.

6. *Recommendations*

This Study Week has examined the interrelations between quality of life, agriculture and agroforestry, that is, the manner in which these activities must use land resources and various plants and animals to guarantee to every human being the goods necessary for an acceptable quality of life, a goal that science can and must make every effort to realize. In view of this, and at the end of their work, the participants in the Study Week have formulated the following recommendations:

1. To be globally relevant, every action plan should blend universal and unique features. While universal features arise from basic human rights and moral obligations, unique features are needed to satisfy specific cultural, ecological, scientific, technological, economic and political conditions prevailing in given countries and regions. To achieve a harmonious interdependence of these features, all efforts should be made to integrate in an appropriate manner traditional and modern technologies. Full use must therefore be made of advanced sciences and technologies, such as genetics, microbiology, biotechnology, plant, animal and soil sciences, computer science, remote sensing, system analysis, and so on.

2. It is urgent to give priority to the acquisition of a clear understanding of integrated environmental protection systems, which combine forestry, agriculture and animal husbandry, in order to optimize land use in tropical environments as well as in temperate zones. Such multicrop systems with diversified outputs, such as food, fiber and energy production, are important for humankind's quality of life. Efforts must therefore be made to introduce new elements into the organization and direction of educational programs concerning these combined systems.

3. All discriminatory legal and socioeconomic constraints on women should be eliminated. Since women are primary agricultural operators in Africa and in many other developing regions of the globe, those constraints which hamper their activities in this sector should be eliminated as soon as possible. Education, political decision processes, marketing and trade facilities should be made accessible to them.

4. Modern biotechnology will contribute to the development of plants and animals which are more resistant to diseases and insects and to climatic and soil constraints. These developments will increase yields and the quality of foodstuffs, and improve processing values. A greater commitment and coordination on the part of governments and international organizations is therefore necessary in order to support effective and constant scientific research in this sector.

5. Educational structures for the potentiation of agricultural productivity must guarantee not only the flow of information and the development of technologies but also foster cooperation between research institutions (e.g., cooperation between research centers sponsored by universities and industries). It is important that local human resources be developed through exchange programs for students, professors and research fellows. Regional and international networks must be set up to implement such programs and to facilitate the exchange of highly qualified experts and students.

6. Ethical choices must be made at all levels. It is important that especially the foreign debt and the subsidization policies of major producers of agricultural commodities be reexamined in conformity to the principles of social justice and of authentic human development.

7. Global trends toward uniform cultural practices and, consequently, toward monocultures are destructive of agricultural diversity and of rural values. Local, national and regional agricultural practices and traditions must therefore be respected even when new systems are introduced.

8. Prices of agricultural commodities seldom reflect the input of human creativity, effort and energy. To stem or even reverse disorderly urbanization especially in developing countries, the price of labor in rural communities must be made as commensurate as possible with the price of labor in urban centers, and the social and cultural levels of rural communities must be improved.

9. Efforts to bring about agrarian reform have often failed to

produce social equity. Although such reform is not a universal panacea, in some cases unused lands possessed by affluent individuals or conglomerates could be made available to small farmers, if necessary even through foreign aid.

10. The right of farmers to establish cooperatives has not always been guaranteed in many countries and regions, thus impeding agricultural diversification and increased productivity. Such associations should be encouraged as a means to an ecologically sound introduction of new technologies and management of lands, as well as to a more efficient system of distribution and marketing of agricultural commodities.

11. Economic factors influence the acquisition of new varieties and the introduction of new technologies. Wherever necessary, foreign aid should be made available to increase agricultural productivity through these means.