Proceedings of

Fertilizer Efficiency Research and Technology Transfer Workshop for Africa South of the Sahara

Douala, Cameroon
January 21-25, 1985

Organized by

International Fertilizer Development Center
Muscle Shoals, Alabama 35662
U.S.A.

Cosponsored by

Institute of Agronomic Research
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Republic of Cameroon

Preface

As with all the continents of the planet earth, Africa's agricultural production systems are a complex mixture of increasing sophistication and retrogradation.

What makes Africa different from the other continents is that overall it has a static or declining level of total agricultural production; this, combined with a rapid population growth has created increasingly serious economic and social problems for many of the national governments of the continent.

Agricultural production is essentially based on the exploitation of soil moisture and fertility by farmers whose management skills and resources affect the level of productivity.

For Africa south of the Sahara rainfed agriculture is the major source of food crops. However, although rainfall is erratic and droughts—or at least periods of moisture stress during crop growth—are common, low soil fertility is a major modifiable factor limiting crop yields.

Historically, this fact was recognized by farmers and overcome by the use of lengthy fallow periods and, to a more localized degree, by the use of crop residues and animal manures. With these systems, a stable but low level of crop production could be maintained without recourse to fertilizer.

Unfortunately, stable traditional systems are based on subsistence farming and low population densities. Ultimately, increases in crop production on low-fertility soils must be based on the judicious use of fertilizers. Effective organic matter recycling and the use of legumes can reduce the need for fertilizers but cannot replace them entirely. Over large areas, inputs of fertilizer phosphorus, sulfur, potassium, calcium, and magnesium will be essential for increasingly productive systems, and nitrogenous fertilizers, irrespective of the developments in legume production, will be the key to high yields of improved cereal varieties.

The central theme of this workshop was the efficient use of fertilizers; however, workshop sessions also focused on the necessity and difficulty of combining fertilizer use with sound soil and water conservation practices and with organic matter recycling and the use, where possible, of legume crops and animal manures.

Given that fertilizer is needed and will be needed in increasing quantities in Africa, the main thrust of the workshop was to highlight the need for cost-effective use of fertilizers, in other words, the improvement of the agronomic and economic benefits to be derived from fertilizer use.

The papers presented, therefore, covered what in fact is a complete marketing approach to the use of fertilizers—the identification of the need for and the provision and use of fertilizers in the most cost-effective manner.

This customer-oriented approach to fertilizer use was at the core of many lively discussions, and both the research- and extension-oriented participants greatly benefitted because the complexities of developing a sound national fertilizer sector with the efficient use of fertilizers as a key objective were fully discussed and appreciated.

Evaluation of the workshop showed that participants considered its technical aspects an unqualified success.

Dennis H. Parish
Director, Outreach Division
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September 16, 1985

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The Development and Mechanics of the FERATT Workshop

Workshop Development

Over the past several years, IFDC has been heavily involved in research, technical assistance, and training programs covering a wide range of fertilizer-related subject areas and target audiences in developing countries. Evaluation of these activities showed clearly that directors of agricultural research and extension could benefit from a workshop type program whose objectives would be to review the state of the art of soil fertility management and particularly of the role of the improved efficiency of fertilizer use in relation to increased food production.

IFDC was encouraged in this belief by the National Research Council publication, Chemistry and World Food Supplies: Research Priorities for Development (1983) whose working group report on "Soil Fertility and Plant Nutrition" stated:

> This working group has recommended a research framework for consideration by AID and the donor agencies and has identified five priority areas needing research. In order of importance, they are:
> --Improving fertilizer use efficiency;
> --Restoring degraded lands;
> --Minimizing environmental stress;
> --Alleviating soil physical constraints to plant nutrition;
> --Improving soil productivity using microorganisms.

The Green Revolution of Asia was based on those areas having ample sunshine, controlled water, and adequate fertilizer supplies, combined with high-yield potential cereal varieties.

For Africa, breakthroughs in crop production have already occurred with selected crops and areas, but the impact of modern technology on the small food-producing farms of Africa is marginal or nil over much of the continent.

The workshop as conceived was felt to be of particular relevance to the Africa situation where areas of low soil fertility, low fertilizer use, or low food crop production are currently receiving major international interest.

The controversy continues as to whether Africa's agricultural strategy should be food crop or export crop oriented, but the outcome will have no effect on the major thesis of the workshop, which is that the efficient use of increasing quantities of fertilizers is a sine qua non of short-term African agricultural development.

A major problem facing IFDC in running any type of program is the inability of most developing country governments to allocate scarce foreign exchange to support national level participation.

IFDC was fortunate therefore in being able to obtain the agreement of the International Fund for Agricultural Development (IFAD) to utilize IFAD funds allocated to IFDC as partial support of a FERATT Workshop in Africa.

IFDC therefore developed a workshop program specifically for sub-Saharan Africa entitled Fertilizer Efficiency Research and Technology Transfer (FERATT), with the following goal, objectives, and rationale.

Goal

To develop and strengthen research and extension capability to achieve more effective programs in fertilizer efficiency research and subsequent technology transfer.

Objectives

1. To review the state of the art in soil fertility management and the respective roles of organic matter, biological nitrogen fixation, and fertilizers in African food production.
2. To formulate action guidelines for initiating or strengthening existing research and extension programs aimed at identifying and transferring more efficient fertilizers and fertilization practices.

Rationale

1. The projected nutritional requirements of the sub-Saharan African population cannot be effectively met by national food production programs with the present generally low fertility of the soil resource base. An increase in the soil fertility levels of the major food production areas is therefore needed.
2. Improved soil fertility must be achieved in a manner that is cost effective and acceptable to farmers. Achievement of this objective will require:
    a. A political and social commitment to support increased national food production.

   b. The development and transfer to farmers of fertilizer use technology relevant to the farmer's site and situation, i.e., to the farmer's market and socioeconomic situation, to his cropping and farming system, and to the plant nutrients his soil must receive for optimal crop production.

3. Soil fertility can be improved by three farm-level actions:
   a. Efficient nutrient recycling.
   b. Increased use of biological nitrogen fixation (BNF).
   c. Efficient use of fertilizers.

There are constraints to the use of each of these actions and each action in itself is only a partial solution. Therefore, an integrated plant nutrient supply system combining all three actions is needed.

4. For the development and transfer of relevant fertilizer use technology, effective national soil fertility and fertilizer use action programs are needed. Implementation of such action programs requires a balanced mix of research, extension, marketing, policy, and other activities to ensure that both short- and long-term soil fertility problems are addressed.
5. Agricultural research and extension directors can play a key role in establishing effective soil fertility and fertilizer use action programs.

The program, details of which are given in Appendix III, was designed to stress both the limitations and the benefits of fertilizer use in sub-Saharan Africa. The agronomic, the socioeconomic, and the political aspects of fertilizer sector development were fully discussed.

The Workshop was aimed at senior-level personnel from both anglophone and francophone sub-Saharan Africa with an equal mix of research and extension interest. Details of the participants given in Appendix IV show that this was in fact achieved.

An international resource faculty with wide experience in sub-Saharan Africa and knowledge of the problems of fertilizer sector development were invited to give keynote addresses, and selected country papers describing research and extension activities were also presented. The keynote and country papers represent a valuable resource base.

Issue Identification and Development of Policy Options

In order for fertilizers to play a sound and significant role in increasing agricultural production, policy, research, and extension related issues need to be identified and suitable corrective actions taken.

The mechanics used for facilitating identification of major issues and the development of possible policy options for their solutions were as follows:

1. The documents listed in Appendix V were used as resource documents.
2. Question-and-answer sessions followed the session presentations.
3. Session reviews were made by each of the session chairmen.
4. Expert panels reviewed each subject matter area and question-and-answer sessions followed.
5. Small group discussions--The results of these small group discussions were synthesized by experienced international specialists. These group discussions were initially based on four distinct subgroups, namely, research-oriented anglophone and francophone, and extension-oriented anglophone and francophone, respectively. This approach means that the first two series of group discussions were essentially peer unilingual groups with common career development interests. The third session, while still unilingual, now brought together the research and extension interests of the workshop participants. The plenary session gave the opportunity for full workshop discussion of the highlights of the group findings.

The whole workshop program paid particular attention to the following linked issues:

1. Improving fertilizer efficiency research.
2. Improving fertilizer technology transfer.
3. Integrating fertilizer research and technology transfer.

Issues adversely affecting progress were identified and policy options to improve the situation were developed. The workshop findings represent the melding of the views of highly experienced individuals of very widely different backgrounds. Their value lies in their highlighting a range of major issues where policy, financial, and technical actions are needed if national talent is to be harnessed in such a way that the maximum beneficial impact of fertilizer use by the farmer can be achieved.

DISCOURS DU MINISTRE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA RECHERCHE SCIENTIFIQUE A L'OUVERTURE DU SEMINAIRE SUR "LA RECHERCHE SUR L'EFFICACITE DES ENGRAIS ET LE TRANSFERT DE LEUR TECHNOLOGIE EN AFRIQUE"

Douala, le 21 Janvier 1985

Monsieur le Gouverneur de la Province du Littoral,
Monsieur le Délégué du Gouvernement auprès de la Commune Urbaine de Douala,
Monsieur le Représentant du Centre International pour le Développement des Engrais,
Mesdames et Messieurs les Séminaristes,
Honorables Invités,
Mesdames, Messieurs.

Il m'est particulièrement agréable de présider ce matin la cérémonie d'ouverture du séminaire sur "la Recherche sur l'Efficacité des Engrais et le Transfert de leur Technologie en Afrique", organisé par le Centre International pour la Développement des Engrais.

Je voudrais tout d'abord, adresser mes sincères remerciements à toutes les personnalités qui ont bien voulu, malgré leurs multiples occupations, rehausser de leur présence cette cérémonie; leur présence ici témoigne, s'il en était besoin, de l'importance qu'elles accordent au développement de l'agriculture de nos Etats et partant, à tout effort tendant à en accroître la productivité.

Je voudrais également adresser mes plus vives félicitations aux organisateurs pour l'honneur fait au Cameroun en le choisissant pour abriter le présent séminaire. Il m'est agréable de voir dans ce choix, la marque de confiance et les bonnes dispositions du Centre International pour le Développement des Engrais (IFDC) à l'égard de notre pays.

Excellences,
Mesdames et Messieurs.

C'est avec un réel plaisir que je salue la présence à cette cérémonie des représentants de la FAO, de la Banque Mondiale, de l'ICRISAT, de l'ITTA à qui je souhaite au nom du Gouvernement, et en mon nom personnel une chaleureuse bienvenue au Cameroun et un agréable séjour dans notre capitale économique.

Permettez-moi aussi de saluer la présence à ce séminaire d'éminents spécialistes et chercheurs venus de différents pays d'Afrique apporter leur précieuse expérience à la réussite de cette rencontre.

La haute qualité des séminaristes témoigne de la volonté des organisateurs de tout mettre en oeuvre pour permettre l'examen approfondi d'un thème qui faut-il le rappeler, constitue l'un des facteurs essentiels de l'augmentation de la productivité de l'agriculture.

Mesdames, Messieurs.

L'occasion me semble bonne à ce niveau de dire quelques mots sur l'importance des objectifs poursuivis par votre séminaire, il vise en effet à:

-faire le point des connaissances sur la gestion de la fertilité des sols, et les rôles respectifs de la matière organique, de la fixation biologique de l'azote, et des engrais dans la production alimentaire en Afrique;

-formuler les directives précises pour l'initiation et le renforcement des programmes de recherche et de vulgarisation destinés à identifier et recommander aux paysans les engrais plus adaptés et les techniques de fertilisation plus efficaces.

Il me plait de noter que ces objectifs vont dans le sens des orientations générales de notre politique agricole, à savoir:

-améliorer le rendement de la production agricole,

-assurer l'autosuffisance alimentaire du pays,

-élever le niveau de vie des populations.

En ouvrant le 5e Comité agro-pastoral de Bamenda le 13 décembre dernier, le Chef de l'Etat, S.E. Paul BIYA rappelait à propos de l'agriculture et de l'élevage, je cite: "Le rôle normal de ces deux secteurs est d'assurer l'autosuffisance alimentaire à tous les Camerounais, mais ils représentent la source la plus sûre de devises nécessaires à nos efforts de développement. C'est dire que tout en étant pourvoyeurs de nombreux emplois, l'agriculture et l'élevage sont aussi le pivot de nombreuses industries locales" fin de citation.

Pour atteindre cet objectif, le Gouvernement accorde la plus haute priorité à l'accroissement de la productivité de l'appareil de production agricole, et dans cette optique, les engrais sont appelés à jouer un rôle fondamental.

A cet égard, le Gouvernement mène plusieurs actions pour la promotion de l'utilisation des engrais, en particulier des subventions sont accordées à l'achat d'engrais pour différentes cultures. A cela s'ajoutent les aides à l'installation de jeunes agriculteurs, et qui comprennent les principaux intrants agricoles dont notamment les engrais.

Il me plait également de noter que cette politique suivie par le Cameroun a porté des fruits. Dans son discours au dernier Comité agro-pastoral de Bamenda, le Président Paul BIYA constate ce résultat en ces termes: "Alors que dans certaines parties du monde, il y a des gens qui connaissent de sérieux problèmes alimentaires et malgré les conditions climatiques défavorables qui prévalent parfois dans notre pays, nous pouvons affirmer qu'au Cameroun aujourd'hui tout le monde mange à sa faim".

Mesdames,
Messieurs les Séminaristes.

Nous nous devons de reconnaître que si dans de nombreux Etats Africains beaucoup a été fait en matière de développement agricole, de grands efforts restent cependant à fournir pour assurer l'autosuffisance alimentaire. En effet, un fait préoccupant demeure le déséquilibre qui existe en Afrique entre la demande de produits alimentaires qui croît plus vite et la production vivrière qui marque souvent le pas.

L'effort à fournir en matière de production vivrière est donc considérable. Il est cependant encourageant de noter que notre potentiel de production est loin d'être saturé, car il est techniquement possible de satisfaire la demande alimentaire en prenant des mesures énergiques et en dégageant des moyens appropriés.

Mesdames, Messieurs.

L'Agriculture africaine est malheureusement obligée de supporter des coûts parfois très élevés des produits de consommation intermédiaires, parmi lesquels je ne citerai à titre d'exemple que les engrais, les pesticides, les matériels agricoles, les carburants et les dépenses de transport.

En préconisant une intensification de la production agricole basée sur une forte utilisation d'intrants, peut-on raisonnablement ignorer le fait qu'en Afrique les agriculteurs éprouvent de grandes difficultés à s'approvisionner en raison de l'insuffisance des moyens de communication d'une part, et des prix des facteurs de production qui connaissent une ascension vertigineuse d'autre part?

La stratégie de recherche que vous serez amenés à proposer devrait donc tenir compte des conditions économiques de production, de manière à optimaliser l'utilisation de engrais et des techniques de fertilisation. A cet égard, vos réflexions devraient viser à dégager des solutions qui permettent aux producteurs d'améliorer la rémunération de leur travail. Car en tout état de cause, il faut faire l'argent avec l'agriculture et ne pas faire l'agriculture avec l'argent.

Mesdames, Messieurs.

Se pencher uniquement sur les problèmes de fertilisation ne suffit pas, car je ne vous apprends rien en disant que, la croissance de la production agricole est basée en réalité sur une diversification des thèmes de recherche. Ainsi, par exemple, la Révolution Verte lancée à la suite des travaux génétiques du Dr. Borlaug, à qui j'ai le plaisir de rendre hommage, fondée sur l'emploi des semences sélectionnées n'a pu donner ses pleins effets que là où ont été offertes les meilleures conditions de sol, d'irrigation, de fertilisation et de protection phytosanitaire.

Il est tout aussi fondamental de reconnaître que l'utilisation des facteurs modernes de production ci-dessus énumérés, suppose une prise de conscience de leur rôle et de leur importance par les producteurs eux-mêmes. Il s'agit donc d'un changement de mentalités de la part des agriculteurs car, ceux-ci doivent être convaincus que la terre représente un capital qui ne peut durablement fructifier que par une exploitation rationnelle.

Mesdames, Messieurs.

Dans la conjoncture mondiale et africaine d'aujourd'hui, votre séminaire revêt une importance particulière. Il se situe, en effet, dans une période caractérisée par la menace grandissante de la sécheresse et, face à ce spectre, il n'est pas inutile de rappeler que nos pays fondent de sérieux espoirs sur les résultats de travaux menés dans tous les domaines de la recherche agronomique.

Dans le cadre de la mission globale d'appui au développement assignée au Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, l'Institut de la Recherche Agronomique, qui est l'un de nos cinq Instituts de Recherche est investi d'une mission fondamentale, à savoir exécuter des recherches en vue:

-d'assurer l'autosuffisance aussi bien de nos cultures d'exportation que de nos cultures vivrières,

-d'augmenter la productivité aussi bien de nos cultures d'exportation que de nos cultures vivrières,

-d'améliorer les conditions de vie des populations,

-de favoriser la création d'emplois.

Mesdames, Messieurs.

La mission de la Recherche Agronomique Camerounaise étant ainsi sommairement rappelée, notre Gouvernement reste pleinement conscient de l'effort qu'il faudrait fournir pour renforcer la liaison entre la Recherche, la Vulgarisation et l'Enseignemet, en vue:

-d'accroître l'utilisation sur le terrain des résultats de la recherche,

-d'assurer une meilleure adéquation des opérations de recherche par rapport aux besoins,

-d'élaborer des programmes d'enseignement mieux adaptés aux réalités du terroir.

Il est évident qu'une étroite liaison Recherche-Enseignement-Vulgarisation, ne portera de fruits qu'avec une participation et une responsabilisation des paysans eux-mêmes. Ceux-ci étant, en dernière analyse, les principaux bénéficiaires des programmes d'enseignement et de recherche agricole, devraient jouer un rôle "moteur" dans la mise en oeuvre de la politique de développement rural.

Mesdames et Messieurs.

Le Renouveau National pour lequel le peuple camerounais a passé un contrat de solidarité et de confiance avec le Président Paul BIYA implique l'édification d'une Société Nouvelle faite d'hommes et de femmes libres prenant de plus en plus en mains la responsabilité de leur devenir. Il s'agit là de l'un des défis essentiels qui interpellent tout peuple majeur.

Messieurs les Séminaristes.

La complexité, la diversité et l'interaction des problèmes de fertilisation des sols, requièrent une approche globale dans la recherche des solutions les plus appropriées.

Les problèmes que pose le développement agricole en général et ceux de l'utilisation des engrais en particulier se situent dans le cadre d'une problématique mondiale. Leur solution requiert nécessairement une solidarité internationale.

L'organisation de ce séminaire par le Centre International pour le Développement des Engrais est déjà une éloquente manifestation de cette solidarité. Je reste pour ma part, convaincu que par la profondeur de vos discussions, vous aboutirez, au terme de vos travaux, à des recommendations pertinentes et réalistes, lesquelles constitueront pour nos Etats une source d'inspiration pour leurs programmes d'action futurs.

C'est donc plein d'optimisme et en toute confiance que je déclare ouvert le séminaire sur la recherche sur l'efficacité des engrais et le transfert de leur technologie en Afrique.

Vive la Coopération Internationale!

I am also pleased to point out that these policies followed by the Government of Cameroon have had good results. Let me quote once more from our President, His Excellency Paul Biya: "Whilst in certain parts of the world there are people who have serious food problems, we, in spite of the occasional periods of adverse climate in Cameroon, can say today that everybody is adequately fed."

Ladies, Gentlemen, Seminarists,

We have to admit that although a lot has been done by the African countries as far as farming is concerned, great efforts are still necessary in order to ensure nutritional self-sufficiency. Indeed, a worrisome fact remains in that there is an increasing disequilibrium between the ever-growing demand for food and an often static food production sector.

The effort needed to increase food crop production is considerable. Nevertheless, it is encouraging to know that our production potential is far from being achieved. It is still possible to meet our food requirements through the energetic use of known technologies.

Ladies and Gentlemen,

Unfortunately, African agriculture sometimes has to pay very high prices for such essential products as fertilizers, pesticides, farm equipment, and transport.

In specifying the intensification of agricultural production based on the use of purchase inputs, it is difficult not to ignore the fact that in Africa farmers have serious problems in obtaining timely and adequate input supplies because of poor communications. Further, the constantly rising price of imports is a major constraint to their use.

The research strategies that you will propose will have to take into account the economics of production conditions and the need to optimize the use of fertilizer with correct fertilization practices. Any solution must enable the producers to increasingly profit from their labors. We must make money from farming and not use money to create inefficient farming.

Ladies and Gentlemen,

Attention to the problem of fertilizing the soil is not enough since, as is commonly known, increased agricultural production is based on diverse agricultural research. The Green Revolution that followed Dr. Borlaug's genetic research has only given full results where selected seeds, the best soil conditions, irrigation, fertilizer, and phytosanitary protection are used. I take personal pleasure in saluting Dr. Borlaug for his outstanding work.

The introduction of modern crop production packages requires that farmers understand the components of these packages and how to use them to achieve maximum yields.

The farmer must change his approach to farming and realize that his soil represents a source of capital that must be carefully managed if yields are to be maintained over long periods.

Ladies and Gentlemen,

In the situation in which the world and Africa find themselves today, your workshop is particularly important. It takes place in a period which is characterized by the growing menace of drought. Faced with this threat it is important to recall the great expectations which our countries have of results from all areas of agricultural research.

The fundamental mission of the Ministry of Higher Education and Scientific Research and the Agronomic Research Institute (IER), which is one of five of our research institutes, is to carry out research with the objectives of:

1. Ensuring food self-sufficiency.
2. Increasing yields of both food and export crops.
3. Improving the standard of living of the population.
4. Creating opportunities for employment.

Ladies and Gentlemen,

Such briefly is the mission of the IRA. Our Government is fully conscious of the efforts that will be needed to strengthen the liaison between research, teaching, and extension in order to:

1. Apply the results of research in the field.
2. Ensure that research activities are related to our needs.
3. Develop teaching programs better adapted to the realities of the regions of our country.

It is evident that close liaison between research-teaching-extension will need the support and participation of the peasants themselves. After all they are in the end the beneficiaries of agricultural research and teaching, and they must therefore act as the "motor" of rural development.

Ladies and Gentlemen,

National renewal, binding in confidence the people of Cameroon and President Paul Biya, implies the building of a New Society by free men and women taking more and more into their own hands the responsibility of their future. This is one of the major challenges that all nations must face.

Gentlemen and Workshop Participants,

The complexity, diversity, and the interaction of problems relating to the fertilization of soils are such that a global approach is needed to find the most appropriate solutions.

The problems posed by agricultural development in general and of the use of fertilizers in particular are world problems. Their solution needs international solidarity.

The organization of the workshop by IFDC is a clear manifestation of this solidarity. For my part, I remain convinced that by the depth of your discussions you will develop pertinent and realistic recommendations that will be a source of inspiration for our countries in their future action programs.

It is therefore with optimism and confidence that I declare open the workshop on Fertilizer Efficiency Research and Technology Transfer in Africa.

Long live international cooperation!

Keynote Papers

THE LIMITED RESOURCE FARMER AND AFRICA'S FOOD PRODUCTION CRISIS[1]

D. W. Norman

Introduction

Africa is a continent of harsh contrasts. Great diversity exists not only among its people but also in its climate and soils. Neither the climate nor the soils are particularly favorable to agriculture. Climatically, over half of tropical Africa has too little rainfall, whereas at the other extreme, some areas are dense rain forests. Apart from a few regions, soils are of poor quality, and those in much of Africa rate among the world's poorest.

Coupled with this is a population growing at an annual rate of 2.7%, which in mid-1982 had reached 498.0 million or 10.9% of the total world's population (Lewis and Kallab, 1983). Although, as recently as 1980, more than 69% of Africa's labor force was employed in agriculture, food production per capita decreased by 1.2%/year between 1970 and 1980 (Lewis and Kallab, 1983). This has resulted in a decreasing degree of food self-sufficiency (World Bank, 1981). As a result, during the same 1970-80 period food imports per capita increased at a rate of 6.5%/year and by 1980 accounted for 18.7% of the total value of imports. This is a level about twice as high as that in Asia and Latin America, where during the 1970-80 period food imports as a share of total imports in fact decreased (Lewis and Kallab, 1983).

The decline in the food self-sufficiency index (World Bank, 1981) has a high price both in human and economic terms. From a human viewpoint the price is inadequate nutrition with per capita caloric intake falling below minimum nutritional standards in most sub-Saharan countries. This has been exacerbated because of the current drought prevailing in more than 30 African

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[1] The author is grateful for the constructive comments of Dr. A. Biere on an earlier draft of this paper, although the current edition does not always reflect his views.

countries. Economically the cost is high since inadequate domestic food production is increasing the demand for food imports at a time when grain prices are rising and many African governments face acute balance of payments and foreign exchange problems. Thus, the only short-term solution for many countries is to become more dependent on food aid from the high-income countries.

A few years ago a study by the U.S. Department of Agriculture and the U.S. Agency for International Development (1980) showed the implications of this trend. Estimates given in the study indicate that by 1990 in sub-Saharan Africa there would be an import gap of 11.5 million tons (cereal equivalent) if 1975 real per capita incomes and producer price patterns continued to prevail. Bringing diets up to minimum caloric consumption levels of about 2,300 calories per person per day would require about 12.4 million tons annually. If real per capita incomes increased, then the import gap would be larger. Unfortunately, however, real per capita incomes decreased between 1975 and 1979. Thus, continuation of 1979 income and price patterns would reduce the import gap but increase the unmet food needs. Because of considerable regional disparities, results from the study indicate that unmet food needs are likely to be most severe in the Sahel, central Africa, and east Africa.

Therefore, it appears that if growth in food production continues to follow historical patterns, there will continue to be large increases in the paying demand for imports by 1990 but very little reduction in the quantity required to satisfy unmet food needs.

It is obvious, therefore, that Africa is a continent in the grip of an agricultural crisis. For the period 1969-71 to 1977-79 only 7 of 39 countries had an annual positive growth rate in agricultural production per capita, and only 10 of the 39 countries achieved such a performance with reference to food production (World Bank, 1981). Not surprisingly, as a result of the poor performance of the agricultural sector, there has been in recent years a high rate of rural-to-urban migration with an annual growth rate in population as high as 5.9% for sub-Saharan Africa in the 1970s (World Bank, 1981).

After briefly examining why food production has failed to keep pace with demand in Africa, we can assert that an important potential contributor to solving this problem is the limited resource farmer. This leads to a brief discussion of the milieu in which farmers operate as a prelude to an examination of how to design and test relevant improved technologies and policies that will enable them to attain their full potential. It should be noted that a bias exists in the paper toward examples from the semiarid areas of Africa, where the author has had the most experience. However, there are no doubt comparable examples from wetter areas that support the general theme of this paper.

Factors Contributing to Shortfalls in Food Production

In recent years many factors have contributed to the poor performance of agriculture in Africa, particularly with respect to food production. No attempt is made here to examine these in detail, but three that have some bearing on the topic of this paper are as follows.

Traditional Agriculture and Changing Factor Ratios

The potential productivity of much of the land in Africa--given the present state of knowledge--is limited. Traditionally African farming systems were well adapted to the low population densities that used to prevail. Such systems as shifting cultivation and its variant, ring cultivation (Marchal, 1977), were rational responses to maximizing the productivity of limited labor in relation to perceived unlimited amounts of land. Self-sufficiency characterized two vital aspects of such traditional farming systems: first, providing for family needs and second, perpetuation of the farming system year after year without depending on commercial inputs of any kind. Certain changes, however, have upset the traditional symbiotic relationships between the farmer and the natural environment. The farmers are living in a dynamic environment that is changing over time ("vertical" dimension). What they are today is partly a product of what has happened in the past ("historical" subdimension), and what they or their descendents will be in the future ("prospective" subdimension) is partly a function of what happens now. However, a farmer's decisions today are partly a function of his dependency on and relationships to the world around him, i.e., the community he lives in, linkages with the world outside the village, etc. (the "horizontal" dimension). Rapidly increasing populations have placed progressively greater pressure on farming systems traditionally designed for abundant land. The problem has been that extensive indigenous farming systems have, in general, not been able to change rapidly enough to intensive farming systems, where ultimately maximizing the return per unit area (e.g., net return per hectare) becomes more important than maximizing the return per unit labor (e.g., net return per hour of labor put in at the labor bottleneck period). Difficulties arise with a reduction of fallow time as land fertility regeneration is also reduced. This worsening fertility situation could be improved by the use of increasing amounts of manure; unfortunately, supplies of manure are limited (Norman, Newman, Ouedraogo, 1981). It would appear that over the last 20 years yields per hectare of major food crops have not been increasing as rapidly in sub-Saharan Africa as in other parts of the world (World Bank, 1981). Yields of such crops under such circumstances are only likely to increase with increased participation in the marketplace for purchasing such inputs as improved seed and inorganic fertilizer--something that, as discussed next, has not always been actively encouraged for food crops.

Distorted Policies and Support Systems

Colonial powers were largely responsible for initiating strategies that emphasized the production of export cash crops, usually at the expense of food crop production. During colonial days production of export cash crops such as coffee, rubber, groundnuts, and cotton was stimulated through the construction of railways and roads (Lele, 1975). Farming families responded by devoting surplus land and labor to producing these crops with the help of traditional or indigenous technologies.[2] However, in many areas rising population densities eventually placed a limit on this strategy. Consequently, research institutions throughout Africa concentrated on developing land-intensive improved technologies for export cash crops. Thus, the trend was started, which in some countries continues until today, in which improved technologies and support systems (e.g., input distribution systems, extension and institutional credit services, and product marketing programs) favored export cash crops at the expense of domestic food crop production.

Several factors have perpetuated this trend. For example, post-independent needs for foreign exchange encourage continuation of export cash crop production. In fact, as late as 1976-78 almost 40% of the total value of exports

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[2] Some people have questioned that there was always surplus labor. Rather labor was sometimes reallocated from food crops to export cash crops to provide cash to pay taxes (Kafando, 1972).

from sub-Saharan Africa was contributed by agriculture (World Bank, 1981).[3] Another reason, as is indicated by several World Bank studies on west African countries, is that export cash crops appear to be more efficient in converting domestic resources into foreign exchange than food crops such as millet, sorghum, rice, and maize are in saving foreign exchange (World Bank, 1981). This implies that it could be rational for countries to export cash crops and use the foreign exchange to import food crops. However, the comparative advantage that many countries appear to possess in producing export cash crops has probably been artificially induced. For example, the bad competitive position of food crops is due in part to a lack of relevant improved technology and support systems. Attention to readjusting the balance between export cash crops and food crops is overdue especially in an era when global food shortages are likely to increase.

Lack of Relevant Agricultural Research

There appears to have been a definite evolution in the approach to agricultural research in Africa (Norman, Simmons, and Hays, 1982). Very simplistically, it can be divided into four stages.

1. In the first stage, as indicated above, agricultural research was largely restricted to boosting the output of export cash crops. Colonial governments made sure that research contributions were used by producers; however, although some producers did profit, benefits to producers were not of central concern.
2. In the second stage the idea of selectively transferring technology to developing countries from developed countries supplanted the earlier approach, but the new approach was predicated on the notion that someone knew what was best for agriculture in a developing country. That resulted in attempts to import technology wholesale--sometimes with success but often with disastrous results. Where the wholesale transfer worked, dual agricultural economies often evolved. For example, in the case of Zambia, the economy that was frequently nurtured and protected became the modern sector of agricultural production; the other remained primitive and traditional.

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[3] This excludes petroleum exports from Nigeria.

3. Then a third concept of developing agricultural technology within the low-income countries evolved. The unsuitability of directly transferred technology contributed to the shift. The idea was that by using as building blocks the elements that made technological change successful in high-income countries researchers could develop unique and locally relevant technologies with a high degree of potential success.
4. In the fourth stage those three essentially "top-down" approaches have been largely supplanted but not entirely replaced by a grass-roots or "bottom-up" strategy. It is this latest stage of evolution that provides the foundation for the farming systems approach to research (FSAR) discussed later in the paper.[4]

Among reasons for the changed thinking, perhaps the most fundamental was the repeated failure of other approaches to improve the livelihoods of dispersed rural populations and also meet the needs of the urban sector. Policies and technologies incompatible with the agroecological, sociopolitical, and economic environments were advocated (Hardin, 1977). As a result, adoption rates were low except where compulsory measures were taken or where extraordinary input subsidies were extended, and the results expected did not materialize. The reason is that where the well-being of rural populations was improved neither the size nor the distribution of benefits matched expectations.[5]

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[4] It could be argued that FSAR has not replaced the "top-down" researcher-oriented approach but rather has involved expanding the traditional approach. The expansion fundamentally involves asking the researcher to expand his knowledge base and getting him to use nonexperimental as well as experimental methods of investigation. Research is a creative process involving both the conscious and subconscious mind. The subconscious is important in the creative component of technology development. Science as known today is largely a product of temperate zone cultures and has had a close comfortable symbiotic relationship with those cultures. Because of this symbiotic relationship the subconsious element is largely a function of temperate zone cultures which may be irrelevant in working in other cultures and societies. Therefore, FSAR has made it possible to fill the gap that existed when taking science and technology to other cultures and societies; this implies that FSAR is an extension of current "top-down" methods rather than being a "bottom-up" method _per se_ (Biere, personal communication).

[5] The Green Revolution that has had such an impact in Asia is a good example of this. Although the sucess in terms of production should not be ignored, distributional problems engendered by such technology in South Asia, for example, have been widely portrayed as having led to worsening many farmers' positions vis-a-vis other farmers' achievements (Saint and Coward, 1977).

It is increasingly being appreciated that this checkered pattern of success will not be altered until the linkages among the various participants in the research process (sponsoring government or agency, research institution, extension service, and farmers) are strengthened and mutual accountability is increased. The first three largely "top-down" approaches, characterized by relatively tenuous linkages among participants, have functioned poorly. The FSAR has a "bottom-up" orientation and, conceptually at least, helps to ensure two-way linkages between the farmers and other participants in the research process. This approach to research in low-income countries is largely a product of the late 1970s and is analogous to techniques used by commercial firms to measure their success in sales. They first try to determine what the customers want and then formulate a product to fulfill the want (demand). Although tailoring improved technologies to potential farmer customers and ultimately achieving greater production are clearly the objectives of the "bottom-up" research strategies, there has been increasing recognition that the farmers have something of value to contribute to the development of technologies as well. The realization that listening to farmers and observing what they can do can help to improve the potential for increased efficiency in the allocation of research resources emphasizes the need for two-way communication between the researchers as well as extension workers and the farmers.

Solution to the Food Production Problem--
The Small or Limited Resource Farmer

The change in the approach to agricultural research has paralleled and perhaps been stimulated by changes in attitudes and perceptions about the role of the limited resource farmers and whether and how they should be helped. Political realities, in terms of ensuring some degree of food security in an increasingly uncertain world, are forcing many governments to refocus attention on developing agriculture. Another compelling argument justifying development of agriculture is its significance as an employer of people. One of the most important problems in most African countries, and potentially one of the most socially disruptive, is the issue of finding employment for rapidly growing populations. It is difficult to be optimistic about the ability of nonagricultural sectors to absorb all increases in the labor force.[6] The nonagricultural employment would have to increase 8.7%/year for sub-Saharan Africa as a whole--an impossible objective. Although countries in Africa should obviously continue encouraging generation of employment in nonagricultural sectors, realities appear to dictate, in the short and medium term at least, that larger numbers of people--not smaller--will be dependent on agriculture as a means of livelihood. Combining the reality of large numbers of people having to derive their living from agriculture with the food production problem, the issue becomes not only one of food production but also one of who produces--since those who do not produce are generally those who cannot consume. Large-scale schemes in Africa generally have had a poor history (Norman, 1981) and, in addition, raise the possibility of substituting capital for labor. Therefore, in general, the most realistic strategy has become one of helping the mass of small or limited resource farmers to improve their productivity. Is such faith misplaced? Will limited resource farmers respond? Many people today would answer with an unequivocal yes. There is certainly plenty of evidence becoming available to support such an assertion. However, as implied earlier, certain conditions have to be fulfilled. Technologies, in order to be improved and relevant as far as the farmer is concerned, have to be compatible with the farmer's resources (natural and human), the support systems he is exposed to, and the priorities or goals that he has adopted.

Understanding the Limited Resource Farmer

As the concluding sentence of the last section implied, it is essential that the design and dissemination of relevant improved technologies must be built on an understanding of the farmer's situation. Surprisingly perhaps--although anthropologists have been telling us this for years--this can be an extremely complex task. Indeed unraveling this has been the subject of many farm-level studies over the last 20-30 years.

At the risk of oversimplification, a useful starting point for obtaining an understanding of the limited resource farmer's milieu, is that

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6. This assumes for Africa as a whole that the population growth rate is 2.7%/year and the proportion of the labor force in agriculture is 0.31 (Lewis and Kallab, 1983).

of looking at some of the determinants of a farming system (Figure 1). The operator of the farming system is the farmer--or, more correctly in the African context, the farming family--since to farmers the means of livelihood and the economic, social, and cultural welfare of their households are intimately linked and cannot be separated.

In achieving a specific farming system, the members of the farming household allocate certain quantities and qualities of basic types of inputs (land, labor, capital, and management) to three processes (crops, livestock, and off-farm enterprises) in a manner which, given their knowledge, will maximize their goals. Some of the underlying determinants in the farming system, however, are outside the control of the individual farming family.

Simplistically, the "total" environment in which farming households operate can be analytically divided into two parts: the technical (natural) element and the human element. The technical element determines the types and physical potential of the livestock and crop enterprises and therefore forms the necessary conditions for what the farming system can be. Constituents of the technical element include physical and biological factors, often modified to some extent by man as a result of technological developments--for example, enhancing water availability through irrigation, improving soil quality by adding fertilizer, breeding plants for yield stability during drought, etc. However, the farming system that actually evolves is a subset of what is potentially possible. The determinant that produces the sufficient conditions for the presence of a particular system is the human element characterized by two types of factors--exogenous and endogenous.

Exogenous factors (i.e., the social environment) largely out of the control of the individual farming family will influence what the family will do or is able to do. These factors can be divided into three broad groups: community structures, norms, and beliefs; external institutions which on the input side include extension, credit, and input distribution systems and on the output side include markets; and other influences such as population density and location.

Endogenous factors, on the other hand, are those the individual farming household to some degree controls, including the four types of inputs mentioned earlier: land, labor, capital, and management. It is important to recognize that these resources vary among households, regions, and countries on the basis of quantity and quality, both of which influence the performance and the potential of the system. In addition, these resources may or may not be owned by the household. Access to the resources may vary, which may limit their use. This, in turn, may affect the goals and performance of the farm family. Nevertheless, it is the farming family that ultimately decides on the farming system that will emerge, although it is influenced and sometimes constrained by the technical element and exogenous factors.

The farming system obviously is complex, which explains why some technology thought to be relevant often has not been adopted or, when it has, why the degree of adoption has varied widely. Failure to consider the human element in agricultural research has contributed to many so-called "improved" technologies being irrelevant.

In terms of technology development, farming families have often been viewed as homogeneous, whereas the scheme in Figure 1 would indicate a considerable degree of heterogeneity (the "heterogeneous" dimension).

Understanding the interaction between the "horizontal" dimension and "historical" subdimension is important in helping to explain the heterogeneity that currently exists and in predicting what might happen in the future ("prospective" subdimension) as a result of specific changes such as adoption of a certain type of technology.

A large number of possible implications arise from the multiple interactions mentioned in the above discussion. A few that are of some relevance to the central focus of the workshop, in terms of what constitutes relevant technology and support systems, are discussed in the following five sections. An attempt to pull some of the major points together is made in the sixth section.

Assessing Goals or Objectives of Farming Families

As in other parts of the world, farming families in Africa have aspirations that include as the most important elements income, effort avoidance, and risk avoidance (Norman and Binswanger, 1982). In economic terms this can be stated as rural people trying to increase their utility (satisfaction), which increases with income but decreases with increased effort and higher levels of risk. This can be restated as maximizing income for any given level of effort and risk or, alternatively, reducing risk or effort for a given level of income.

Attempts to maximize utility take place within a given set of constraints. As these constraints change, the way in which utility is maximized is also likely to change.

The higher the degree of subsistence orientation, the greater is the concentration on food crops. The traditional complex family unit so common in Africa (Meillassoux, 1960) was compatible with this food self-sufficiency orientation and ensured survival in the absence of formal external labor and credit markets. For example, large family units provided control over a larger supply of labor and other resources. This orientation, together with very limited opportunities for earning cash from other sources, means that cash available for buying nonagricultural commodities or for agricultural activities is extremely limited. In addition, under such circumstances the problem cannot be alleviated through credit markets that are usually poorly developed. Therefore, implications of developing relevant improved technologies under such circumstances are as follows:

1. There should be an emphasis on food crops that are acceptable in terms of taste and storability.
2. The technology developed should require minimum dependence on the market system, and other inputs required for their adoption should be within the capacity of the family unit itself (e.g., labor).

Consequently, in terms of soil fertility maintenance, nutrient recycling and the increased use of biological nitrogen fixation are likely to be more appropriate than the use of inorganic fertilizer.

In semiarid areas at least, there are also temporal implications in terms of relevant improved technology. This is because of the limited and often unreliable growing season for rainfed crops resulting from low levels of rainfall, which are combined with erratic inter- and intra-annual distribution. Balcet and Candler (1981) working in northern Nigeria concluded that family strategies at the beginning of the growing season tend to be very averse to taking risks and are aimed at attaining food self-sufficiency. This need dominates during the period between the start of the growing season and the establishment of the food crops. If the rains are good, this period of concern will usually end at the first weeding. If the rains are bad, however, such strategies will dominate until much later in the season. After this critical stage is past and food supplies are assured, then given the right incentives, other crops might be grown. Therefore, in terms of developing relevant improved technologies for regions where the desire for food self-sufficiency dominates actions, three additional implications arise:

1. Technologies that are divisible and flexible with regard to timing of application and intensity of use are more likely to be accepted because they can be adjusted sequentially depending on the type of season.
2. Technologies that give results at the critical germination period are likely to be more readily adopted because the farming families are particularly focusing on indicators that would mark the end of the "safety-first" period.
3. Improved technologies often require that parts of the farming system be rearranged to suit the changing relative scarcities in labor, time, and/or other resources. Because early in the growing cycle the farming families are more averse to risks, improved technologies that require rearrangement of resources at that time are less likely to be adopted.

However, almost everywhere that a food self-sufficiency orientation exists in Africa, agriculture is in a state of transition. Earlier in the paper, mention was made of the influence of railways and roads on developing the export cash crop market which enabled farmers in west Africa to use surplus resources, particularly labor and sometimes land, in producing the required crops. Later, as surplus resources were used up, increased emphasis was placed on disseminating improved technologies together with the requisite support systems in terms of modern inputs, credit, and extension services. At the same time, a lack of both favorable marketing policies and relevant improved technologies capable of substantially increasing food production no doubt contributed to their lack of market integration.[7] Thus, a food self-sufficiency orientation continues to be of overriding importance in the poor areas where no export cash crops are possible, whereas a confused mixture of food self-sufficiency and income maximization appears to prevail in many areas where export cash crops can be produced. However, a shift away from food self-sufficiency toward an income maximization orientation has a profound

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[7] For example, many African countries' governments, in a largely unsuccessful attempt to keep food prices low for the politically volatile urban consumer, have entered the food crop marketing system and paid low producer prices for food crops (World Bank, 1981). However, this has not prevented higher retail prices for food crops being charged in rural areas near the time of harvest.

effect on the lives of farming families and also has important implications in terms of what constitutes a relevant improved technology.

As indicated earlier, large or complex family units are compatible with a food self-sufficiency orientation. However, the development of market systems and access to new information through the extension services reduces the premium formerly attached to self-sufficiency. Thus, complex family units lose some of their relevance and eventually disintegrate into smaller nuclear family units, a trend which is currently occurring in many parts of Africa.[8] Two examples illustrating the ways in which development of market systems can bring about such changes are as follows:

1. The demand for more financial independence on the part of individuals within complex family units results in greater proportions of fields formerly under the control of the family head (i.e., common fields) being reallocated for individual use, thereby subverting the possibility of attaining food self-sufficiency and decreasing the benefits to be derived by such units staying together.
2. For a number of reasons, institutional credit programs are often directed only at family heads (e.g., in Senegal). This can therefore mean differentiation in terms of types of technology applied on the common fields under the control of the family head and those under the control of other family members (Venema, 1978). This undoubtedly would encourage the multiplication of family heads and the division into smaller nuclear family units.

Therefore, the development of market structures in aiding the development of product and factor (e.g., labor, credit, and sometimes land) markets opens up opportunities for people to benefit individually. Regardless of whether this is good or bad, it must be emphasized that, since it is likely to continue, it has important implications in terms of relevant improved technologies.

A shift toward an income-maximization orientation permits a degree of commercialization in the farm enterprise through the marketing of products the proceeds of which, together with funds obtained through institutional

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[8] For a brief review of the reasons given in the literature, see Norman, Newman, and Oedraogo (1981). It is suggested that some of the reasons given can be related to the rationale presented in this paper.

credit programs, can be used to purchase modern inputs, extra labor, equipment, etc., required for the adoption of improved technologies. Thus, the potential for developing improved technologies that bring about substantial increases in productivity is much greater than under the more restrictive conditions surrounding a food self-sufficiency orientation.

As explained earlier, some farming families may have both food self-sufficiency and income maximization objectives. For example, Balcet and Candler (1981) suggested that once farming families feel that the critical stage for fulfilling food needs is past in any particular year they will slowly change their objective to one with the income maximization at some specific level of risk. In contrast to their attitudes earlier in the season, farming families may be willing to accept improved technologies that require considerable reallocation in resources. In addition, assumption of a degree of income maximization can help make cash available to purchase modern inputs for those crops that provide self-sufficiency. Of course, it is possible that cash could come from other types of enterprises such as livestock and off-farm employment. In such cases, marketing of crops to provide cash would not be so important. This in fact is likely to be the case in Botswana, as is discussed later in the paper.

Increasing Productivity of the Most Limiting Factor

Obviously, if farmers want to increase production from their farm and either land or labor is currently being fully utilized, the only way this can be done is to identify ways of improving the productivity of the most limiting factor without increasing the degree of risk beyond that which the farmer is willing to accept. The following discussion hopefully helps to illustrate the possible complexities of this in the semiarid areas of Africa as factor ratios change with increases in population density.

In general, the seasonality of rainfed agriculture in the semiarid regions causes special problems involving labor peaks or bottlenecks during specific periods of the rainy season and underemployment particularly during the dry season.

This is one of the reasons why a substantial percentage of farming families in the semiarid regions of Africa supplement their income from agriculture through working in other occupations within or outside their areas, particularly in the dry season.[9] The severity and nature of labor bottlenecks during the rainy season are determined in part by the length of the growing season (the shorter this is, the more peaked is the labor activity), the type of technology being used, and the power source (Norman, Newman, and Ouedraogo, 1981). At the risk of oversimplifying, it is possible to make the following generalizations on technology and seasonal labor bottlenecks:

1. With only hand labor and indigenous technology, the time and the amount of weeding are often most limiting. The weeding bottleneck might be accentuated if the rains are particularly good (Unite D'Evaluation, 1978). Land preparation and planting also are sometimes considered to be bottlenecks, particularly when timing is important. Timing becomes a significant issue as one moves north through the savanna areas of west Africa when the growing season becomes shorter (Unite D'Evaluation, 1978).
2. The introduction of improved land-intensive technology (e.g., seed and fertilizer) without changing the power sources shifts the bottleneck to the time of harvesting the increased yields. That statement, however, should be interpreted carefully because timing is still a particularly critical factor in the weeding operation (Haswell, 1953; Matlon and Newman, 1978). Also, for certain crops one can argue that time of harvest is really not such a serious bottleneck; the rains are over, and fairly serious damage in the field is unlikely, although maize can be attacked by rodents and other cereals by birds.
3. Changing the power source from hand to animals but retaining indigenous or traditional technology, apart from ridging equipment to be used with oxen, only accentuates the weeding bottleneck. Larger areas of land are often prepared which, because the weeding equipment is inadequate, have to be weeded mainly by hand (Tiffen, 1971; Jones, 1976). In addition, the harvesting bottleneck becomes more accentuated when land preparation and hence planting operations are carried out more quickly and efficiently than before the power change.
4. A combination of animal power with ridging, planting, and weeding equipment, together with improved land-intensive technology, eases the weeding

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[9] Such work patterns on a monthly basis often show a negative correlation with agricultural activities on farming families (Norman, Newman, and Ouedraogo, 1981).

bottleneck but tends to accentuate the harvesting bottleneck even further (Faye, 1978), although that can be eased somewhat by using a cart for removing the harvest from the field.

Although the above discussion helps illustrate how labor bottlenecks can be influenced by the type of technology and the power base used, there is another complication introduced in that farmers are operating in a dynamic environment that changes over time. Mention was made earlier of the influence of changes in population density. The increases in population density that are occurring throughout Africa help bring into focus three problems that exist in different parts of the savanna (Norman, Simmons, and Hays, 1982).

1. In areas of low population density, the peak demand period for labor is likely to be a major constraining factor on expanded output.
2. In areas of transition to high population densities, it is possible that both a labor and a land constraint will emerge. The peak demand period for labor will be a constraining influence, and land will emerge as a problem because soil fertility will decline under population pressure. The possible dual nature of these constraints will be exacerbated by the increasing need, in order to sustain a satisfactory level of living, for farm families to spend more time in activities that require year-round commitments, including off-farm, income-earning activities as well as caring for cattle owned by the family. As land becomes more of a constraint, the value of cattle in contributing to maintaining soil fertility will become greater. However, the problem of feeding the livestock also will become greater and quite likely will involve a change to more labor-intensive methods.
3. In areas of very high population density where labor becomes surplus, land is likely to be the most constraining factor.

With the inability of the nonagricultural sector to absorb substantial increases in population, it is likely that scenarios (2) and (3) above will become increasingly significant. To date, the changes in the constraints articulated above have largely been overcome within the traditional farming system framework. Crop diversification and the adoption of various ways of increasing labor input on the family farm are being used to overcome the problem of the labor bottleneck. Raising cattle and seeking off-farm occupations are being used to combat the problem of decreasing soil fertility. In fact, some of the traditional practices are consistent or compatible with changes in factor ratios.

A good example of such a practice is that of mixed cropping which until the last decade was often decried as being primitive and backward. The results in Table 1 of a study of farmers done some years ago in the Zaria area of northern Nigeria indicate superiority of crop mixtures for improving returns to the most limiting factors whether it be labor or land. The gross margin per hectare was 60%-70% higher for crop mixtures depending on how the cost of labor was determined. In terms of the return to labor, the gross margin per annual workhour expended on mixed crop fields was the same as that on growing crops in sole stands. That was because the annual labor input for growing crops in mixtures was higher than for crops in sole stands. However, when labor applied during the labor bottleneck period (i.e., June and July) was considered, the return per workhour during that period was 20% higher for crop mixtures. Mixed cropping therefore not only alleviated the labor bottleneck in physical work terms but also paid off in terms of returns to that limited seasonal labor. Finally, the need for security was a criterion farmers often cited for growing crops in mixtures. In fact, the results indicated that growing crops in mixtures gave a more dependable return (Norman, Pryor, and Gibbs, 1979). That was not surprising because different crop species in a given mixture are likely to respond differently to variations in weather and day length and to insect and disease attacks. As a result, failure or partial failure of one crop can sometimes be counteracted by compensatory growth by another.

However, with the possible exception of mixed cropping there is a limited potential for continuing to overcome the problems of increasing population densities by using indigenous solutions. Consequently, if nothing is done to lessen these constraints, involution is likely to occur.[10] Also, even if the requisite incentives are present, the low productivity of both land and labor under such systems probably will not permit the generation of sufficient surplus food production to feed the rapidly increasing urban population.

The future therefore has to lie with developing and introducing relevant improved technologies. The scenario of problems given above can be reduced to two basic constraints with relative significance depending to a larger extent on the seasonality of agriculture and population pressure: first, improving the productivity of labor, particularly at bottleneck periods, and

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[10] Involution means a higher total income in an area but, because of population increases, a lower income per capita.

second, improving the productivity of land on a sustainable basis. Improved technology development needs to address these issues in order to increase the productivity of the existing farming systems. However, concluding that mechanization can be used to solve the problems of seasonal labor bottlenecks and that biochemical technology can increase land productivity is too simplistic. As well as these direct effects such technology changes could have important indirect effects. For example, the deep plowing (enfouissement) advocated in Senegal and undertaken with mechanical equipment has been viewed as a possible way to sustain land productivity.

From an economic viewpoint Hayami and Ruttan (1971) emphasized in their induced-innovation hypothesis that, although to increase productivity it is necessary to increase the return to the most limiting factor, that action alone will indirectly affect the use or productivity of other inputs (Table 2). Some examples follow:

1. Labor-saving technologies such as the draft animals and relevant equipment, if used at peak labor periods, can improve the productivity of labor and therefore permit a larger area to be cultivated without a decrease in the productivity activity per hectare. Other labor-saving technology such as the use of herbicides and animal-drawn equipment to reduce the burden of hand weeding and improve timeliness of operations can improve productivity of the land.
2. Yield-increasing technologies (e.g., improved seed; fertilizer; pest, disease, and weed control; improved cultural practices; etc.) will usually increase labor requirements, provided there is no change in the power source. Depending on circumstances, such as the increase in yield, these technologies can have either a positive or negative impact on labor productivity.
3. Obviously yield-increasing technologies combined with labor-saving technologies are likely to have positive effects on both land and labor productivity.

It is unfortunate that the natural bias of agronomists has tended to be toward increasing return per hectare rather than increasing labor productivity, even though this may be more important in certain situations. An example of a possible problem with this orientation is an improved technological package consisting of SK5912 sorghum, seed dressing, fertilizer, a high stand density, etc., which was tested with a sample of farmers in northern Nigeria over a 2-year period, one of which was a drought year (Norman, Simmons, and Hays, 1982). As expected, there was a substantial increase of more than 80% in net return per hectare by using oxen primarily for land preparation and some interrow cultivation (Table 3). However, because labor was a more limiting factor than land, a more relevant criterion to its use would be net return per workhour put in during the labor bottleneck--in this case June and July. The net return for total workhours was only slightly higher when oxen were used and lower per workhour put in during June and July. Both ratios were estimated to be lower when only hand labor was used. Two important implications of these results are as follows:

1. The results indicate that the adoption of the improved technological package involved substantially more labor. It is important to assess the possible severity of the problem of increasing labor requirements in areas where labor is the most limiting factor. Increases in labor requirements occurring during periods when labor is underemployed obviously would be more acceptable than those occurring during periods of peak employment. In the case of the improved sorghum package, almost 70% of the increased labor requirements was devoted to harvesting the increased yield. This brought about a new labor peak, but on balance it was probably less serious than the one involving weeding when timing was so critical.
2. The results indicate that acceptability of yield-increasing technologies in labor-scarce areas may sometimes be increased through combining them with labor-saving technologies such as draft animals and equipment and thereby increasing labor productivity during peak labor periods. Therefore perhaps it is not surprising that in the Francophone countries of west Africa animal traction has been perceived by governments as a means of intensifying production on a given amount of land when combined with yield-increasing technologies, although farmers often viewed it in a more traditional way as a means of increasing the area that can be cultivated (i.e., extensification).

Introduction of animal power especially in west Africa has accompanied the development of a market system because funds had to be provided, usually from selling agricultural produce, to purchase the equipment and often the animals. As mentioned above, strong emphasis on yield-increasing research and less emphasis on labor-saving research appear to have promoted the use of support systems on the input side that have emphasized yield-increasing technologies. As a result, the most successful introduction of oxen has occurred where farmers have most widely adopted the yield-increasing technologies for export cash crops (e.g., cotton in Mali Sud and groundnuts in the Sine Saloum area of Senegal).

However, this does not negate the assertion that, given the availability of relevant labor-saving technologies and relevant support systems that permit their adoption, there would be a greater tendency to increase the areas cultivated. Nevertheless, the above example does illustrate the complexity of tracing the possible impact of different strategies and the dangers of not looking at various relationships within the farming system.

Breaking Constraints or Exploiting Flexibility

The previous section has emphasized the issue of constraints in terms of land or labor and the necessity of dealing with them in a systematic way if productivity and therefore production are to be increased. However, there are two possible ways of dealing with an identified constraint: (1) break the constraint and (2) avoid the constraint by exploiting the flexibility in the farming system.

A simple technical example would be the possibility of different strategies to deal with a particular disease on sorghum. The constraint may perhaps be broken by applying a seed dressing (requiring an input distribution system), breeding a disease-tolerant sorghum (a long-run strategy requiring an input distribution system), or exploiting flexibility in the farming system by planting the sorghum at a sub-optimal time (in terms of yield potential) which reduces or eliminates the disease attack.

The decision on which approach to use in dealing with constraints will depend on their severity, the flexibility that exists in the existing farming system, and the availability of potential improved strategies that break the constraints or exploit the flexibility. Two examples help illustrate this point and the necessity of having a perspective about the whole farming system.

Exploiting Flexibility with a Cotton Technology, Northern Nigeria--In northern Nigeria a technological package for growing cotton, involving planting in June and applying fertilizer and spraying several times, was tested with farmers over a 4-year period.

In the area where this technology was tested, farming families tended to be short of labor and averse to risk but open to opportunities for profit maximization subject to a food security constraint. That set of constraints and objectives reflected the need to guarantee food supplies, to maximize returns to labor, and to recover cash involved in undertaking any technological change.

The results in Table 3 indicate that the net return per hectare of improved cotton was considerably higher than the returns from growing cotton by using the indigenous technology. Yet even though the net returns per hectare of improved cotton were higher, virtually no farmers adopted the improved cotton recommendations in their entirety. Reasons were numerous.

First, as the results in Table 3 indicate, the average labor inputs required for growing improved cotton were 56% higher than those for producing cotton by using traditional or indigenous technology. Although the higher yield compensated for the higher labor costs and increased the annual return per workhour by 13%, the return per workhour during the June labor bottleneck was less than for the cotton grown with indigenous technology. Second, because the improved cotton had to be planted earlier than the traditional cotton, a labor conflict emerged and the farmer had to choose between weeding his food crops or planting the improved cotton. Whereas the cotton researchers had compared traditional and improved cotton yields on research plots, the farmers had analyzed improved cotton as part of their total farming system. Analysis revealed that the farmers had not compared improved cotton technology with the traditional cotton technology but instead with the labor requirements and returns from food crops. Thus, one of the major reasons for rejecting the so-called improved cotton was the incompatibility of the proposed technology with endogenous factors such as family labor bottlenecks and labor availability for food production. Other reasons for nonadoption were related to the difficulty of transporting large amounts of water required for spraying and the lack of market structure development for providing extension, fertilizer, etc. Because of these factors recommendations were developed for cotton planted in July rather than in June. Although the potential yields of cotton planted later would be lower than those of cotton planted early, they would still be potentially higher than yields obtainable using indigenous practices, and such an adjustment would fit in with current farming systems and the household profit expectations. Thus, flexibility in the farming system was exploited in this example. Incidentally, also recommended was the replacement of a water-based insecticide with an oil-based one, which could be applied with an ultra-low-volume sprayer and which greatly reduced the labor inputs for spraying.

Breaking the Planting Constraint, Botswana--The second example pertains to Botswana where rainfall is only half that of northern Nigeria and where the interannual and intraannual distribution of rainfall is even more erratic. In such a climatic environment there is little flexibility in the farming system, since a key management factor is the ability of farmers to undertake timely operations for plowing, planting, weeding, etc., in order to make more water available for germination and plant growth and to improve the efficiency of water use. Ability to pursue "timeliness" is, however, not a function of management alone but also of resources available to a farmer in the form of draft power.

For example, in our current work in Botswana we have in one area defined six types of farmers distinguished by whether their plowing operation is done with owned or hired (including shared) cattle, donkeys, or tractors. Although farmers all have one overriding problem, that of pursuing timely operations, the relevance of alternative solutions will vary according to the resource base of the farmers. Obviously it is much easier for a farmer owning a tractor to ensure timeliness than it is for a farmer who has to hire donkeys. The challenge is to develop relevant technologies for the poorer resource farmers as well as for farmers having access to greater resources. In terms of timely plowing, this likely will involve different types of equipment and may involve different planting methods. Therefore, the major emphasis in our current Botswana work is on breaking the constraint around timely planting rather than exploiting flexibility within the farming system. Farmers in essence have already recognized this in their traditional strategies. Like farmers elsewhere they have cushioned themselves against disaster through following other enterprises, particularly livestock (emphasizing cattle) and off-farm jobs. Therefore, particularly in this situation, one cannot think of crop agriculture in isolation from other sources of income. Few farmers perceive crop production as a way of producing surplus. Rather they attempt to meet some of their subsistence requirements from it. Consequently, under such circumstances one has to view investment in risky crop enterprises in relation to investing in other areas such as livestock and off-farm activities. It is also likely that, in such a situation, in order to increase crop productivity it will be necessary to consider seriously the livestock component and its interaction with crops and to accept the fact that farmers will be reluctant to invest much money in crop production. This perhaps deviates from what one is likely to find in the savanna areas of west Africa where crop agriculture is a much more central part of the livelihood of most of the farmers.

Deciding on Single Trait or Packages of Technologies

Developing improved technologies may involve incremental or single-trait changes or may incorporate packages of factors. Packages of practices have tended to be the major emphasis on the part of agronomists working on experiment stations.[11] Of course, the major advantages of packages include the complementary or synergistic effects on relationships among the various components. Improved seed, for example, may respond better than indigenous varieties to the addition of inorganic fertilizer. Disadvantages of packages involve the more complex methodologies in putting them together and increased difficulties in getting farmers to adopt them in their entirety. For example, it is likely to be more difficult to convince farmers to adopt an improved technology completely when their current farming systems have been little influenced by externally introduced improved technologies. Also packages often require more complex management and more coordinated support systems for their adoption. All other things being equal, single-trait changes are obviously preferable. One could argue, however, that when this comes at too high a cost as a result of ignoring synergistic effects, then packages of practices should be developed. However, where the farmer is initially unlikely to adopt the package in its entirety, it is justifiable to use an incremental approach toward the extension of a complete package if the farmer obtains an improved return from using that component. Research workers can help guide extension personnel as to the optimal order in which the various components of the package should be extended.

An interesting example illustrating the potential for this pertains to the hybrid maize program which was so successful in Kenya. Careful experimental work showed that the most important determinants of yield in descending

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[11] Although some would challenge that the major emphasis by agronomists on experiment stations is package development, the author believes that this often happens by default since the *ceteris paribus* conditions in many experiments are such that farmer adoption of the levels of the nonexperimental variables used in the experiment will often involve additional changes other than, for example, simply applying different levels of fertilizer.

order of significance were timely planting, type of seed, weeding, and plant population. In the absence of good husbandry, fertilizer was actually unprofitable. The results are illustrated diagramatically in Figure 2. As Gerhart (1975) concluded, it is dangerous to recommend the use of expensive fertilizer in the absence of high levels of crop husbandry. He suggested that a second-best solution, therefore, would be to extend the improved seed combined with better husbandry practices for a low-cost, high-return solution. Gerhart (1975) found from a survey in west Kenya that most farmers had discovered the solution for themselves although the extension service had continued to recommend the full package of practices. It is apparent that the extension and adoption process could have been made more efficient if an incremental approach to the extension of the complete package had been suggested by research workers.

Therefore, in tailoring improved technologies to the needs of farming families it is apparent that a wider, greater, and more efficient impact can be achieved by observing the following conditions:

1. Whenever possible an incremental approach to the extension of the complete package could be suggested by research workers, rather than the usual approach in which much valuable information is withheld from farmers who discover it the hard way later. In order for such steps to be more readily acceptable to farmers, it would be desirable, assuming <u>ceteris paribus</u> conditions, for the initial steps to involve the least changes in the farming system and involve divisible inputs such as improved seed, fertilizer, etc., with the steps requiring more fundamental changes in the farming system (e.g., purchase of oxen plus equipment) being reserved for later in the adoption process. This technology ladder, however, cannot always be followed, particularly if synergistic effects are very high. In Botswana, unfortunately, as earlier implied, the first step up the technology ladder is the necessity of having draft power and relevant equipment to pursue timeliness of operations. Because they traditionally are livestock people, many farmers already have draft power; however, it is difficult to identify how those who do not have draft can be helped with divisible inputs such as fertilizer until policy/support programs, which are in the process of being implemented, can provide them with the means of draft power.
2. Because of the heterogeneity of farmers, it is likely that any package developed will be optimal for only a few farmers. The complex total

environment in which they are operating means that they often have to make compromises that depart from the optimal path. Guidelines on the part of research workers could be very useful in helping farmers to determine a second-best path. For example, if a farmer, because of illness in the family, plants 1 month later than recommended, it would be helpful for him to know whether all, half, or none of the recommended fertilizer should be applied. Such fallback strategies are seldom articulated by research workers, which as a result complicates the job of extension workers responsible for guiding the farmer. Another variant on this general theme applies, for example in Botswana, to the lack of predictability of rainfall distribution within a year. This means that strategies farmers pursue will vary according to how the year develops. Scientists at experiment stations have not developed technologies using the decision-tree approach--the mode under which farmers are forced to operate.

Assessing Interactive Effects

Traditionally villages in many parts of Africa--for example, in the west African savanna--whether nucleated or dispersed in a settlement pattern, had a strong sense of community, often with a strong hierarchical system of control (Ramond, Fall, and Diop, 1976). This control was not considered to be very exploitive, however, since individuals could only possess usufructuary rights to the land (Maymard, 1974). Haswell (1975) has pointed out that communities had a "shared poverty" concept, with poverty being determined by the technical element, climate, and soil. The close-knit communities and mutual interdependence and responsibility prevented the patron-client relationships that existed from becoming overly exploitive. Although some question the lack of exploitation in traditional societies (Ernst, 1976; Kafando, 1972), many now argue that the potential for exploitation or inequalities developing is now becoming greater.

Recent population increases, concomitant with increasing contact with the outside world, have contributed to a breakdown of the community spirit, an increase in individualization, and less assumption of responsibility for one's fellowman. In other words, poverty is becoming individualized.

Matlon (1977), working in northern Nigeria, concluded that there was a trend toward increasing inequalities in income distribution at the village level. Diminishing sanctions against individualistic behavior and the development of land, labor, and capital markets have increasingly enabled those having control of wanted resources to gain what is sometimes perceived as "unfair returns" at the expense of those who have no control. For example:

1. In certain areas, where some preferred types of land are very limited, cases have been reported of land being commandeered by the elite who have acquired the benefits of that land for their own use (Agbonifo and Cohen, 1976).
2. A problem frequently found in the savanna areas of west Africa is seasonal hunger (soudure) (Raynault, 1973) in which, due to declining food stores, food intake is often lowest when the demands of the agricultural cycle are highest--that is, just prior to the next harvest. In order to survive, some families--obviously the poorer ones--often are compelled to do one of two things:
    a. Sell their labor to better endowed farmers to the neglect of their own farms, thereby having to accept a lower income from their own farms for short-term survival until the next harvest (Matlon, 1977).
    b. Obtain consumption credit which is repaid at high explicit or implicit rates of interest at harvest time.
3. Because of limited resources, governments providing support systems often find it difficult to provide them at the level that would be desirable. Consequently, access to such systems is often confined to the more influential and economically powerful families. Also problems are developing with reference to the adoption of certain types of technology. For example, in Mali a few years ago the prices of cash crops increased less rapidly than the prices of animals and equipment (CRED, 1977). Thus, the adoption of animal traction has slowed down; this has created an increasing dichotomy between those who already possess animal traction and those who do not (Ernst, 1976).

The above discussion indicates that, although interregional variation in land/labor ratios discussed earlier in the paper can be quite large, it is also likely that intraregional differences in land/labor ratios are increasing. However, this does not mean that the land/labor use ratios differ. In India it has been found that although there is a substantial variation in land/labor ownership ratios the land/labor use ratios differ much less. The reason for the narrowing of the ratio is that factors such as land and labor are exchanged in rental markets (Ryan and Rathore, 1978). Ryan and Rathore (1978) suggested that current policies aimed at improving the access of operators of small farms to institutional credit markets will result in even more similar factor use ratios between large and small farms. Binswanger (1978) found that both large and small farmers were moderately risk averse. Therefore on the basis of both factor use ratios and risk-averse grounds it was concluded that little could be gained by developing different improved technologies for small and large farmers. Rather, emphasis should be placed on relatively profitable and stable technologies for all farmers and improved accessibility of small farmers to input support systems (i.e., modern inputs, credit, and extension).

Unfortunately, there are no directly comparable studies to ascertain whether the same conclusions would apply in countries in Africa. It could be hypothesized, however, that in areas of high land/labor ratios where the amount of land cultivated is largely a function of the family labor force, factor use ratios are not likely to differ significantly. In areas of lower land/labor ratios, the sophisticated exchange/mobilization mechanisms for exchanging factors appear to give way to rental markets. Although these would appear to encourage a move toward more equal factor use ratios, it may well be that because of the poorly developed input support systems, there is often inequitable access, which thus preserves differences in factor use ratios. However, even if this is the case, some would argue that the solution may often be more one of adjusting accessibility to the support systems rather than of developing many different improved technologies, but the difficulties of doing this should not be underestimated. Of course, if the trend to more equal factor use ratios is not operating in a competitive type market, there is room for exploitation. The author currently believes that, given the situation in the semiarid areas of Africa, some differentiation of technologies is the only pragmatic solution if the needs of different farmers are to be addressed in the near future.

Summary

Figure 3 demonstrates graphically some of the discussion of the last five sections and illustrates the difficulty of the task of developing improved technologies in different parts of the west African savanna. The schematic diagram arrays along different axes five interwoven variables: household goals, market and support system development, population density, market opportunities, and primary technology development requirements (Norman, Simmons, and Hays, 1982).

Several conclusions are implicit in the scheme and help summarize some of the discussion in the five preceding sections.

1. Population density is important; it affects the technology emphasis. In areas of low population density (areas 1 and 4) labor-saving strategies are more significant, whereas in areas of high population density (areas 3 and 6) yield-increasing strategies are required. At intermediate levels of population density (areas 2 and 5) both technological options must be taken into account.
2. Market system development permits household goals to be redefined. With the development of market systems, it is possible for the traditionally important goal of food self-sufficiency to become at least partially diluted in favor of a more commercialized agriculture that involves entering the market place. In general, however, the history of market-system development in the west African savanna shows that developing markets for improved inputs and input-related services has lagged behind those relating to the product-marketing side. Therefore, the introduction of the improved technologies for crops may be slowed, particularly in areas where market systems for improved inputs and input-related services are still relatively poorly developed (areas 1 and 3). As was mentioned earlier, historically there has been a bias in market-system development particularly on the input side toward those areas where rainfall is high enough for export cash crops to be grown (areas 4 and 6).
3. While the ability of oxen to substitute for human labor is an obvious attraction, cost factors affect their potential in the west African savanna. Where new inputs are part of a technology package, their ability to substitute for or to complement other inputs must be considered. Because oxen are not part of the current food production sector, labor-saving technologies involving animal traction have worked better where rainfall is adequate to allow export cash crops (areas 4 and 5) rather than where market system development is poor (areas 1 and 2). Also, they have worked better when combined with yield-increasing technologies intrinsically more relevant to an area like 6.
4. Input delivery systems and input-related services are likely to be more relevant in areas where land is a constraint. Yield-increasing technologies--including use of improved seed, fertilizer, and pesticides, which are the primary focus of most technical scientists--make it easier for scientists to

develop improved technologies suitable for an area like 6 than for one like 4. Also with scientists' current orientation, prospects are not good for developing technologies that will benefit farming families in areas such as 1 to 3, where market systems are generally poorly developed. Greater relevancy, although perhaps not with spectacular increments in productivity, could be achieved in such areas through scientists changing their orientation from modification of the environment to fit the plant, to modifying the plant to fit the environment.

5. The interventionist approach to market system development is critical in ecologically fragile areas. It is unreasonable to expect major technological breakthroughs in ecologically fragile areas such as 3 without substantial inputs from outside agriculture. Thus, in such an area some emphasis might be placed on developing improved technologies that require market-structure development and, through their potential, on providing the pressure for that development. It is in areas 2 and 3 that the greatest challenges lie; not only are marketing systems poorly developed there but also the unexploited carrying capacity of the land is low compared with that in areas 5 and 6.

Although the above discussion focusses on the interdependency between support systems (market-structure development) and improved technologies from an interareal perspective, earlier there was discussion on interdependencies that exist within villages between the two types of factors. Within communities it is obviously desirable to design and implement strategies that will help all farming families. Such strategies involve designing relevant improved technologies and support systems. Heterogeneity within the villages must be recognized in designing such strategies. The challenge is to find ways to help the disadvantaged farming families. It is easy, for example, to design improved technologies suitable just for large-scale farmers, but it is almost impossible to design improved technologies that are suitable only for small-scale farmers. Another problem results from accessibility to support systems. Where they are limited or there is a hierarchical village-authority structure, the probability of differential access is greater than elsewhere. The problem in such situations is to design a cost-efficient support system that will ensure equitability of access and at the same time will not alienate the village leadership.

Implementing An Approach for Improving the Productivity of Agricultural Research

The primary aim of investing public resources in agricultural development is to increase overall productivity of the agriculture sector--and therefore the welfare of the individual farming families--in the context of the entire range of private and societal goals, given the constraints and potentials imposed by the determinants of the existing farming systems. Two ways of increasing productivity are as follows:

1. Development and dissemination of relevant improved practices and technologies that use resources previously underutilized and/or increase the productivity of resources already being utilized.
2. Development of relevant policies (e.g., pricing system) and support systems (e.g., extension, credit, improved distribution programs on the input side, and markets for the products produced).

As emphasized earlier, both components are needed to facilitate increased agricultural productivity. Decisions on which strategy is to be used to increase agricultural productivity depend to some extent on the types of technologies and support (policy) systems that would be relevant and the relative weight between the two. Strategy decisions also determine the approach to be used in developing technologies and support systems. For example, emphasis on voluntary change of the mass of farmers implies using a farming systems approach (FSAR) which is best directed toward developing technologies and support systems that respond to the needs of limited resource families.

The Farming Systems Approach to Research

There clearly are a number of critical contributors to the agricultural development process: researchers and planners responsible for developing improved technologies and appropriate institutional frameworks and farmers who, with the help of the extension workers, improve the productivity of their farming systems. Obviously strong linkages among these various contributing factors are of crucial importance. Increasing realization of this has led in recent years to an emphasis on the FSAR. This approach, involving working directly with the farmers is a more "bottom-up" or "micro to macro" orientation compared with the more "top-down" or "macro to micro" orientation of research work that starts with the experiment station or the upper echelons of Planning Ministries. It is obviously beyond the scope of this paper to discuss in detail what the FSAR is, but a schematic framework is given in Figure 4. Four stages of research can be delineated as follows:

1. Descriptive or Diagnostic Stage--the actual farming system is examined in the context of the "total" environment to identify constraints farmers face and to ascertain the potential flexibility in the farming system in terms of timing, slack resources, etc. An effort is also made to understand goals and motivation of farmers that may affect their efforts to improve the farming system.
2. Design Stage--a range of strategies is identified that is thought to be relevant in dealing with the constraints delineated in the descriptive or diagnostic stage. Information for designing such strategies comes from experiment station work, from researcher-managed and researcher-implemented work on farmers' fields, and from other farmers.
3. Testing Stage--a few promising strategies arising from the design stage are examined and evaluated under farm conditions to ascertain the suitability for producing desirable and acceptable changes in the existing farming system. This stage consists of two parts: researcher-managed and farmer-implemented trials and finally farmer-managed and farmer-implemented testing, which is the final level of testing of an improved proposed strategy.
4. Dissemination Stage--the strategies that were identified and screened during the design and testing stage are implemented.

In fact, there are no clear boundaries between the various stages. Design activity, for example, may begin before the descriptive and diagnostic stages and may continue into the testing stage as promising alternatives emerge from researcher-managed and farmer-implemented trials--where farmers and researchers interact directly. Similarly, testing by farmers may mark the beginning of dissemination activities.

In essence, the approach involves putting the farmer, as the consumer of the improved technologies, in the center of the stage. In addition the approach involves tapping the body of knowledge possessed by farmers, requires the use of an interdisciplinary approach, increases the emphasis on exploiting complementary and supplementary relationships in the farming system, involves the dynamic and iterative approach, and is complementary with the experiment station-based agricultural research. With reference to the last attribute, the farming systems approach contributes in two ways:

1. By fine tuning, through adaptive testing at the farm level, technologies developed at experiment stations. Successful testing gives rise to successful dissemination (all other things being equal) and results in the improvement of farming families' welfare.
2. By responding to failure under adaptive testing at the farm level, which results in closer specification of requirements for improved technology development that can be fed back to experiment station-based research programs. Hopefully, this will contribute to the cost-efficient development of improved technologies that will improve the welfare of farming families in the future.

Analogous linkages, although rarely done to date, could be established with planning and development agencies with reference to proposed policy/support program changes.

The involvement of farmers in FSAR gives them a voice in the research process and ensures the use of evaluation criteria relevant to them. For the farming family, evaluation criteria for the adoption of the improved technologies can be divided into the following groups although it should be emphasized that they are not entirely mutually exclusive:[12]

1. Necessary conditions determine whether the farming family would be able to adopt the improved practices. Such conditions would include technical feasibility, social acceptability, and compatibility with external institutions, that is, support systems.

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[12] The evaluation criteria given relate to the individual farming family and ignore the possible impacts on other farming families and on the productivity of agriculture in the future. Therefore, if these are taken into account, relevant technologies not only would require researchers to consider compatibility with the technical element, exogenous and endogenous factors (i.e., "horizontal" dimension), but also would require:

a. Recognition of the heterogeneity of farmers ("heterogeneous" dimension) in terms of both resource base and social and/or economic power that is a product of both the "historical" and "horizontal" dimensions--through adapting different technologies that fulfill equity considerations.
b. Recognition of possible repercussions from the adoption of the technology (i.e., "prospective" dimension), not only in terms of environmental instability but also in terms of unequal distribution of benefits, and the design of technologies and institutions that would ensure that such abuses would not develop.

2. Sufficient conditions determine whether the farmer would be willing to adopt the improved practices. Obviously the necessary conditions will be influential in determining this willingness. Sufficient conditions will include the compatibility of the improved practices with the goal(s) (self-sufficiency, profit maximization, etc.) of the farming family, the resources they have access to, and the farming system they currently practice.

In conclusion, few would debate the logic of the FSAR. However, there are still many challenges to overcome before its creditability is established. The locational specificity of FSAR work and the fact that work is undertaken with limited numbers of farmers--hopefully representative of much larger numbers--add to the perception of some that such research is expensive. In arriving at such conclusions, costs sunk in developing experiment stations and low returns from past research endeavors are likely to be heavily discounted or even ignored. Because of the complementarity of farming system research activities and other research approaches, there appears to be little value in comparing the benefit/cost ratios of different research approaches. However, a challenge does exist in minimizing the cost of such work as follows:

1. Seeking ways to reduce the time to move through the four research stages.
2. Maximizing the returns from such research by making results as widely applicable as possible.
3. Seeking better but not necessarily best (optimal) solutions to farmers' problems.

Concluding Comment

The assignment for this paper was to give an overview of research on African farmers' practices and the potential for change. Attention has been focussed on how an understanding of those practices can help in designing relevant improved technologies for limited resource farmers. Hopefully, the paper has shown that farmers, or rather farming families, are rational and responsive to technologies and policy/support systems that are "tailor made" to their situation. The move to the view in the 1970s and 1980s of farmers as sophisticated customers of technologies who can articulate their needs and at the same time participate in the technology development process has provided the basis for much more efficient change in the future. FSAR is consistent with the philosophical change on the part of many agricultural researchers.

At the same time, the complexity of the change process, the relatively harsh natural environment in much of Africa, and the economic problems facing Africa as a whole need to be emphasized. Potential for change is present, but realities dictate that change could be slow and difficult.

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Table 1. Sole and Mixed Crops on Rainfed Land, Zaria Area, Northern Nigeria, 1966-67[a]

Variable	Sole Crop	Crop Mixtures	% Change From Sole to Crop Mixtures
Labor (workhours/hectare)[b]			
Annual	362	586	61.9
Labor--peak period (June/July)	122	158	29.6
Yield (kg/ha)			
Millet	-	366	-
Sorghum	786	644	-18.1
Groundnuts	587	412	-29.8
Cowpeas	-	132	-
Cotton	213	189	-11.3
Gross margin (N/ha) with labor			
Not valued	36.79	59.48	61.7
Costing hired labor only	33.41	54.02	61.7
Costing peak labor only	30.57	51.42	68.2
Costing all labor	18.33	29.29	59.8
Gross margin (N) per			
Annual workhour	0.10	0.10	0.0
Workhour during peak period[c]	0.20	0.24	20.0

a. The weighting system used in calculating the labor inputs and yields involves weighting the different enterprises according to their relative contribution to the total area under sole or crop mixtures (Norman, 1974).

b. These include fieldwork only. Since the productivity of labor, depending on the task, varies according to age and sex, different types of labor were expressed in terms of a common denominator, work-equivalent.

c. Labor inputs outside the peak period were costed.

Source: Norman, Simmons, and Hays, 1982.

Table 2. Relationship Between Types of Required Technology and Land/Labor Ratios

Land/Labor Ratio	Technology Required	Productivity of[a]	
		Land	Labor
High	Labor saving	I + or -	D +
Low	Yield increasing	D +	I + or -

a. D = direct impact.
I = indirect impact.
\+ = positive impact.
\- = negative impact.

Table 3. Average Inputs and Returns From Improved Technological Packages Using Oxen Power, Daudawa, Northern Nigeria, 1973/74

Variable Specification	Cotton		Sorghum	
	Indigenous	Improved	Indigenous	Improved
Yield (kg/ha)	409	721	667	1,364
Inputs (per ha)				
Fertilizer (N:P:K)	1:0:0	27:22:0	0:0:0	95:46:0
Labor (workhours)[a]				
Total	276	430	199	337
June-July	55	110	46	100
Harvesting	124	221	102	196
Costs (N/ha)				
Nonlabor costs	9.22	31.00	11.71	40.92
Labor[b]	23.41 (60)	36.07 (76)	20.53 (56)	34.72 (62)
Net return				
N/ha	19.68	40.73	45.01	81.62
N/workhour[c]				
Total	0.15	0.17	0.32 (0.32)	0.33 (0.28)
June/July[d]	0.33 (1.67)	0.38 (1.41)	1.02 (0.90)	0.83 (0.63)
Excluding harvesting	0.20	0.25	0.54	0.63

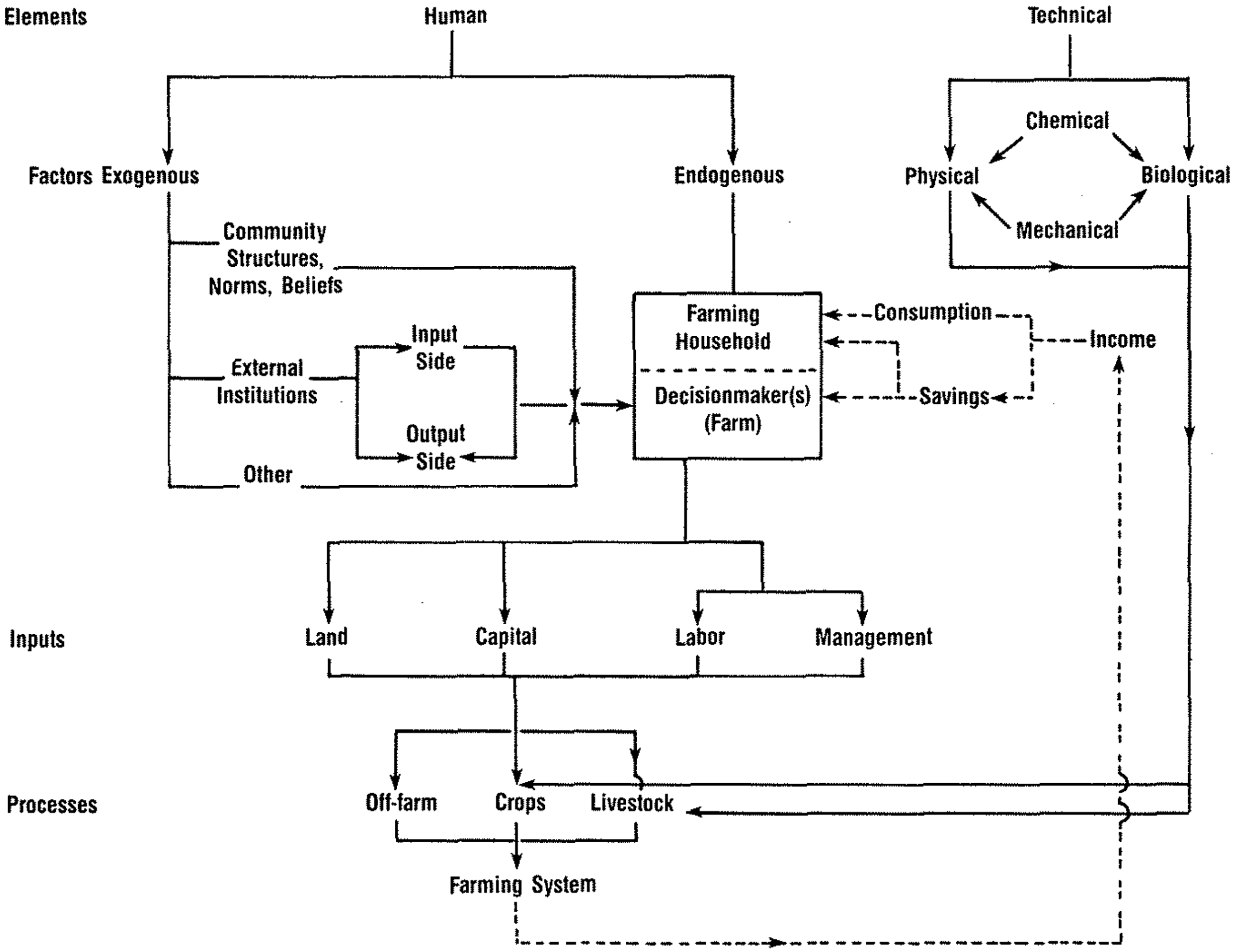
a. Excludes threshing and time spent traveling to and from the field.

b. Includes imputed value for labor. Each figure in parentheses represents the proportion of labor hired.

c. The figure is calculated by subtracting from value of production (N/ha) the sum of nonlabor costs (N/ha) and total labor costs excluding labor in denominator (N/ha) times the opportunity cost of capital (assumed to be 12%), all divided by the number of hours in the denominator. For sorghum the figures in parentheses represent the estimated return when no oxen were used, that is, all labor is hand labor.

d. Because, under indigenous conditions, planting of cotton was done in July, the figures in parentheses express the return per workhour put in during June.

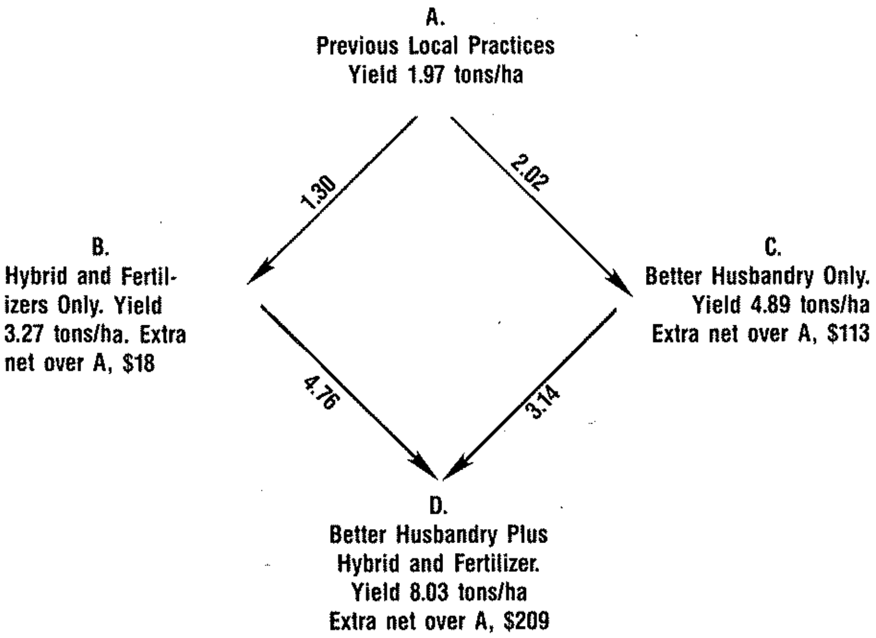
Source: Norman, Simmons, and Hays, 1982, and Norman, Newman, and Ouedraogo, 1981.



Note: Broken lines represent results of farming system.

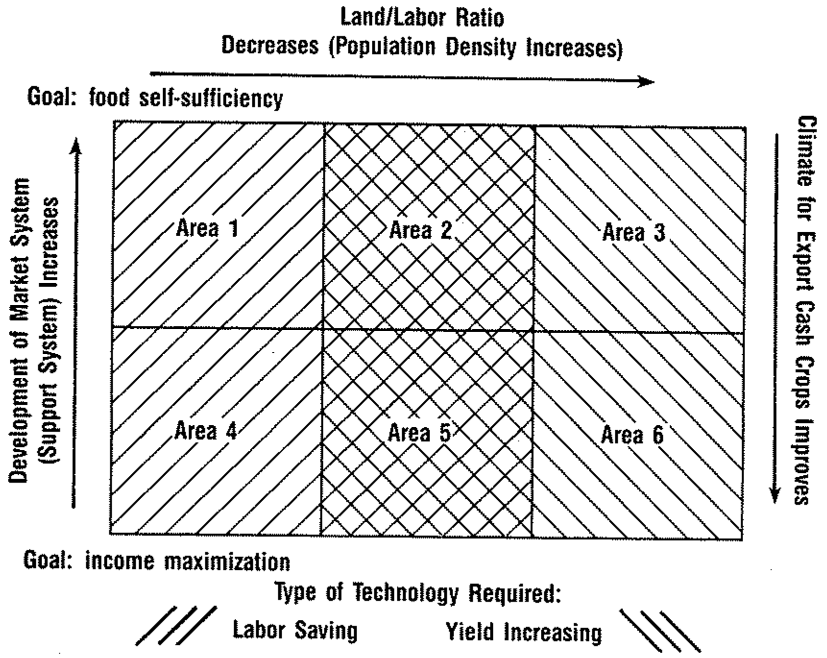
Source: Norman, Simmons and Hays (1982).

Figure 1. Schematic Representation of Some Farming System Determinants.



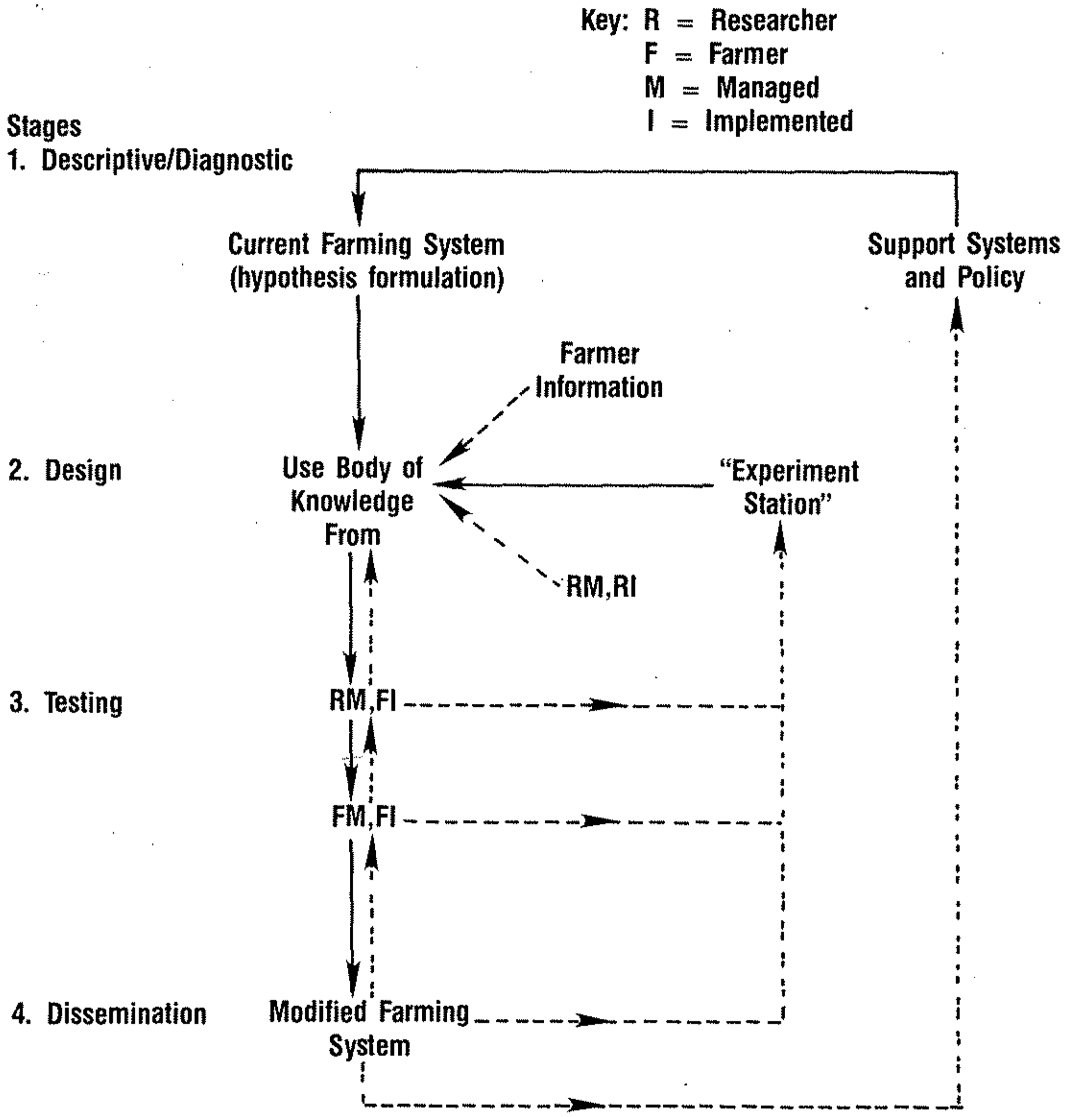
Source: Based on work done by Allan, quoted in Wortman and Cummings (1978).

Figure 2. Maize Diamonds in Kenya.



Source: Norman, Simmons and Hays (1982).

Figure 3. Schematic Breakdown of Relationship Between Population Density and Market System Development.



Source: Modified version of IER (1977).

Figure 4. The Farming Systems Approach (References on the Farming Systems Approach to Research Include Byerlee et al (1981); Gilbert, Norman, and Winch (1980); Hildebrand (1976); Shaner, Philipp and Schmehl (1981); Zandstra et al (1981).

LES SOLS A PROBLEMES DE L'AFRIQUE SUB-SAHARIENNE CARACTERISTIQUES PEDOLOGIQUES ET DISTRIBUTION SOUS-REGIONALE

R. Sant'Anna

English Summary

Although Africa has a large land surface, the availability of good agricultural land is limited. Increasing population pressure not only exhausts existing soils through more intensive use but is also leading to the cultivation of marginal soils that become eroded and even sterile as a result of poor management.

Those soils of Africa south of the Sahara that have major constraints to their use are listed as Fluvisols, Gleysols, Arenosols plus Regosols, Vertisols, Solonchaks and Solonetz, Planosols, and Histosols.

In total, these soils cover about 40% of the land area. Until their basic limitations for agricultural use (mainly water-related problems) are overcome, fertilizer use will be of limited value in these soils.

I. INTRODUCTION

L'Afrique sub-saharienne s'étend approximativement sur 23.000.000 km^2 entre les parallèles 35° de latitude sud et 25° de latitude nord et 17.40 de longitude ouest et 50° de longitude est. Sur cet ensemble les terres arables occupent 13.500.000 km^2 pour une population de 404 millions d'âmes.

L'agriculture dans cette partie du continent, en dehors de quelques ilôts, est dans sa très grande partie encore à un stade peu développé et aurait à priori fait penser que l'emprise de l'homme sur la terre est encore assez faible. Malheureusement tel n'est pas le cas et si l'on peut affirmer que l'Afrique sub-saharienne dispose d'assez de terres pour nourrir sa population, l'on est en droit de reconnaître que les disponibilités en bonnes terres sont très limitées et sont de plus inégalement réparties tant au niveau sous-régional qu'à l'intérieur d'un même pays.

Les besoins alimentaires d'une population sans cesse croissante, associés aux effets des calamités naturelles de ces dernières années ont conduit à la mise en culture sans précaution adéquate des zones marginales avec comme résultat, l'aggravation des phénomèmes d'érosion, et/ou la stérilisation du milieu.

A partir des données de la carte FAO/UNESCO des ressources en sols du monde, l'on se propose dans cette communication de faire ressortir l'étendue des zones marginales où les sols de par leurs contraintes intrinsèques constituent à l'heure actuelle des sols à problèmes eu égard aux techniques de mise en valeur.

II. LES SOLS A PROBLEMES

A. Définition et limite de l'étude

Un sol à problèmes est un sol qui de par sa nature et indépendamment des conditions climatiques, présente des contraintes sérieuses à sa mise en valeur, contraintes qui exigent la mise en oeuvre de techniques spéciales d'aménagement et des investissements de beaucoup supérieurs à ceux nécessités par les autres types de sols.

Les contraintes sont souvent de nature physique ou chimique et sont liées à:

1. la faible profondeur de matériaux
2. la texture des matériaux: texture trop légère ou trop lourde
3. la présence des sels
4. l'excès d'eau
5. un environnement climatique austère: semi-désert, désert
6. faible niveau de fertilité.

Dans les pages qui suivent les problèmes liés à la faible profondeur du matériau (sols squelettiques) de mêmes que ceux d'un environnement climatique austère et ceux liés au faible niveau de fertilité du matériau ne seront pas abordés, tant il est vrai que les exigences de la mise en valeur de ces sols sont assez connues et que ces derniers sont le plus souvent mis en défense pour éviter l'érosion pour les uns, les autres bénéficiant d'un apport d'éléments fertilisants. Par contre les problèmes liés à la présence des sels, à une texture trop légère ou trop lourde du matériau à un excès d'eau, seront étudiés. Il est bien entendu que le type de texture peut être la cause de l'excès d'eau.

Les types de sols intéressés d'après la carte FAO/UNESCO des ressources en sols du monde sont:

a. Fluvisols, Gleysols, Planosols, Histosols.
b. Les Vertisols.
c. Les Solonchaks et les Solenetz.
d. Les Arenosols et les Regosols.

Ces sols seront étudiés successivement et, avec le souci premier de faire ressortir les caractéristiques pédologiques limitantes essentielles, les recommendations qui s'imposent quant à leur mise en valeur et leur étendue par sous-région seront énoncés.

B. Types de sols

a. Les Fluvisols:

Il s'agit de sols généralement jeunes dérivés d'alluvions ou de colluvions récentes et ne présentant aucune différenciation d'horizon sinon une stratification liée à la nature des dépôts. Des couches de matériaux sableux grossiers peuvent dans certains cas alterner avec d'autres constituées par des matériaux plus fins. La grande diversité des matériaux d'apport influe fortement sur les propriétés du sol et ne permet pas l'identification d'un problème specifique aux Fluvisols. La teneur en matière organique décroit généralement en profondeur.

La mise en valeur de ces sols est liée à la nature des matériaux d'origine, au mouvement de l'eau dans le sol et à la zone écologique où ils se trouvent. Parfois une homogénéisation du profil par un labour profond s'impose. Dans les zones alluvionnaires où l'eau ne constitue pas un goulot d'étranglement par son abondance, ces sols sont d'excellents milieux pour la culture maraîchère, la riziculture et voire même pour des cultures pérennes (palmier à huile au Sud Benin et au Togo).

Dans les matériaux sableux grossiers, le pédoclimat est généralement sec et le plus souvent ces sols sont réservés à des spéculations peu exigeantes et à enracinement peu profond (cultures du mil et sorgho au nord Cameroun par exemple). Ils sont très importants dans un grand nombre de vallées africaines où ils apparaissent le plus souvent en association avec les gleysols, les vertisols et les regosols.

b. Les Gleysols:

Il s'agit de sols à hydromorphie plus ou moins permanente. L'hydromorphie confère à ces sols une couleur plus ou moins grisâtre avec présence de taches ocre-rouge, ou gris verdâtre suivant l'ampleur de l'hydromorphie. La différenciation texturale n'est pas souvent très bien marquée. Le pH peut être acide ou basique.

Les problèmes que l'on rencontre dans la mise en valeur de ces sols sont essentiellement liés à la présence plus ou moins permanente de l'eau (toxicité en fer et en molybdène; déficience en azote et en manganèse...etc.).

Ils sont utilisés pour la culture du riz et constituent dans certains pays d'excellents pâturages de saison sèche.

c. Les Planosols

Ces sols qui se rencontrent sur toutes les positions topographiques présentent à un niveau plus ou moins profond, un horizon durci (harde) imperméable à l'eau. La structure poreuse de l'horizon de surface devient très compacte en profondeur, empêchant tout mouvement de l'eau, d'où inondation périodique de ces sols. Les niveaux utiles de ces sols sont fonction de la profondeur des horizons de surface où l'on rencontre la majeure partie des racines. Le problème de ces sols est la pauvreté des horizons de surface en éléments nutritifs associée à une capacité d'échange très faible. Sans irrigation, le maintien d'un régime d'humidité favorable dans les horizons superficiels, constitue aussi un problème non négligeable.

Des labours profonds ont dans certains cas donné des résultats très satisfaisants. Partout où la saison des pluies est courte, des cultures à enracinements peu profond donnent d'assez bons résultats, ailleurs ces sols constituent des zones à pâturage extensif.

d. Les Histosols:

Il s'agit de sols saturés d'eau avec présence de matériaux végétaux partiellement ou entièrement décomposés (tourbe). Le drainage est très pauvre et la teneur en matière organique est très élevée (60% et plus). La texture est généralement fine. A l'état submergé ces sols ont un faible potentiel d'oxydo-réduction et le pH tend à la neutralité. Dans ces conditions l'évolution de la matière organique donne naissance à des substances qui comprennent du CO_2, CH_4, H_2, des acides gras, des acides organiques, des aldehydes, cétones, alcools, amines, H_2S...etc. Ces produits non seulement entrent en compétition avec l'oxygène et les éléments nutritifs autour des racines des plantes cultivées sur ces sols, mais ils peuvent aussi inhiber leur pouvoir sélectif d'où une absorption désordonnée de certains éléments nocifs et les risques de toxicité qui peuvent en résulter.

Sous culture maraîchère, des déficiences en cuivre et molybdène ont souvent été signalées et quelquefois celles du bore.

Les zones occupées par ces sols (zones tourbeuses) sont très dangereuses pour l'homme et les animaux. Partout où c'est nécessaire l'on procède à un drainage limité permettant le maintien d'un taux d'humidité favorable à la conservation du milieu et à la mise en culture.

e. Les Vertisols

Il s'agit de sols à argiles gonflantes, de couleur plus ou moins foncée et présentant en saison sèche des fentes de retrait plus ou moins profondes et un micro-relief constitué par une multitude de petites élévations (relief gilgaï). La texture est argileuse sur l'ensemble du profil (plus de 35% d'argile).

Humides, ces sols sont peu drainants et plastiques, secs ils ont une consistance très dure. Suite à leur imperméabilité, ils sont très souvent en saison pluvieuse recouverts d'eau. Le premier problème dans un vertisol est avant tout un problème de perméabilité lui-même lié à la nature de l'argile et à la structure du matériau. Le taux de saturation en base est très élevé avec, dans le complexe adsorbant, une dominance de calcium et de magnésium. Partout où le pH est très élevé, on enregistre une faible teneur en phosphore. Des carences en azote sont souvent liées à un excès d'eau et à une faible teneur en matière organique. Ils sont néanmoins d'excellents sols, très fertiles de par la nature de leurs matériaux. Des labours profonds sont parfois nécessaires pour augmenter la pénétration de l'eau. Ils occupent de larges superficies au Burkina-Faso, en Ethiopie, en Afrique du Sud, en Somalie, au Sudan et en Tanzanie où ils portent des cultures de canne à sucre, de riz, de coton, et de blé.

Leur mise en valeur pose des problèmes liés à la texture argileuse avec faible perméabilité, à la concentration possible en sodium échangeable qui peut en faire des sols à alcalis. Une amélioration lente de la structure est toujours possible par des apport répétés d'engrais verts. Des amendements à base de $CaSO_4$ (gypse) peuvent améliorer les propriétés physiques par la diminution du rapport Na/Ca échangeables. Les pratiques culturales doivent s'orienter vers la conservation de l'eau d'infiltration au cours de la saison sèche et le drainage en saison des pluies.

f. Les Solonchaks

Il s'agit de sols dérivés d'anciens sédiments marins et d'estuaire, riches en pyrites et sulfures ferreux et en soufre. Ils sont extrêmement acides et empêchent toute végétation quand ils sont exposés à l'air. Submergés et en conditions anaérobiques, ces sédiments sont neutres à alcalins et portent des telmatophytes tolérants aux sels. Le riz y est cultivé mais les productions restent assez faibles et aléatoires. Les facteurs mis en cause par différents auteurs dans le mauvais développement du riz sont les suivants:

- excès d'aluminum
- excès de sulfate ferreux
- forte acidité
- forte carence en phosphore et en oligo-éléments

L'aménagement des solonchaks s'avère souvent difficile à cause de leur position topographique en bassins fermés, sans possibilité de les lessiver par une irrigation abondante et le drainage de l'excès d'eau qui évacue les sels.

Ils occupent des superficies plus ou moins importantes en Angola, Botswana, Ethiopie, Kenya, Madagascar, Mauritanie, Niger, Nigéria, Sénégal...etc.

g. Les Solonetz:

Ce sont des sols contenant peu de sels solubles mais du sodium échangeable en quantité suffisante pour être toxique pour les plantes.

Le pH est souvent supérieur à 8 mais peut être de l'ordre de 6 dans les sols où il y a présence de calcaire. Dans ces sols, le problème de toxicité pour les plantes est lié à un pH assez élevé, la présence de sodium en excès et une carence en azote, phosphate et potasse. Sous condition alcaline, l'on constate des déficiences en microéléments comme Zn, Cu, Mn, Fe.

La structure des sols est très souvent peu développée (présence de Na); l'aération et la perméabilité très pauvres.

Ils occupent des superficies importantes au Kenya, Namibie, Nigéria, Somalie, Soudan, République Sud Africaine, Tchad, Zambie, Zimbabwe.

Ils sont le plus souvent exploités en pâturages extensifs mais l'on y pratique çà et là des cultures de blé, de mil et de maïs (sols à alcalis).

La mise en valeur des solonetz dépend essentiellement de la possibilité de remplacer le sodium échangeable par le calcium et d'empêcher la remontée d'une nappe saline et alcaline.

h. Les Arenosols:

Il s'agit de sols sableux à sablonneux à différenciation d'horizon peu marquée. La teneur en argile est le plus souvent inférieure à 10%; le taux de matière organique est très faible, le pH souvent acide. Ils sont souvent chimiquement assez pauvres (faible teneur en azote, bases échangeables, P_2O_5). Malgré leur apparence, ces sols quand ils sont profonds et situés dans des zones écologiques favorables, constituent de bons supports pour les végétaux. En effet, le stockage de l'eau se fait sur une plus grande épaisseur et le manque de discontinuité texturale favorise la remontée capillaire de cette eau.

Les Arenosols se rencontrent dans toute la Région sub-saharienne; mais les grandes étendues se trouvent dans le Sahel ouest africain, en Angola, au Botswana, au Soudan, en République Sud-Africaine, au Tchad, au Zaïre...etc.

En zone de savane, ils sont le plus souvent le domaine du pâturage intensif avec çà et là des cultures de mil et même de haricots. Partout où la pluviométrie est favorable, ces sols sont cultivés en arachide, manioc, maïs et riz.

i. Les Regosols

Ils se différencient des précédents par une richesse relative en éléments fertilisants et la présence de matériaux grossiers plus ou moins consolidés. Les formations dunaires des zones cotières de l'Afrique tropicale sont dans leur grande majorité des regosols. Les problèmes de ces sols sont identiques à ceux des Arenosols, sauf s'ils sont dérivés de matériaux calcaires. Les formations regosoliques sont particulièrement bien développées en Angola, Ethiopie, Mali, Niger, Tchad, Soudan, Somalie...etc., où ils constituent la majeure partie de sols désertiques pour lesquels la pluviométrie est le facteur le plus limitant.

C. Distribution Sous Régionale

A partir des données de la carte mondiale des ressources en sols, les sols décrits ci-dessus se répartissent comme ci-dessous (Tableau 1). Les données du tableau, de part la nature des informations disponibles, se réfèrent plutôt à des associations de sols où l'élément dominant reste le type de sol désigné.

Il ressort de l'examen du tableau 1 que plus du tiers de la zone africaine sub-saharienne est le domaine des sols à problèmes. Dans cet ensemble les Arenosols et les Regosols viennent en tête suivis de très loin par les gleysols, les Vertisols et les Fluvisols. L'Afrique Australe est la sous-région où les sols à problèmes occupent une plus grande étendue (un peu plus de la moitié de la superficie totale).

En guise de Conclusion:

D'après ce qui précède, la superficie couverte par les sols à problèmes est loin d'être négligeable, d'autant plus que dans le cadre de cette communication certains types de problèmes n'ont pas été abordés. L'étendue réelle des zones occupées par les sols à problèmes ne sera mieux cernée que dans la mesure où l'on pourrait disposer d'études pédologiques plus détaillées.

Les sols à problèmes présentent une série de facteurs adverses qui limitent leur mise en culture. La fertilisation de ces sols reste étroitement liée au type de problème en cause. Dans beaucoup de cas, une bonne maîtrise de l'eau semble être le préalable à toute mise en valeur.

Tableau 1. Distribution Sous-Régionale (1,000 ha) (%)

Superficie Occupée par les Sols à Problèmes (1000 ha) et Entre Parenthèses le Pourcentage par Rapport à la Superficie Totale

Association à dominance de:	SOUS-REGIONS					Total Région Sub-saharienne
	Ouest	Centre	Est	Australe	Les Iles de O. Indien	
Fluvisols	13,100 (2.10)	14,120 (2.60)	30,800 (5.09)	11,300 (2.30)	2,300 (0.40)	71,620 (3.10)
Gleysols	15,900 (2.6)	56,620 (10.50)	21,730 (3.60)	31,900 (6.6)	3,100 (5.20)	29,250 (5.60)
Arenosols + Regosols	147,800 (24)	100,200 (18.60)	122,000 (20.1)	151,500 (31)	8,400 (14)	529,900 (23)
Vertisols	5,000 (0.8)	9,800 (1.8)	64,300 (10.6)	21,350 (4.70)	750 (1.30)	103,000 (4.4)
Solonchaks + Solonetz	4,250 (0.7)	6,650 (1.2)	18,650 (3.1)	21,060 (4.3)	520 (0.8)	51,400 (2.2)
Planosols	2,910 (0.4)	3,850 (0.7)	1,870 (0.3)	7,100 (1.4)		15,730 (0.70)
Histosols	150 (0.02)	3,900 (0.7)	5,450 (0.9)	2,600 (0.5)	210 (0.3)	12,310 (0.53)
TOTAL Sous-Région	189,380 (30.9)	195,140 (36.2)	264,800 (43.70)	248,610 (51.2)	15,280 (25.7)	913,210 (39.70)

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FERTILISATION DES CULTURES VIVRIERES ET FERTILITE DES SOLS EN AGRICULTURE PAYSANNE SUB-SAHARIENNE

Christian Pieri

English Summary

For 20 years, CIRAD/IRAT, in close collaboration with national agricultural research and development organizations, the extension services, and particularly since 1974, with the farmers themselves, has brought to bear its resources and skills with the goal of establishing a sound basis for the improvement of soil fertility at the farm level. The effort has been particularly strong in Benin, Burkina Faso, Cameroon, Ivory Coast, Madagascar, Mali, Niger, Senegal, and Togo.

The research philosophy guiding IRAT's work was that of attempting, within the socioeconomic limits of the small farmer and the national resources available, to assist in making those changes necessary to ensure that the long-term fertility status of the soils was improved or at least maintained.

The research work already carried out has shown that there is a sound agrotechnological base for the intensification of agricultural production.

The use of fertilizers is an essential component of this agrotechnological base. For the long term, however, the rational recycling of organic matter and the use of geological fixation of nitrogen together with the exploitation and use of natural mineral resources (phosphates, limestone, etc.) must be encouraged.

Unfortunately, there is little visible impact on crops following the use of crop residues and lime. The sound long-term effects of these practices do not count with the small farmer who is, quite naturally, interested only in his standing crops.

The experience of the last 20 years has shown that it is very difficult to intensify traditional foodcrop production by the introduction of innovative techniques. The failure to adopt new technologies should not be blamed on the farmers, however, because only with sound national planning policies can the necessary impetus be given.

So far as soil fertility is concerned, for many countries, and particularly those in the semiarid regions, it is necessary to:

- Restructure the countryside by reemphasizing the role of agroforestry.
- Control common grazing and effectively recycle crop residues using enclosed livestock.
- Improve the rural infrastructure, communications, input availability, credit, etc., particularly for the noncash crop areas.
- Establish a sound pricing system for both inputs and the crop produced.

In the vast dimensions of Africa, the task of both initiating and maintaining change will be enormous.

I. Introduction

L'amélioration et le maintien de la fertilité des sols cultivés africains dans la région sub-saharienne au Nord de l'Equateur est devenu un problème d'une brûlante actualité.

En effet, à l'échelle du sous-continent, on constate que le taux de croissance démographique devient un des plus élevés du globe, et que les terres agricoles se dégradent par suite de la rupture du fragile équilibre entre le taux d'occupation des terres (par les hommes et les troupeaux), la fertilité naturelle des sols, et la production alimentaire. La sécheresse persistante dont souffre cette partie du monde depuis 1972 rend cette situation dramatique d'autant que toutes les projections de besoins alimentaires faites à l'an 2000 montrent que l'Afrique, pour nourrir sa population, devra fortement accroître sa production agricole. Cet accroissement requiert à la fois, l'extension des surfaces cultivées, l'augmentation de l'intensité de culture (nombre de cycles culturaux par an), mais aussi et surtout une amélioration de la productivité des terres qui à elle seule devrait représenter 51% de l'accroissement total (cf, tableau 1).

Pour répondre à un tel défi il est urgent que soient dégagées des solutions au problème de l'amélioration de la fertilité naturelle, très généralement faible, des sols africains. Ces solutions dépendent de facteurs et conditions techniques mais aussi des données sociales, économiques et politiques, propres à chaque pays et trop souvent négligées.

Depuis plus de 20 ans le CIRAD/IRAT a cherché à apporter sa contribution à la solution de ce problème complexe en collaboration avec plusieurs organismes de recherche nationaux (ISRA au Sénégal, l'IER au Mali, l'IDESSA en Côte d'Ivoire, l'IBRAZ au Burkina Faso, l'INRAN au Niger, l'IRA au Cameroun, la recherche agronomique du Togo, du Bénin) avec des sociétés de développement (SAED, SODEVA, CMDT, CIDT, SODECOTON...) des services de vulgarisation nationaux, et de plus en plus depuis 1974, en collaboration avec des agriculteurs (Unités Expérimentales Sénégal) directement associés au processus de recherche-développement engagé.

Cette expérience acquise sur une longue période a bien montré que rien ne pouvait être valablement et durablement entrepris sans une étroite collaboration entre tous les agents du développement rural : agriculteur, vulgarisateur, encadreur, chercheur, responsables nationaux du développement rural... Cependant il est clair comme le souligne le PNUD dans un document récent que : "on ne peut faire de progrès et améliorer le niveau de vie qu'à partir du moment où il existe une base agrotechnique valable pour augmenter la production, et à cette condition seulement."

L'objet de cet article est d'esquisser la synthèse des contributions de la recherche agronomique francophone, à l'élaboration des bases agrotechniques de l'amélioration et du maintien de la fertilité des sols cultivés sub-sahariens, en soulignant le rôle majeur de la fertilisation dans l'accroissement de la productivité des terres et en précisant les conditions techniques d'une utilisation efficiente des fumures minérales et organiques dans l'environnement physique, économique et humain propre à cette partie du monde.

II. Le Rôle Potentiel de la Fertilisation dans l'Accroissement des Rendements et le Maintien de la Fertilité

2.1. Position du problème

La fertilisation joue un rôle essentiel dans l'amélioration des rendements des cultures. Cependant, tout particulièrement dans le cas des cultures pluviales annuelles sub-sahariennes, cette pratique d'intensification doit être envisagée dans le cadre de systèmes de cultures et de production répondant à trois objectifs majeurs:

- assurer l'auto suffisance alimentaire, et la satisfaction des besoins primordiaux des familles paysannes,
- maintenir à un niveau optimal la fertilité des terres,
- réduire les risques de toutes natures encourrus par l'agriculteur notamment climatiques et économiques.

C'est dire que tout en recherchant les conditions requises pour une efficience optimale de la fumure, il est important de ne pas perdre de vue que les techniques mises au point doivent être appropriées aux conditions des agriculteurs à très faibles ressources économiques, agriculteurs qui représentent plus des deux tiers de la population agricole du sous continent (BIRD, 1981).

2.2. Rôle potentiel des engrais dans l'accroissement des rendements des cultures

Dans sa synthèse des recherches conduites en agronomie de 1969 à 1974 l'IRAT (1975) a montré que le potentiel d'accroissement de rendements des principales cultures vivrières africaines et malgaches était considérable.

Grâce à une détection préalable des principales carences minérales des sols (CHAMINADE, 1965) puis à la mise au point d'une part de fumure de redressement permettant de corriger ces carences, et d'autre part de fumure d'entretien adaptées aux cultures, on a expérimentalement démontré que les rendements suivants pouvaient être obtenus:

Maïs	10 t/ha	Madagascar, Côte d'Ivoire
Sorgho	4 t/ha	Carmeroun-nord
Mil	3 t/ha	Sénégal
Riz irrigué	9 t/ha	Madagascar, Côte d'Ivoire
Riz pluvial	7 t/ha	Cameroun-ouest

Le rôle majeur de la fertilisation dans l'obtention de hauts niveaux de rendement se manifeste dans toute la zone d'étude et tout particulièrement dans le domaine des sols ferrallitiques désaturés des zones tropicales humides (ROCHE, 1974) très pauvres chimiquement mais ayant de bonnes propriétés physiques.

Dans les zones tropicales semi-arides les effets de la fertilisation ont été d'autant meilleurs que l'apport d'engrais est associé à des techniques de travail du sol permettant d'améliorer les médiocres qualités physiques et hydriques des profils culturaux (CHARREAU, NICOU, 1971).

C'est ainsi qu'ont été mis au point des systèmes de cultures d'intensité progressive associant fumure et travail du sol (TOURTE, 1971), les systèmes les plus intensifs apparaissant comme les seuls capables de dégager de plus fortes values monétaires et d'assurer le maintien de la productivité des terres (cf. tableaux 2 et 3).

2.3. Fertilisation et maintien de la fertilité des sols

On sait que les systèmes de cultures itinérants, étudiés notamment par GREENLAND (1970) sont certes peu productifs mais assurent relativement bien le maintien de la fertilité naturelle (faible) des sols. De tels systèmes qui minimisent les risques et les efforts (NORMAN et BINSWANGER, 1982) ont cependant un avenir de plus en plus limité compte tenu de la pression sur la terre.

C'est ainsi qu'on a prouvé qu'il fallait 7 années de jachère pour que des champs épuisés par des cultures successives de mil et d'arachide au Sénégal, puissent retrouver leur niveau de fertilité naturelle initiale (CHARREAU, 1972).

Or les jachères disparaissent (la superficie en jachère dans le bassin arachidier du Sénégal représente désormais moins de 2% de la surface cultivable).

C'est pour cela qu'en Afrique de l'Ouest francophone, dès les années 60, les agronomes se sont préoccupés du maintien de la fertilité des sols dans le cadre d'une agriculture fixée.

Des dispositifs expérimentaux de longue durée ont été mis en place pour suivre l'évolution de la fertilité des sols sous culture continue, sans engrais, avec fumures minérales, avec fumure organique et minérale. Une liste de ces principaux dispositifs (et des écrits qui s'y rapportent) est donnée en annexe. Il convient de signaler que beaucoup ont plus de 10 ans d'âge, celui de SARIA (Burkina Faso) ayant dépassé le cap du quart de siècle!

2.3.1 Evolution des rendements:

L'enseignement apporté par ces études peut se résumer ainsi:

a. grâce à la fertilisation la culture continue est potentiellement possible dans les conditions de climat et de sols en Afrique de l'Ouest: les résultats du Sénégal, du Mali, du Niger, du Burkina Faso, du Nord Cameroun, du Centre et Ouest Côte d'Ivoire, le montrent.

b. la mise en rotation des cultures et notamment l'alternance céréale et légumineuse (cf. figure 1) permet une meilleure valorisation de la fertilité des terres.

c. comme il a été déjà souligné le travail du sol (labour) par son effet améliorateur des conditions d'alimentation hydrique des cultures dans les zones les plus arides, permet non seulement une meilleure valorisation de la fumure (tableau 3) mais dans certains cas une amélioration continue de la productivité des terres lorsque engrais minéraux et résidus de récolte sont apportés, malgré les aléas pluviométriques annuels (cf. figure 2).

d. dans les zones semi-arides pour le système mil-arachide, on constate cependant une évolution rapide des besoins en engrais, notamment azotés, qui deviennent d'année en année plus élevés.

e. après une première période de culture continue s'étalant de 2 ans (Sénégal, Burkina Faso) à 5 ans (cas GAGNOA en Côte d'Ivoire) on observe une chute des rendements et une moindre efficience de l'engrais dans le cas des systèmes de cultures où l'on n'apporte que des engrais minéraux (cf. figure 3 et 4): en conditions de milieu semi-arides la fumure minérale seule, même abondante, ne permet pas d'élever, et maintenir à un haut niveau, la productivité des terres cultivées en continu.

f. les effets d'apports de matière organique sont divers, selon leur nature (engrais vert, résidus pailleux, compost, fumier) et les milieux où ils sont effectués:

- MARQUETTE montre que pour restaurer le niveau de productivité des terres de barre du Togo (sols ferrallitiques désaturés, climat tropical humide à deux saisons des pluies) il suffit d'effectuer l'enfouissement d'engrais vert de légumineuse cultivée pendant 12 mois ou restituer les résidus compostés de la récoltre de maïs.
- VELLY et LONGUEVAL (1976) observent que l'enfouissement de tiges de maïs sur les Hauts Plateaux malgaches (sols ferrallitiques très désaturés, climat tropical humide d'altitude) est très efficace pour maintenir les rendements et même accroître le taux de matière organique des sols.
- quant à la zone tropicale semi-aride les nombreux travaux de GANRY (1977-1984) cités en bibliographie, ceux de CHABALIER (1976), de GIGOU (1982), de PICHOT (1981) et de PIERI (1982) tendent à prouver que les rendements des cultures et la productivité des terres ne peuvent être maintenus que si l'on restitue des produits organiques déjà transformés, comme le compost et le fumier (cf. figure 5).

L'établissement des bilans minéraux de ces divers systèmes de culture, et l'étude de l'évolution des caractéristiques chimiques des sols où ont été réalisés ces expérimentations de longue durée, permettent de mieux comprendre le rôle essentiel que jouent les restitutions organiques dans le maintien de la fertilité des sols en Afrique de l'Ouest.

2.4. Bilans minéraux et évolution des caractéristiques chimiques des sols

Une mise au point récente a été publiée sur ce sujet pour la zone climatique semi-aride (PIERI, 1983).

A titre d'exemple les tableaux 4 et 5 correspondant à des calculs de bilans minéraux établis après 17 années de culture au Sénégal font ressortir les deux points fondamentaux suivants:

- avec fumure N P K annuelle et restitution de paille de céréales, présence de fumure N P K, le bilan apparent en azote (N Engrais + N fixation + N résidus - N exporté par les récoltes) est négatif.
- les bilans apparents et les bilans établis à partir de l'évolution des stock minéraux dans les sols (0-30 cm) ne sont en grave désaccord: le sol s'est en effet beaucoup plus appauvri en N que le bilan apparent le laissait prévoir, et il en est de même pour le bilan calcique gravement déficitaire.

En fait il s'avère nécessaire de prendre en compte la plupart des termes de ces bilans pour établir un diagnostic d'évolution de fertilité valable. Les flux internes au sol, de minéralisation de la matière organique et de passage des éléments minéraux sous forme disponible à partir des réserves, la lixiviation, les pertes gazeuses d'azote, les apports atmosphériques sont autant de facteurs à prendre en compte pour établir des bilans, qui seront sinon erronés, s'ils se limitent à la comparaison exportations minérales par les cultures-apports d'éléments fertilisants.

Evoquons brièvement quel peut être l'impact d'une sous évaluation des pertes par lixiviation et par érosion, et d'une surévaluation des effets de la fixation biologique de N_2.

2.4.1. Pertes par lixiviation

Les tableaux 6 et 7 relatifs à des zones tropicales semi-arides et tropicales humides donnent une évaluation de ces pertes.

Contrairement aux idées reçues, les pertes en zone semi-arides ne sont pas mineures, du fait de la distribution très irrégulière des pluies notamment en début de cycle de culture et en sols très sableux.

Il est intéressant d'observer que sous céréales traditionnelles (mil et sorgho) les pertes en eau et en éléments minéraux sont mineures par rapport à des cultures à enracinement moins profond. On note aussi l'étroite relation entre pertes en azote nitrique et entrainement de Ca et Mg notamment en zone semi-aride.

2.4.2. - Pertes par érosion

Pour les mêmes raisons (irrégularité de la pluviosité) l'érosion est loin d'être négligeable dans la zone semi-aride d'Afrique de l'Ouest.

ROOSE (1980) observe en effet qu'en Afrique occidentale les pluies sont érosives car 3 à 60 fois plus aggressives qu'en régions tempérées, les pertes moyennes en éléments minéraux qui en résultent se situent dans les limites suivantes:

C = 80 à 1,900 kg $ha^{-1}an^{-1}$
N = 15 à 80 kg $ha^{-1}an^{-1}$
P = 3 à 30 kg $ha^{-1}an^{-1}$
K = 10 à 55 kg $ha^{-1}an^{-1}$
Ca = 15 à 70 kg $ha^{-1}an^{-1}$
Mg = 10 à 35 kg $ha^{-1}an^{-1}$

Le tableau 8 donne des indications sur les pertes moyennes (période 1958-1963) en éléments minéraux mesurés sous diverses cultures à Madagascar.

Comme les pertes en terre annuelles ne suivent pas une loi de distribution normale mais plutôt log-normale, l'évaluation des pertes en nutrients a été faite en tenant compte de la moyenne géométrique des pertes en terre.

Ces valeurs moyennes obtenues cachent malgré tout une grande diversité de situation.

Ainsi dans le cas de la culture à plat de maïs faite en 1962-63 les pertes en terre ont atteint 67,8 tonnes/ha, et en conséquence les pertes minérales, mesurées dans la fraction solide (terre déposée dans les cuves de mesure) et la fraction liquide (suspension) ont été les suivantes:

	Erosion "solide"	Erosion "liquide"
	(kg/ha)	
Matière organique	2,915	146
N	173	-
P_2O_5	16	1
CaO	30	39
MgO	7	4
K_2O	4	9

Les pertes minérales et organiques par érosion et ruissellement sont donc susceptibles de peser très fortement dans la balance minérale des systèmes de cultures développée en zone de savane humide.

L'érosion "solide" la plus novice, est la cause majeure de la perte en matière organique des sols. Elle entraine aussi des pertes en azote et phosphore non négligeables. Les eaux de ruissellement sont plus particulièrement cause des pertes en cations Ca, Mg et K.

2.4.3. Fixation symbiotique

La quantité d'azote fixée par une légumineuse donnée, en un lieu donné, varie très largement selon les conditions du milieu et, pour ce qui concerne les zones arides et semi-arides, surtout en fonction de l'alimentation hydrique de la culture.

GANRY et WEY (cités in WETSELAAR et GANRY, 1982) donnent pour différentes légumineuses cultivées au Sénégal, les valeurs suivantes de pourcentage d'azote absorbé provenant de la fixation symbiotique (Nf):

- 20 à 70% pour une même variété d'arachide
- 0 à 58% pour un même cultivar de soja,

pourcentages essentiellement influencés, selon ces auteurs, par les périodes de sécheresse, la présence ou non dans les sols d'azote minéral et/ou de souches efficientes de Rhizobium.

Le cas de l'arachide est essentiellement intéressant à souligner (tableau 9) car on constate qu'une pluviométrie inadéquate peut entrainer une chute de rendement modérée (21%) alors que la quantité Nf est réduite de près de 70%: l'arachide puise alors 75% de l'azote dont elle a besoin dans la réserve azotée et organique du sol qu'elle contribue ainsi à appauvrir.

On arrive alors à la constatation suivante: loin de toujours améliorer le bilan N du sol, certaines légumineuses peuvent au contraire contribuer à l'appauvrissement en azote de ceux-ci (WETSELAAR et GANRY, 1982).

2.4.4. - Conclusion

Cette brève évocation des résultats obtenus par les agronomes de la zone francophone d'Afrique (et de Madagascar) montre clairement que la fertilisation est un moyen puissant d'accroître les rendements des cultures, dans le cadre d'une agriculture stabilisée.

Cependant, cette itensification des culture, sans sole de repos (jachère de longue durée) pose des problèmes particulièrement aigus en Afrique semi-aride comme le souligne PICHOT et al. (1981):

> "Les engrais minéraux binaires (N P) ou ternaires (N P K) procurent des augmentations de rendement pendant quelques années mais provoquent un appauvrissement du sol en bases et une acidification préjudiciables aux cultures. Cette évolution qui est liée aux apports d'engrais azotés, se traduit en particulier, par l'apparition d'une déficience en potassium et d'une toxicité en aluminium dont les effets sur l'installation des plantules sont très importants. Les apports de matière organique au sol: enfouissements d'engrais vert et de résidus de récolte ou apports de fumier permettent d'atténuer voire de juguler ces effets néfastes des fumures minérales. Cependent l'enfouissement des pailles de sorgho une année sur deux ne suffit pas pour éviter à terme l'acidification et l'appauvrissement en bases. Seuls les apports de fumier qui, compte tenu des doses appliquées, correspondraient au sein d'une exploitation à un véritable transfert de fertilité, permettent de maintenir la productivité du sol."

En conclusion la mise au point de systèmes intégrés d'intensification agricole et de maintien de la fertilité des sols cultivés en milieu paysan suppose, dans le contexte agronomique et économique de l'Afrique de l'Ouest que l'on mette au point des techniques permettant un recyclage efficace des résidus organiques produits dans les exploitations agricoles, une fixation biologique de N_2 atmosphérique la plus élevée possible, et une utilisation optimale des coûteux engrais minéraux, techniques à moduler selon les systèmes de cultures et le contexte agroclimatique varié de la zone sub-saharienne.

III. Problèmes Liés à La Pratique du Recyclage des Résidus Culturaux

La pratique du recyclage des résidus culturaux pose trois séries de problèmes:

a. quels que soient les résultats expérimentaux intéressants obtenus par ce recyclage, existe-t-il vraiment dans les exploitations agricoles actuelles des résidus culturaux disponibles à des fins d'amélioration et maintien de la fertilité?

b. l'enfouissement de résidus organiques à C/N élevé ne peut-il engendrer des effets dépressifs immédiats sur les cultures (allélopathie, "faim d'azote," pertes en N-engrais),

c. quels sont les modes de recyclages organiques que l'on peut actuellement préconiser en zone tropicale ouest-africaine?

3.1. Disponibilité en résidus organiques dans les exploitations agricoles

- Dans les agrosystèmes tropicaux, la partie exportable de la plante est variable en fonction du système de production de l'agriculteur et des besoins domestiques de sa famille. En effet, les pailles de céréales sont très souvent valorisées en dehors de la parcelle culturale, soit pour l'alimentation des animaux, soit pour la construction des habitations, soit pour la cuisson des aliments. Quant aux pailles de légumineuses, il est clair qu'elles sont maintenant considérées par les agriculteurs comme une partie essentielle de la récolte, en particulier dans les régions soudano-sahéliennes ($P < 1,000$ mm).

- Les enquêtes réalisées en diverses régions du Sénégal (ALLARD et al., 1983) ont permis d'évaluer dans les conditions réelles, les quantités de pailles produites et celles qui sont susceptibles d'être recyclées à des fins agronomiques (tableau 10).

On s'aperçoit ainsi que les quantités disponibles sont très limitées en particulier dans les zones où se pose avec acuité le problème des énergies domestiques. Des observations semblables ont été faites au Burkina Faso sur le plateau MOSSI (SEDOGO, 1981). La raréfaction des sources de bois de chauffage intensifie la collecte des pailles de mil et sorgho et leur utilisation comme combustible.

- Dans les zones plus pluvieuses la collecte est bien plus faible et les possibilités de valorisation agronomique restent importantes.

Ainsi une première constation s'impose: la disponibilité en résidus organiques est souvent très limitée et particulièrement critique dans les zones d'élevage des régions semi-arides d'Afrique.

3.2. Effets de l'enfouissement de résidus organiques sur la nutrition des cultures

Quelques travaux réalisés au Sénégal ont mis l'accent sur des phénomènes de phytotoxicité dus à des composés phénoliques contenus dans les pailles de mil (GANRY et al., 1978), ou dans l'ensemble des résidus culturaux du sorgho (BURGOS-LEON et al., 1980). Ces phénomènes ne semblent cependant jouer un rôle majeur que dans le cas des enfouissements réalisés immédiatement avant le semis. En effet, la biodégradation des composés phénoliques des pailles demande environ trois semaines en période pluvieuse.

D'autres expérimentations ont permis de constater un effet "faim d'azote" sur les cultures, en particulier en l'absence d'engrais azoté (GIGOU, DUBERNARD, 1979; GIGOU, 1980) et uniquement en cas d'apports massifs de paille. Quand les quantités correspondent à celle que l'on peut récolter normalement (3 à 5 tonnes/ha) et qu'il y a répétition des enfouissements, on n'observe généralement que des effets modestes et généralement positifs sur les rendements. Les enfouissements de paille ont par ailleurs des effets beaucoup plus nets sur les bilans potassiques (PIERI, 1982) ou sur l'acidité du sol.

Les travaux réalisés au Burkina Faso montrent que le compostage des pailles de sorgho supprime l'effet "faim d'azote" (cf. tableau 11).

Le fumier cumule semble-t-il tous les avantages: effet positif sur la nutrition potassique, suppression de la toxicité aluminique, et surtout effet très positif sur la fourniture en azote comme le prouve les mesures de minéralisation de l'azote faites par SEDOGO sur différents résidus organiques (cf. figure 6).

De nombreux travaux ont eu lieu enfin sur l'effet du recyclage organique sur le coefficient d'utilisation des engrais minéraux azotés et sur la contribution de ces engrais à l'azote des grains de céréales (cf. tableau 12).

Il est donc particulièrement important de souligner que les apports de résidus organiques n'ont pas diminué l'efficience des engrais azotés, dont la contribution[1] à la constitution azotée des grains se situe toujours en moyenne à 35%.

3.3. Modes de recyclage des résidus organiques

Comment donc peut-on gérer les résidus culturaux?

Si on écarte la solution traditionnelle, mais peu économe en azote, du feu courant (ou de l'écobuage pratiqué dans les zones montagneuses volcaniques) il reste 4 possibilités:

- mulch
- enfouissement
- compostage aérobie ou anaérobie
- transformation par les animaux

Les travaux de recherche réalisés par l'IRAT relatifs à la fertilité des sols ont porté presque exclusivement sur les trois dernières solutions.

3.3.1. Pratique de l'enfouissement des pailles

Labour ou pseudo-labour ? Labour de fin de cycle ou labour de début de cycle?

De nombreuses expérimentations réalisées au Sénégal et en Côte d'Ivoire, sur ce sujet, mettent en évidence les difficultés considérables que l'on rencontre pour enfouir des pailles entières, dans le cadre des systèmes de culture non motorisée.

Il ne semble donc pas faisable de préconiser cette solution pour une agriculture mécanisée en traction animale.

3.3.2. Le compostage

Longtemps considéré comme irréaliste, cette solution présente l'avantage de pouvoir être réalisée en divers endroits: sur la parcelle elle-même, au niveau de l'habitation ou du groupe d'habitations. Elle peut fournir un produit plus facile à enfouir que les pailles et même de l'énergie.

La transformation des résidues culturaux en compost peut en effet, être faite par voie semi-aérobie: compostage en tas ou en fosse, ou encore par voie anaérobie par fermentation méthanogène fournissant du BIOGAZ.

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[1] (Contribution = $\frac{\text{(N - Engrais) dans les grains}}{\text{N total des grains}}$ %

Ces diverses possibilités ont été étudiées principalement au Sénégal en liaison avec l'ORSTOM et au Burkina Faso avec le CIEH. Un prototype de "digesteur en continu" a été mis au point par l'IRAT et le biogaz produit permet à LOSSA (Niger) depuis 4 ans de fournir l'énergie nécessaire à une ferme irriguée pilote (FOREST, 1980).

Cependant du point de vue de la fertilité des sols, les résultats de GAGNOA (Côte d'Ivoire) et de BAMBEY (Sénégal) montrent que le compost n'est pas la panacée. Notamment dans les sols très sableux du Sénégal, les résultats obtenus montrent que sous culture continue l'amélioration du stock de matière organique (C, N) n'est envisageable que si les techniques culturales associent amendement organique et fertilisation.

La comparaison de plusieurs résidus de récolte (pailles de mil et de sorgho, coque d'arachide) compostés ou non a également été faite. L'incorporation au sol de 10 tonnes/ha de résidus organiques bruts ou de 8 tonnes/ha de compost ne procure un véritable enrichissement que dans le cas des coques d'arachide compostées.

Ce résultat semble particulièrement intéressant dans un pays comme le Sénégal où l'arachide joue un rôle économique important.

En conclusion sans penser dans l'immédiat à une valorisation monétaire de la fabrication du compost par la production systématique de biogaz et d'énergie à bon marché, il ne faut pas sous estimer l'intérêt que présente ce "paquet technologique" pour la zone tropicale humide où l'élevage bovin est faible ou nul mais où le potentiel et la disponibilité en biomasse sont élevés. Cette "filière biogaz" semble aussi particulièrement appropriée aux exploitations agricoles en bordure d'une source d'approvisionnement en eau permanente (vallées du Niger, du Sénégal, mares et étangs dans la zone maritime du Bénin, du Togo, etc...).

Sans suivre cette filière n'oublions pas que le simple tas de paille se compostant sur place, est une pratique envisageable, et en tout cas déjà souvent utilisée par certains agriculteurs africains (les Bamileké du Cameroun qui pratiquent aussi l'écobuage).

3.3.3. Le fumier

Le développement de la traction bovine dans certaines régions d'Afrique a sensiblement modifié les modalités de la valorisation par les animaux des débris végétaux présents dans les champs après récolte. Traditionnellement en effet, les résidus végétaux étaient consommés par des troupeaux nomades pendant la saison sèche; parfois, cette utilisation donnait d'ailleurs lieu à des contrats entre paysans et pasteurs car les effets des déjections animales sur la fertilité du sol sont connus, en particulier dans les zones soudano-sahéliennes. Avec le développement d'un élevage sédentaire, une concurrence s'établit entre les paysans et les pasteurs, l'appropriation des résidus se développe et se traduit par un ramassage assez soigneux et la constitution de meules à proximité des habitations. Dans les parcs où sont gardés les troupeaux sédentaires, les déjections des animaux s'accumulent en se mélangeant à la terre, ce qui donne la poudrette de parc, dont la composition est très variable et la valeur agronomique assez limitée (cf. tableau 13).

Une des actions connues susceptibles d'améliorer la qualité du fumier consiste en la réalisation d'étables-fumières permettant de récupérer un fumier moins terreux, mélés de débris végétaux.

Des études ont été également réalisées sur les meilleures modalités d'utilisation du fumier (GANRY, GUIRAUD, 1978). Il apparait ainsi que l'enfouissement est très utile pour limiter les pertes d'azote dans l'atmosphère et ralentir la minéralisation de la matière organique.

Le fumier, dont on peut valoriser l'emploi et améliorer la production, n'en reste pas moins la seule solution offerte aux régions semiarides d'agriculture et d'élevage de la zone soudano-sahélienne pour permettre une élévation durable de la fertilité des sols.

3.4. Conclusion

Quelles que soient les preuves expérimentales des multiples intérêts, voire de la nécessité, du recyclage des résidus organiques de nombreuses limitations existent dans la systématisation de cette pratique en agriculture paysanne africaine.

Dans les zones semiarides, la biomasse produite en faible quantité est l'objet d'utilisation multiples qui laisse peu de place à un emploi rationnel dans le cadre d'une politique, à moyen terme, de maintien de la fertilité pourtant vitale pour l'avenir agricole de ces zones. L'amélioration de la production et de l'utilisation du fumier parait être la seule voie à suivre.

Dans les zones plus humides, il semble exister plus de possibilités mais il sera nécessaire de mettre au point des "filières" de recyclage des résidus qui, outre leur intérêt pour le maintien de la fertilité, permettront de dégager un revenu supplémentaire immédiat justifiant aux yeux des agriculteurs l'effort supplémentaire (équipement pour transporter, arroser, enfouir, ...) qui leur est proposé. La filière biogaz + petite irrigation est un exemple intéressant, le compost produit à même la parcelle restant une pratique simple certainement vulgarisable, et en tout cas déjà pratiqué par certains agriculteurs (Cameroon).

IV. Améliorations Possibles de L'Efficience de la Fixation Symbiotique par les Légumineuses[2]

Les difficultés pratiques d'un recyclage effectif des résidus culturaux dans les exploitations agricoles conduisent à attacher une grande importance à l'amélioration du bilan azoté des sols grâce aux légumineuses. Les observations faites plus haut (§2.4.3.) montrent que le rôle positif que peuvent jouer ces espèces fixatrices d'azote n'est pas assuré, et qu'il convient de mettre au point des systèmes de cultures qui permettent d'approcher de la "fixation potentielle."

Pour un système fixateur donné, cette activité optimale est en fait toujours diminuée par différents facteurs; ces facteurs peuvent être liés à la bactérie, à la plante, ou aux conditions de milieu dans lesquels fonctionne la symbiose.

Les actions que l'on peut envisager d'entreprendre à ces trois niveaux sont ici brièvement présentées.

4.1. Actions sur la bactérie

Dans certaines conditions, l'absence quasiment complète de bactéries fixatrices adaptées dans le sol permet une action, par inoculation.

Tel est le cas du soja au Sénégal dans bon nombre de sols de la zone soudano-sahélienne. Comme le montrent les tableaux 14 et 15, l'inoculation a permis d'améliorer la levée, les taux d'azote dans la plante et les rendements de cette culture.

Au cours des dernières années l'IRAT a beaucoup étudié avec l'ISRA (Sénégal) les problèmes particuliers liés à la pratique de l'inoculation: choix et évaluation de souches, préparation d'inoculum dans un fermenteur approprié (WEY, 1983; MONTANGE, BEUNARD, 1984), mise au point de techniques d'inoculation (WEY, SAINT MACARY, 1982; WEY, 1983). On a pu montrer que l'inoculation des

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[2] Ce chapitre reprend l'essentiel d'un exposé présenté au CNEARC par H. SAINT MACARY.

semences de soja au Sénégal n'était pas à conseiller et que l'inoculation du sol était préférable (cf. tableau 16); cette opération peut être réalisée grâce à un semoir épandeur dont le prototype a été mis au point à cette occasion.

Cependant dans le cas d'autres systèmes fixateurs, et notamment de l'arachide, il a été montré que l'inoculation était sans effet (GANRY, WEY, NDIAYE, 1976) (Cf. fig. 7).

4.2. Action sur la plante

Bien que le choix de la variété permettant une efficience maximale de la symbiose soit une voie de recherche très prometteuse, il est souvent difficile de mettre en oeuvre des actions concrètes dans ce domaine.

GANRY (1984) souligne cependent l'intérêt dans la pratique agricole de choisir des variétés de soja qui:

- d'une part soient <u>économes</u> <u>en</u> <u>azote</u>, c'est-à-dire des variétés pour lesquelles les quantités de N minéral provenant du sol et de l'engrais, nécessaires pour obtenir 100 kg N-plante, soient les plus faibles possibles

$$(\text{coefficient } e = \frac{\text{N minéral absorbé})}{\text{N total plante}}$$

- d'autre part, favorisent le maintien du stock N du sol, en considérant que la quantité de N contenue dans les feuilles (et normalement restituées au sol à la récolte) soit au moins égale à la quantité de N-sol utilisée

$$(\text{coefficient } m = \text{N feuilles} - \text{N-sol} > 0)$$

Le tableau 17 montre un exemple d'application de ce double critère, sur 4 variétés créées au Sénégal et comparées à Jupiter, variété qui s'avère être une des plus épuisantes de la fertilité azotée du sol.

4.3. Actions sur le milieu

Le plus souvent dans la pratique, selon l'expérience de l'IRAT, ce sont les actions sur le milieu qui ont le plus grand impact sur l'amélioration de l'efficience de la fixation symbiotique et le rendement des légumineuses chez lesquelles ne se posent pas de problèmes d'inoculation.

4.3.1. Lutte contre les stress hydriques

L'effet des stress hydriques sur la fixation a déjà été souligné plus haut et est illustré par la figure 8 (GANRY, 1982).

Toutes pratiques culturales permettant d'améliorer l'alimentation hydrique des légumineuses, notamment au stade jeune, ont une importance considérable, comme il sera montré plus loin.

4.3.2. Lutte contre l'acidité

Bien que des différences d'efficiences aient été observées sur des systèmes fixateurs en condition de bas pH, il ne semble pas que les bactéries soient directement affectées par les bas pH.

Dans une expérimentation récente (cf. fig. 9) on a fait d'abord pousser des plants de soja pendant (0, 1, 2, 8, 12, 16, ...) jours en milieu nutritif à pH 6, puis en les maintenant pendant la suite à pH 4. On a observé que la nodulation est normale lorsque la période favorable (pH = 6) est supérieure ou égale à 10-12 jours; la production (et l'efficience) elle n'est affectée que lorsque la période favorable est inférieure à 2 jours (SAMSON, 1984).

Ainsi, la phase de formation de nodosités est certes très sensible à l'acidité, mais il y a possibilité de rattrapage, car l'efficience ne semble pas être modifiée par l'acidité.

On reproduit ainsi expérimentalement les conditions d'un amendement localisé au champ, ou d'un enrobage de semences qui maintiendrait un environnement physico-chimique favorable pendant une brève période (DENARIE, 1968). Cette technique très peu onéreuse serait aussi efficace qu'une application massive d'amendement dont le but serait d'élever le pH du sol acide à un niveau jugé classiquement satisfaisant (pH 5.5).

Ces deux techniques sont actuellement en cours de comparaison à Madagascar dans le cadre d'un système de culture soja-maïs, car les besoins en chaux ne doivent pas être appréciés uniquement d'après le comportement de la culture de soja mais aussi en prenant compte les exigences du maïs (sensibilité à Al, besoin en Mg).

4.3.3. Pratiques culturales

Le tableau 18 et la figure 10 montrent l'impact considérable des techniques de préparation du sol et de fumure sur les rendements de l'arachide et la fixation symbiotique de N_2. Le labour et l'apport de fumier associé, avec ou sans chaux, s'avèrent très efficace améliorant à la fois la croissance racinaire et l'efficience de la fixation symbiotique de l'arachide qui béné ficie de conditions hydriques et minérales plus favorables.

Il faut faire cependent remarquer que l'intensification et le fait de favoriser le développement végétatif de la plante peut rendre celle-ci plus sensible en cas de stress hydrique. La fixation étant une des premières activités du système fixateur à être pénalisée, il convient d'être prudent dans les conditions de climat semi-aride.

4.4. Conclusion

Le recours dans les systèmes de cultures aux légumineuses doit être recommandé dans cette région. Légumineuses à graines voire fourrage et engrais vert de légumineuses, sont des sources d'azote "gratuit" particulièrement intéressantes en agriculture paysanne africaine.

Cependent dans de nombreux cas du fait, soit d'une présence insuffisante de bactéries efficientes adéquates, soit de cultivars mal adaptés, ou de conditions du milieu physique impropres (stress hydrique, acidité, pauvreté minérale), l'efficience de la fixation azotée peut être fortement réduite et le bilan azoté de la rotation céréale-légumineuse s'avérer déficitaire (cf. tableau 19).

De bonnes pratiques culturales permettant de pallier les contraintes imposées par un milieu défavorable (manque d'eau, acidité) sont alors souvent les actions les plus significatives que l'on peut entreprendre pour améliorer l'efficience de la fixation symbiotique de N_2 par les légumineuses.

Dans ce domaine comme dans celui de l'introduction des légumineuses fourragères dans des systèmes stabilisés de production agricole et animale, de gros efforts de recherche et de vulgarisation restent à faire.

V. Optimisation de L'Utilisation des Engrais Minéraux

Que ce soit pour améliorer la nutrition minérale des cultures, on ne peut envisager d'accroître durablement la productivité agricole des terres, même dans le cas d'un recyclage efficient des résidus culturaux (cf. §3.3.2), sans avoir recours aux engrais minéraux.

Les trois objectifs que l'on doit se fixer en matière d'optimisation de l'emploi des engrais minéraux en région sub-saharienne sont:

a. corriger les carences minérales qui limitent la fertilité potentielle des sols,

b. suppléer à "l'offre" minérale des sols pour satisfaire à la "demande" des cultures "intensifiées,"

c. limiter, et pour le moins ne pas accroître, les risques encourrus par les agriculteurs qui emploient les engrais minéraux, notamment les risques climatiques (péjoration des effets de stress hydrique en cas de pluviosité aléatoire) et économiques (non rentabilité).

5.1. Correction des carences minérales des sols

En Afrique comme à Madagascar le cas le plus fréquemment observé est celui de la carence phosphatée.

De nombreux travaux ont été réalisés sur ce sujet (PICHOT, TRUONG, BEUNARD, 1979) ainsi que sur les méthodes de correction de cette carence.

En Afrique de l'Ouest cette carence nécessite pour être corrigée des doses modestes de phosphore (40 à 70 P_2O_5 kg/ha).

Cependant le cas des sols ferrallitiques désaturés ayant un pouvoir d'absorption élevé vis à vis des ions phosphates, est intéressant à considérer, car il semble bien que l'on ait souvent exagéré l'impact réel du phénomène de "fixation," très bien mis en évidence en laboratoire (FARDEAU, 1976) mais dans la pratique agricole moins contraignant qu'on le pensait.

Il apparait en outre que la fumure massive de redressement dont on a pu préconiser l'application en une seule année (sous forme d'investissement foncier dont le coût est pris en charge par la communauté nationale ou internationale et non par le paysan qui ne saurait en supporter le coût) puisse être en pratique progressivement mise en place.

Ceci a été particulièrement étudié à Madagascar où l'on a comparé les effets sur la production et sur les sols d'une forte fumure P initiale (360 kg/ha P_2O_5) comparée à des applications modérées annuelles (45 à 90 kg/ha P_2O_5) de phosphate.

Les principales conclusions ont été les suivantes:

- avec un apport annuel de 45 kg/ha de P_2O_5 on obtient en 4ème année d'application 80% de la production obtenue après application de la fumure forte de redressement,

- malgré l'apparente "rétrogradation" du P engrais, indiquée par les analyses chimiques classiques, son effet résiduel se fait nettement sentir sur les cultures. Cette fraction disponible du P engrais appliqué est d'autant plus grande que les apports sont échelonnés c'est à dire que la proportion des apports P annuels par rapport à la dose initiale (fumure de redressement) est plus élevée,

- le phosphate naturel type Hyper Réno sous forme pulvérulente a, dans les conditions de cette expérimentation réalisée à Ampangabé, la même efficacité qu'un superphosphate triple,

- en définitive si la fumure massive de redressement appliquée en une seule fois, est celle qui permet de dégager la plus value monétaire la plus grande après 5 années de culture, il n'en reste pas moins qu'une fumure P modérée permettant un développement progressif de la production reste une voie très intéressante car elle diminue les risques financiers et les risques de gaspillage (érosion intempestive) toujours élevés (ARRIVETS J. et al. à paraître).

5.2. Fertilisation adaptée aux besoins des cultures

Des nombreuses études existent dans ce domaine, les agronomes ayant étudié les doses, les formes, les modes d'apport, les équilibres minéraux les plus adaptés à chaque culture (IRAT, 1975).

Une attention toute particulière a été portée aux techniques permettant de réduire les pertes par lixiviation sous cultures, en jouant d'une part sur la réduction des teneurs en éléments solubles de drainage (PIERI, 1983).

Ceci conduit à préconiser un fractionnement de l'apport de certains engrais notamment azotés sur céréales (GANRY), voire potassique en zone tropicale humide.

VELLY (1972) cite plusieurs résultats expérimentaux relatifs à l'intérêt du fractionnement de l'engrais K, en conditions de culture intensive. Ainsi à Ampangabe un apport de 90 kg K_2O/ha:

- au semis permet d'obtenir	3,709 kg/ha de grains de maïs
- en 2 fois,	4,134 kg/ha
- en 3 fois,	4,630 kg/ha

L'IRAT a en outre attaché beaucoup d'importance à toutes les techniques qui favorisent le développement des cultures et tout particulièrement l'exploration du sol par un enracinement dense et profond (cf. NICOU, CHOPART). Il faut souligner le fait que les espèces cultivées ont des aptitudes différentes à développer un enrachinement vigoureux, particulièrement dans des zones de savane soumis aux aléas de sécheresse temporaire.

Ceci peut justifier, notamment chez les petits exploitants, l'emploi de cultures associées, les céréales de type traditionnel tel que le sorgho ou le mil d'Afrique de l'ouest, constituant, par comparaison aux cultures de cotonnier ou d'arachide, de véritables "pièges" à eau et à éléments minéraux (cf. §2.4.1).

5.3. Fertilisation et limitation des risques

Pour les agriculteurs à faible ressources monétaires et qui très généralement n'ont qu'un accès très limité (les cultures de rente) au crédit, il est important que l'emploi des engrais minéraux n'augmente pas les risques qu'ils peuvent subir, liés à la pluviosité irrégulière et au rapport de prix généralement très défavorable entre les productions vivrières et l'engrais.

5.3.1. Fertilisation et risque climatiques

On a souligné le rôle potentiel considérable des engrais dans l'accroissement de la production (cf. §2.2, tableaux 2 et 3).

Cependant les valeurs moyennes de rendement cachent souvent une très grande variabilité interannuelle de la production en raison des conditions climatiques de l'année.

Des travaux plus récents, toujours conduits en station de recherches, semblent prouver que la fertilisation est un facteur de production permettant de tamponner ces effets climatiques (stress hydriques, températures élevées), ce qui est classiquement reconnu. Ainsi F. FOREST et J. M. KALMS (1982) dans leur étude de l'influence du régime d'alimentation en eau sur la production du riz pluvial (1984) laissent entendre que, grâce à la fertilisation (30-30-40) cette culture valorise beaucoup mieux l'eau disponible dans la période critique allant de la fin du tallage à l'initiation paniculaire. Par contre, estiment ces auteurs, il ne semble pas justifié d'employer une fumure plus forte, et donc plus coûteuse, en raison des risques climatiques, et donc économiques, encourus.

Cet effet tampon de la fumure existe pour autant que celle-ci soit équilibrée. Ainsi en culture intensive de mil (avec labour profond, contrôle des adventices et des déprédateurs) l'adjonction de K à une fumure phosphoazotée permet de réduire de moitié la variabilité interannuelle des rendements qui, en l'absence de fumure, est du même ordre de grandeur que celle de la pluviométrie (C. PIERI, 1982) (cf. tableau 20).

Dans les deux cas cités, les auteurs expliquent cet effet "tampon" par le rôle de la fumure (associée à une bonne préparation des terres ce qui n'est pas la règle générale en champs paysans) sur la croissance accélérée des cultures et, en particulier, de leurs racines qui ont ainsi accès à un volume de sol plus important et donc à une réserve utile en eau plus abondante. Dans le cas du mil, il s'avère que l'engrais K joue essentiellement sur la vigueur au démarrage de la culture (vitesse de croissance accélérée dans les 15 premiers jours) et peu sur sa nutrition potassique tout au long du cycle cultural.

5.3.2. Réduction du coût des engrais: cas des phosphates naturels

On observe en Afrique francophone que les engrais les plus utilisés sont généralement très concentrés (urée, formule complexe à base de DAP et KCl) en raison du coût très important du transport, coût particulièrement élevé dans les pays enclavés sans frontière maritime ni fabrication locale.

La présence de nombreux gisements de phosphates naturels dans cette partie du monde a naturellement conduit l'IRAT à recommander l'emploi direct de ces engrais potentiels (PICHOT, TRUONG, BEUNARD, 1979) montrant expérimentalement (TOURTE, 1964) que l'on pouvait ainsi préconiser des plans de fumure par rotations culturales basées sur l'emploi successif d'engrais simples (fumure phosphatée de fond, azotée sur céréale, potassique sur arachide, etc...) et non sur des formules complexes NPK adaptées à chaque culture.

Il est vrai cependant que ces phosphates ne sont pas toujours directement assimilables, supportant mal la comparaison avec les formes plus solubles et plus faciles à manipuler par les agriculteurs en raison de leur présentation granulée.

L'IFDC a remis au goût du jour les phosphates partiellement acidifiés que les producteurs d'engrais européens ont progressivement retiré du marché.

Le tableau 21 présente quelques résultats expérimentaux obtenus au Togo et au Burkina Faso avec des phosphates originaires de ces pays et partiellement attaqués par deux sociétés productrices d'engrais (SIVENG et TIMAC).

Incontestablement dans le cas de phosphates naturels, ce procédé d'attaque partielle accroit très sensiblement leur efficience, mais il reste à apprécier l'intérêt économique pour l'agriculteur (coût réduit des engrais) et pour le pays (réduction des importations) de ce procédé qui suppose en définitive que l'on puisse avoir accès à de l'acide sulfurique à bas pris de revient.

Aussi parallèlement à ce procédé industriel, une solubilisation partielle est aussi tentée par le biais du procéde de compostage, les résultats expérimentaux s'avérant pour l'instant variables (Burkina Faso...) et parfois très encourageants (Sénégal, Ganry).

VI. Conclusion Générale

Le bilan des travaux exécutés par la recherche agronomique francophone en Afrique et à Madagascar montre qu'il existe des bases agrotechniques solides permettant d'engager les pays concernés sur la voie de l'intensification agricole qu'il faudra obligatoirement suivre pour satisfaire leur demande alimentaire croissante.

Assurément la fertilisation est une technique de choix pour accroître la productivité agricole dans cette partie du monde mais si l'on veut produire plus et de façon durable il est indispensable de conjuguer les effets des engrais minéraux, du recyclage des résidus organiques et de la fixation biologique de l'azote, en cherchant en outre à optimiser l'emploi des ressources minérales locales tels les phosphates naturels.

L'entretien organique des sols tropicaux, de même que le recours au chaulage dont l'impact immédiat sur les rendements n'est pas toujours visible, bien qu'inévitables, soulèvent de graves problèmes d'application, car ils relèvent d'une stratégie de maintien de fertilité à long terme qu'il faudrait que des agriculteurs, légitimement soucieux du lendemain, voire de survie, ne sont guère enclins à appliquer, pour des raisons plus économiques que techniques vraisemblablement.

L'expérience des dix à vingt dernières années montre malheureusement que dans l'ensemble les systèmes techniques d'intensification des productions vivrières sont très mal passés chez les paysans, ceux-ci se contentant trop souvent de retenir certaines techniques permettant d'étendre jusqu'à la saturation foncière les systèmes traditionnels extensifs.

La situation de crise auquelle il faut faire face peut permettre d'espérer un renversement des tendances, mais il faut bien souligner que cela ne dépend pas que des agriculteurs.

Car il faut que l'intensification agricole, qui doit reposer sur des bases agrotechniques fiables, soit également voulue par tous les acteurs et décideurs nationaux et internationaux du développement rural. Les politiques de prix, voire les législations foncières de plusieurs de ces pays permettent-elles actuellement cette révolution?

Si on s'en limite au seul domaine de la fertilisation des cultures et de la fertilité des sols dans de nombreux pays, particulièrement ceux des régions semi-arides ne faudra-t-il pas aussi:

- amorcer une restructuration du paysage rural dans lequel l'agroforesterie retrouvera la place quelle mérite,
- réglementer la vaine pâture, et l'emploi et la valorisation des résidus de récolte par un bétail sédentaire,
- résoudre les problèmes d'approvisionnement de voies de circulation, de crédit de campagne pour des cultures qui ne sont pas de rente,
- établir un juste équilibre entre prix des intrants et prix d'achat et de vente des denrées agricoles.

L'oeuvre à entreprendre est immense à la dimension de ce vaste continent africain.

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Tableau 1. Contribution aux accroissements de production (%)
(90 pays en voie de développement 1975-2000)

Région	Extension des surfaces cultivées	Intensité de culture	Augmentation du Rendement/ha
90 pays	26	14	60
Afrique	27	22	51
Asie	10	14	76
Amérique latine	55	14	31
Moyen Orient	6	25	69

Source: FAO 1981.

Tableau 2. Effet des thèmes d'intensification sur les rendements d'une succession arachide-mil-arachide (Sénégal, R. TOURTE, 1971)

	Rendement kg ha^{-1}		
Culture	0*	tl	TL
Arachide	950	1,090	1,140
Mil	430	700	1,020
Arachide	960	1,170	1,070

0* = Témoin: sans engrais
tl: 150 kg ha^{-1} 6.10.10 sur arachide, 14.7.7 sur mil-Travail du sol manuel
TL: 500 kg ha^{-1} Phosphate naturel et compléments NSK sur chaque culture-Labour à la charrue

Tableau 3. Rendements du maïs à 9 paliers d'intensification
BOUAKE (Côte d'Ivoire)
Moyennes (1967-1978) en kg/ha

	Grattage superficiel	Labour aux boeufs (12 cm)	Labour profond au tracteur (30 cm) + enfouissement des résidus
Sans engrais	368	483	459
40-40-60*	1,809	1,670	2,330
80-80-120**	2,726	2,690	3,089

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* fumure remplacée par 15 tonnes/ha fumier tous les 3 ans + 20-40-40.
** fumure remplacée par 15 tonnes/ha fumier tous les 3 ans + 40-80-80.

Tableau 4: Bilans minéraux estimés par 17 années de culture d'une rotation quadriennale (Sénégal 1963-1979, SARR 1981).

Termes bilan	N		P_2O_5		K_2O		CaO	
	Témoin	E	Témoin	E	Témoin	E	Témoin	E
E	-746	-1,731	-178	-379	-411	-1,095	-273	-480
F+Nf+O	+252	+956	0	+438	0	+1,353	+364	+571
Bilan	-494	-415	-178	+59	-412	+258	+96	+91

E: exportations minérales par les cultures à la récolte.
F: apports d'engrais.
Nf: quantité N fixée par l'arachide (60% N total).
O: restitutions de résidus organiques.
Témoin: sans engrais
E: fumure NPK vulgarisée + restitution pailles céréales.

Tableau 5: Variations des stocks minéraux du sol en N total, P_2O_5 assimilable, K et Ca échangeables, après 17 années de culture au Sénégal (d'après SARR, 1981)

	N		P_2O_5		K_2O		CaO	
	Témoin	E	Témoin	E	Témoin	E	Témoin	E
	(kg ha^{-1})							
Bilan "sol"	-1,320	-1,200	+10	+55	+12	+44	-571	-1,438

Témoin: sans engrais.
E: avec engrais (cf. tableau 4).

Tableau 6. Pertes minérales par lixiviation sous culture au Sénégal (PIERI 1982), au Cameroun (GIGOU 1982), en Côte d'Ivoire (CHABALIER 1983)

Lieu (Pays)	Pluviométrie mm (Année)	Culture	Drainage mm	Pertes kg $ha^{-1}an^{-1}$				
				N	CaO	MgO	K_2O	P_2O_5
Bambey (Sénégal)	507 (1981)	Mil	9.5	0.3	0.8	0.4	0.3	Tr
		Arachide	100.6	25.1	54.1	13.6	5.2	Tr
Maroua (Cameroun)	705 (1975)	Sorgho	2	Tr	0.1	0.1	Tr	Tr
	683 (1977)	Cotonnier	83	2.1	43.7	12.3	1.7	Tr
Bouaké (Côte d'Ivoire)	633 (1981)	Maïs	210	6.1	36.4	26.2	2.4	Tr
	532 (1981)	Cotonnier	260	7.1	18.0	6.6	2.0	Tr

Tableau 7. Pertes minérales par lixiviation sous cultures fertilisées à Ampangabe (ARRIVETS 1981)

Pluviométrie mm (année)	Culture (Rendement q/ha)	Drainage mm (% pluvio)	Pertes minérales kg/ha			
			N	K_2O	CaO	MgO
1,106 (78-79)	Arachide (30)	457 (41.3)	43.0	20.4	36.4	38.2
1,297 (79-80)	Maïs (46)	393 (30.3)	39.0	14.4	43.4	28.5
	Arachide (-)	420 (32.4)	51.0	15.6	51.8	41.5
	Blé (12)	490 (37.8)	37.0	12.0	28.0	44.8
1,209 (79-80)	Maïs* (59)	379 (31.3)	18.3	8.4	26.6	30.5
	Sol nu*	717 (59.3)	102.7	58.4	109.2	102.4

* Même fertilisation: Nov 72 2 tonnes/ha dolomie, 1 tonne/ha Hyper Reno, 0.5 tonnes/ha KCl

Nov 79 140 N, 30 P_2O_5, 60 K_2O

Tableau 8. Valeurs moyennes du ruissellement des pertes en terre et en éléments minéraux sous différentes cultures en rotation (Nanisana-Ambatobe - Mad., 1958-1963)

		Maïs (+ Pois mascotte)		Arachide		Prairie	
		Plat	Billon	Plat	Billon	1 ère année	2 ème année
Ruissellement % Pmm							
Moyenne 1958-63		11.5	7.5	11.8	11.1	14.7	0.7
Valeurs extrêmes		5.5-17.1	6.2-11.3	3.6-16.0	7.4-17.5	7.6-19.4	0-1.2
Moyenne géométrique		10.5	7.2	9.7	10.7	14.1	0.2
Erosion ton/ha/an							
Moyenne 1958-63		19.1	3.9	12.5	4.1	16.1	0.1
Valeurs extrêmes		1.0-67.8	2.6-5.0	1.4-26.4	2.0-5.6	1.9-33.8	0.1
Moyenne géométrique (1958-63)		8.4	3.8	8.9	3.9	11.4	0.1
Pertes minérales solides (Moyenne 1958-63)							
	Teneurs	(kg/ha/an)					
• MO	4.9% ±0.07%	412	186	436	191	559	5
• N	2.42% ±0.058%	20	9	22	9	28	0.2
• P_2O_5	0.526% ±0.0215%	4	2	5	2	6	Tr
• CaO	1.262% ±0.0715%	11	5	11	5	14	0.1
• MgO	0.176% ±0.0071%	1	1	2	1	2	Tr
• K_2O	0.086% ±0.0030%	0.7	0.3	0.8	0.3	1	Tr

Tableau 9. Effet de la pluviométrie sur l'efficience de la fixation symbiotique de N_2 par des légumineuses (GANRY, WEY, 1982)

Pluviométrie	Culture	Rendement (Qté N mobilisé) (kg/ha)	Pourcentage d'Azote des Parties Aériennes Provenant de Fixation	Sol	Engrais
Satisfaisante*	Soja	2,315 (189N)	55	40	5
	Arachide	1,420 (74N)	66	32	2
Mauvaise**	Soja	835 (68N)	58	38	4
	Arachide	1,126 (59N)	21	75	4

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* Pluviométrie assurant une bonne alimentation hydrique de la plante.

** Pluviométrie insuffisante en quantité et mal répartie.

Tableau 10. Disponibilité en résidus végétaux dans la région centrale du Sénégal (d'après J. F. ALLARD et al., 1983)

Zone	Culture	Pailles (tonnes/ha)	Ramassage (%)	Utilisation	Disponibilité (tonnes/ha)
Nord Bassin Arachidier	Arachide	0.7-1.0	100	Animaux	Nulle
	Mil	1.0-2.0	50-100	Domestique + Animaux	Nulle
	Jachère	0.4-3.0	50-100	Domestique + Animaux	Nulle
Sud Bassin Arachidier	Arachide	0.7-1.7	100	Animaux + Vente	Nulle
	Mil	1.7-3.0	10-15	Domestique	1.0-2.5
	Jachère	0.4-3.0	10-15	Domestique	0.2-2.5

Tableau 11. Effet de différents résidus organiques sur le rendement du sorgho (d'après SEDOGO)

	SARIA - Rendements kg/ha de sorgho	
	Sans apport d'azote	Avec 60 N - urée
Sans apport organique	1,831	2,796
10 tonnes/ha de paille de sorgho	1,652	3,427
10 tonnes/ha de fumier	2,409	3,591
10 tonnes/ha de compost aérobie	2,505	3,688
10 tonnes/ha de compost anaérobie	2,304	3,601

Tableau 12. Effet des résidus organiques sur le coefficient d'utilisation de N - engrais

Culture (Lieu)	Fumure (kg/ha)	Grain (kg/ha)	Coefficient d'utilisation N-Engrais 1er apport	Coefficient d'utilisation N-Engrais 2éme apport
Maïs (Bouaké)	100 N	4,800	27	34
	100 N + 5 tonnes/ha paille	5,150	27	33
Mil (Bambey)	120 N	1,900	13	28
	120 N + 10 tonnes/ha compost	2,200	11	28
Sorgho (Maroua)	50 N	2,870	40	43

$$\text{Coefficient d'utilisation} = \frac{\text{(N - engrais) dans les grains}}{\text{Dose (N - engrais) appliquée}} \%$$

Tableau 13. Richesse minérale moyenne de fumiers prélevés dans les régions de Tananarive, Mahitsy, Ambohimandratrino, Bevalala (Madagascar 1958, 1962, 1965)

Elément	Teneur % M.S.		Valeurs extrêmes
	Moyenne	C.V. (%)	
N	0.68	32.6	0.43-0.96
P_2O_5	0.26	37.1	0.16-0.38
K_2O	0.59	42.8	0.36-0.84
CaO	0.12	61.9	0.06-0.23
MgO	1.48	100.9	0.64-3.71

Tableau 14. Effet de l'inoculation avec différentes souches sur les rendements du soja, Sénégal

	Témoin	Souche USDA 138	Souche "locale" A	Souche "locale" B
Poids sec des nodosités mg/plante	236	1,971	1,730	633
Rendement kg/ha	685	1,583	1,087	682
Azote total des graines kg/ha	38.1	105.9	62.1	37.2

Les souches ont été inoculées par application au sol.

Tableau 15. Comparaison des souches de Rhizobium sur le soja (1975): à Jupiter

	Temoin Non Inocule	Souche G3	Souches Locales (1)				C.V., %	Test F (2)
			Souche SA	Souche SB	Souche OP	Mélange de souches		
Nombre de pieds par ha	356,000	373,000	369,000	379,000	372,000	359,000	5.1	NS
Pourcentage de levée	79.1	83.0	82.0	84.4	82.8	80.0	-	-
Taux d'azote dans les feuilles au 60e jour	2.41(3)	4.23b	3.22a	2.61a	3.01a	2.80a	10.8	HS
Poids frais de nodosités en mg par plante	236	1,971	1,730	633	615	363	59	-
Rendement en graines kg/ha	685a	1,583c	1,087b	682a	685a	704a	23	HS
Taux d'azote dans les graines	5.58	6.69b	5.71a	5.44a	5.61a	5.55a	6.8	HS
Azote exporté par les grains kg/ha	38.1	105.9	62.1	37.2	38.4	39.1	-	-
Nombre de nodosités par plante au 60e jour	2.5	41.4	16.6	12.1	10.2	6.5	73.0	-

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(1) Inoculation liquide du sol.
(2) Les résultats portant la même lettre ne sont pas significativement différents au seuil de P = 0.01 (HS) et P = 0.05 (S).
(3) Les chiffres suivis d'une même lettre ne sont pas statistiquement différents.

Tableau 16. Effet de la méthode d'inoculation sur les rendements du soja au Sénégal

	Année	Témoin (kg/ha)	Inoculé (kg/ha)
Inoculation des grains	1972	993	983
	1973	2,016	2,541
Inoculation du sol	1975	685	1,583
	1978	826	1,528

Tableau 17. Choix de variétés économes en azote et favorisant le maintien de la fertilité N du sol (GANRY, 1984)

Variétés	e %	m
44/A/73	24.4	-0.7
4/73	26.9	-5.6
22/72	19.5	+6.6
26/72	14.4	+7.1
Jupiter	25.0	-6.1

Tableau 18. Effet des techniques culturales sur les rendements de l'arachide. Essai de Thilmakha (Sénégal)

Rendements (kg/ha)	Témoin	Labour	Labour + fumier	Chaux	Labour + chaux	Labour + chaux + fumier
Moyenne 1972-75						
Gousses	815	950	1,177	910	1,024	1,178
Fanes	794	1,031	1,486	913	987	1,455
Année 1981						
Gousses	355	413	669	652	725	816
Fanes	429	487	1,162	802	833	1,367

Tableau 19. Bilan azoté d'un système de culture mil-arachide en conditions semi-arides (Bambey - Sénégal, GANRY, 1982)

Gains kg/ha		Pertes kg/ha	
- Apports atmosphériques	Tr	- Exportations nettes par le mil	-33
- Engrais sur mil	+80	- Exportations nettes par l'arachide	-109
- Engrais sur arachide	+15	- Dénitrification et volatilisation:	
- Fixation symbiotique Nf	+82	· N-sol (2 années)	-50
		· N-résidus organiques (2 ans)	-8
		· N-engrais (2 ans)	-28
		- Lixiviation (2 ans)	-20
Bilan Net:	-71		

Tableau 20. Effet moyen de la fumure potassique sur les rendements en grain du mil en absence de restitution de paille (1973-77)

	Pluie utile (mm)	Témoin	NPK_0	NPK_{30}	NPK_{60}	NPK_{90}
		- - - - - -	- - - - -	(kg/ha)	- - - - -	- - - - -
Moyenne (1973-77)	452	1,278	2,246	2,489	2,513	2,515
Ecart-type	83.8	265	261	188	118	67
C.V. (%)	18.5	20.7	11.9	7.6	4.7	2.7

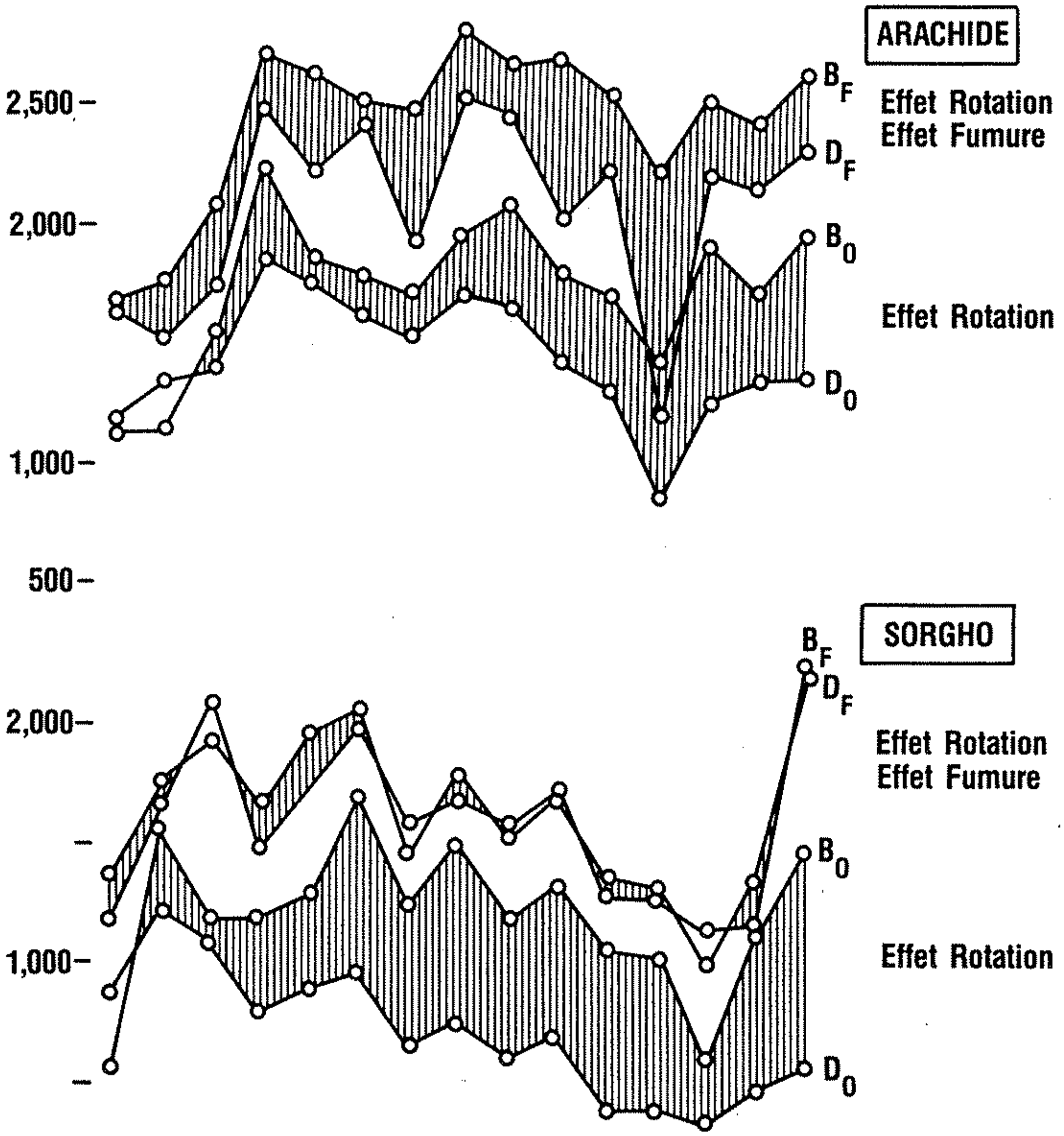
Tableau 21. Comparasison de différentes formes d'engrais phosphatés

TOGO: Experimentation Phosphate Naturel Partiellement Attaqué - Résultats 1983 de l'IRCT et de l'IRAT

	Coton-graine (47 essais)		Maïs (21 essais)	
Traitements	kg/ha	Indice %	kg/ha	Indice %
Témoin sans engrais	777	53	444	51
NPK (phosphate brut)	1,133	77	745	85
NPK (phosphate attaqué à 61%)	1,260	86	817	93
NPK (phosphate soluble)	1,484	100	875	100

BURKINA: Experimentation Phosphate Naturel Partiellement Attaqué - Résultats 1983 à Saria

	Sorgho grain	
	kg/ha	Indice %
Témoin NK	848	69
NPK (phosphate brut)	929	76
NPK (phosphate attaqué à 29%)	1,128	92
NPK (phosphate soluble)	1,217	100



1069	1031	891	1123	630	943	1129	844	1115	1150	1010	1136	720	721		Pluviometrie (mm)
1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Année

Figure 1. Essai Rotations de M'Pesoba (1955-1969).

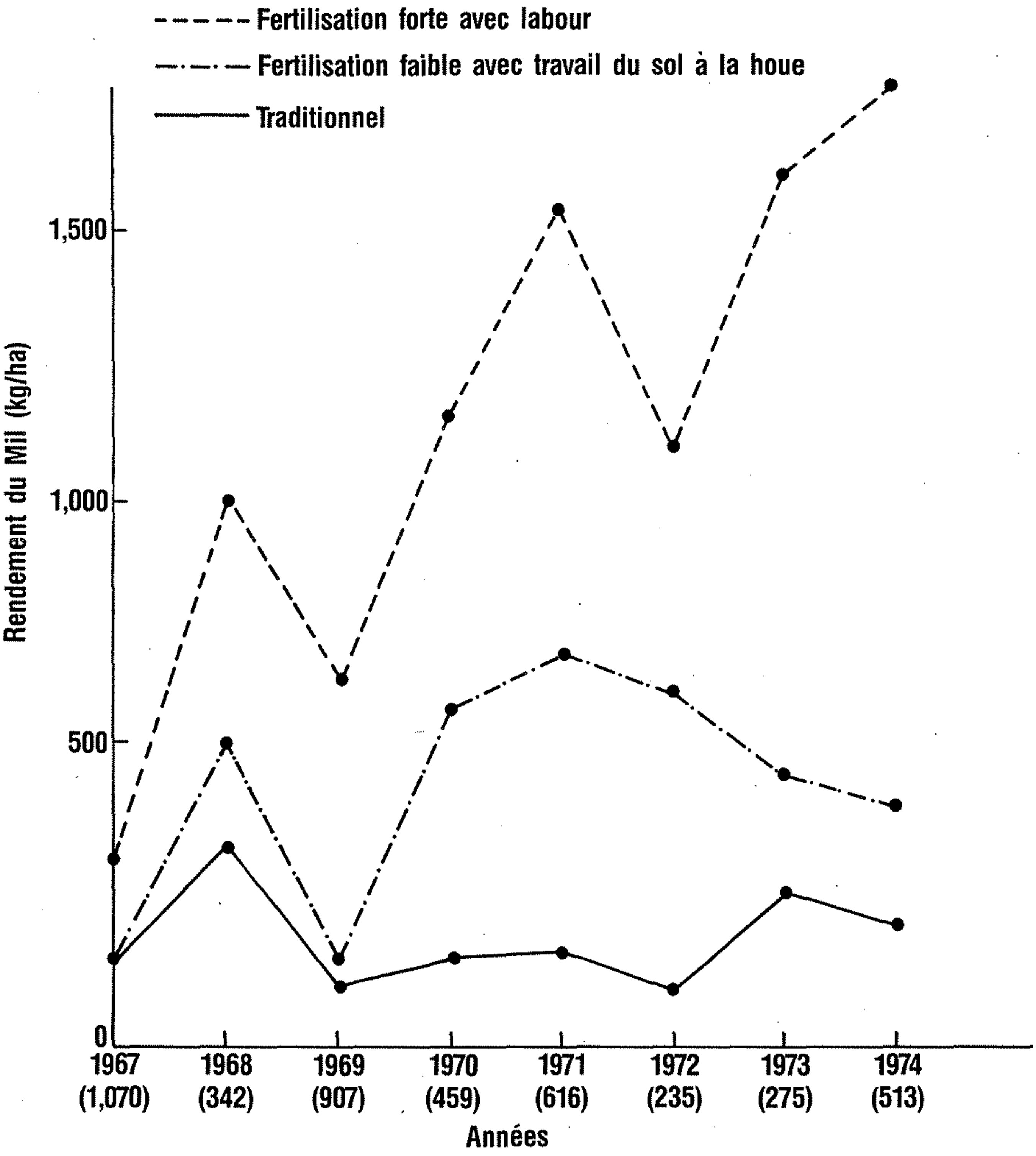


Figure 2. Changements de Productivite dus a la Fertilisation et au Labour (d'après G. Pocthier).

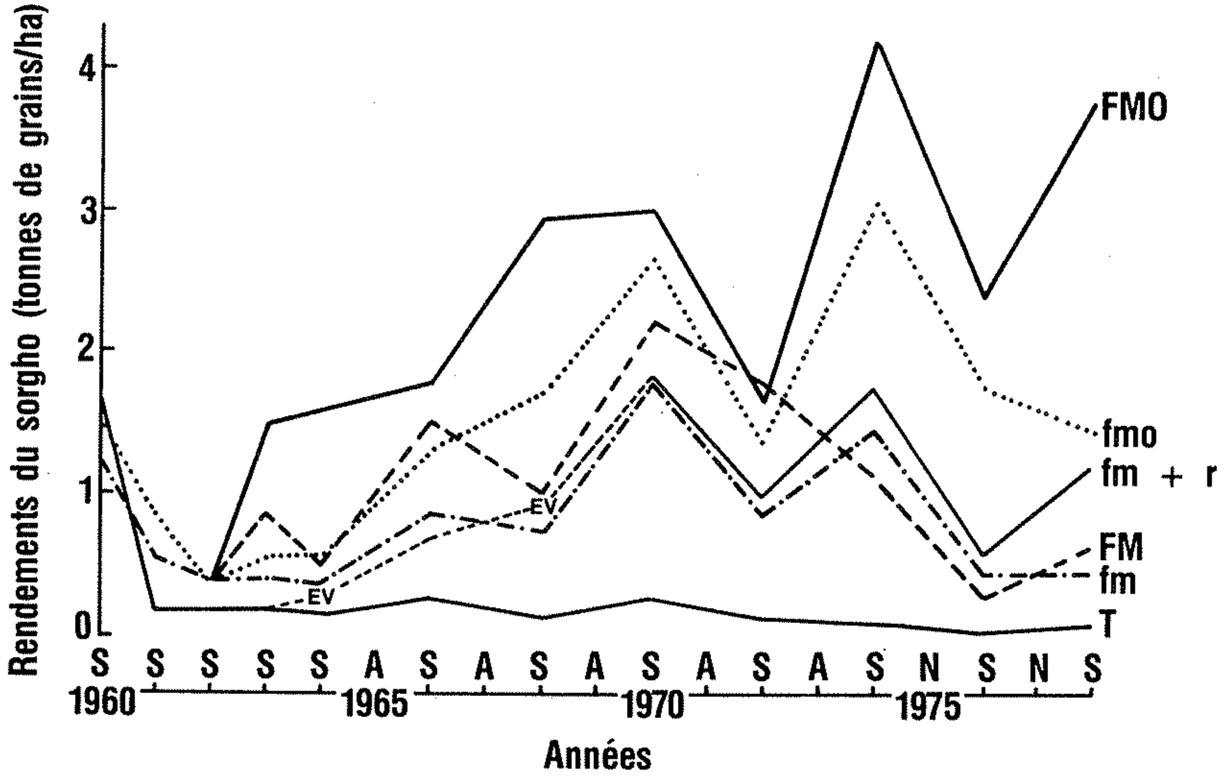


Figure 3. Essai Entretien de la Fertilite—Saria (Alternance Sorgho - Legumineuse).

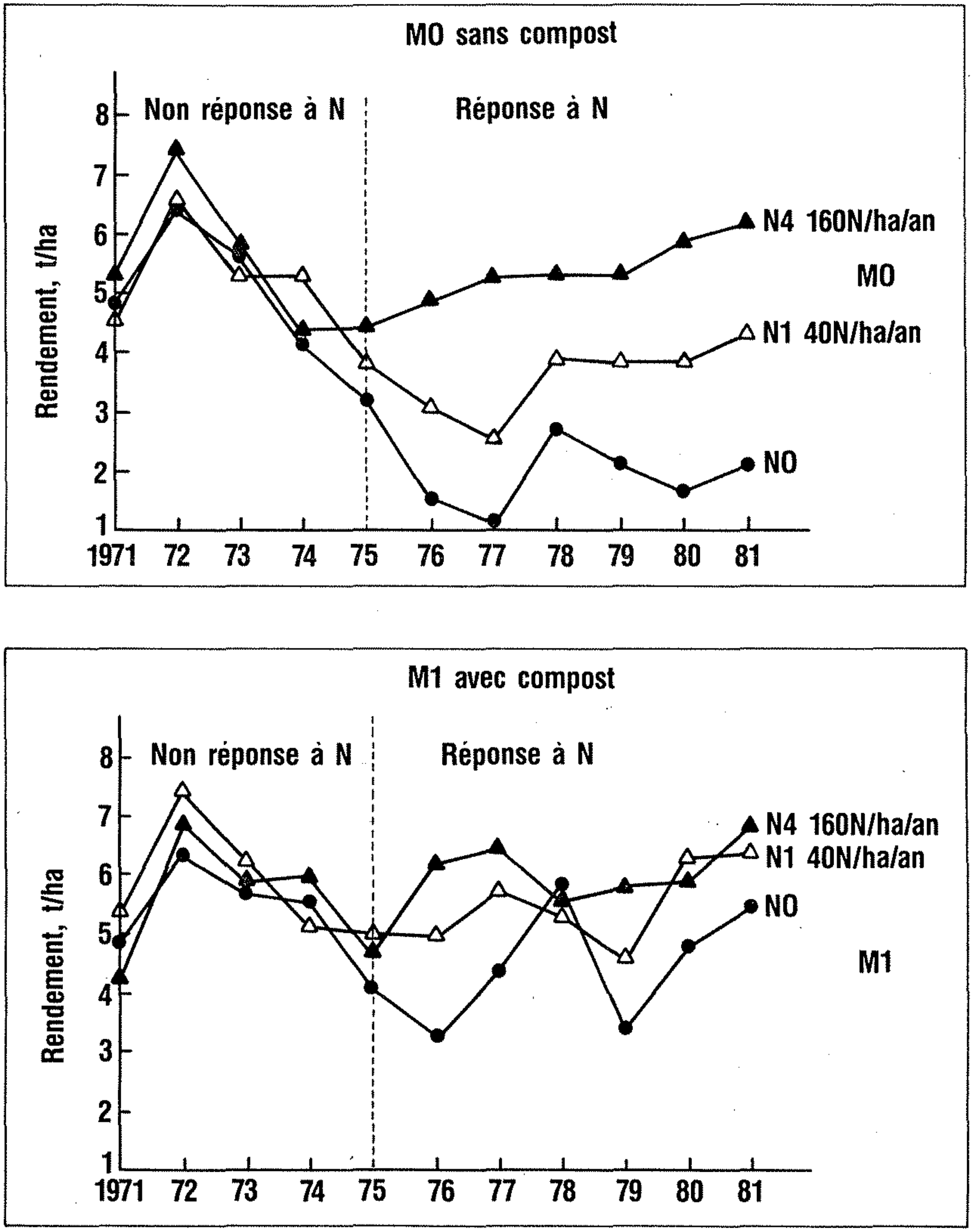


Figure 4. Evolution des Rendements du Maïs en Culture Continue à Gagnoa (Culture de Premier Cycle).

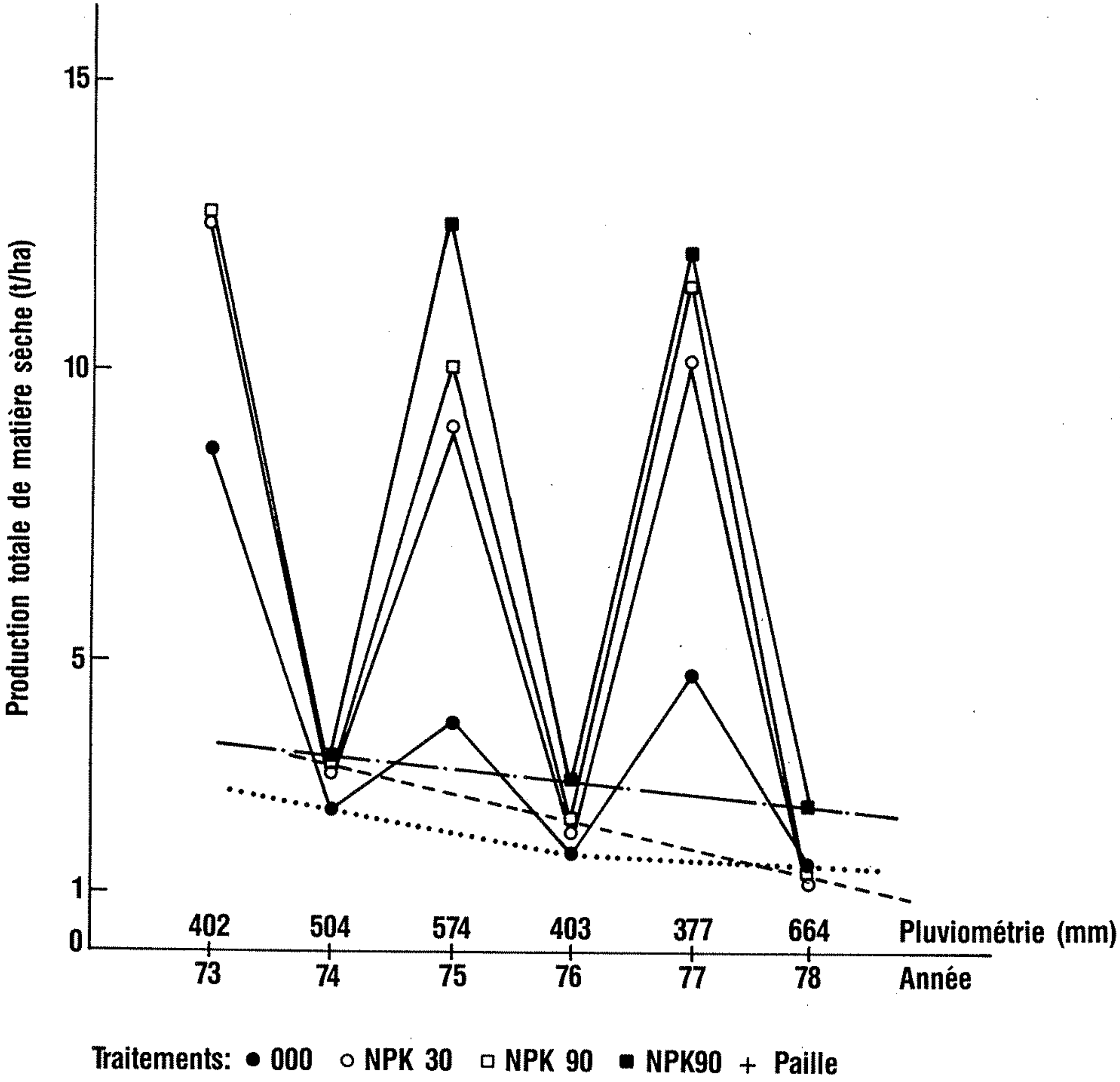


Figure 5. Evolution de la Production Totale de Matière Sèche Végétale Produite de 1973 à 1978 à Bambey.

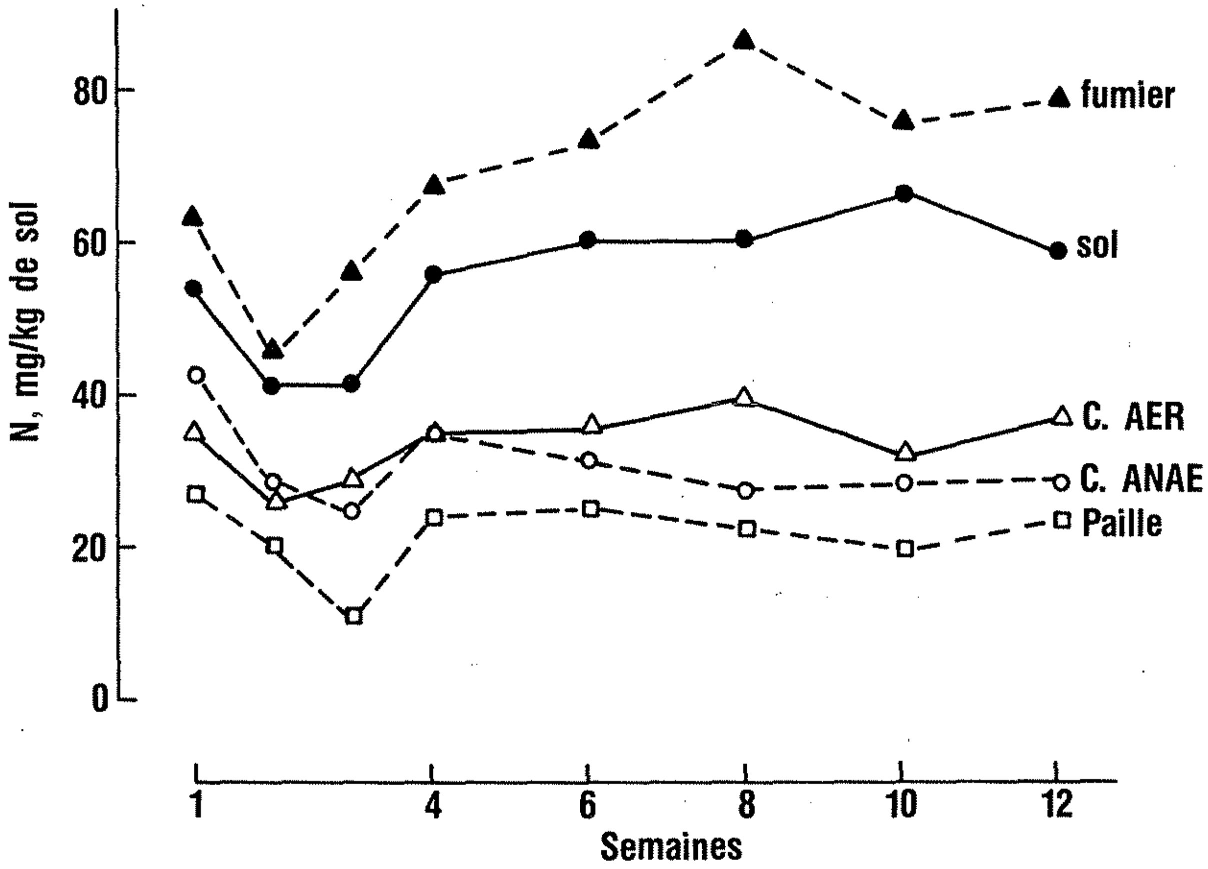


Figure 6. Evolution des Teneurs du Sol en Azote Extrait par Une Solution 0.5 N de K_2SO_4 au Cours d'une Incubation en Présence de Divers Amendements Organiques Ajoutés à Raison de 350 mgC pour 100 g de Sol et de 50 $mg.kg^{-1}$ de N (D'après SEDOGO (29)).

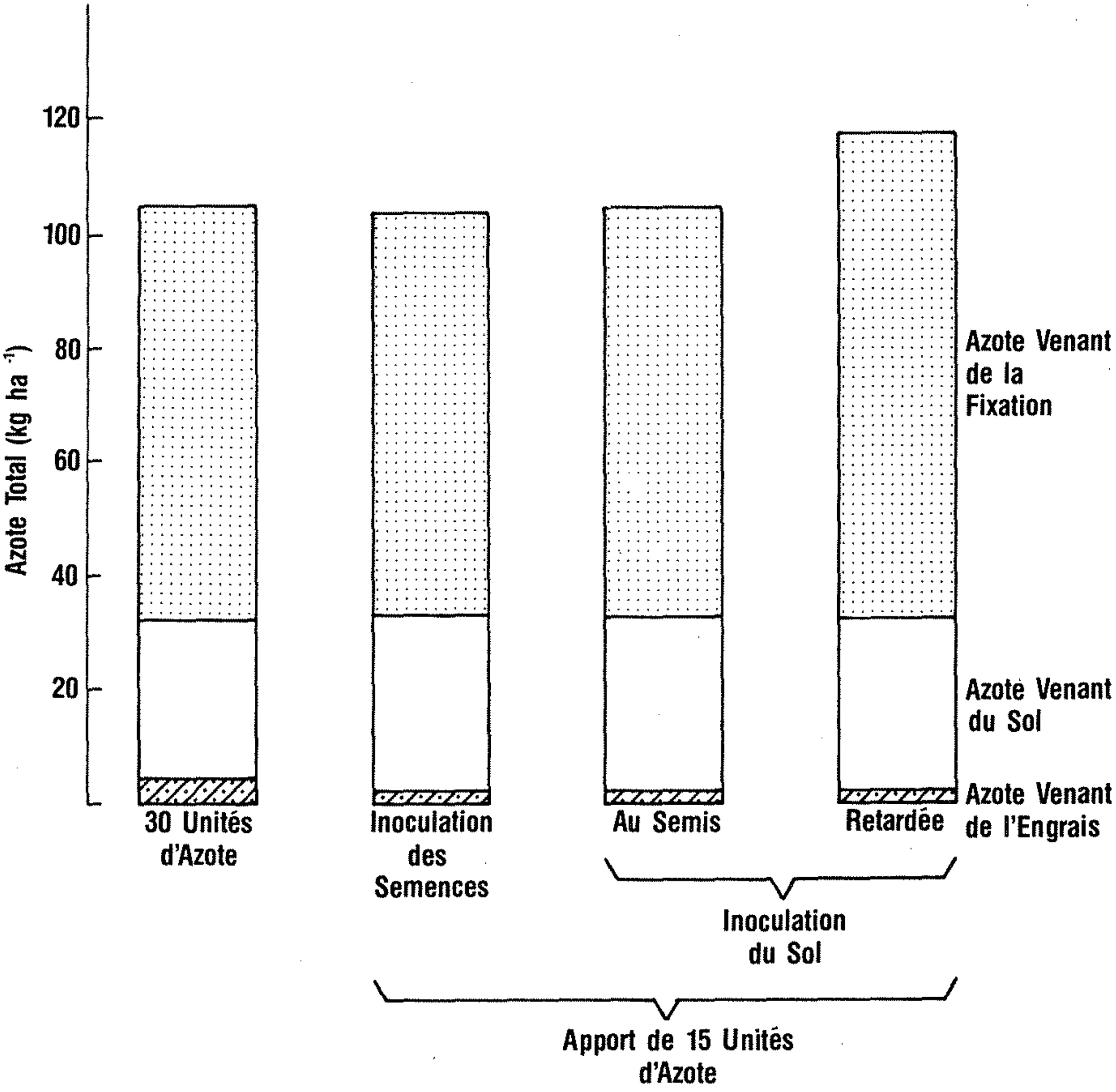


Figure 7. Effet de l'Inoculation de l'Arachide sur les Sources de Nutrition Azotée Bambey 1975.

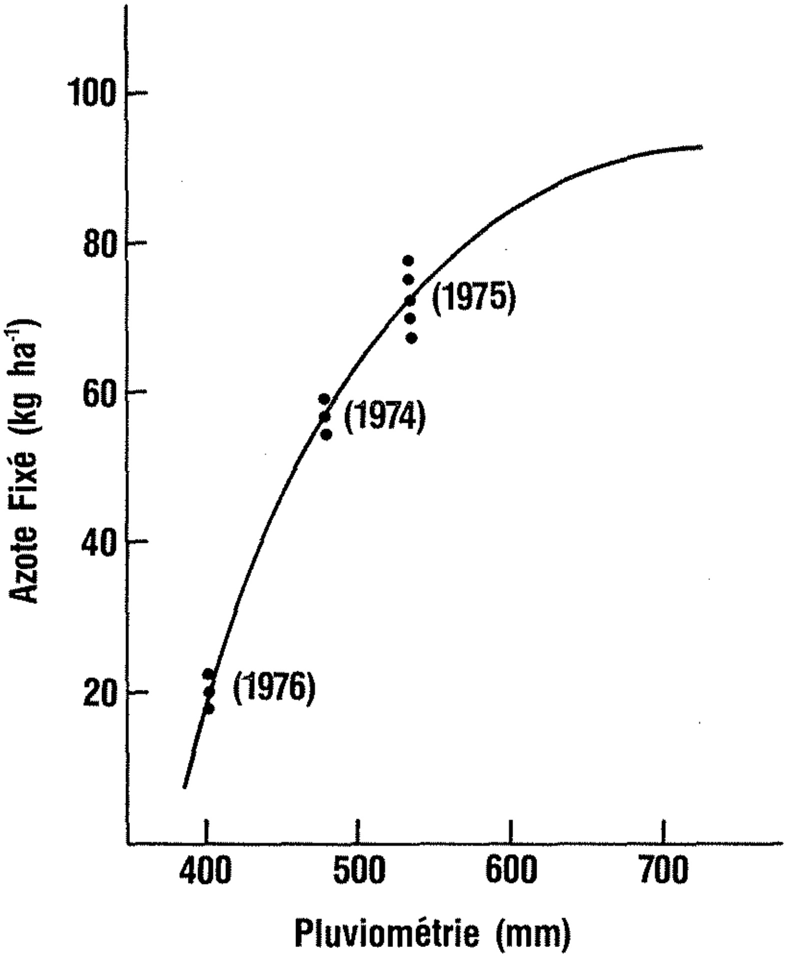


Figure 8. Relation Entre la Pluviometrie et les Quantities d'Azote Fixees par l'Arachide - Senegal.

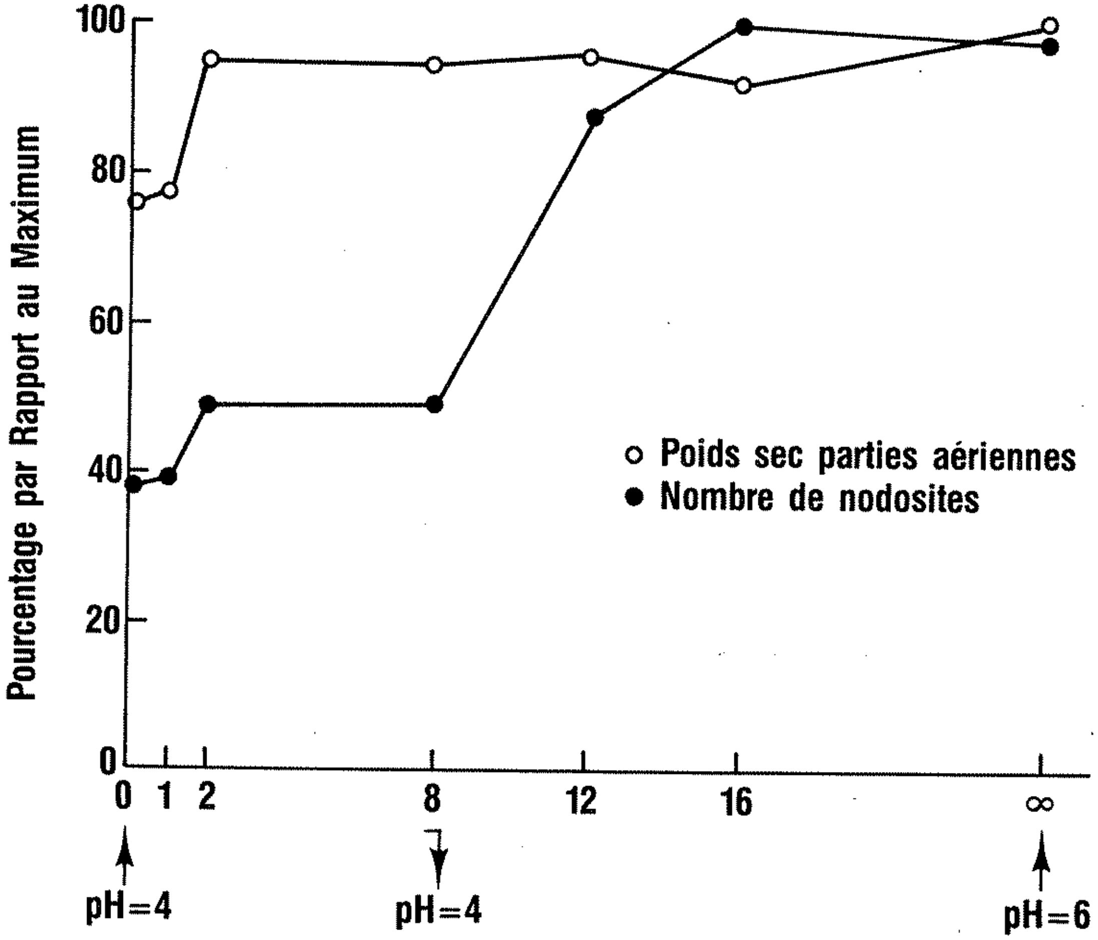


Figure 9. Influence du pH en Debut de Culture sur la Formation des Nodosites et la Production Vegetale.

Les plantes sont placées en début de culture à pH 6.5 et, après des temps variables à pH 4.

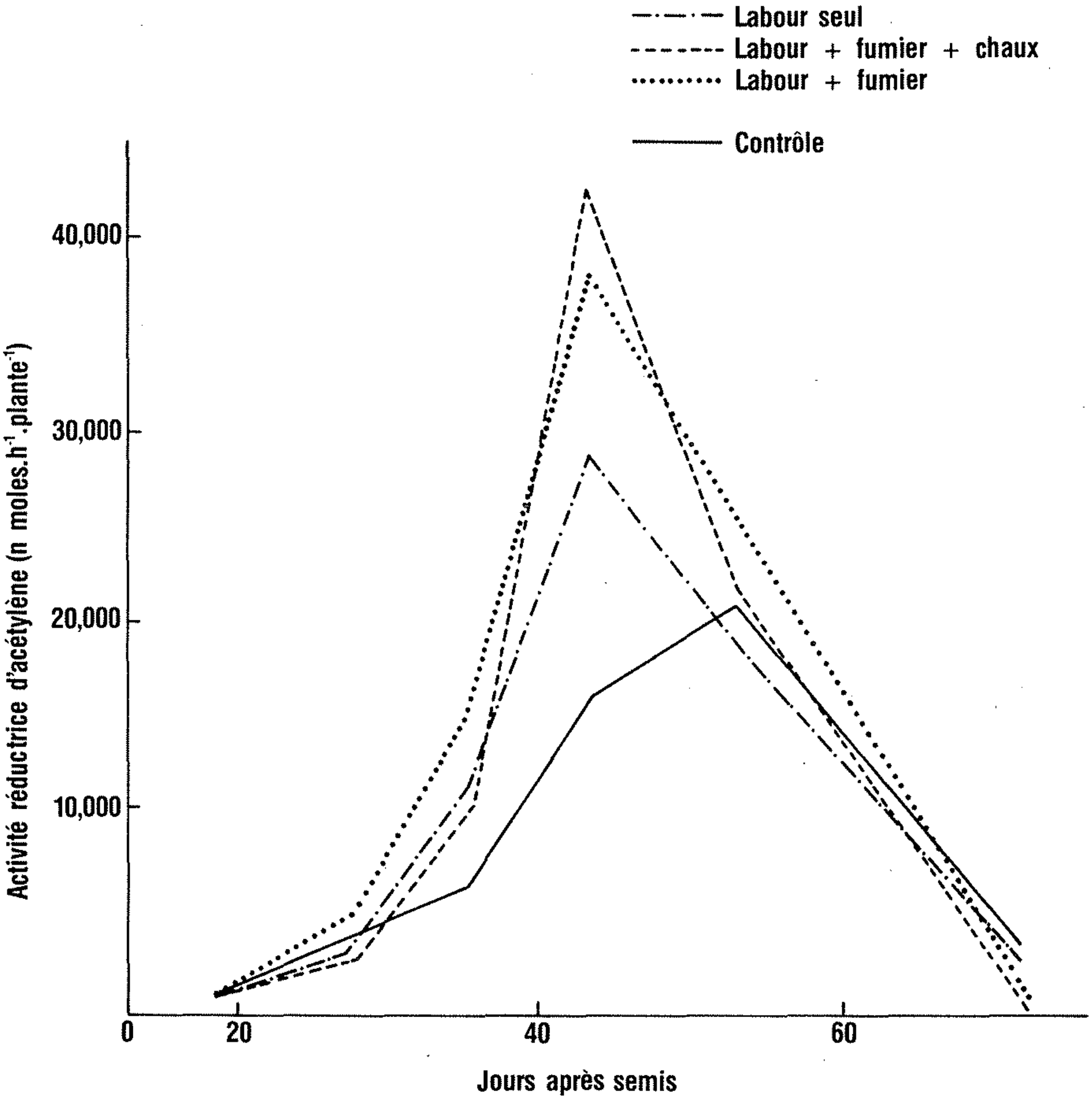


Figure 10. Effets du Travail du Sol, Fumier et Chaux sur la Fixation Symbiotique d'Azote de l'Arachide - Senegal 1974.

ETUDES DE REFERENCE SUR EVOLUTION FERTILITE A LONG TERME

1. ESSAIS DE LONGUE DUREE:

- en zone tropicale sèche:
  - essai de SARIA depuis 1960 (PICHOT et al., 1981, SEDOGO 1981) au Faso
  - essai de NIORO DU RIP de 1963 à 1979 (SARR 1981) au Sénégal
  - essai M'PESOBA de 1955 à 1970 (PIERI 1974) au Mali
  - essai de BAMBEY de 1973 à 1978 (PIERI 1982) au Sénégal
  - essai de N'TARLA de 19.. à 1973 (PICHOT et al., 1974) au Niger
  - essai de MAROUA 1973 à 1977 (GIGOU 1982) au Cameroun
- en zone tropicale humide:
  - essai de GAGNOA de 1971 à 1981 (CHABALIER 1977, K. Akomian 1982) en Côte d'Ivoire
  - essai de BOUKOKO 1965 à 1970 (PICHOT 1971) en R.C.A.
  - essai d'AMPANGABE de 1965 à 1971 (VELLY, LONGUEVAL 1976)
  - essai de DAVIE de 1976 à 1981 (MARQUETTE à publier)

2. DIAGNOSTIC EN CHAMPS PAYSANS:

- en zone sèche:
  - Etude de l'évolution des sols sous culture traditionnelle en Haute Casamance (SIBAND 1972)
  - Les contraintes de la culture cotonnière au Sénégal oriental (ANGE 1984)
- en zone tropicale humide:
  - Dix ans de culture motorisée sur un bassin versant du centre Côte d'Ivoire: évolution de la fertilité et de la production (Le BUANEC 1972)
  - Observations sur l'évolution à long terme de la fertilité des sols cultivés à Grimari R.C.A. (MOREL et QUANTIN 1972)

IITA'S FARMING SYSTEMS RESEARCH IN RELATION TO SOIL FERTILITY

Bede N. Okigbo

Introduction

A farming system consists of an activity or a set of bioeconomic activities in which a farmer or farm family manages resources and inputs (land, labor, fertilizers, crops, farm animals, tools, etc.) purposefully to produce a range of products that satisfy human needs for food, feed, fiber, and other products. In other words, a farming system is an agricultural enterprise involving several activities that are subject to varying degrees of integration and complexity in relation to commodities produced, which may range from one to several crops, or animals, or both. Farming systems are location-specific; therefore, they differ in physico-chemical (soils, climate, water, nutrients), biological (crops, animals, pests, weeds), technological (tools, machines, practices), and managerial (labor, markets, religion, customs, farmers' or community preferences) elements or factors (Okigbo, 1982).

Research is an organized quest for new knowledge, the development of new materials and varieties, technologies, and practices based on the scientific method. Farming systems research (FSR) is a holistic mission-oriented organized quest for new knowledge, materials, technologies, and practices that are continuously required to improve the efficiency and productivity of agricultural production so as to satisfy the increasing demand for food and other products. FSR is the culmination of the increasing recognition that agriculture is a complex bioeconomic activity in which physical, biological, socioeconomic, technological, and managerial factors interact in an intimate and dynamic manner. And research and development efforts aimed at the overall improvement of agriculture must tackle all of these facets simultaneously (Millikan and Hapgood, 1967). More recently, FSR has been considered as an institutionalized holistic research approach in both national and international agricultural research institutions in which efforts, methodologies, and strategies are aimed at improving traditional and existing farming systems through the development of materials, technologies, system components, and production systems that are relevant to the needs and circumstances of the majority of farmers. It entails:

1. Study of traditional and existing farming systems including the farmers' overall environment, production system, decisionmaking processes, input-output relations, constraints to increased productivity, and adoption of new technology. This study is then used as a basis for determining priorities and strategies that ensure relevance of research station studies to farmers' needs and circumstances.
2. Designing and testing of new technologies, system components, and subsystems in order to develop packages of technology for testing on farmers' fields.
3. Continuous on-farm testing, including the monitoring of adoption under farmers' control, the feedback of information to on-station scientists, the adaptation of research programs to meet the farmers' needs and conditions, and the identification of infrastructural and policy requirements.

No details of this fast-growing and developing research approach are presented here. For details, see Okigbo (1977), Gilbert et al. (1980), Norman (1980), and Shaner et al. (1982).

On the basis of its mandate, the International Institute of Tropical Agriculture (IITA) has organized its activities into three programs:

1. Crop Improvement Program
    a. Cereal Improvement: maize and rice programs in identified major environments of Africa in cooperation with the International Rice Research Institute and the International Maize and Wheat Improvement Center.
    b. Grain Legumes Improvement: cowpeas and soybeans.
    c. Roots and Tubers Improvement: cassava, yams, sweet potatoes, and aroids in cooperation with the International Center of Tropical Agriculture and the Asian Vegetable Research and Development Center.
2. Farming Systems Program

    Development of systems for the humid and subhumid tropics worldwide in cooperation with the International Livestock Centre for Africa and other institutions.
3. International Cooperation and Training Program

    Training programs and coordination of collaborative programs for exchange of materials, testing, and manpower development in cooperation with national institutions.

IITA's Farming Systems Program (FSP) Largely a Cropping Systems Program

The principal objective of the FSP at IITA is the development of new technologies, alternative subsystems, and more permanent production systems for higher sustained yields of improved major and some minor food crops to effectively replace the increasingly outmoded traditional fallow systems of the humid and subhumid tropics. Emphasis is given to the needs of the small farmers who grow over 90% of the food in tropical Africa. However, due consideration is also given to either scale-neutral or other technologies that are suitable for large-scale farms that are gradually springing up and whose production systems complement those of small landholders.

The thrust of FSP research and training is in the following areas:

1. Land development and subsequent soil management under more continuous and intensive cropping.
2. Design and development of improved cropping systems including integrated pest and weed management.
3. Mechanization, design, and development of appropriate technologies for operations ranging from land clearing and planting to post-harvest activities that increase output. These technologies should increase the timeliness of operations, minimize drudgery in farming, and decrease the rural-urban migration.
4. Socioeconomic studies that emphasize on-station and on-farm production economics. These studies should identify the socioeconomic implications of new technologies, the constraints to adoption of such technologies, and the infrastructure and policies necessary to ensure adequate incentives and narrow the yield gap between research stations and farmers' fields.

Soil Fertility and Crop Production

Soil fertility is the status of the soil with respect to the amount of nutrients available for crop growth (Brady, 1974).

Various practices have been developed for managing soils in order to maintain or even improve soil fertility levels. Adequate soil management under more intensive cropping is crucial in all efforts aimed at finding solutions to Africa's current food crisis. This paper is devoted to a review of IITA's research in cropping systems, soil management, and fertility maintenance for sustained yields.

Characteristics of Traditional Cropping Systems in Relation to Maintenance of Soil Fertility

Although this paper focuses on progress in IITA's cropping systems research in relation to maintaining fertility of soil and high levels of productivity on a sustained basis, IITA's research is also aimed at advancing the frontiers of knowledge by finding alternatives to shifting cultivation and its related intermittent fallow systems. Therefore this paper will be based on IITA's FSP research, but it will also include relevant examples of results obtained in Africa or worldwide that complement, reinforce, or form the basis of IITA's overall work.

Traditional Cropping Systems in Relation to Maintenance of Soil Fertility

Results of FSR based on both current and secondary data have confirmed that traditional shifting cultivation systems and present transitional farming cropping systems rely on the recycling of nutrients from plants to soils during the period that the land is not in cultivation in order to replenish the soil fertility lost during the cultivation phase. Characteristics of these production systems with regard to soil fertility, maintenance, and cropping systems are summarized below:

1. Farm sizes are small, mostly less than 5 ha, and are aimed at both subsistence and increasingly commercial production.
2. They are "slash-and-burn" clearance systems in which, historically, a long (10-20 years or more) fallow period is followed by a short cultivation phase of 2-4 years. However, there is considerable variation in fallow versus cultivation phase periods (Table 1). The burning releases nutrients tied up in the plant biomass; consequently, the longer the period of fallow the more the biomass and nutrients tied up in vegetation and the more the soil rejuvenation potential (Table 2). This is the basis of the small circle and large circle chitemene systems of central Africa in the miombo savanna ecosystem where piles of vegetation are burned to concentrate ash for nurturing crops. It should be noted that the greater the biomass involved, the more labor required for clearing and the less the area that the farmer can likely farm each year or have available for farming.
3. Increased population pressure and other causes that reduce the period of fallow and increase the frequency of farming usually result in decreases

in soil fertility and productivity (Figure 1). Increased frequency of cultivation also increases soil erosion and degradation.

4. These farming systems involve much manual labor using only simple tools. As a result there is a shortage of labor where farmers are interested in increasing production especially by increasing the area under cultivation.
5. Timing of operations (land clearing, preplanting cultivations, planting, weeding, etc.) are related to the onset, duration, and intensity of prevailing rainfall since irrigation is not widely practiced.
6. These are low-input production systems practiced by farmers who lack credit and capital and sometimes also the knowledge and technology to use a range of modern inputs such as fertilizers, soil amendments, pesticides, machinery, etc.
7. They are also often thought to be of low productivity, but where land is abundant and fallow systems are long, they are highly efficient production systems in terms of the energy input/output relationships (Greenland and Okigbo, 1983). For comparison of various production systems in this regard, see Table 3.
8. Cropping systems practiced usually involve mixed cropping or intercropping, which ensures diversification of production and satisfaction of subsistence needs on a more stable basis and at reduced risk. Additionally, this practice also reduces erosion by ensuring that the soil surface is more protected (Figure 2).
9. Traditional farming systems often involve various field systems centered around the compound garden with varying degrees of integration of crops and livestock. And use of the manures and plant residues ensures the maintenance of soil fertility at least on the compound farms and adjacent fields (Figure 3). The system also involves varying degrees of intensity of agroforestry and association of nutrient-cycling/nitrogen-fixing shrubs or trees with nitrophilic arable crops (Figure 4). Despite the use of several field systems, African agriculture remains largely an upland system and the potential of the relatively fertile valley bottoms and wetland has been scarcely tapped.

The above items are by no means exhaustive but do contain those salient aspects of traditional cropping systems that have fertility implications for the discussions below.

Soils, Lands, and Their Development and Management for Improved Cropping Systems for Sustained Yields Through Technological Developments

During the 15 years since the founding of IITA, the soils research of the FSP has given priority to the following objectives:

1. To provide basic guidelines as to the potential of different soils to sustain improved crop production under changed practices.
2. To determine optimal fertilizers, liming, tillage, and erosion control practices.
3. To devise ways of reducing fertilizer use, by utilizing organic wastes, microbial N fixation, and more efficient phosphate nutrition through mycorrhiza-aided P root extraction.

To ensure achievement of these objectives, studies were launched covering pedology, soil fertility, soil chemistry, soil physics, and microbiology.

The areas covered by the major soil groups in Africa are given in Table 4. Juo and Kang (1979) refined this information by studying 40 benchmark soil profiles in great detail. The detailed studies became the basis of a crop production capability classification and were used to guide IITA's research work on soil fertility management. The nutrient balance of African soils is very fragile, and cropping can lead to serious declines in soil productivity (Figure 1).

According to Juo (1980), large-scale, high-input agriculture has been possible and economical on the fine-textured Alfisols, Oxisols, and Andepts of the East African Highlands. Less success has been achieved with such high-input agriculture on the kaolinitic lateritic and highly compacted Alfisols and Ultisols of the savanna and forest/savanna transition zones of west and central Africa. Arable food or cash crop production on the highly weathered and leached Ultisols and Oxisols requires constant application of such costly inputs as lime, multinutrient fertilizers, and pesticides, and each of these is associated with its own problems if not properly used (Fore and Okigbo, 1974) (Table 5).

Kang and Juo (1981), in a more detailed study, recognized three groups of soils, briefly described below:

1. Kaolinitic low-activity clay (LAC) soils consisting mainly of Alfisols and Ultisols, which occur widely in subhumid regions of tropical Africa. These have a usually coarse to medium textured surface horizon and a more clayey B horizon with a clay content greater than 35%. In west and central Africa

they are commonly associated with rolling topography and have an average slope often exceeding 5%. In areas of high rainfall intensity or erratic rainfall distribution in the humid/subhumid transition zone, soil erosion is a critical factor in large-scale mechanized systems of food production.

2. Oxidic LAC soils consisting mainly of Ultisols and Oxisols that are fine textured with low effective cation exchange capacity (CEC) but large pH-dependent CEC due to the presence of free iron oxides and large specific surface area. These types of LAC soils are derived from volcanic rocks such as basalts or other ferromagnesian rocks. Soils in this group are widespread in the East African Highlands; they have excellent physical characteristics and are much less susceptible to erosion and mechanical compaction. Large-scale commercial food and cash crop farms are located on these soils.
3. Siliceous LAC soils consisting mainly of some Ultisols, Entisols, and Inceptisols, which have a sandy loam surface horizon containing less than 35% clay with over 55% of quartz or other durable minerals. In tropical Africa these are found along coastal regions of west Africa and in the inland Cretaceous and Pleistocene formations. These soils usually occur on flat or gently undulating landscape and are subject to multiple nutrient deficiencies and nutrient imbalance, which limit their use for more permanent food crop production. In the subhumid or savanna areas, low available moisture reserve limits the growth of such crops as upland rice and soybeans with high moisture requirements. While these soils support lush green vegetation in humid areas, the siliceous LAC soils are extremely infertile and acidic. Large-scale forest clearing on these soils may not be feasible unless essential inputs such as lime, multinutrient fertilizers, and pesticides are used.

Management of LAC Soils in Perhumid and Humid Areas

In these areas, where precipitation equals or exceeds potential evapotranspiration for 6-8 months or more and major soils are Ultisols and Oxisols of the kaolinitic and siliceous mineralogical groupings, the dominant crops are tree crops and yams, cassava, maize, cocoyams, etc.

Major factors relating to crop production include:

1. Multiple nutrient deficiencies and nutrient imbalance: Deficiencies in nitrogen, phosphorus, potassium, calcium, and magnesium occur under intensive cultivation. Application of high lime rates easily induces imbalance in

magnesium, zinc, and manganese. High yields are only obtained where multiple nutrient fertilizer and soil amendments are used.

2. Soil Acidity and Liming: With soils having high levels of plant-available aluminum and manganese as well as low levels of calcium and magnesium, the use of liming materials is essential where intensive production is the objective. The introduction of plant varieties with good tolerance to soil acidity and related aluminum toxicity modifies this situation. Thus, IITA's varieties of maize TZPB and of cowpea VITA 1 and 40 have shown marked tolerance to high levels of aluminum. Where lime is needed, quite low levels are adequate, as contrasted to European and North American practices.

   Results of a 5-year liming experiment at the IITA Onne high-rainfall station in southeast Nigeria showed that sustained yields of maize/cowpeas annual rotation can be maintained with low lime rates and balanced (N, P, K, Mg, Zn) fertilizer (IITA, 1978, 1979, and 1980). A lime application of 0.5 ton/ha maintained the yield for 2 years after application. The calcium applied as lime readily leached from the surface layers with appearance of exchangeable aluminum, making high liming rates of no definite advantage. Although liming was needed on cultivated land, no benefit from liming was observed on the uncultivated land during the first 3 years after land clearing (Table 6). The need to apply lime to land newly cleared from bush fallow may be necessary because of the increase in surface acidity due to mixing with subsoil during preplanting cultivation.

3. Effect of Burning: Several workers (Nye and Greenland, 1960; Seubert, 1977) reported beneficial effects of burning in traditional slash-and-burn cultivation systems in highly acid LAC soils. Burning appears to have a liming effect and quick nutrient release from its ash. But recent studies at Onne IITA high-rainfall station showed no significant difference between burning and residue mulching in performance of TZPB maize in which weeds were controlled with herbicide (Table 6). It was concluded that a major advantage of light burning by traditional farmers is that it facilitates seedbed preparation.

4. Role of Trees and Shrubs in Sustaining Crop Yields: Traditional farmers exploited the nutrient-cycling ability of trees and shrubs during fallow periods for the restoration of soil fertility. Increase of population pressure decreased the periods available for fallow and this, in turn,

decreased the numbers of trees and shrubs while increasing the herbaceous weeds, grasses, and ferns. All of these changes reduced the capacity of the fallow to regenerate adequate levels of soil fertility. But in the highly populated areas of southeastern Nigeria, farmers through years of trial and error recognized the superiority of planted woody fallow shrubs such as *Acioa barteri*, *Anthonotna macrophylla* and *Alchornia cordifolia* in the rejuvenation of the soil as compared with herbaceous fallow (Obi and Tuley, 1973; Okigbo and Lal, 1979). With these species, planted tree fallow appears to be effective with periods of only 2-4 years as compared with 6-8 years for natural bush regrowth. This finding constitutes the basis of the current IITA alley cropping system reported later.

Management of LAC Soils of the Humid/Subhumid Transition Zone

This area is dominated by the less leached Alfisols under secondary forest/bush vegetation. Major tree crops are cocoa, kola, and oil palm in addition to food crops such as cassava, yams, maize, and soybeans in a bush fallow/arable rotation system. The nature of the landscape, the soil properties, and the occurrence of high-intensity tropical rainstorms predispose the area to soil erosion on sloping land under conventional tillage (Lal, 1976). This constraint is minimized and high yields are sustained through annual cultivation using a maize-cowpea rotation with a judicious application of fertilizers (Kang, Spain, and Uehara, 1984).

Nutritional deficiencies encountered in this zone consist mainly of N, P, and K, but deficiencies of Mg, S, Zn, and Fe have been reported in maize, cowpeas, and upland rice (Kang and Fox, 1980). The P requirements are usually low, and there are high residual effects; N responses and requirement depend on the nature of the vegetation before it was cleared. The K requirements are usually low and depend largely on the parent materials and soil texture with soils from the siliceous group requiring more K than those of the kaolinitic group. Iron deficiency may occur on soil deficient in organic matter as occurs in continuously cropped land. Magnesium deficiencies have been observed in maize in a similar situation. The soils in this region contain high total amounts of Mn, and acidification due to application of acidifying fertilizers may cause Mn to reach toxic levels in the soil. Guidelines for soil fertility management and incidence of micronutrient deficiencies and ways of correcting them are reported in Kang (1983), Kang and Osiname (1985), Kang and Juo (1981), and Kang, Spain, and Uehara (1984).

Physical Characteristics of the Soil in Relation to Management of Land Development and Conservation for Sustained Yields

Under tropical humid and subhumid climatic conditions plant nutrients are maintained in a more or less closed system under a climax vegetation and under secondary forest or bush depending on the length of period of fallow. But removal of the cover of forest or vegetation and subjection of the land to intensive cultivation, as is the practice in temperate countries, is fraught with problems. Failure or disappointing performance of large-scale mechanized farming operations in the tropics attest to this. The time-tested, age-old shifting cultivation and fallow systems have proved more stable. Unfortunately, the traditional system cannot meet the levels of food production needed by the burgeoning population and the increasing indirect demands for agricultural products.

Experiments at IITA and elsewhere have shown that removal of forest and subsequent soil management under various cropping systems results in varying levels of disturbance of the equilibrium of the hydrologic, microclimatic, chemical, and biotic environments (Figure 5). The altered conditions are not favorable for long-term maintenance of fertility and sustained productivity. Adverse effects produced by deforestation or removal of vegetation by fire or mechanical means include the following:

1. Exposure of the soil to tropical rainstorms leads to increased erosion, losses, soil degradation, loss of fertility, and decreased productivity.
2. Excessive runoff and the unpredictable periods of drought, which may occur even in the rainy season, result in decreased effective rainfall, which may be made more severe by the decreased water-holding capacity of the soil due to a reduction in organic-matter content. Drought stress adversely affects the energy status within the plant as well as the plant's ability to absorb and translocate nutrients. This results in reduced yields and poor quality of the product.
3. Transient flooding may occur as a result of removal of vegetation. Subsequent preplanting cultivation and crusting may cause anaerobic conditions in the soil, which suppress plant growth and reduce crop yields; these conditions may also decrease uptake of the nutrients (N, P, K, Ca, Mg, Zn, Cu). Depression of the uptake of Mn, Al, and Fe have been reported also.
4. Changes in energy balance resulting from removal of the insulating effect of vegetation on the soil which is then subjected to the effects of direct

insolation, precipitation, and desiccating winds. The resultant high temperatures may have adverse effects on the growth of seedlings which exhibit chlorotic conditions indicating deficiencies in N, P, K, Ca, and Mg in maize, cowpeas, and other tropical legumes. Even processes such as nitrogen fixation may be curtailed while organic-matter decomposition is accelerated and subsequent release of ions greatly promoted with deleterious effects on nutrient and water retention, microbial life, etc. (Lal, 1981). For the effects of high temperatures on maize seedlings and organic matter see Table 7.

The overall relationship between deforestation and crop failure is presented in Figure 6. The land development practices recommended below form the basis of crop residual management practices and tillage practices developed by IITA and being tested in cooperation with national programs and institutions in several locations in sub-Saharan Africa.

Recommendations on Land Development for Soil Conservation and Fertility Maintenance

The following guidelines for land development and initial cropping and subsequent management are based on IITA work (Lal, 1978; Hartmans, 1981; IITA, 1978, 1979; Lal, 1981; and IITA, 1982).

1. In general, the extent of the removal of vegetation and the method of clearing should be related to subsequent crops to be grown and the cropping system used. For example, the establishment of tree crops does not require total mechanical clearing of vegetation and removal of roots and stumps. Slashing, debarking, and chemical poisoning of trees and light burning are all that is required.
2. Because land clearing and arable crop production disrupt the overall equilibrium of the soils and the forest ecosystem, it is recommended that land-saving strategies that give priority to increased production per unit area be encouraged rather than expansion of the area under cultivation. As far as possible, clearing of steep slopes should be avoided.
3. Wherever it is still possible and economical, manual clearing, ring barking, and tree poisoning, which do not unnecessarily disrupt the soil, should be encouraged, but care should be used in the choice of chemicals and the way they are used to prevent accidental poisoning and to minimize environmental pollution.

4. Where mechanical clearing is used, care should be taken to ensure (a) that disturbance of topsoil is minimal; (b) that as much litter, roots, and stumps are left in place as possible; (c) that the land is not cultivated when it is wet; and (d) that the soil is compacted as little as possible with the heavy machinery. A tractor with a front-mounted shear blade has been found to result in minimal soil disturbance.
5. Because removal of the vegetation results in soil erosion and degradation, care should be taken to keep the soil surface covered with crops or crop residues. Clean tillage should be avoided where possible.
6. After the land has been cleared, mixed cropping-relay cropping systems should be used. Reduced tillage and the use of various plant residue mulches and related covers are helpful in minimizing soil erosion and degradation. Various effects of clearing and subsequent tillage and cropping patterns are shown in Table 8.

Cropping Systems, Soil Fertility, and Fertilizer Use

Most of the FSP cropping system studies conducted on station in Ibadan, Ikenne, and Onne were aimed at (a) studying the nutrient requirements of different crops in different environments, (b) studying the effects of different cultural treatments on crop response to fertilizers, and (c) studying crop performance in different cropping patterns.

Single Crop Performance and Response to Fertilizers

The crop yields obtained vary with (a) variety, (b) fertilizer levels with respect to type and amount of required nutrients, and (c) associated cultural practices and location. For example, rice yields were found to vary with fertilizer level, spacing, method of weeding, source fertilizer, etc. (Tables 9 and 10). There is also the need to take into account not just yields but also the cost of various operations involved in the different treatments. Table 11, for example, shows differences in cost of operations and total inputs and net income. Optimum economic response, not maximum yield, is of interest.

Sole Crop Rotations

Data on individual crop species or varietal response to fertilizers and other inputs are of limited value in assessing complex cropping systems over several years. With the general exception of perennial crops and wetland rice, which can be grown continuously on a given piece of land, worldwide experiments have demonstrated the advantages of rotations in controlling diseases and pests, spreading labor demand more evenly throughout the year, diversifying production, and exploiting the nutrients and inputs supplied more efficiently, for example, nutrients from different parts of the soil profile, etc. For this reason, some attention has been given to evaluating the performance of crops when grown in sequence with other crops, and it has been found that the practice sometimes increased yields (Table 12).

Intercropping Patterns and Sequences

There has been considerable interest in intercropping since the studies of Andrews (1970) and the advent of FSR, which confirmed the widespread use of this cropping pattern among small or traditional farmers. Advantages usually include higher total production with reduced risk of crop failure, more stable yields, diversified products that ensure a more balanced diet, nearly constant yields with minimum investment on storage, more even distribution of labor throughout the year, more efficient use of limited resources or inputs, and the potential for satisfying subsistence and cash requirements on one piece of land, etc. Studies at IITA have not only confirmed the widespread use of intercropping but also the overall higher productivity of intercrops--for an example of increased productivity under intercropping see Table 13. It is obvious that in most of the mixtures in which yams and maize occur the total calories and gross returns significantly increased while there is marked variation among other combinations. There are also often savings in labor, which are distributed among crops in the mixture and sometimes also in fertilizers. Where maize is intercropped with cassava, there appears to be no need for special fertilizer application to the cassava crop. There does not appear to be any major significant effect of nitrogen fertilizer when it is applied to intercropped maize and cassava. While it is obvious that mixtures may require more fertilizer than any individual component in the mixture, the method of determining the optimum fertilizer for mixtures has not been reliably developed. A slight increase in fertilizer applications above that needed for the most sensitive crop in the mixture appears to be sufficient for reasonably high yields. Where cultivated crops are intercropped with perennials, some competition for nutrients is often observed; it would appear, however, that this depends very much on the depth of the perennial crop root system and the extent to which there is also competition for water, sunlight, etc., among crops in the mixture. Experiments on farmers' fields in southeastern Nigeria indicate, for example, that with the exception of yams, shade from associated perennial crops (trees) significantly reduces the fertilizer response (see Table 14).

Residue Management and Response to Fertilizers

As already indicated above, in the highly weathered LAC soils in tropical Africa maintenance of adequate vegetation or other kinds of cover is effective in protecting the soil against erosion, ensuring greater water infiltration rate, reducing temperature fluctuations, reducing fertilizer loss, and maintaining adequate levels of organic matter in the soil. An adequate cover also suppresses the growth of weeds and creates a favorable environment for the growth of soil microfauna and flora. Various kinds of mulch differ considerably in their effectiveness in this regard. At IITA the effects of mulches on soil conservation and on the crops grown have been studied with (a) dead mulches from cover crops, (b) live mulches, and (c) miscellaneous plant residue mulches, polythene and industrial wastes.

Studies With Dead Mulches From Cover Crops

Lal, Wilson, and Okigbo (1978) studied the effects of leguminous and grass mulches on crop performance on a degraded Alfisol. They observed that cover crops had significant effects on the chemical and physical properties of the soil. Different cover crops affected organic carbon, nitrogen level, CEC, and available phosphorus differently. *Melinis minutiflora* and *Glycine wightii* resulted in the highest organic carbon contents (1.75% and 2.10%, respectively) in the top 10 cm of the soil. Available P was highest in *Stylosanthes* and the control plots; this indicates that sometimes mulches may immobilize certain nutrients. Earthworm activity was over 40 times higher under mulches in maize and cowpeas during the first 2-4 weeks after planting. Mulching also had significant effects on yields of test crops (Table 15). Lal (1978) reported that about 5 tons of mulch/ha significantly reduces soil erosion. Apart from the nutrients that they may supply, some organic mulches have marked effects in ensuring longer lasting benefits to the soil.

Studies With Living Mulch

At IITA studies of effects of living leguminous mulches such as *Centrosema pubescens*, *Arachis repens*, and *Psophocarpus pallustris* have been carried out. Results after 3 years indicated that over five seasons of continuous cropping without nitrogen application yields of maize in the live mulch were superior (2.0 tons/ha) to either yields in control with no tillage (0.8 ton/ha) or yields with conventional tillage systems (1.0 ton/ha). In these studies, maize in the live mulch showed little or no response to nitrogen fertilizer application. In addition, leguminous covers *Centrosema* and *Psophocarpus* gave sustained yields under these low input levels. The leguminous mulches supplied about 60 kg/ha of N to the soil. Live mulches competed with associated crop for moisture (this varied with the species of cover crop) while the most vigorous living mulches (*Centrosema* and *Psophocarpus*) eliminated the need for weeding. The live mulch, low-input crop production system facilitates production of crops such as maize on steep slopes, but a considerable amount of work needs to be done to select those mulches that do not compete seriously for water. Other studies are needed to determine the range of crops to which this method is applicable.

Studies With Miscellaneous Mulches

At IITA studies have also been conducted with miscellaneous plant residues and industrial waste mulches including polythene, rice husks, sawdust, etc., with maize, cassava, soybeans, and cowpeas as test crops. These mulches produced markedly different effects on weeds, yield, runoff and erosion, crop yields, soil temperature, and microbial activities. Phenomenal increases in cassava yields (30 tons/ha) occurred with polythene mulch as compared with 16 tons/ha on bare plots (see Table 16). These observations indicate that mulches have many varied effects, which are not due to their nutrient-supplying effects alone. Mulching may temporarily immobilize some nutrients, but in the long run it does conserve soil fertility. Also, experiments at IITA demonstrate that nematode incidence is more related to associated crop than to the mulch treatment alone.

Alley Cropping and Improved Fallow Systems

The most widespread agricultural production system in the humid and subhumid tropics is shifting cultivation, which for a long time was regarded as primitive. However, recent interest in studies of traditional farming systems and concern about environment have shown that shifting cultivation is an ecologically sound and relatively energy-efficient production system that relies on the nutrient-recycling capability of trees and shrubs to maintain soil fertility lost during the cultivation phase. It is also known that other successful agricultural production systems in the humid tropics that have few adverse effects on the environment include tree crop plantations, the coconut/pasture/livestock production system, and Asian wetland rice. But food production in the humid tropics involves the growing of arable crops that have marked adverse effects on the environment and also require a considerable amount of inputs such as fertilizers, soil amendments, and pesticides needed to ensure high yields under various environmental stresses. In the alley-cropping technique early maturing, preferably leguminous trees and shrubs are grown with food or arable crops (Kang, Wilson, and Lawson, 1984) In this system the trees or shrubs fix nitrogen and recycle nutrients with their deep root systems, provide biomass for fuel, supply plant residues for mulch, furnish stakes for viney crops such as beans, and provide various other products. The arable crops are planted in between the rows of shrubs or trees, which when located along the contour constitute an effective soil conservation measure. In the alley-cropping system, the leguminous trees and shrubs play the same roles as traditional deep-rooted fallow shrubs such as _Acioa barteri_, _Anthonotha macrophylla_ and _Alchornea cordifolia_. This makes alley cropping with _Leucaena leucocephala_ and _Glyricidia sepium_ more attractive than the herbaceous fallows, which the farmers regard as less useful than the woody shrubs. With alley cropping only the small fraction of the field on which the woody shrubs are located is in fallow and consequently does not need a considerable area of land as does the traditional fallow. Alley cropping does not eliminate the need for fertilizers but reduces the amount of fertilizers necessary and at the same time supplies organic residues, which also improve the soil's physical structure and facilitate a favorable environment for biological or microbial activity in the soil. Tables 17a and 17b (unpublished data, B. T. Kang) show the beneficial effects of alley cropped _Leucaena_ and _Glyricidia_ prunings on the yields of maize and cowpeas. With alley cropping a permanent agricultural system can be practiced, and in it can be integrated various rotations, and tillage systems.

Need for an Integrated Approach in Farming Systems Research in Relation to Fertilizer Use and Development of Improved Cropping or Farming Systems

The above discussion demonstrates that increased and sustained yields require a package of technologies in which climate, soils, species varieties, cultural practices, and machines interact to ensure that a given input produces its maximum effect, which must also be economically attractive to the farmer. According to Keller (1982) due consideration must be given to the following:

1. Concept of maintenance of soils' capacity to yield.
2. Concept of environmentally suitable plant protection.
3. Concept of optimization of both yield and crop quality.

These concepts call for the following considerations:

1. Environmental analysis with respect to climate, soil, topography, pests, diseases, and weeds. A given crop is best adapted to a given environmental condition, and the more favorable the environmental condition the more beneficial the response to a unit of input and often the smaller the range of inputs required. A cropping system should be adapted to the climatic and prevailing soil conditions most favorable for its performance.
2. Use of the soil capability classification discussed earlier enables one to choose the environmental conditions that have the highest potential for the cropping system and give lower priorities to areas of medium or marginal potential.
3. With an integrated approach, due consideration should also be given to limiting factors and constraints of physical, biological, socioeconomic, technical, and managerial nature so that all technologies developed for a given farming system are compatible and are economically and socially acceptable. For example, a no-tillage system cannot be effectively practiced by the farmer who has no suitable equipment for planting through a thick layer of crop residues.
4. For all farmers, fertilizer use is imperative for sustained yields in all cropping systems, but farmers differ in their resource endowments. Consequently, use must be made of biological nitrogen fixation, mycorrhizal phosphate extraction enhancement, integrated pest management, and appropriate technologies to ensure that the farmer's practices are economically

viable and ecologically sound. Fertilizer is but one of the key inputs in crop production, but its full potential can be realized only through increasing efficiency of use and sensitivity to socioeconomic and other factors that affect farmers' return on their investment in its use. Fertilizer use is affected by the incentives given to the farmer, and various infrastructural and policy issues that determine the availability, forms, quantities, and timeliness of the fertilizers must be resolved in addition to continuous research and training of both extension staff farmers and policymakers. It is mainly through a holistic FSR approach that the above problems can be tackled in their proper perspective.

Conclusion and Recommendations

Considerable progress has been made in establishing the fact that for optimum yields to be achieved on a continuing basis fertilizer use is imperative. But economic and ecological considerations require that continuing research be carried out to:

1. Ensure greater efficiency of use with effort directed toward reducing losses, especially of nitrogen, and minimizing any possible environmental hazards in fertilizer use.
2. Minimize the amount needed and the cost of fertilizers used by farmers, especially farmers in the humid tropics who lack credit. The potential exists for biological processes that facilitate improved nitrogen fixation, mycorrhizal phosphate extraction, etc.
3. Develop reliable methods for determining the amounts, forms, and methods of fertilizer application for different cropping systems including intercropping, relay cropping, and rotations in various ecological zones.
4. Determine how best to economically utilize inorganic and organic fertilizers to maximum advantage on the basis of scientifically rational and practical reasons rather than on sentiment and superstition.
5. Ensure that due consideration is given to problems of fertilizer use in crop improvement and possible interactions of varieties with fertilizers and the crop environment.
6. Ensure that appropriate technologies are developed to enhance fertilizer application and use in different cropping systems where the use of certain

inputs may be constrained by the cropping patterns involved. Mechanization, which minimizes drudgery and ensures timeliness of operations, cannot currently be applied to various operations in intercropping systems as compared with sole cropping.

7. Alley cropping, no-tillage, and effective plant residue management constitute elements of a permanent agricultural production system that can replace shifting cultivation. There is need to determine the limits of their use in various environments, including the best forms of use and how and when to use them.
8. African agriculture remains largely an upland system. A study of improved cropping systems for wetland areas and associated fertilizer application practices, their ecological limitations, and production economics should be given high priority.

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Table 1. Variation in Fallow Periods

No.	Place	Annual Rainfall (mm)	Crop	Fallow	Periods in Years				Typical Value for R	Remarks
					Normal		Excessive			
					C	F	C	F		
				Moist Evergreen Forest Zone						
1	Sarawak	c.3,800	Hill rice	Forest	1	12	2	12	7	Early abandonment of land necessary to prevent invasion of *Imperata*
2	Guatemala	3,400	Maize	Forest	1	4			20	"Ando" type soil
3	Liberia	2,000-4,500	Rice, manioc	Forest	1-2	8-15			11	
4	Sierra Leone	2,300	Rice, manioc	Forest	1-5	8	1.5	5	12	Grasses (esp. *Chasmopodium* sp.) invade with excessive cultivation
5	Nigeria (a) Umuhia	c.2,300	Yams, maize, manioc	*Acioa barteri*	1-5	4-7	1.5	2.5	21	Loam derived from tertiary sands and clays; stumps of fallow carefully preserved
				Moist Semi-Deciduous and Dry Forest Zone (including humid zone of derived savanna)						
6	West Africa	1,500-2,000	Maize, manioc	Moist semi-deciduous forest	2-14	6-12			25	
7	Central Uganda	c.1,300		Elephant grass	3	8	1	2	27	
				Savanna Zone						
8	Ivory Coast	1,200		*Imperata*	2-3	6-10	2-3	4-6	24	
9	French Sudan	1,000-1,300		Short bunch grass	3	12-15			18	

Source: Nye and Greenland, 1960.

Table 2. Amount of Biomass in Fallows

Location	Approximate Age (years)	Biomass (tons/ha)	Nutrients N	P	K	Ca	Mg	Soil
			- - - -	- - -	-(kg/ha)-	- - - -	- -	
Kade, Ghana	40	330	1,797	123	804	2,479	340	Ultisol
Yangambi, Zaire	5	86	383	23	338	287		Ultisol
	18	143	549	76	397	551		
Cerare, Colombia	5	68	357	22	320	181	40	Aeric Ochraquox
	16	203	712	55	495	558	156	
	"Virgin"	184	740	27	277	431	133	
Marafunga, New Guinea	40 (montane thicket)	592	1,415	74	1,227	2,060	452	Andept
Manaus, Brazil	"Virgin"	504	3,294	67	500	528	275	Orthoxic Paleudult
Merida, Venezuela	"Virgin" montane	462	1,088	62	1,470	894	253	Aquic Humitropept

Source: Greenland and Okigbo, 1983.

Table 3. Productivity of Different Agricultural Systems, Energy Inputs, and Energy Output/Energy Input Advantages (E_r)

Area	Crops	Energy Output (GJ/ha/annum)	Energy Input (GJ/ha/annum)	E_r
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	(Rainfed) 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
U.S.A.	(Irrigated) Rice (5,700 kg)	84.1	65.5	1.3
U.S.A.	Maize (5,100 kg)	76.9	29.9	2.6
U.K.	Wheat (3,900 kg)	56.2	17.8	3.3
U.K.	Maize (5,000 kg)	61.7	26.4	2.3
U.K.	Potato (26,300 kg)	56.9	36.2	1.6

Source: Greenland and Okigbo, 1983.

Table 4. Estimated Extent of Major Soil Groups in Africa (million ha)

Group (Order)	Area in Africa (10^6 ha)	Percentage Coverage		
			World	
		Africa	Group Area	Total
Oxisols	550	22.4	50.0	11.2
Alfisols	550	22.4	68.8	11.2
Ultisols	100	4.1	18.2	2.0
Aridisols	840	34.3	93.3	17.1
Vertisols	40	16.3	40.0	0.8
Entisols	300	12.2	75.0	6.1
Inceptisols	70	2.9	17.5	1.4
	2,450	114.6		

Source: Sanchez after Drosdoff (adapted from Sanchez, 1976).

Table 5. Mean Maize Grain Yields (pounds dry grains/acre)

Fertilizer Treatments	Limed at 200 lb/Plot	No Lime	Fertilizer Treatment Ranked Means*
N P K Mg + manure	7,086	4,857	5,971 a
N P K Mg + silage waste	4,037	3,318	3,677 a
N P K Mg	4,037	2,490	3,263 a
N P K Mg	3,616	2,214	2,916 b
N P - Mg	2,062	392	1,227 bc
Cow manure	726	508	617 c
N - K Mg	399	211	305 c
- P K Mg	327	131	229 c
Check--no fertilizer	160	73	116
Lime means	2,494	1,577	

* Means followed by the same letter(s) are not significantly different at the 5% level.

Source: Fore and Okigbo (1974).

Table 6. Effect of Residue Management, Fertilizer Application, and Liming on Yield of Maize Grown on Typic Paleudult in Eastern Nigeria

Residue + Fertilizer Treatment	Year 1978	 1979	 1980
	(kg/ha)		
A. Residue burned			
Control	1,190	595	1,391
NPK Mg Zn	2,302	2,233	3,587
NPK Mg Zn + lime[a]	3,008	2,355	3,702
B. Residue mulched			
Control	1,140	556	1,493
NPK Mg Zn	2,878	1,682	3,137
NPK Mg Zn + lime[a]	3,495	1,799	3,377

a. Lime at rate of 1 ton/ha applied in 1978 and 1980.

Source: E. Okoro, Ph.D. Thesis, University of Manitoba.

Table 7. Influence of Soil Temperature Stress (40°C) in the Seedling Stage of Maize on Grain Yield

Stress Duration (days)	Grain Yield (g/plant)	Number of Grains/Cob	Unit Grain Weight (g/100 grains)	% Empty Grains	Number of Cobs/10 Plants
Control	191.1	477	39.8	5.0	10
2	172.3	385	36.2	8.1	9
4	148.9	448	37.9	4.4	8
6	84.3	310	36.6	27.0	8
8	78.4	249	36.5	44.4	7

Source: Lal, 1981.

Table 8. Land Clearing: Effects of Methods of Deforestation and Tillage Systems on Soil and Water Loss, Grain Yield, and Tons of Soil Lost per Ton of Grain Produced

	Soil Loss Erosion (tons/ha)	Water Loss Runoff (mm)	Grain Yield (tons/ha)	Soil Loss, tons/ton Grain Yield
Traditional method	0.01	2.64	0.5 a	0.02
Manual clearing--no tillage	0.37	15.50	1.6 b*	0.23
Manual clearing--conventional tillage	4.64	54.30	1.6 b	2.90
Crawler tractor (shear blade)--no tillage	3.82	85.66	2.0 b	1.91
Crawler tractor (tree pusher/root rake)--no tillage	15.36	153.06	1.4 b	10.97
Crawler tractor (tree pusher/root rake)--conventional tillage	19.57	250.33	1.8 b	10.87

*Figures followed by the same letter are not different at a 5% level of significance.

Table 9a. Effect of Straw and Lime on Rice Yield (kg/ha) in an Inland Swamp at Magbolontor, 1977

Treatment	Without Lime	With Lime	Mean
SR	1,606	2,025	1,816
SP	2,068	2,337	2,203
SB	2,048	2,326	2,187

LSD for cell means = 251
LSD for time means = 325
CV for time means = 9.1%
SR = straw removed
SP = straw plowed
SB = straw burned

Table 9b. Effect of Different Fertilizer Levels on Rice Yield (kg/ha) in Inland Swamp at Magbolontor, 1977

Fertilizer Level	Yield
Control	1,748
N_{50}	1,933
N_{50} P_{40}	2,167
N_{50} P_{40} K_{40}	2,428

Table 9c. Nitrogen and Potassium Response of Cassava Varieties

Treatment		Tuber Yield				
N	K	30,572	3,055	4,488	30,337	Mean
- - -(kg/ha) - - -		- - - - - - -(tons/ha)- - - - - - -				
0	0	14.6	17.1	20.8	14.4	16.7
50		16.4	17.4	21.6	11.7	16.7
100		17.8	15.9	13.4	10.8	14.5
150		15.3	16.7	14.1	13.1	14.8
0	50	18.0	22.3	17.8	12.4	17.6
50		20.4	18.1	16.9	18.0	18.4
100		24.4	16.6	14.2	5.9	15.3
150		25.1	12.9	22.8	7.3	17.0
0	100	24.9	22.5	18.4	9.7	18.9
50		25.3	15.5	16.6	12.2	17.3
100		23.5	18.8	21.1	13.8	19.3
150		20.7	18.0	17.8	23.5	20.0
0	150	23.4	23.8	16.9	16.2	20.1
50		23.8	20.0	11.3	18.2	18.3
100		20.3	19.1	20.5	14.7	18.7
150		21.6	19.6	16.9	11.3	17.4
Mean		21.0	18.4	17.5	13.3	-
C500.50%				2.55		

Source: IITA Annual Report, 1982.

Table 9d. Effect of Soil Amendments on Rice in Inland Swamp. Mean Grain Yield at Magbolontor, 1977

Treatment	Without Lime	With Lime	Mean
	(kg/ha)		
SR $N_0P_0K_0$	1,283	1,752	1,518
N_{80}	1,479	1,912	1,705
$N_{80}P_{40}$	1,684	2,167	1,926
$N_{80}P_{40}K_{40}$	1,977	2,267	2,122
Mean	1,606	2,025	1,816
SP $N_0P_0K_0$	1,797	2,071	1,934
N_{80}	1,931	2,141	2,036
$N_{80}P_{40}$	2,179	2,391	2,285
$N_{80}P_{40}K_{40}$	2,363	2,743	2,553
Mean	2,068	2,337	2,203
SB $N_0P_0K_0$	1,635	1,948	1,792
N_{80}	2,017	2,097	2,057
$N_{80}P_{40}$	2,210	2,372	2,291
$N_{80}P_{40}K_{40}$	2,330	2,885	2,608
Mean	2,048	2,326	2,187

LSD (0.05) for cell mean = 312.
CV = 9%.

SR = straw removed.
SP = straw plowed.
SB = straw burned.

Table 10a. Effect of Some N Fertilizers and N Rates on Yield of IITA Maize TZA x TZB at IITA (Egbeda and Apomu Soil Series) and at Ikenne (Alagba Soil Series)

N Source	Rate of N	Apomu Series	Egbeda Series	Alagba Series[a]
	- - - - - - -	- - - - - -(kg/ha)-	- - - - - - -	- - - - - - -
Check	0	4,205	5,953	2,392
Ammonium sulfate	60	5,150	7,501	3,584
Ammonium sulfate	120	5,519	7,417	3,668
Urea	60	5,193	7,230	3,905
Urea	120	5,549	7,297	3,307
Sulfur-coated urea	60	4,810	6,991	3,410
Sulfur-coated urea	120[b]	5,229	6,994	3,760
Calcium-ammonium-nitrate	60[b]	5,657	7,966	3,386
Calcium-ammonium-nitrate	120[b]	5,346	7,170	3,280
Urea-ammonium sulfate	60	5,307	6,204	3,769
LSD 0.05		801	1,182	742

a. Experiment initiated in 1973.

b. Treatments added in 1973 to Apomu and Egbeda soil series.

Table 10b. Effect of Some P Fertilizers and P Rates on Yield of IITA Maize TZA x TZB at IITA (Egbeda and Apomu Soil Series) and at Ikenne (Alagba Soil Series)

P Source	Rate of P	Apomu Series	Egbeda Series	Alagba Series
	- - - - - - -	- - - - - -(kg/ha)-	- - - - - - -	- - - - - - -
Control	0	2,954	2,419	3,343
Triple superphosphate	20	3,629	3,378	3,799
Triple superphosphate	40	4,009	3,884	4,105
Triple superphosphate	60	4,277	4,386	4,225
Ammonium-orthophosphate	20	4,201	4,124	4,080
Ammonium-orthophosphate	40	4,270	4,706	4,237
Ammonium-polyphosphate	20	4,036	4,996	4,096
Ammonium-polyphosphate	40	4,431	4,996	4,096
20-20-0 (35% W.S.)	20	4,153	4,199	3,944
20-20-0 (35% W.S.)	40	4,467	4,912	4,181
20-20-0 (50% W.S.)	20	4,069	4,259	3,911
20-20-0 (50% W.S.)	40	4,521	4,978	4,065
LSD 0.05		292	390	225

W.S. = water soluble

Table 11. Differences in Cost of Operations and Total Inputs and Net Income

Operation	Conventional Tillage Time[a] (h)	Conventional Tillage Cost (US $)	No Tillage Time (h)	No Tillage Cost (US $)
Spraying (preplant)	-	-	0.6	9.60
Mowing	1.2	19.20	1.2	19.20
Plowing	3.0	32.00	-	-
Harrowing	1.0	19.20	-	-
Fertilizer application	1.6	12.80	1.6	12.80
Seeding	2.0	22.40	2.0	22.40
Spraying (post-plant)	0.6	9.60	0.6	9.60
Additional cost of paraquat	-	-	-	38.00
Total Cost, US $/ha		134.40		111.60
Total Time, h/ha	10.4		6.0	

Operation	Conventional Tillage (US $)	No Tillage (US $)
Field operations including paraquat spray	220	320
Harvesting and post-harvesting costs	200	200
Materials (fertilizers and herbicides), etc.	625	625
Total inputs	1,045	1,135
Income	2,000	1,600
Net Income	995	465

---

a. It is assumed that the time saved due to 12% reduction in cultivated area in the conventional tillage is offset by the time lost due to additional maneuvering between terraces.

Source: Couper, Lal, and Claassen, 1979.

Table 12. Effects of Fertilizer Application and Annual Rotation on Main-Season Grain Yield of Maize, Cultivar TZB on Egbeda Soil Series (Oxic Plaeustalf 13u)

Treatment Before 1976	Rotation	Grain Yield 1975	Grain Yield 1976
		- - (kg/ha)	- - -
No fertilizer, no weeding	Maize and sweet potatoes	356	5,735[a]
No fertilizer, weeding	Maize and sweet potatoes	2,466	5,865[a]
Fertilizer, no weeding	Maize and sweet potatoes	4,369	5,895[a]
Fertilizer, weeding	Maize and sweet potatoes weeding	5,877	6,031
Fertilizer, weeding	Maize and cassava	6,283	6,031
Fertilizer, weeding	Maize and cowpeas	6,061	5,883
Fertilizer, weeding	Maize and pigeon peas	6,603	5,994

[a] In 1976 main-season crop was weeded and fertilized.

Fertilizer applied to each main-season maize:
$N_{120}P_{39}K_{50}$
and to minor-season sweet potatoes, cassava, cowpeas, and pigeon peas, N_{40} kg/ha.

Table 13. Caloric Equivalents and Gross Returns of Different Intercropping Mixtures Observed at IITA in 1975

Cropping Pattern	Caloric Equivalent					Gross Return				
	Maize	Melons	Cowpeas	Yams	Total	Maize	Melons	Cowpeas	Yams	Total
						(kg/ha)				
Yams				16.4	16.4				3,022	3,022
Maize	10.5				10.5	647.2				647.2
Melons		3.3					444.5			444.5
Cowpeas			4.5		4.5			216.2		216.2
Yams + maize	10.3			7.1	17.4	640.4			1,310	1,950.4
Yams + cowpeas			3.3	8.7	12.0			531.8	1,431	1,762.8
Maize + melons	8.8	0.3			9.1	563.3	24.5			588
Maize + cowpeas	6.1		2.8		8.9	368.9		24.5		
Yams + maize + cowpeas	6.8		0.5	8.1	15.4	421.9	28.0	46.8	1,490	1,987
Yams + maize + melons + cowpeas	5.5	0.3	3.7	10.1	19.6	342.4	35.0	321.4	1,865	2,564

Source: IITA Annual Report, 1975.

Table 14. Effect of Shade and Fertilizer on Yields

	Village[a]			
	Owerre-Ebeiri (H)	Umuokile (M)	Okwe (L)	Mean Yield
	(t/ha)			
Maize[b]				
Shade, no fertilizer	0.30	0.15	0.66	0.37
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[c]				
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) H,M,L = high, medium, and low density.

(b) Maize yields in the medium-density village are not representative due to damage by goats.

(c) 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.

Table 15. Effect of Various Covers on Yield

Cover Crops	Maize	Cowpeas	Pigeon Peas	Cassava
a. First Arable Crop				
Panicum	3.13	0.37	1.19	-
Setaria	5.77	0.49	0.86	-
Brachiaria	5.17	0.76	1.27	-
Melinis	5.18	0.63	1.19	-
Centrosema	5.79	0.76	1.23	-
Pueraria	4.77	0.84	1.12	-
Glycine	5.05	0.65	1.04	-
Stylosanthes	5.17	0.61	1.17	-
Control	4.87	0.50	1.06	-
	Cowpeas	Maize	Soybeans	Cassava
b. Second Arable Crop				
Panicum	0.62	1.69	0.50	3.50
Setaria	0.71	2.97	0.91	7.90
Brachiaria	1.04	3.80	1.14	17.39
Melinis	0.87	3.43	0.77	18.85
Centrosema	0.76	3.73	0.75	15.01
Pueraria	0.79	3.44	0.80	19.49
Glycine	0.71	3.02	0.93	14.12
Stylosanthes	0.67	3.11	0.91	19.83
Control	0.43	2.06	0.51	8.05
LSD (0.05)	0.06	0.53	0.23	2.53

Table 16. Effects of Various Mulches on the Yield and Performance of Maize, Cassava, Cowpeas, and Soybeans (IITA: 1975 and 1976)

Treatment	Cowpeas		Soybeans	
	Late 1975	Early 1976	Late 1975	Early 1976
Bare	0.67	0.59	0.43	0.58
Rice husks	0.82	1.14	0.48	0.79
Sawdust	0.95	0.93	0.73	1.91
Maize storer	0.99	1.11	0.88	1.99
Maize cobs	1.03	1.07	0.64	1.35
Guinea grass	1.08	2.09	0.87	1.53

	Cassava	Maize 1975	
	Fresh Weight of Roots (t/ha)	Early	Late
Bare	16.4	0.84	0.18
Fine gravel	22.9	1.26	0.59
Pigeon pea tops	22.9	1.03	0.42
Rice husks	28.3	1.15	0.50
Black polythene	30.5	1.28	0.60

Table 17a. Main-Season Grain Yield of Maize Variety TZPB Alley Cropped With Leucaena Leucocephala on Apomu Loamy Sand (Psammentic Ustorthent) as Affected by Application of Leucaena Prunings and Nitrogen

N Rate	Leucaena Prunings	Year 1979	1980	1981[a]	1982	1983
(kg N/ha)		- - - - - - - - - -	- - -	(tons/ha)	- - - - - -	- - - - - -
0	Removed	-	1.04	0.48	0.61	0.26
0	Retained	2.09	1.91	1.21	2.10	1.92
80	Retained	3.54	3.26	1.89	2.91	3.16
LSD .05		0.36	0.11	0.29	0.44	0.79

---

a. Maize crop seriously affected by drought during early growth.

Source: B. T. Kang, unpublished data.

Table 17b. Main-Season Grain Yield of Maize Variety TZPB and Seed Yield of Minor-Season Cowpea Variety VITA 6 Alley Cropped With Glyricidia Sepium Grown on an Alamba Sandy Loam (Oxic Paleustalf) at Ikenne in Southern Nigeria

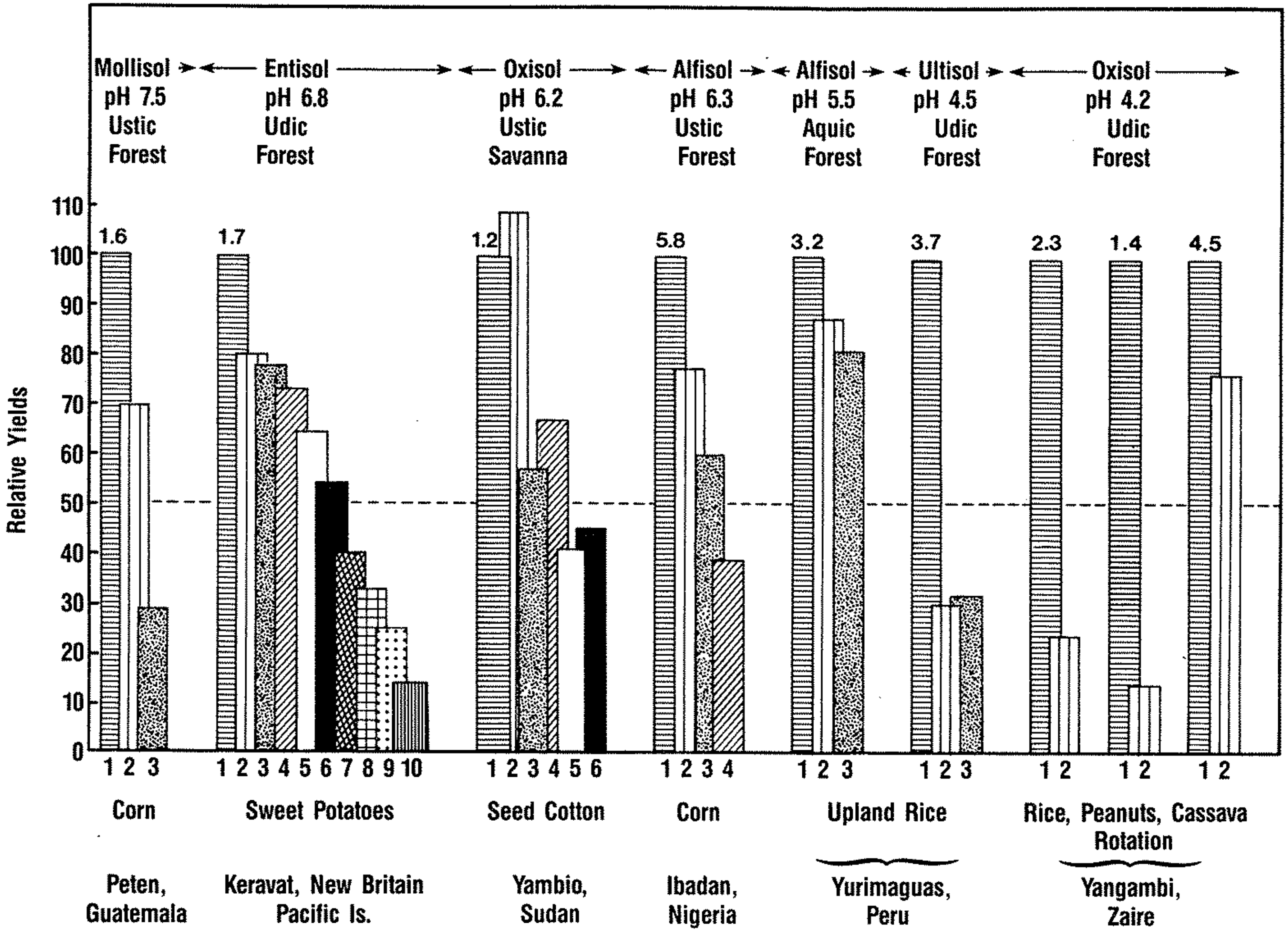
Treatment N Rate	Glyricidia Prunings	Yield Maize[a]	Cowpea[b]
(kg N/ha)		- - - - - - (kg/ha)	- - - -
0	Removed	2,609	738
0	Retained	3,037	818
40	Retained	3,291	820
80	Retained	3,125	994
LSD .05		427	187

---

a. N applied to main-season maize.

b. Cowpea plantings followed maize in minor season and received no N application.

Source: B. T. Kang and G. F. Wilson, unpublished data.



Numbers on top of histograms refer to economic crop yields (tons/ha).

Numbers on x-axis refer to consecutive crops.

(Source: Sanchez, 1976)

Figure 1. Yield Decrease in Relation to Years of Cultivation.

Table 17a. Main-Season Grain Yield of Maize Variety TZPB Alley Cropped With Leucaena Leucocephala on Apomu Loamy Sand (Psammentic Ustorthent) as Affected by Application of Leucaena Prunings and Nitrogen

N Rate (kg N/ha)	Leucaena Prunings	Year 1979	1980	1981[a]	1982	1983
		(tons/ha)				
0	Removed	-	1.04	0.48	0.61	0.26
0	Retained	2.09	1.91	1.21	2.10	1.92
80	Retained	3.54	3.26	1.89	2.91	3.16
LSD .05		0.36	0.11	0.29	0.44	0.79

---

a. Maize crop seriously affected by drought during early growth.

Source: B. T. Kang, unpublished data.

Table 17b. Main-Season Grain Yield of Maize Variety TZPB and Seed Yield of Minor-Season Cowpea Variety VITA 6 Alley Cropped With Glyricidia Sepium Grown on an Alamba Sandy Loam (Oxic Paleustalf) at Ikenne in Southern Nigeria

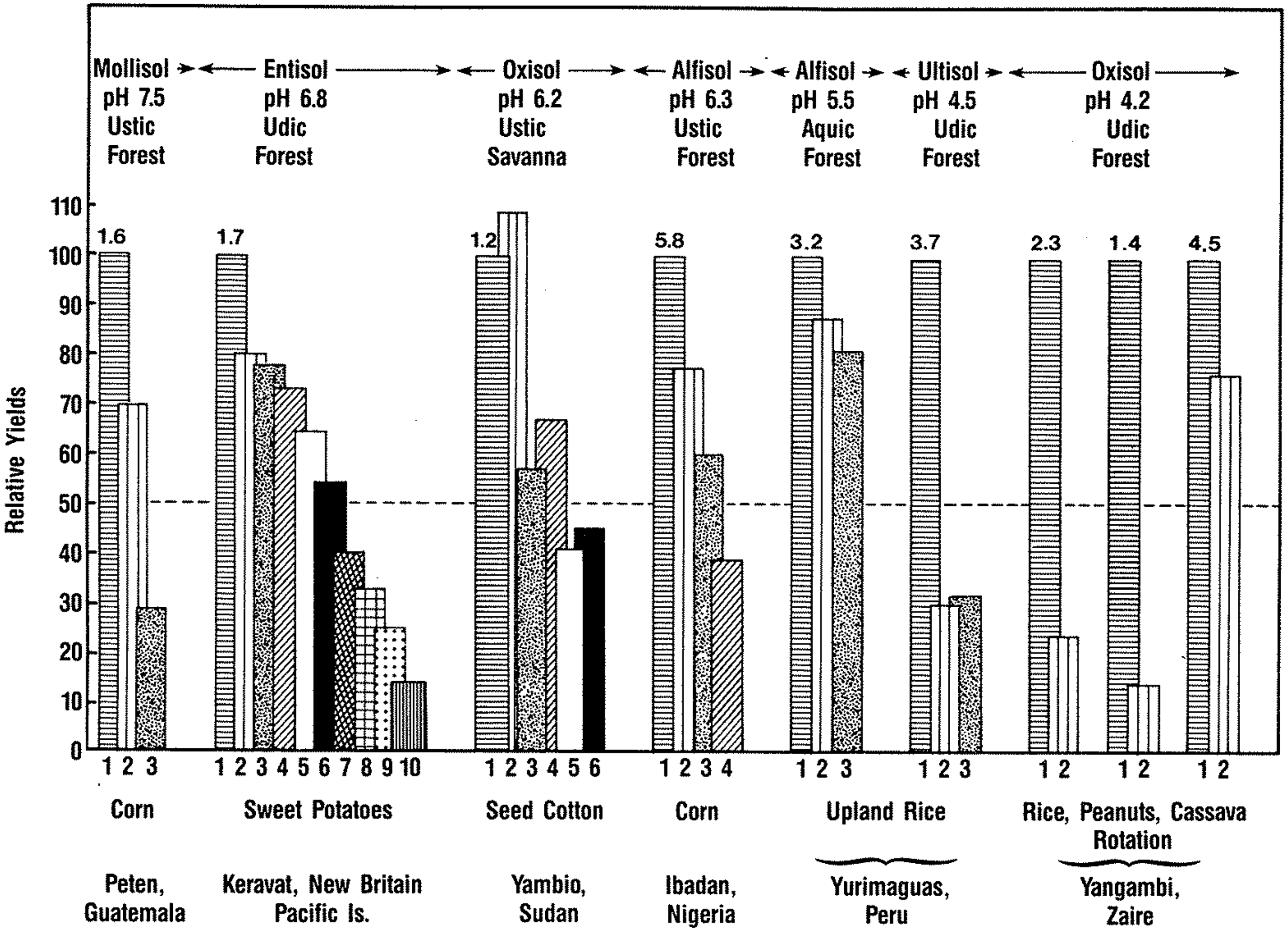
Treatment N Rate (kg N/ha)	Glyricidia Prunings	Yield Maize[a]	Cowpea[b]
		(kg/ha)	
0	Removed	2,609	738
0	Retained	3,037	818
40	Retained	3,291	820
80	Retained	3,125	994
LSD .05		427	187

---

a. N applied to main-season maize.

b. Cowpea plantings followed maize in minor season and received no N application.

Source: B. T. Kang and G. F. Wilson, unpublished data.



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N Rate (kg N/ha)	Leucaena Prunings	Year 1979	1980	1981[a]	1982	1983
		(tons/ha)				
0	Removed	-	1.04	0.48	0.61	0.26
0	Retained	2.09	1.91	1.21	2.10	1.92
80	Retained	3.54	3.26	1.89	2.91	3.16
LSD .05		0.36	0.11	0.29	0.44	0.79

---

a. Maize crop seriously affected by drought during early growth.

Source: B. T. Kang, unpublished data.

Table 17b. Main-Season Grain Yield of Maize Variety TZPB and Seed Yield of Minor-Season Cowpea Variety VITA 6 Alley Cropped With Glyricidia Sepium Grown on an Alamba Sandy Loam (Oxic Paleustalf) at Ikenne in Southern Nigeria

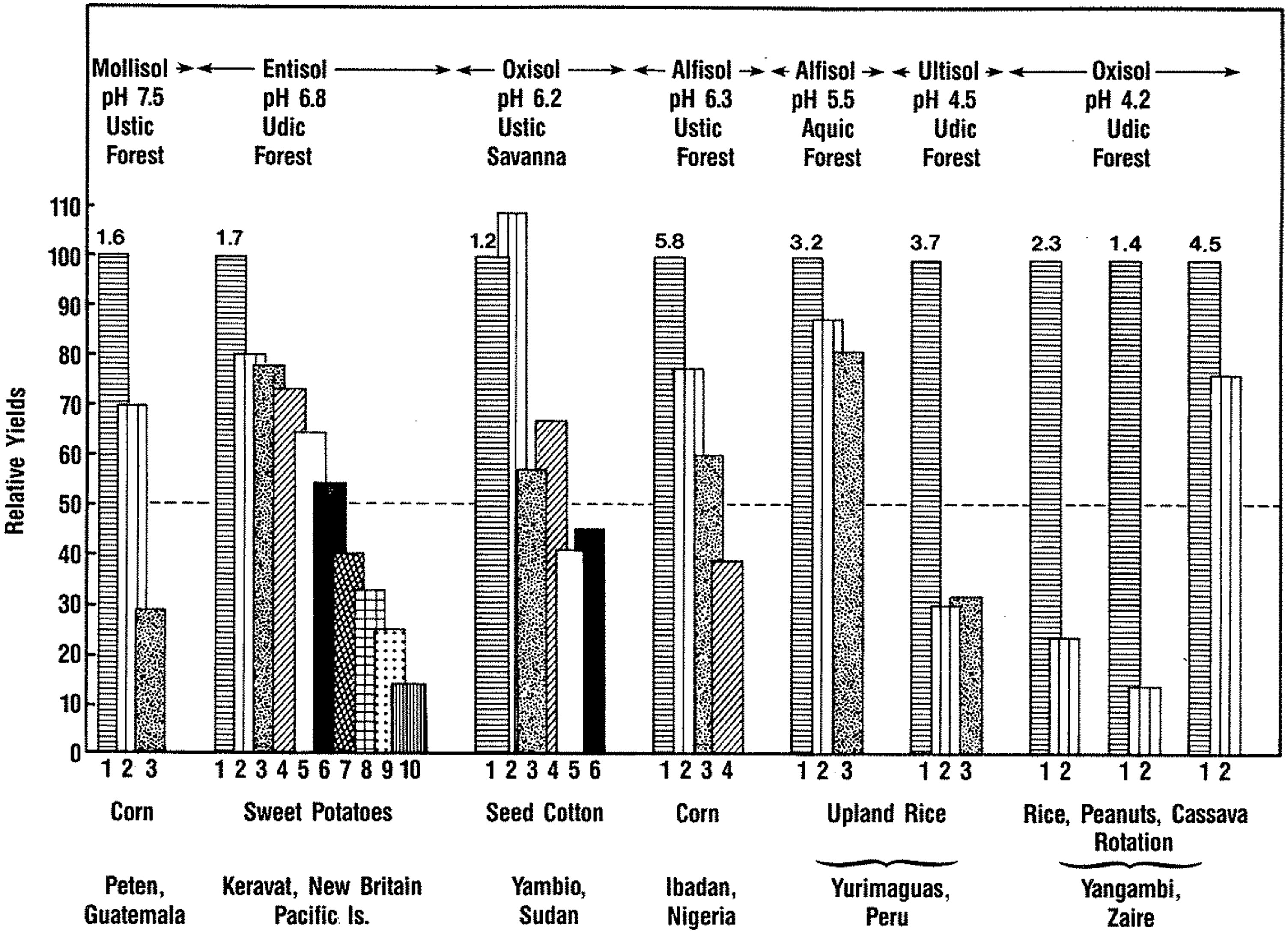
Treatment N Rate (kg N/ha)	Glyricidia Prunings	Yield Maize[a]	Cowpea[b]
		(kg/ha)	
0	Removed	2,609	738
0	Retained	3,037	818
40	Retained	3,291	820
80	Retained	3,125	994
LSD .05		427	187

---

a. N applied to main-season maize.

b. Cowpea plantings followed maize in minor season and received no N application.

Source: B. T. Kang and G. F. Wilson, unpublished data.



Numbers on top of histograms refer to economic crop yields (tons/ha).
Numbers on x-axis refer to consecutive crops.

(Source: Sanchez, 1976)

Figure 1. Yield Decrease in Relation to Years of Cultivation.

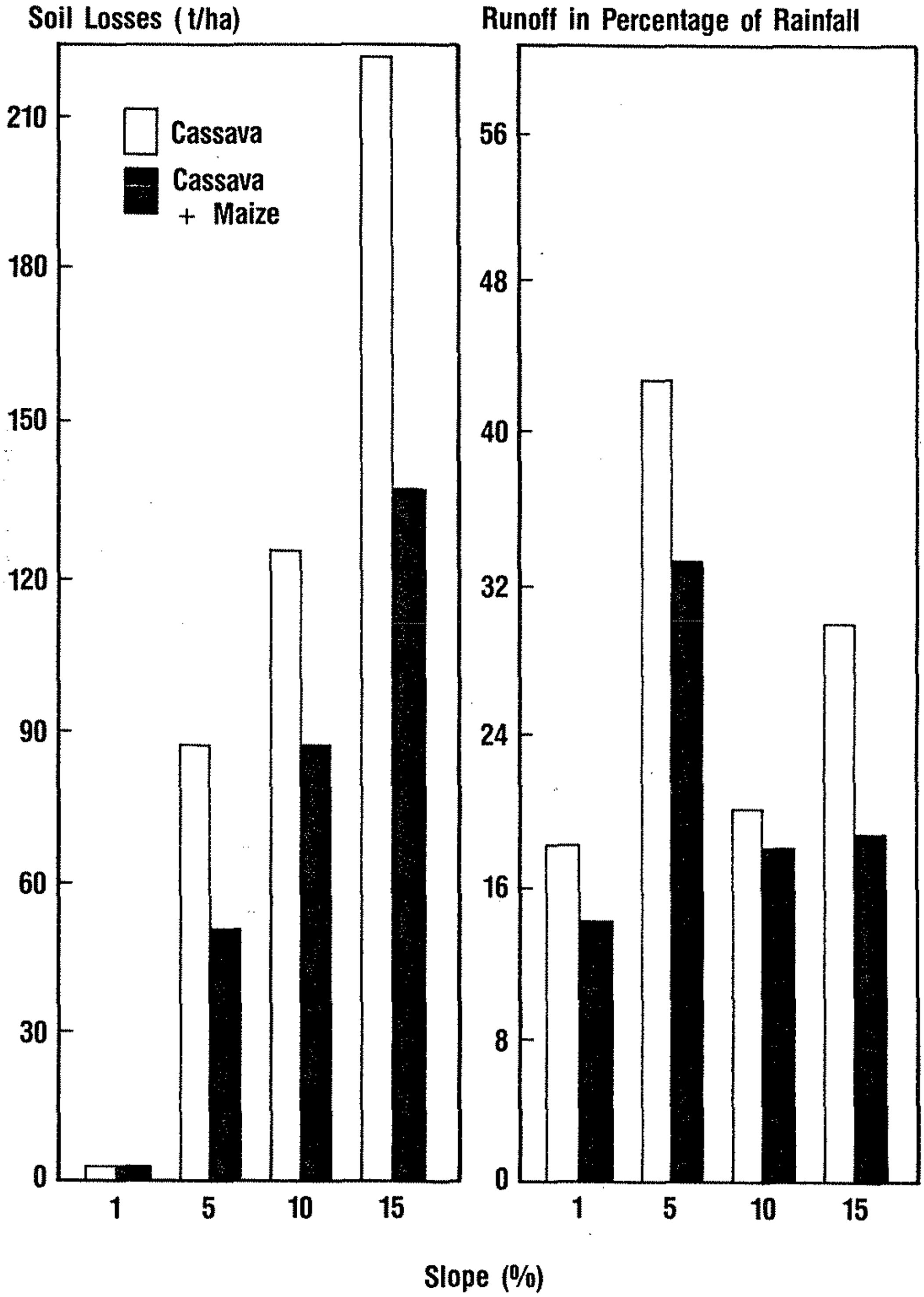
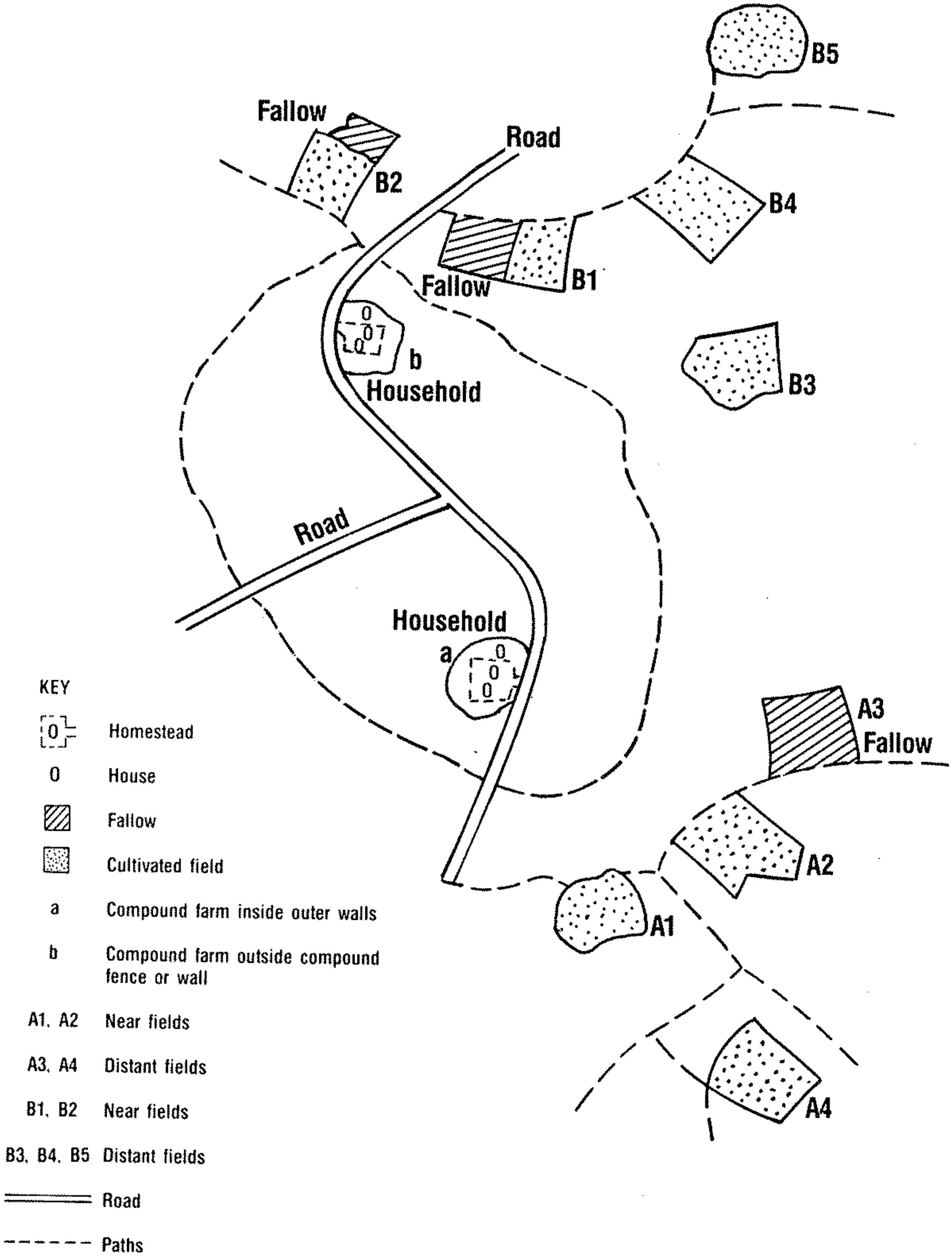


Figure 2. Soil Losses and Runoff Under Sole Crop of Cassava Compared to Mixed Crop of Cassava and Maize.



Source: Okigbo, 1982.

Figure 3. Schematic Diagram of Compound Farms in Relation to Associated Field Systems in Traditional Farming Systems of the Humid Tropics of West Africa.

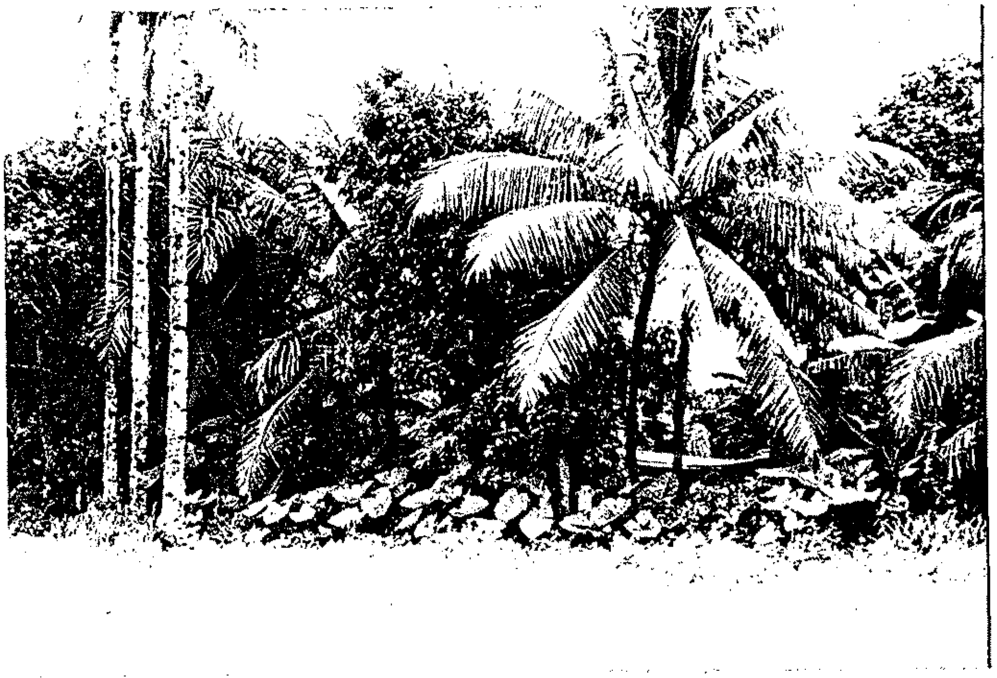


Figure 4. Typical Compound or Homestead Garden in Humid Tropics in Anambra State of Nigeria, Showing a Multistoried Structure and Diversity of Species. Note Ground Layer of Shade-Tolerant Cocoyams (*Colocasia* and *Xanthosoma* spp) and Herbaceous Species, Shrubby Layer of Bananas, Plantains, Applying of Fruit Trees, Then Almost Continuous Layer of Tall Coconuts, Star Apple (*Chrysophylluum* spp), African Breadfruit (*Treculia* spp) and African pear (*Dacryodes* sp).

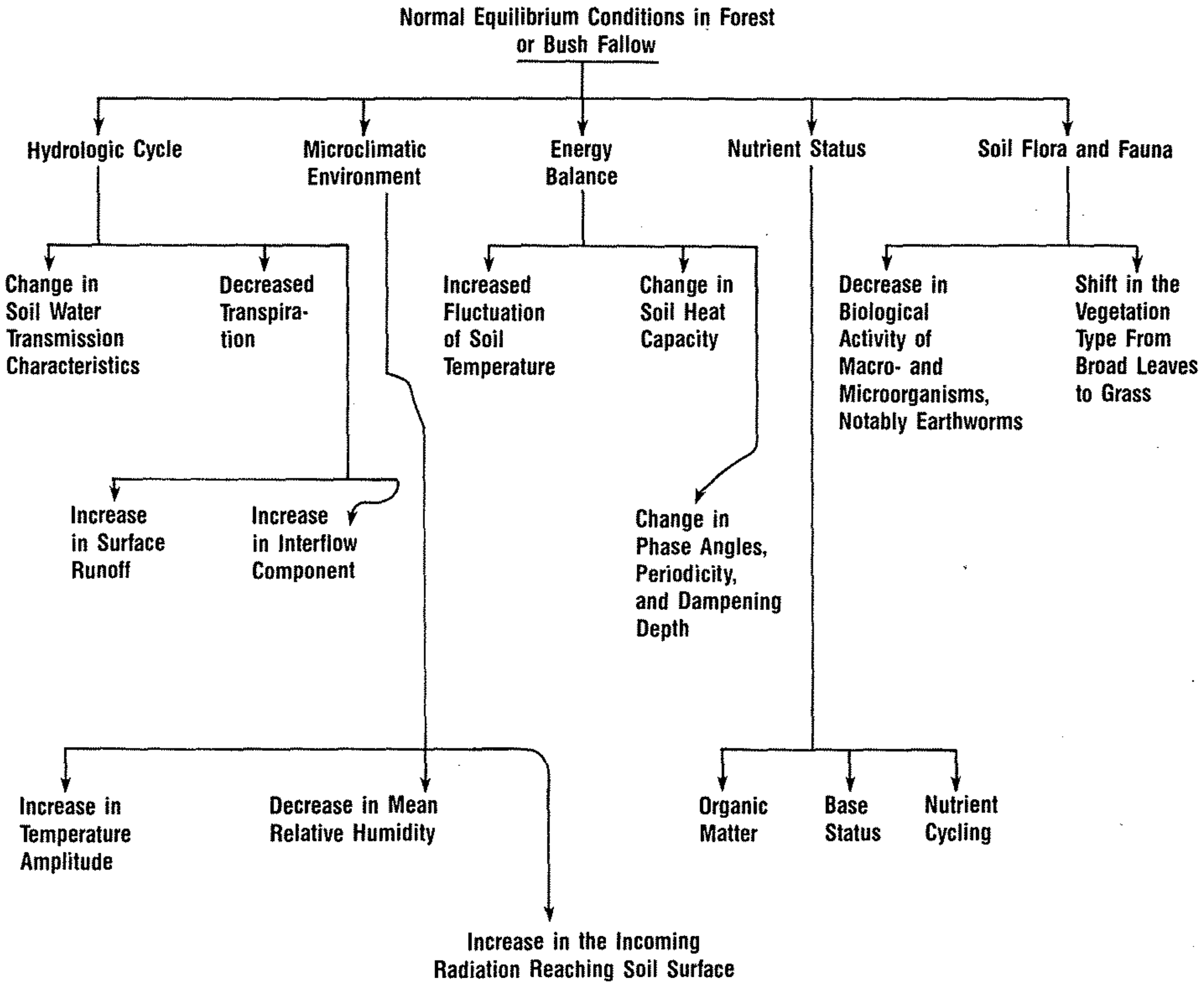


Figure 5. Alterations in Soil Microclimatic Environments by Deforestation and Intensive Culturation of Tropical Soils (After Lal, 1981).

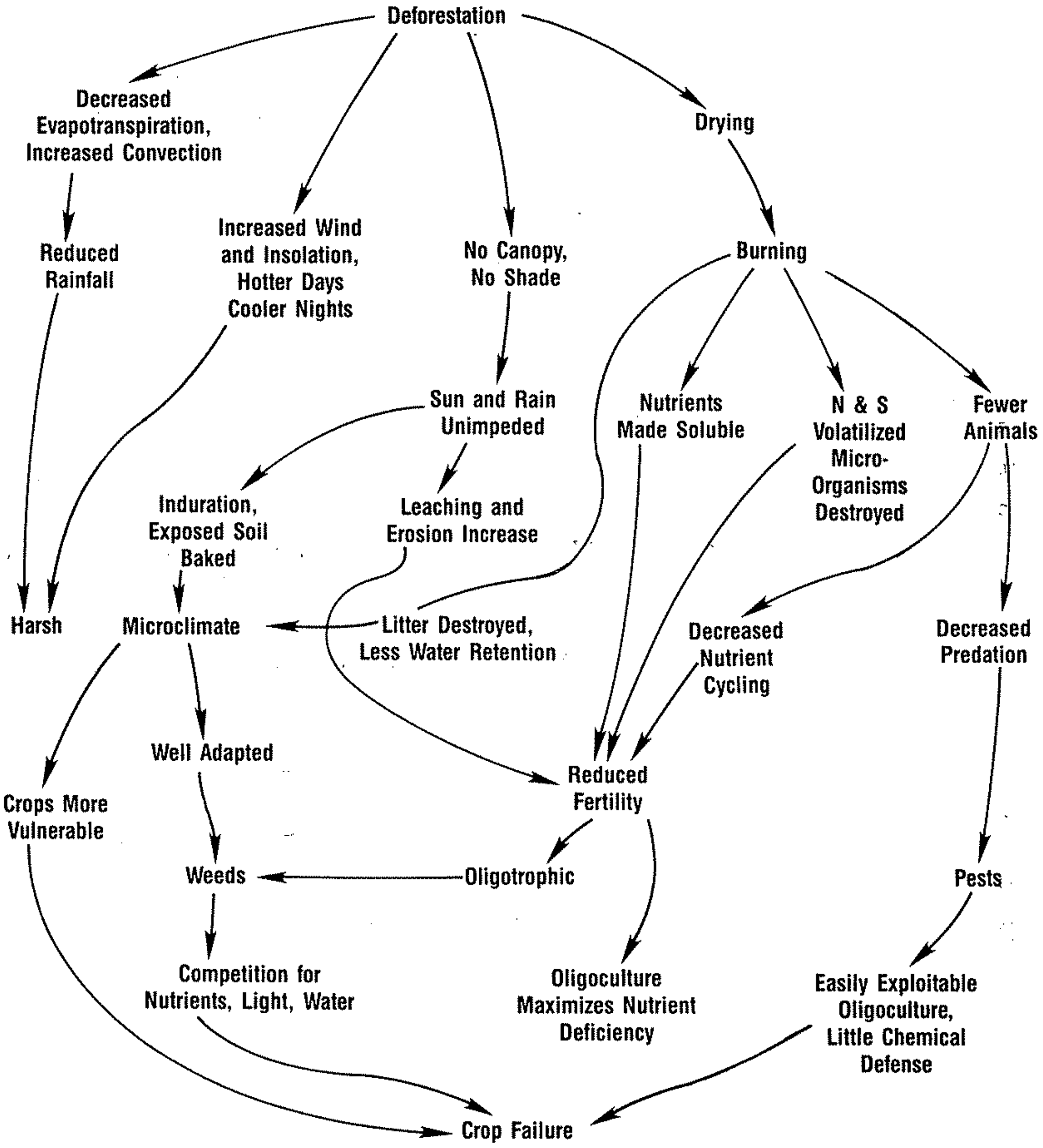


Figure 6. Relationship Between Deforestation and Crop Failure (Goodland and Jookman 1977 From Quereshi, 1978).

FERTILIZERS AND SUB-SAHARAN AFRICA

Dennis H. Parish

IFDC has recently reviewed the role of fertilizers in Africa's agricultural future (Sheldon et al., 1984). The review brought out clearly the need for the development of well-managed fertilizer sectors if the current pressing food supply problems are to be overcome.

Of the continents, Africa has become the largest importer of food, surpassing developing Asia, which has five and one-half times its population. The amount of cereal imported into Africa today is several times that of the 1970s and now exceeds the entire cereal exports of Canada (FAO, 1981).

Given good genetic plant material and sound agronomic practices, water and soil fertility are the keys to high crop production levels. The importance of water in crop production cannot be overstressed, but apart from countries like Egypt, irrigation plays only a minor role in Africa's crop production. Africa's agricultural future lies in the rainfed areas, and improvements in soil and water conservation at the farm level are key elements in maintaining and improving crop yields.

Drought is a factor in the rainfed areas. As a case in point, during 1983 Zimbabwe shifted from being a net grain exporter to being a net importer, mainly as a result of a serious drought. However, drought should not be overemphasized. Even for the Sahel area drought is not the number one problem; poverty of the soil is that problem. Throughout Africa, low-fertility soils are a major constraint on crop production.

Fertilizers are expensive ex-factory, and their distribution and storage costs are very high because of their seasonal use and bulky nature. By careless management the farmer can turn a potential profit source into a net loss and waste both his restricted reserves and national foreign exchange.

Fertilizers can contribute to increased crop production only in areas with adequate physical and institutional infrastructures. Physical infrastructure requirements include adequate transport and storage facilities; institutional infrastructure needs include good crop and input marketing services including credit and an adequate information base. In Africa, therefore, increased national crop production will come mainly from those rather restricted areas having a sound infrastructure able to deliver fertilizers to farmers who will use them in a cost-effective manner.

This paper reviews the various components that make up the fertilizer sector and identifies both the problems and needs of sub-Saharan Africa. The solutions are known, but to become realities they require a full commitment from governments.

The Need for Fertilizers

Fertilizers are used to make a profit. They make a profit because, without them, the soil is incapable of supplying the nutrients needed for economic crop yields.

Soil fertility management, however, is a complex issue. Although the farmer is interested primarily in his profit in the short run, the government is interested in maintaining and improving the soil resources of the nation. Governments must be concerned with the total fertility of the soil and not just in maintaining or increasing fertilizer use by pricing policies.

Organic matter recycling and the use of legumes are generally regarded as essential if soils are to remain productive and if dependency on fertilizer use is to be lessened. Organic matter recycling is labor intensive and must be developed by the farmer himself; the government's role here is to encourage the farmer by education and financial reward in terms of attractive crop prices.

Many of the soils of Africa are fragile, both chemically and physically, and the use of nitrogenous fertilizer and potash salts will aggravate problems of soil acidity where these already exist and lead eventually to problems even in more favorable areas. The national use of limestone to alleviate the effects of soil acidity on crop yields can only be made as part of a government-supported scheme, but in this particular area, most governments have been inactive.

This being said, because in the soils of Africa there is widespread deficiency in phosphate and N and low soil reserves of K, S, and other nutrients, fertilizers are essential for high yields.

Undoubtedly, when high soil fertility and good water regimes are combined with adequate sunshine, good agronomic practices, and modern crop varieties, very high yields can be obtained.

Under low-fertility conditions and periods of water stress, common conditions in many parts of the continent, yields can be improved and stabilized by improved agronomic practices and fertilizer use. However, the whole question of intensive versus extensive cultural practices now comes into play. Whether it is worthwhile for a traditional farmer to change agronomic practices without also using fertilizer and related inputs is problematic.

In Asia, the introduction of high-yielding varieties (HYV) of rice was linked to correct plant populations, the use of younger seedlings for transplanting and weed and pest control, and, of course, fertilizer. This approach has made HYV rice in Asia the major consumer of fertilizer, whereas traditional varieties continue to be grown in traditional ways with little or no fertilization.

Experience with hybrid maize in Kenya showed that when this crop was treated as an entirely "new crop" farmers accepted the recommended practices readily, including fertilizer use.

Cereals and Fertilizer

Throughout the developing countries, fertilizer use by the farmers is restricted to cash crops and primarily to HYV rice followed by HYV wheat and then maize. The situation in sub-Saharan Africa is similar, with the sequence of rainfed cereals in terms of increasing rainfall and soil fertility needs being as follows:

Millet → Sorghum → Maize

Compared with maize and rice, little improvement has been made in improving millet varieties, and for this crop the major soil fertility constraint is low soil phosphate. Improved sorghum varieties are becoming increasingly available, but many of these require high fertilization and cannot compete with local varieties when grown under typical small-farmer conditions, or with maize when rainfall and soil fertility are adequate. Good maize varieties are available, and fertilizer use is needed and indeed is used for good yields.

Upland rice has not been improved very much anywhere in the world, and traditional practices of cultivation continue. Irrigated rice grown under sunny conditions uses fertilizer very effectively, but high levels of management are needed.

Root Crops and Fertilizers

The root crops--yams, cassava, and cocoyams--are widely grown in Africa; yield data are provided in tabular form for west Africa in terms of calorific and protein yields (Coursey and Booth, 1977).

	Calorific Production (Cal x 10^6/ha)	Protein Production (kg/ha)
Cassava	8.2	37
Yams	5.7	107
Sweet potato	7.4	96
Cocoyams	4.5	80
Potato	4.7	128
Maize	3.2	32
Sorghum	2.4	70
Soybean	0.8	78

As with the cereals, millet and sorghum, researchers have a difficult task improving on traditional root crop varieties, but good progress is being made (Leakey and Wills, 1977).

Cassava--Cross breeding and selection of cassava plants for disease resistance was started in 1937, and over the past decade the International Institute of Tropical Agriculture has made good progress in this endeavor. Production of this crop is, however, associated with intercropping and the low use of inputs. Cuttings of good varieties are not reaching the farmer.

Yams--Yam production is very labor intensive. Yields can be increased by good agronomic practices, including selection of seed material, mulching, staking, good weed control, and growing in pure stands. Although yams respond well to fertilizers, little or no fertilizer is used on this crop, and traditional extensive production prevails.

Sweet Potatoes and Cocoyams--These two root crops have been but little improved, and traditional production practices are the rule.

Plantation Crops and Fertilizers

Well-maintained stands of oil palms, coconuts, rubber, tea, coffee, cocoa, bananas, sugarcane, etc., can all use fertilizer effectively in terms of increased crop production. Under small-farm conditions, however, unless the standard of management is good, fertilizer use will probably be uneconomical.

Fertilizer Use

Historically, the use of fertilizer in sub-Saharan Africa started with the plantation industries and the small-farmer cash crops such as groundnuts and cotton. If a farmer has a steady market for his cash crop, he will develop the confidence to invest in purchased inputs not only for the cash crop but also for use on his subsistence crops.

The effect of a cash crop monopoly is well illustrated in Figure 1 where the historical total nutrient consumption of the Ivory Coast is compared with the nutrient consumption of the Compagnie de Developpement des Textiles (CIDT) which is a cash crop monopoly organization covering the savanna zone of the Ivory Coast.

An unreliable cash crop market will kill the farmer's confidence, and carefully nurtured input-output crop production schemes will collapse. Reestablishment of confidence will take many crop seasons. Figure 2 taken from Uganda data (Hahn, 1984) illustrates such a collapse.

Fertilizer use statistics for Africa have been collated by IFDC (IFDC, 1981). Current trends indicate that fertilizer consumption in 1985/86 will be 4.3 million tons of nutrient and 5.0 million tons in 1990/91 (IFDC data). These increases are not nearly large enough to increase yields and agricultural production to the extent needed for Africa to become food self-sufficient (Table 1) (IFPRI, 1981).

Opportunities for Reducing the Cost of Fertilizer

Fertilizer should be purchased only on the basis of cost effectiveness. However, product quality, i.e., granules instead of powder, and convenience, i.e., multinutrient versus straight fertilizers, play a role in the choice; of course, convenience carries with it a price premium which may or may not be compensated for in terms of crop production economics.

Low-analysis fertilizers are more expensive to bag, distribute, and store than are the equivalent nutrients in concentrated fertilizers, and therefore the international trend has been toward the use of high-analysis fertilizers.

Three factors which affect the final cost of fertilizer applied in the field must be examined:

1. The technology of production.
2. Choice of nutrient carrier.
3. Handling, distribution, and storage.

The Technology of Production

Until large fertilizer markets have been built up, production units with a low level of capital investment and a flexible operation should be the prime objective.

Table 2 shows the range of fertilizer production units available. Only countries with ample supplies of cheap energy can consider ammonia/urea units; diammonium phosphate (DAP) units, however, need local supplies of phosphate rock and cheap sulfuric acid.

Handling, Distribution, and Storage

Efficient handling, distribution, and storage of fertilizers are essential if costs are to be kept as low as possible. With the tremendous distances and generally poor hinterland infrastructure, the landlocked countries of Africa in particular face enormous problems. Inefficient logistics not only increase fertilizer costs but can also reduce the efficiency of its use--fertilizer that arrives late or not at all or that is of the wrong kind can reduce anticipated crop yields and destroy the carefully nurtured confidence of the farmer in relying on input supplies. Examples of costs associated with the physical distribution of fertilizers are given in Table 3 (Trupke, 1983).

Choice of Nutrient Carrier

Nitrogen--Although ammonium sulfate and ammonium nitrate are effective fertilizers, they are being replaced in world trade by urea. Urea is a concentrated fertilizer (46% N) and is equally as effective as other sources when incorporated into the soil. Surface-applied urea can lose considerable quantities of N by ammonia volatilization, and strong farmer education is needed to prevent surface applications.

Phosphate--The selection of the most cost-effective phosphate fertilizer is complicated because the degree of water solubility, the crop being fertilized, and the nature (acidity) of the soil affect agronomic results.

Generally, on acid soils for perennial crops, ground natural phosphate rock is useful, whereas the soluble phosphate is more suitable for annual crops. Ground rock phosphate, single superphosphate (SSP), DAP, and NPK materials based on nitrophosphates are all used in Africa.

Potash--For potash, the situation is quite simple. Potassium chloride is used where chloride is not harmful to crop growth or quality; otherwise, potassium sulfate is used.

Sulfur--Sulfur is widely deficient in Africa and can be supplied easily as ammonium sulfate or as SSP and, of course, as elemental S.

Trace Elements--These are usually applied as salts, but organic compounds "chelates" are available for special use. Boron is widely used in Africa, and other trace elements are of value in specific areas.

Increasing Fertilizer Use

Fertilizer use in Africa has not developed as many planners hoped it would. If faults are to be identified, then probably the key failing has been the lack of farmer service in terms of guidance and customer service (Mathieu and de la Vega, 1978).

So far as farmer interest in fertilizer use is concerned, there are three challenges:

1. To increase the economic effectiveness of fertilizer in those areas where it is a major input.
2. To introduce sound fertilizer practices into those areas where little or no fertilizer is used.
3. To ensure that ready supplies of conveniently packaged fertilizer are available to the farmer as and when he needs it.

The reduction of fertilizer costs can go some way toward meeting the first challenge, but improving crop response per unit of nutrient applied offers the greatest opportunity to improve fertilizer use economics. This can be achieved through improving fertilizer recommendations by making them more site and situation specific, i.e., more sensitive to rainfall, soil and crop management conditions, and the farmers' socioeconomic status.

As regards the plantation crops, fertilizer research in Africa is acknowledged internationally as being outstanding, and the knowledge has been applied in the past. With the cotton crop, although once again it must be stressed that the work is also internationally recognized, the prime objective has been the production of cotton. Recently, the need to look more closely at the total farm cropping pattern and practices has been more heavily stressed, but much work remains to be done.

The adoption of recent advances in the design of farm-level fertilizer trials and modern statistical and economic interpretations of these trials could lead to more relevant fertilizer recommendations for the small farm in terms of quantity, type of fertilizer, cropping systems, and methodology of application; however, the needed experiments must be carried out in farmers' fields. Farmer and extension staff involvement with the field research work is essential if relevant and acceptable fertilizer recommendations are to be developed, particularly where the nonfertilizer-using farmers are the target.

The third challenge involves more than just an adequate distribution system; it also involves the whole philosophy of modern marketing which identifies the need for and encourages the use of correct fertilization practices through integrating the research, extension, distribution, and production components of the fertilizer sector.

Unless development of the fertilizer sector is based on sound overall marketing/planning, instead of the use of fertilizer and related inputs as beneficial but isolated development tools, governments will find themselves paying dearly in terms of subsidies, wasted capital investments, large foreign exchange import bills, and farmer disenchantment with modern agricultural practices.

Given that crop and input prices are correctly established and that the fertilizer products needed by the farmer are known, then the two key factors in developing fertilizer use are (1) availability of the product at the time and place the farmer needs it and (2) the awareness of the farmer that the products he needs are available and that their use will benefit him economically. It is a fact that most statal and parastatal organizations are unwieldy and unable to respond to the day-to-day changes in supply and demand at the farm level in a cost-effective way. The farmer cannot plan ahead when it comes to fertilizer and related input purchases. Fertilizer products must be readily available when crop and climatic conditions are suitable for their use.

Government agencies throughout the world have attempted to solve this supply problem by building expensive storage facilities and filling them with products which were sold only slowly, if at all; this approach often leads to a huge loss of investment and credibility in the farmers' eyes.

Fertilizer is an expensive material, and it should be treated as such. The farmer must make a financial commitment to use the fertilizer, and, in return, the supplier must be sensitive to his needs. No other system is acceptable. Free fertilizer, poor quality material, removal of farm-level decisionmaking, and lack of farmer knowledge all impede the rational growth of fertilizer use. Given a good education-oriented supply system, farmers will find the cash or credit to purchase the offered inputs. A responsible well-trained private sector can reinforce greatly the impact of the state extension service by ensuring that supply constraints are eliminated. The farmer should purchase his inputs from a dealer who understands the products he is selling and how these materials should be used. Such well-trained dealers with sound subject-matter knowledge are invaluable to the extension service. The development of the private sector must be carefully planned and monitored by the government to ensure that the farmer receives a quality service without excessive markups.

Summary

Africa is an increasingly important importer of food, although the potential for self-sufficiency remains.

Although inadequate or badly distributed rainfall reduces crop yields, low soil fertility is the major controllable constraint reducing crop production. The recycling of organic matter and the use of leguminous crops can help, but fertilizers are essential over large areas of Africa. Fertilizers are expensive, and the form, rate, and time of application and placement must be optimized if their use is to be profitable.

Plantation crops and small farmer cash crops such as cotton and maize bring economic benefits when correctly fertilized. With the traditional cereals, millet, and root crops, factors other than the low soil fertility reduce the farmer's interest in fertilizer.

Fertilizer costs could be reduced by improved products, production techniques, and handling and use. Only a carefully integrated fertilizer sector can help African nations stimulate farmer use of fertilizers and increase national benefits from its use.

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Table 1. Fertilizer Nutrient Requirements for Selected African Countries

	Use 1975	Requirement 1990	Use in kg/ha	
			1975	1990
	('000 t NPK)			
Ethiopia	14.0	151.6	2.4	16.8
Sudan	50.0	317.8	12.7	37.9
Kenya	27.2	102.9	10.6	29.3
Mali	2.0	42.5	0.2	18.4
Burkina Faso	0.6	42.4	0.1	12.4
Niger	1.2	50.5	0.1	12.3
Chad	1.0	24.2	1.3	14.9
Somalia	3.0	13.7	3.5	23.4
Mauritania	0.7	5.1	1.1	19.1
Senegal	26.0	62.4	18.2	27.1

Table 2. Typical Investments for Fertilizer Complexes (1983 US $)

Product	Process Units	Capacity (tpd product)[a]	Fixed Investment (US $ million)
Urea	Ammonia (gas) Urea	1,700	350
Diammonium phosphate	Sulfuric acid Phosphoric acid DAP	1,300 (600 P_2O_5)	200
Ammonium nitrate	Nitric acid Ammonium nitrate	1,800	100
Granular NPK compounds	Granulation	500	15
Bulk-blend NPK compounds	Bulk blending	500	5

a. tpd = tons per day.

Table 3. Fertilizer Physical Distribution Costs in Africa

Country	Costs (US $/ton)
Gambia	41.50
Kenya	133.33
Nigeria	136.97
Sierra Leone	149.31
Sudan	166.73
Tanzania	238.50

Source: Trupke, H. 1983. FAO data, Rome.

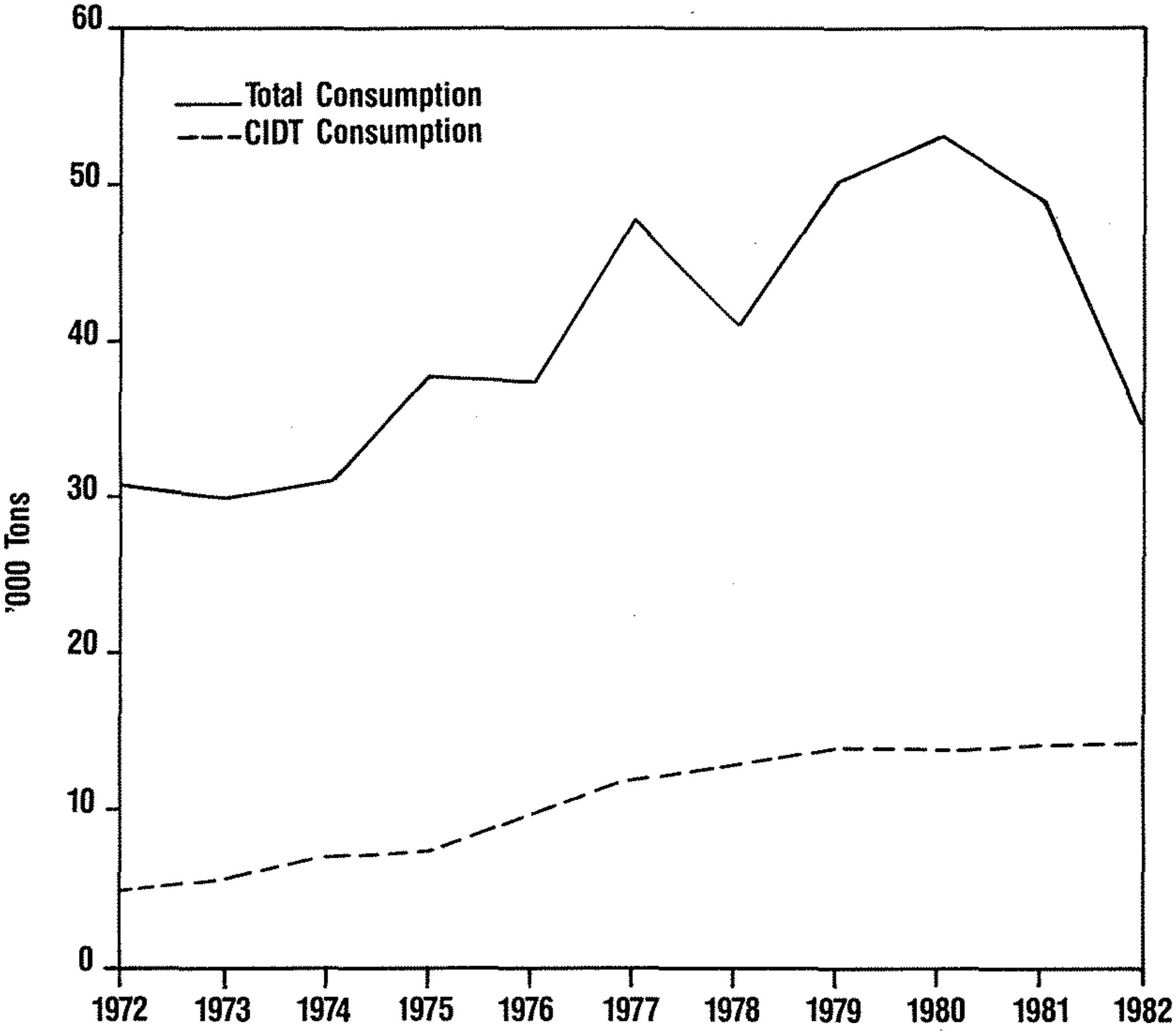

Figure 1. Fertilizer Nutrient Consumption in Ivory Coast (N + P_2O_5 + K_2O).

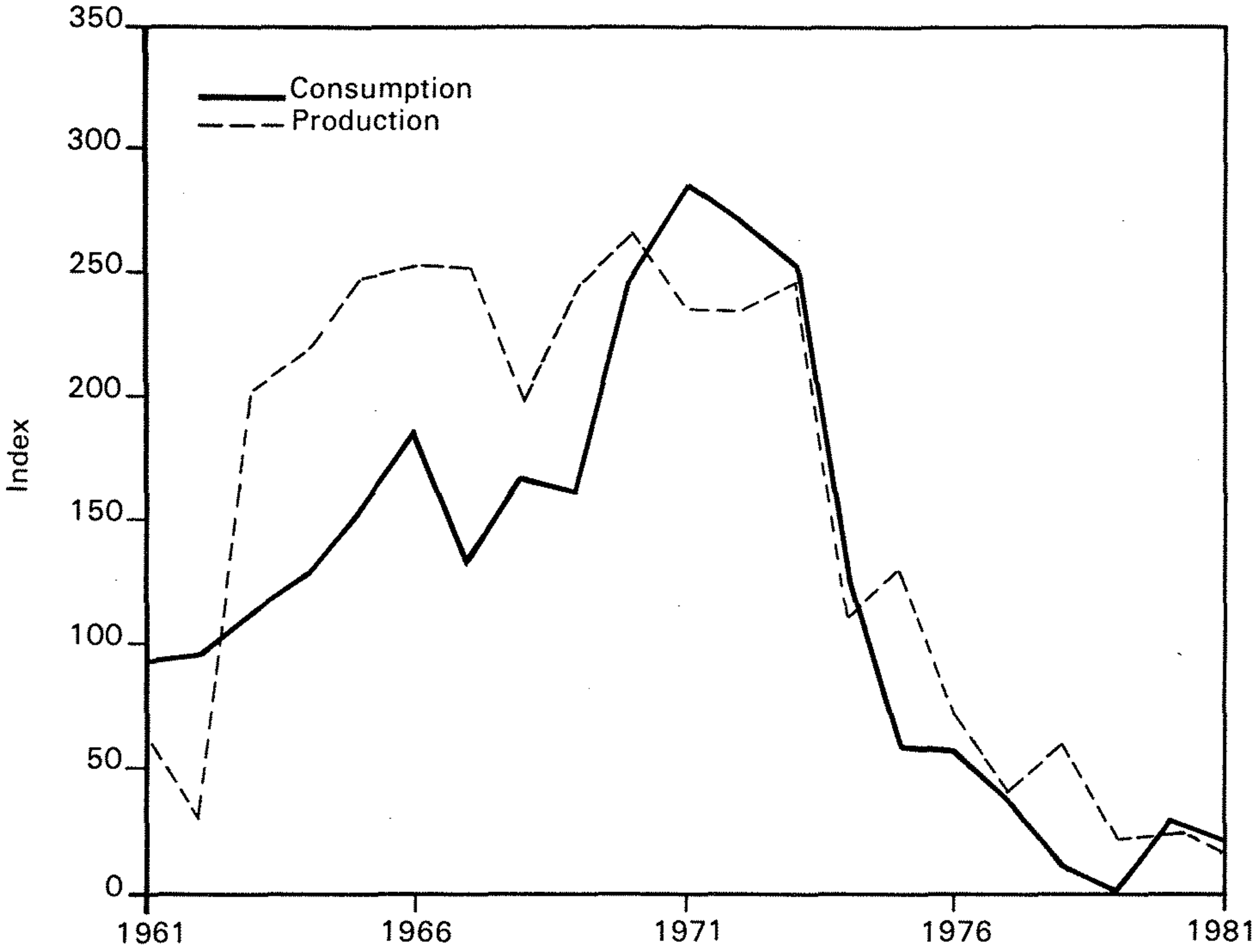

Figure 2. Uganda: Index of Fertilizer Consumption and Cotton Production.

APPROPRIATE FERTILIZER TECHNOLOGY FOR SUB-SAHARAN AFRICA[1]

Dennis H. Parish

Appropriate Technology

"Appropriate technology" is a term that means different things to different people. This is understandable because technology that is appropriate in one location may not be appropriate in another. For the purpose of this paper, appropriate fertilizer technology is taken to be that technology that takes full advantage of the resources of a country or district, including mineral, energy, land, and human resources, to produce fertilizer products that are well adapted to the local needs and does so with minimum expenditure of capital and foreign exchange.

From this definition it follows that selection or development of appropriate technology requires good national-level knowledge of the human and mineral resources and a good understanding of soil fertility needs--for primary nutrients, secondary nutrients and micronutrients, as well as for soil amendments. The degrees of development of the existing and of the planned infrastructure improvements also are important.

Appropriate Production Technology

Adaptation of Older Technology

Modern technology has evolved in developed countries with the objective of lowering costs by decreasing labor costs and by building high-capacity plants. As a result, the factories are large, expensive, complicated, and highly mechanized. The output of these plants is so great that their products must be marketed over a large area. Such plants are

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[1] Based on the paper by T. P. Hignett and D. H. Parish presented at the British Sulphur's Fertilizer 83 International Conference, London, England, November 13-16, 1983.

often unsuitable for developing countries where fertilizer demand is small, transportation costs are high, and low-cost labor is abundant. In some cases appropriate technology for small countries or remote districts of large countries can be derived from older processes and equipment that were used 20 or more years ago. However, no technology should be adopted without a full study by independent specialists.

Appropriate Level of Pollution Control

Pollution control should be appropriate to the local conditions. Whether an emission is polluting or not often depends on the quantity and where it is discharged. For example, sulfur dioxide (SO_2) is a normal constituent of the atmosphere; two-thirds of the sulfur oxides that reach the atmosphere come from natural sources. If the concentration in the plant and its vicinity is kept within safe limits, it is unlikely that there will be any damage to plants, animals, or people; in fact, SO_2 emissions can be an aid to agriculture by supplying needed sulfur (Terman, 1978).

Pollution control, however, must not be ignored; when building a plant (or correcting problems on an existing plant), pollution control measures should be carefully planned to accomplish the following purposes:

1. Protect the health of workers in the plant and of the people in the community by avoiding harmful concentrations of known pollutants in the atmosphere in and around the plants.
2. Avoid damage to crops and other vegetation.
3. Prevent deterioration of the quality of water in streams, lakes, estuaries, or harbors and protect other industries and people who use the water.
4. Maintain aesthetic values that are essential to pleasant surroundings and to the attraction of tourists.

Pollution control planning should be done on a common-sense basis with respect to the specific location because it is the impact of the pollutant on the environment that is important, not the actual concentration of the pollutant at the source.

Nitrogen Fertilizers

Supplying nitrogen fertilizers to landlocked developing countries often presents a very difficult problem. Importation can be very expensive, even when the price at the source is low, where transportation facilities are poor or limited in capacity.

It has been demonstrated that relatively small ammonia plants (100- to 300-tpd capacity) can be economical in developed countries when inexpensive feedstock is available and there is a freight advantage to offset the disadvantage of the plant's small scale. However, facilities for production of ammonia and its conversion to solid nitrogen sources are complicated even when simplified as much as possible, and construction of such plants in remote areas may be expensive where infrastructure is poor. Also, capacity utilization may be low because of the lack of maintenance skills and difficulty in obtaining spare parts.

Where moderately priced electricity is available, electrolytic hydrogen may be considered as feedstock for ammonia production. In fact, there were 21 ammonia plants based on electrolytic hydrogen in 1930 (out of a world total of 80 plants). The electrolytic process is simpler than processes that use coal, coke, natural gas, or naphtha, and the construction cost is lower for small plants (less than about 250 tpd). Unfortunately, there are few locations where low-cost electricity is available although water-power potential in sub-Sahara Africa is enormous.

Since ammonia costs only about one-half as much as urea or ammonium nitrate and can be transported economically by ship, barge, or pipeline, countries that are favorably located may find it economical to import ammonia for conversion to ammonium nitrate, sulfate, phosphate, or mixtures of these materials.

The Kettering Research Institute (U.S.A.) has promoted the concept of using small hydroelectric plants to fix atmospheric nitrogen by using an electric arc (Treharne et al. 1981). A typical 3 kW-prototype unit is capable of fixing 1 ton of nitrogen per year; about 90% of the electrical energy is dissipated as heat, and this could possibly be recovered for practical use. The gaseous product of the arc process is dissolved in water to give dilute (2%) solution of nitric acid. Ground limestone is used to neutralize the solution, and the resulting dilute calcium nitrate solution is used directly as a fertilizer. Such an approach appears to have potential in remote mountain regions such as those that occur in Nepal, and pilot schemes are being developed.

The example of the People's Republic of China (PRC) is unique in the extent to which it uses appropriate technology to produce both nitrogen and phosphate fertilizers. The PRC has some 1,400 nitrogen fertilizer plants of which more than 1,300 are classified as small, ranging from 5,000 to 20,000 tpy of ammonia ("Efficient Use," 1982). One type of standard small plant started out with 3,000 tpy of capacity. Most of these small plants use anthracite as feedstock although other types of coal can be used after conversion to briquetted char. The product is mainly ammonium bicarbonate.

Over 60% of the PRC's nitrogen fertilizer consumption in 1980/81 was reported to be "other nitrogenous fertilizer" (other than ammonium sulfate, ammonium nitrate, or urea) (FAO, 1981). The small plants serve local areas of about 25-km radius and thus greatly relieve the national transportation system.

These small ammonia plants, although relatively simple, still require advanced expertise in building high-pressure compressors, pressure vessels, and other equipment. In addition, few countries have coal or other feedstock available at as many localities as the PRC does.

In summary, it would seem that the prospects for developing an economical, indigenous nitrogen industry in small landlocked countries that lack feedstock are not very good.

Phosphate Fertilizers

Appreciation of the value of nitrogen, phosphorus, and potassium salts in increasing crop yields precedes the science of crop nutrition and the industrial production of chemical fertilizers.

However, the move to extensive crop production in the 18th century, associated with the Industrial Revolution, still relied almost entirely on the use of leguminous crops as a source of nitrogen and the recycling of crop residues, mainly as farmyard manure, as the sole source of phosphate and potash.

Under these conditions the depletion of soil fertility was primarily caused by the export from the farm of wheat or other cereals and animal products, all of which are high in phosphate and low in potassium.

In Africa crop stalks and dried foliage are used for many purposes and almost the total aerial portion of the crop may be removed from the field. This practice, of course, removes significant quantities of all plant nutrients but particularly of potash.

Single Superphosphate

Single superphosphate (SSP) was by far the most important phosphate fertilizer for over 100 years and is still an important fertilizer. It can be produced by uncomplicated processes and equipment, and its effectiveness as a source of phosphorus is unquestioned. Also it contains calcium and sulfur, which may contribute to soil fertility, and sometimes trace elements originating from the phosphate rock. Its main disadvantage is its low analysis, about 16%-22% P_2O_5. Because of its low analysis, it is usually made in small plants in the market area.

Single superphosphate may be a good choice for developing countries (and for some developed countries) that have either sulfuric acid or phosphate rock or both. This is especially true when both phosphorus and sulfur are needed for good crop growth, which is the case in many parts of Africa.

Direct Application of Phosphate Rock

Direct application of finely ground phosphate rock may be the least expensive way to supply phosphorus to crops in large areas of the world. The practice is well established in several developed and developing countries; it is estimated that about 8% of the world's phosphate fertilizer use is supplied by direct application of phosphate rock (Sheldrick and Stier, 1978). Its use is especially attractive when indigenous phosphate rock is available; however, use of imported rock may be economical in many cases. The best results are obtained on well-watered acidic soils and with relatively reactive rocks.

The advantages of using ground phosphate rock for direct application are as follows:

1. Low cost, especially for indigenous rocks.
2. Low capital investment.

3. Low requirement for technical skill.
4. Small energy requirement.
5. Suitability of rocks unsuitable for chemical processing (high carbonate or high chloride rocks, for example).
6. Avoidance of long delays for constructing processing equipment.
7. Low importance of economy of scale and capacity utilization.
8. Supply of calcium and sometimes other nutrients in addition to phosphorus.

The practice has certain distinct disadvantages that cannot be ignored. The most notable of these are the following:

1. The phosphate content in phosphate rock often is considerably less than that found in high-analysis conventional phosphates; thus, its competitiveness for markets at increasing distances from the mine site is limited.
2. Different phosphate rocks vary considerably in chemical reactivity and their agronomic effectiveness is strongly influenced by soil, crop, and climatic conditions (Peng and Hammond, 1979).
3. The handling properties of finely divided rock are often cited as being objectionable. It should be noted that in Malaysia, where agricultural workers are very highly paid, powdered phosphate rock spread by hand is a major fertilizer.

In the late 1800s and early 1900s, several of the state agricultural universities in the United States conducted long-term field experiments on the use of ground phosphate rock; the tests showed that the practice was quite profitable. The average yield increase was about equal to that obtained with superphosphate, but the superphosphate cost four times as much for an equal amount of P_2O_5 (Hopkins, 1913).

Cyril Hopkins was one of the early advocates of ground phosphate rock; he suggested applying about 1 (short) ton/acre of ground rock containing about 30% P_2O_5 every 6 years (Hopkins, 1913). This is equivalent to an annual rate of about 110 kg/ha of P_2O_5. However, most tests were made with lower application rates. Hopkins also advocated a rotation including a legume, which was to be plowed under to enrich the soil with nitrogen and organic matter. He believed that decaying organic matter was very beneficial in solubilizing phosphate rock in the soil. Most of the early research in the United States was conducted with Tennessee phosphate rock, which unfortunately was later found to be one of the least reactive rocks.

Many farmers in the United States started phosphate fertilization first by using ground rock, and the annual U.S. consumption rose to more than 1 million tons in the 1950s. Later, the consumption declined when high-analysis, granular, soluble phosphates, such as DAP, became available from Florida and freight cost increases made the products more competitive with ground rock.

Partially Acidulated Phosphate Rock

Partially acidulated phosphate rock has been produced in several European countries and in Brazil and is still being produced in sizable quantities in a few countries. Acidulation of ground phosphate rock with about 50% of the sulfuric acid that is required for single superphosphate gives a product that may contain about 23% total P_2O_5, of which about one-half is water soluble and hence readily available; the remainder will behave like the rock from which it is made. The product has the obvious advantages of lower cost due to saving of sulfuric acid and higher analysis than SSP. Also, it is a good source of sulfur where that element is deficient, and the $S:P_2O_5$ ratio is closer to that required for most crops. When made under proper conditions, the reaction is rapid and complete, and the product does not require curing.

Potash Fertilizers

Insoluble minerals containing potash include certain feldspars, micas, glauconites, and shales. Such minerals are the original source of soil potash, and centuries of weathering have rendered the potash more or less available to crops. The ground minerals have been applied to the soil in a few cases, but the results usually were disappointing.

All vegetation contains potash, and the residues from cereal crops (stalks, straw, etc.) contain as much as 80% of the K_2O that was taken up by the crop. Returning such residues to the soil helps to conserve potash. If the residues are burned, the potash remains in the ash. Wood ashes usually contain a fairly high percentage of potash, and such ashes were the first potash fertilizers.

Potassium chloride (KCl), the major potash fertilizer, will remain the major commercial source of potash. When crop quality is important, potassium sulfate may be used.

Other Plant Nutrients

Appropriate fertilizer technology should not be confined to N, P, and K. There are many cases where secondary elements, micronutrients, and soil amendments will improve yields or reclaim land that is not now productive. Where micronutrients are needed it may not be necessary to use refined water-soluble salts. Since micronutrients are needed in small amounts, even low-grade ores can be useful for local purposes. Quite often direct application of the ores with little or no processing can be effective. Industrial byproducts should not be overlooked. Cement dust, for example, may contain useful amounts of potash and secondary elements. Blast furnace slag and basic slag contain lime, magnesia, micronutrients, and sometimes phosphorus. Naturally, care must be used in considering agricultural use of industrial wastes to avoid application of toxic or potentially toxic elements to the soil.

Mixed Fertilizers

Crops need many nutrient elements for optimum growth, but fertilizers containing nitrogen, phosphorus, and potassium account for almost all the world's supply. However, sulfur is becoming increasingly important in developing countries, and supplementary magnesium is used on many plantation crops so that significant tonnages of fertilizers containing these two nutrients are now being used. Local deficiencies of trace elements also occur; zinc deficiency in flooded rice is particularly widespread. Total tonnages of trace elements used are, however, relatively small.

Persuading the farmer to use the correct rate and type of fertilizer nutrient on his crops is a problem that exercises the minds and resources of the governments of many developing countries.

The problem of balanced fertilization is two-sided: many fertilizer recommendations made in developing countries are not site specific and are based on experiment station trials, which often give much higher yields than the average farmer can achieve, and conversely many farmers do not fertilize in an optimum way even for their lower yields.

In the Punjab, the most agriculturally developed state of India, Kemmler (Personal Communication, 1983) has shown that for the wheat crop nitrogen use ranges from 70% to 150% of the recommended rate, while phosphate use ranges from 50% to 110% and potash use only 10% to 30% of the recommended rate.

When fertilizer recommendations and use practices do not match, it is essential that the research agronomists, the extension staff, and the farmers become involved in identifying the reasons for the disparity and in developing corrective measures.

Cash and inputs credit programs that give the farmer a package of desirable practices, including specified quantities and types of fertilizer, ensure that the farmer at least acquires the officially recommended fertilizer. Such package credit programs have been widely used with success in Africa by the crop monopoly organizations.

In India control orders require fertilizer retailers to stock both phosphate and potash at a specified level in relation to their sales of nitrogen.

With a free market situation, the only route is to educate the farmer to maximize his returns by using the correct rates and ratios of fertilizer nutrient.

When all the nutrients to be used in an agricultural area come together at one point, whether it is port, railhead, or road, then the need for and desirability of producing NPK fertilizers at that point must be examined.

A strong case can be made for any one of the following three alternatives:

1. Continuing to move products as separate and distinct materials.
2. Mixing the incoming nutrients using current bulk-blending technology.
3. Processing the incoming nutrients to make granular complex fertilizers.

The final choice of technology will depend on the local situation.

With a typical small farm of 1-2 ha and individual plots of about ¼ ha, the farmer using hand spreading will have all the flexibility he needs for varying fertilizer dressings by field, by crop, and by season, even though he purchases straight fertilizers.

Bulk blending is attractive as an alternative to handling straight N, P_2O_5, and K_2O through the distribution system, but the risk exists that the nutrient ratios delivered to the system will be overtailored. The proud comment of a typical U.S. bulk blender is that he produces 50 different grades on a regular basis and could produce 100 grades if necessary. Of course, such "overcustomization" is unnecessary in developing countries, but even if only a few major grades are made, in practice farmers will probably find themselves being forced to take grades not totally adequate for their need.

Granular fertilizers have achieved great popularity among the small farmers of Africa because of the reliability of the products. Blue, green, or red high-quality fertilizer granules cannot be counterfeited by backyard operators; this fact, together with the strong sales pitch of "every granule contains the same nutrients as every other granule," certainly attracted a loyal clientele for the producers of granular fertilizers. Complex fertilizers continue to be of great interest for upland crop production to the high-value cash crop grower, and they are favored by cotton development schemes in Africa particularly.

In the final analysis hand application of the cheapest solid materials as straights is probably the most economic route, but it is also the one that relies most heavily on the farmer's knowledge of the nutrients needed. Therefore, the relevance of the next lowest cost solution, that of bulk blending, must be evaluated.

There is a general trend toward manufacturing concentrated fertilizers in large plants at or near the source of the raw materials and shipping the products in bulk to consuming areas. This trend is likely to continue (Sheldrick, 1983). Bulk shipment of finished products requires reasonably free-flowing materials so that products such as urea, diammonium phosphate, and potash can be loaded and unloaded from ships, barges, and railcars rapidly. Therefore, these materials will likely be produced in granular form to avoid serious caking. The availability on the world market of an abundance of these high-analysis, reasonably priced materials will encourage bulk blending because blending adds very little to the cost of bulk shipment, storage, handling, bagging, and distribution. While blending has long been popular in the United States and Canada, there appears to be a growing trend for the practice to spread to other countries. There is much interest in this approach in west Africa.

Although bulk blending is a simple process, there are elements of technology that should not be ignored. Production of satisfactory blends in developing countries requires more care than in cooler, less humid climates. Unlike the common practice in the United States of mixing and applying blends on the same day, in most countries the blends must be bagged, stored, and transported through the distribution system to the farmer. Thus, the blends must have good physical properties, and the bags must have adequate strength and resistance to moisture penetration if they are to reach the farmer in usable condition.

Some developing countries have a tendency to neglect the quality of both straight and mixed fertilizers and their packaging when better technology would be appropriate to the climatic conditions and the available distribution facilities. It is unfortunate that many countries appear willing to spend huge sums of money on manufacturing facilities but fail to provide facilities to make a better quality product and deliver it to farmers in usable condition.

Appropriate Distribution and Handling Systems

Fertilizer is only of interest to the farmer if it is available to him in the form and at the place and time that he needs it.

An effectively planned and executed distribution system is required to make a timely supply of fertilizer conveniently available to the farmer. Africa's current transportation infrastructure arose mainly from historical needs. The sheer distances involved increase the fertilizer distribution problems. Distance factors may be considered in relation to India, which would usually be considered a "large" country. Africa, however, has almost 10 times the land area with only about 70% as many people. Investment in transportation facilities in Africa therefore requires a very much higher cost per person than in India.

Most fertilizers are imported so that overall movement is almost all inward from the coastal areas. Not only are long supply lines involved (Figure 1) but also many countries are landlocked (Figure 2) (IFDC data). These countries constitute a significant proportion of the land area and have double problems. They consist of (1) very high costs for transportation of imported fertilizers and raw materials and (2) similar high costs for export of any agricultural or industrial products.

For land transportation over long distances, the most practical and economic method is by rail. Unfortunately, the railway systems throughout Africa remain fragmented and generally in need of modernization. For example, there are three different principal gauges used on the continent. Because of such practical problems and political difficulties, there is relatively little movement between countries.

There is a lack of the skilled management necessary for both planning and operating of the existing systems. For example, governments may hold freight rates at historic, now uneconomic, levels. At the same time they fail to provide the necessary capital or operating funds for maintenance, operation, replacement, or modernization of the system.

Road transport remains the mainstay of most transport systems. Specific development funds must be devoted to expansion of farm-to-market transport means, which range from trucks for longer distance movements to animal-drawn carts, small-wheeled vehicles, and head carrying.

For efficient transportation of large tonnages by sea, rail, and road, the technologies of the developed countries are applicable. Examples are the use of modern self-discharging bulk ships in Indonesia and the operation of block trains, or unit trains, in India and other countries. At the rural level, however, the majority of product is moved on animal-drawn carts, bicycles, tricycles, or by head. Improvements are available on the design of ox carts and of the animal harness in India; these significantly increase the payload.

It is in handling operations that the social and economic pressures to maximize use of manual labor are most apparent. As higher tonnages are moved, use of large numbers of manual workers can lead to inefficiencies, and a degree of mechanization is appropriate. For example, in loading fertilizer manually to vehicles at high rates, considerable congestion may be created. Use of flat trolleys and simple bag elevators to lift bags from ground level to above the vehicle deck can considerably speed up the operation and reduce congestion without changing its essentially manual-intensive nature. Reduction of vehicle congestion and hence waiting time can have economic benefits that are not always recognized. Similarly for stacking or destacking in large warehouses, the use of bag elevators or forklift trucks can eliminate a lot of unproductive manual lifting and speed up the operation.

It is in handling of imported fertilizer that systems from fully mechanized to fully manual may be used simultaneously, side by side, and each can be considered appropriate to the situation. The value to a developing country of importing fertilizer in bulk and bagging in or near the receiving port is now generally recognized. This practice avoids the high cost of bagging and of stevedoring in the developed country, provides local employment in the receiving country, and allows use of indigenous packaging materials. Estimates of savings on shipments from the U.S. Gulf to India or Bangladesh are up to $30/ton overall and $50/ton in foreign exchange. At this high level, even the cost of relatively sophisticated portable dockside hoppers and bagging machinery can be recovered on one cargo. Even without this equipment, it has been demonstrated, particularly in India, that bulk imports can be handled efficiently with virtually no mechanical equipment. Fertilizer can be lifted out of the ship in rope and cloth slings and dumped into simple hoppers or onto the ground. It is then bagged manually and weighed on simple suspended beam scales, which are manufactured locally. Bags can be hand sewn but are preferably machine sewn by using portable electric machines. A variant of this system is to bag volumetrically in the hold and adjust the weight ("standardize") at a shore location.

A mechanized system can achieve higher rates, and a manual system produces lower costs--both subject to effective management! Mechanical and manual systems have been observed side by side, and the manual bagging system costs US $0.50/ton.

The 50-kg bag in itself is an example of a technology appropriate to the developing countries. It provides the necessary protection for the product, it can be handled throughout the distribution system by completely manual methods, and it is often an appropriate unit quantity for use by the ultimate consumer, usually a small farmer. Additionally, local bag materials or materials appropriate to the local supply situation can be used. In the developed countries, moves toward mechanization have been toward unitization of the bags, by palletization or mini-bulk (1-ton bags) as in Europe, or toward all-bulk delivery systems as in the United States. Unitization of bags or mini-bulk is difficult to introduce in the developing countries because there is practically no mechanical handling equipment available outside the ports and production centers. It would be easier to move to an all-bulk system than to a unitized bag system, although the bulk system is likely to create severe quality- and loss-control problems.

Although the 50-kg bag has become, because of industry pressure, almost a universal standard in developing Asia, Indonesian urea producers do use a 25-kg bag. Since the body weight of millions of Asian farmers is only around 40 kg, the attraction of the 25-kg bag is enormous. This attraction is strengthened by the fact that in Indonesia, Bangladesh, and India much fertilizer is sold "grocer shop style" in lots as low as 2 kg. Data from Bangladesh (K. L. Moots, Personal Communication, 1983) show that two-thirds of the fertilizer there is sold in small amounts from the bag. If a small farmer is ever at risk, it is when he is buying from a dealer using scales and an open bag of fertilizer. Industrially sealed and tamper-proof products should not be solely a requirement of the pharmaceutical companies.

Methods of warehousing for larger quantities of bagged fertilizer are similar in both developed and developing countries. For smaller warehouses, not enough attention is given to designs employing local methods or use of local materials. Designs are also occasionally inappropriate in assuming, for example, that rain falls vertically! Observation in the tropics under storm conditions suggests that the rain's direction is often nearer to the horizontal, and this must be allowed for.

A topic not properly addressed in either developed or developing countries is the question of ventilation of warehouses for bagged fertilizer in humid areas, tropical or otherwise. On technical grounds it is clear that under most conditions fertilizer warehouses should not be ventilated and should be kept as tightly closed as possible. This is accepted for bulk storage, but bag storage is for some reason perceived differently. Fertilizer storage buildings should only be ventilated under low-humidity conditions, which means daytime, sunny and bright!

Appropriate Farm-Level Fertilizer Technology

The farmer receives from the fertilizer industry a physical product which he applies to his crops to increase his profits.

In terms of efficient fertilizer use, farmers fall short of required standards not only in the levels of needed nutrients applied but also in the following areas:

1. Correct timing and rate of fertilizer application.
2. Accurate distribution of fertilizer in the field.
3. Optimum placement of fertilizer, particularly regarding depth.

In all of these areas, improvements in field practices would result in improved fertilizer use efficiency.

In mechanized agriculture, poor field application practices result from very critical dates of crop planting; this practice leads to an overloading of the whole application system during a few days each season and to the failure of the farmer or fertilizer distributor to correctly set fertilizer metering and application devices for each crop. The technology available is adequate, but its use may not be.

On the other hand, for the small farmer of the developing countries, the human hand and a rather ineffectual plow or a hand hoe are all that is available for fertilizer application.

Significant efforts have been devoted to introducing new or improved agricultural implements to the small farmer to increase his productivity and financial reward, but success has been limited.

Upland Crops

For upland crops the NIKART project, designed by the Overseas Division of the National Institute of Agricultural Engineering in England in close collaboration with ICRISAT and based near Hyderabad, India, is now being widely tested in Africa (ICRISAT, 1982).

The objective of the NIKART project was to make available to the farmer a low-cost, simple, animal-drawn machine that would ensure the quality and timeliness of farmer operations. Included in the accessories is a simple fertilizer drill that allows good band placement of fertilizer along the crop row. The major objective of the NIKART project now is to reduce costs by developing a construction technology suitable for local entrepreneurs, in terms of the materials available to them and, particularly important, the low level of skill and quality of equipment available to them (Barwell, 1983).

The NIKART, by permitting timely, deep, and accurate placement of fertilizer, has the potential of improving the returns that millions of small dryland farmers receive from their crops.

Summary

Appropriate fertilizer technology is defined as that technology that enables a country to take full advantage of mineral, energy, land, and human resources to produce effective fertilizer products with a minimum expenditure of capital and foreign exchange. Selection or development of appropriate technology demands the integration of a high level of local knowledge and wide knowledge of the chemistry and technology of fertilizers.

Modern fertilizer units are designed with the twin objectives of benefitting from economics of scale and reducing labor costs; neither of these objectives is necessarily relevant to the developing-country situation where smaller and simpler plants may be advantageous.

A similar situation occurs with the distribution and handling systems and also at the farm level; simplicity, reliability, and low capital investment levels are the keys.

For nitrogen, the critical factor is the availability of a convenient and cheap energy source; thus, the development of farming systems using biological nitrogen fixation may be the preferable route in some areas.

Because of the variability in the fertilizing value of naturally occurring phosphates, chemical phosphates became extremely popular. The reduction of transport and handling costs by use of high-analysis material led to diammonium phosphate (DAP) and triple superphosphate (TSP) becoming major sources of fertilizer P. The value of ground phosphate rock and of low technology sulfuric acid-based phosphates needs to be reexamined.

Costs of potash fertilizers could be reduced by using low-grade products in some cases, and careful recycling of crop residues would reduce the need for potash.

Secondary and minor elements occur widely in many geological deposits, and the exploitation of these materials as cheap sources of plant nutrients should be developed.

Handling and distribution technologies can be made appropriate by using a combination of modern and traditional methods.

Finally, the advantages of careful timing and placement of fertilizer in upland crop production is illustrated by the work at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

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Figure 1. Areas Within 500 km of African Ports.

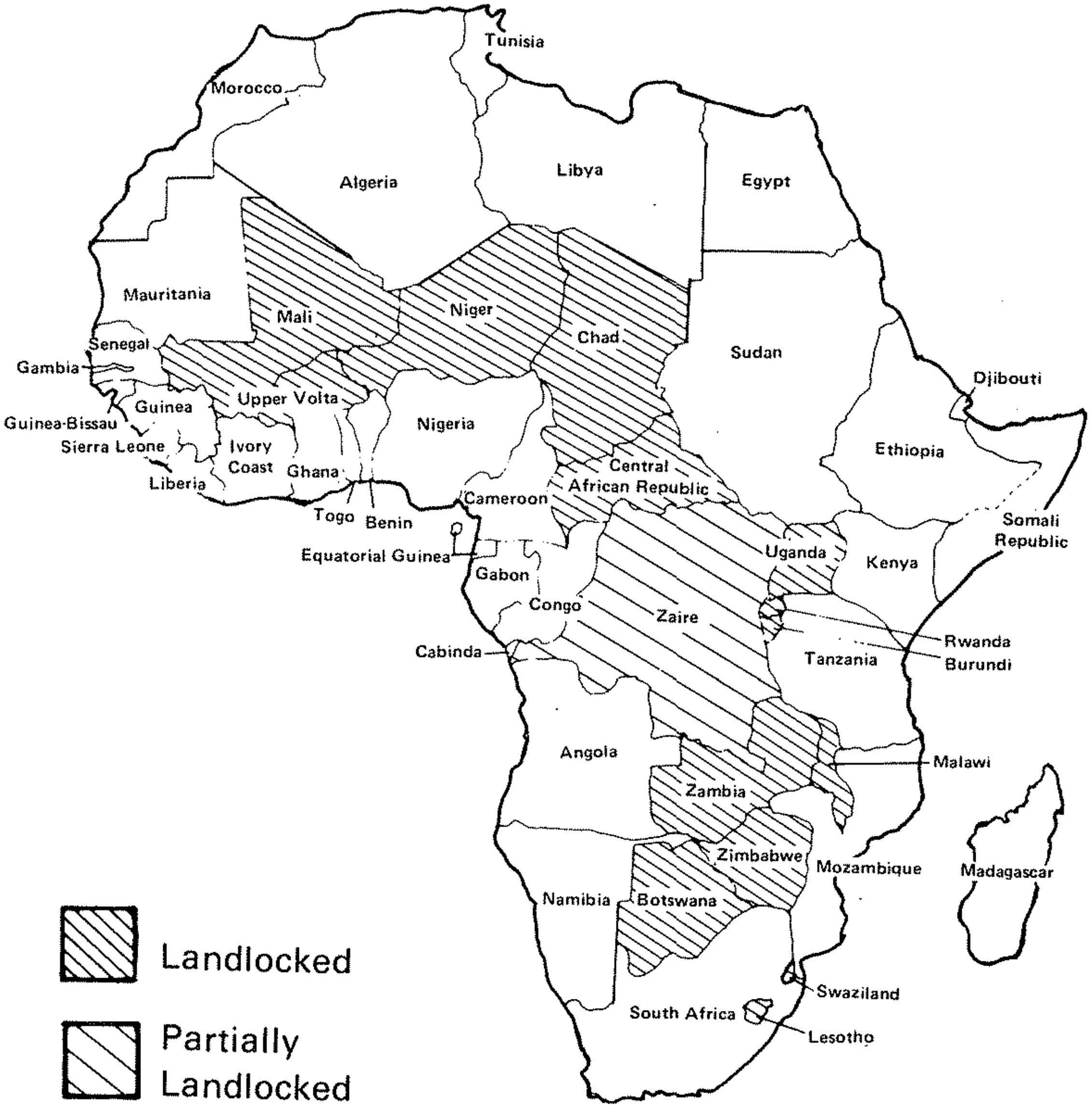

Figure 2. Landlocked and Partially Landlocked Countries.

COOPERATIVE RESEARCH ON MANAGEMENT OF PHOSPHATE AND NITROGEN FERTILIZERS IN SUB-SAHARAN AFRICA

Uzo Mokwunye and P.L.G. Vlek

Fertilizer Research of IFDC

The principal aim of the fertilizer research program of IFDC is to help eliminate constraints to efficient fertilizer use. Such research involves:

1. The production and delivery of fertilizer to the farmgate at the lowest possible cost.
2. The proper management and use of this costly input by the farmer to ensure efficient use by the crop. This research must result in increased and more profitable crop production in order to lead to adoption by the farmer.

The chances for successful introduction of fertilizer in the tropics and subtropics vary widely with the agroclimatic and socioeconomic environment. In areas where fertilizer availability is not a constraint to fertilizer use, the present pattern of adoption is a indicator of the potential use of fertilizers. Generally speaking, fertilizers are preferentially used on cash crops and on foodcrops grown under the least risky conditions, such as irrigated wheat and rice. On rainfed crops, fertilizer use is concentrated in areas with reasonably assured rainfall (Sidhu et al., 1982). Adoption of fertilizer use appears little influenced by the farm size, but it does seem to drop rapidly with distance from the market and with the lack of credit, particularly for the small farmers (Sidhu et al., 1984). Unfortunately, little information on these aspects has so far been collected in appreciable areas of the developing world.

In the past 10 years IFDC has established research activities to develop cheaper sources of phosphatic fertilizer by examining the agronomic potential of phosphate deposits indigenous to various regions. A host of such local deposits has been characterized and evaluated for direct application. Numerous rock processing techniques have been studied for situations where direct application proved unsuitable. Much of the early research focused on Latin America where an active program was put in place to test the agronomic effectiveness and economic benefits from the use of alternative P products under widely different agroecological conditions and cropping systems and by using a variety of management techniques (Hammond and Leon, 1983).

Nitrogen research, on the other hand, has deemphasized the production of alternative sources and concentrated on the evaluation of existing commercial products as a function of fertilizer management. The program systematically studies the fate of fertilizer N in key cropping systems and evaluates the magnitude of N losses and means of curbing such losses in different agroecological zones. Thus far, the program has identified several cropping situations where losses of applied N are unacceptably high, and it is testing modifications in fertilizer management practices that eliminate this waste, notably in flooded rice (Vlek and Fillery, 1984). The emphasis in this N program initially was placed on Asia.

Most of the research activities referred to so far have focused on regions/crops where the use of fertilizer has been clearly established. For instance, fertilizer consumption on flooded rice to date amounts to 3 million tons annually, over 90% of which is in the form of urea. With an estimated loss of 30% or more, primarily due to volatilization of ammonia (Fillery and Vlek, 1985), elimination of this loss mechanism might save more fertilizer than currently is consumed in sub-Saharan Africa. Such payoffs adequately justify the fertilizer efficiency research investment. However, in regions where the role of fertilizer may still be in doubt (e.g., arid and semiarid regions), priority should be given to identifying the role that fertilizer may play in (1) enhancing agricultural output, (2) sustaining soil fertility, and (3) improving the lot of the farmer. Such research should involve the key nutrients, cropping systems, and alternative management practices. Undoubtedly, the programs of the Food and Agriculture Organization of the United Nations (FAO) in various countries have given impetus to providing an inventory of fertilizer-responsive regions in the world.

Agricultural Development in Sub-Saharan Africa

For most countries in sub-Saharan Africa, the decade of the 1970s was marked by severe economic strains. The following trends were characteristic of the period:

1. Low income growth--income growth in the sub-Saharan region lagged behind all others of the least developing countries.

2. High balance of payment deficits and rapidly rising budget deficits.
3. High population growth rate--approximately 3% per annum was the highest in the developing world.

The primary cause of the catalog of woes is the lagging growth in the agricultural sector--a sector that dominates the economies of all sub-Saharan countries. On a per capita basis, food production declined a shocking 1.1% between 1961 and 1980. A broad-based agricultural development is crucial for increasing incomes, employment, and export earnings. Raising the incomes of the rural poor who are mostly farmers is essential for expanding the revenue base for the government, and it creates a domestic market for the goods and services produced in a rapidly growing urban sector.

To revive the ailing agricultural sector requires a combination of ingredients including the availability of technical packages that are adapted to local conditions, timely supply of key inputs, effective extension services, and reasonable pricing policies. Among the key inputs are fertilizers which play a key role in most efforts to stimulate food production in developing countries. In Africa, fertilizers accounted for 20% of the increase in cereal yield during the 1960s and 1970s (Pinstrup-Anderson, 1976). It is estimated (FAO, 1979) that by the year 2000, 73% of the expected increase in agricultural output in Africa will come from increased production per unit area. In addition to improved management practices, increased use of fertilizers will play a key role in the attainment of this objective.

The increase in energy prices beginning in 1971 combined with general inflation and increases in construction costs reversed a downward trend in fertilizer prices. By 1980 the world price of urea was four times the 1971 low (Mudahar and Hignett, 1982).

In 1982, sub-Saharan Africa consumed 720,000 tons of fertilizers--or less than 1% of world consumption. A disturbing statistic is that while fertilizer consumption is steadily rising in the rest of the developing world, the 3.4 million tons of fertilizer consumed by African countries in 1982/83 represents a 4% decline from the 1981/82 figure.

The high cost of imported fertilizers and the unavailability of foreign exchange are the main stumbling blocks to expansion of fertilizer consumption in sub-Saharan Africa (Figure 1). Recognizing this situation, the Council of Ministers of the Organisation of African Unity (OAU) at its Thirty-sixth Ordinary Session held in March 1981 recommended the establishment of an African Center for Fertilizer Development. It was proposed that this center be a joint OAU/IFDC undertaking. In the meantime, IFDC sought and obtained funds from the International Fund for Agricultural Development (IFAD) to expand its fertilizer research activities in Africa.

The Tropical African Environment

Compared with the geology of other continents, the geology of Africa as a whole and of tropical Africa in particular is relatively simple. The continent is a vast crystalline Precambrian plateau consisting primarily of granite, gneisses, and schists of the basement complex rocks overlain by various sedimentary formations (quartzites, limestones, dolomites, and phyllites). These formations cover about a third of the continent. In west Africa sandstones cover major portions of Ghana, Togo, Benin, Mauritania, Senegal, Mali, and Guinea. Paleozoic outcrops are virtually absent from equatorial and southern Africa. The only formations of the Mesozoic era in tropical Africa are the Jurassic sandstones and gypsum-carrying clays extending south of the Ethiopian massif, the Cretaceous limestones and clays in Nigeria, and scattered remnants of late Triassic volcanic activity. Old Tertiary surfaces, sometimes covered by ferruginous crusts, subsist in west Africa to the south of the Niger and Chad basins; between the basins of Chad, the Nile-Bahr el Ghazal, and the Zaire; and around the basins of Lake Victoria and Lake Kioga. The Kalahari deposits consisting of polymorphous sandstones, aeolian and fluviatile sands, and lacustrine calcareous lenses, crop out extensively in Botswana, Namibia, Zimbabwe, Angola, Zaire, and the Congo. The Tertiary period is also characterized by volcanic activity, principally in east Africa.

The greater part of the superficial deposits are of Quarternary formations. Volcanic formations border the faulted areas. Aeolean sand deposits form the loose formations of the south Sahara and the Kalahari, extending as far north as the equator. As in other locations, the Quarternary period in tropical Africa was characterized by frequent climatic changes of alternate wet and dry periods. It was during this period that extensive ferralitization or lateritization of the vast Sudanian zone took place. It was the alternating climates in combination with the parent rock that, to the greatest extent, influenced the pedology of tropical Africa.

The parent materials of the soils are not necessarily similar to the weathered bedrock. In fact, many parent materials in tropical Africa are polygenetic residues, reworked and exhausted sediments, or aeolean sands, and the nature of the original parent rock is difficult to establish. In general, parent materials currently exposed to pedogenesis in tropical African landscapes are poor in alterable minerals. The most favorable exceptions are parent materials formed directly from underlying rock or volcanic ashes, the black tropical clays of the Nile-Bahr el Ghazal and Chad basins, and various recent alluvia.

Soils and Soil Fertility

Most of the soils of tropical Africa belong to the orders Alfisols, Oxisols, and Ultisols. These are extremely old, weathered, and moderately to highly leached oxidic kaolinitic soils. The Ultisols and Oxisols have excellent physical properties but very low base saturation. Aluminum toxicity is often a problem in these soils. The soils are characterized by low cation exchange capacity (CEC) and are relatively infertile. The CEC of the kaolinitic clays changes drastically as the pH of the soil solution changes. These clays, therefore, are known as variable charge clays. In the virgin state or after a long fallow period this variable-charge characteristic is of little consequence. The relatively high organic matter contents help to buffer the soil. However, problems arise when the vegetation is cleared and the soil is cultivated. As a result of cultivation, organic matter drops, CEC drops, and the soil becomes progressively more acid (Ralph, 1983). In addition to the chemical problems, Lal (1978) showed that Alfisols and Ultisols in west Africa have weak aggregation and low water-retention capacity (<10 g/100 g) which can be further reduced on a volumetric basis by the presence of substantial quantities of gravel.

Nitrogen and phosphorus are the two most limiting nutrients in soils of tropical Africa. The native N content of the soils is strongly related to the content of organic matter, which varies with rainfall and altitude. The range is from less than 0.1% in semiarid areas to over 10% in high rainfall, high altitude, and forest areas. Under traditional farming systems prolonged bush fallows (10 or more years) are used to build up soil organic matter content, improve N supply, and produce high crop yields. In areas of year-round high temperatures and adequate moisture, rapid decay of soil organic matter is promoted. For example, a secondary forest fallow (8-10 years) was found to supply enough N for only one cropping year (IITA, 1977) in the humid region of Nigeria.

Deficiency of P is most acute in the drier ecosystems of tropical Africa. In some soils of the west Africa savanna region, P deficiency is so acute that plant growth virtually stops as soon as the seed reserve of phosphate is exhausted. Udo and Ogunwale (1977) reported that total P in sandy soils in Nigeria was as low as 100 ppm. Alfisols formed on basaltic parent materials had up to 400 ppm total P. An appreciable portion of the P in tropical African soils is in the organic form. Values as high as 51% of total P in the form of organic P have been recorded for forest soils in Ghana (Acquaye and Oteng, 1972). Ayodele and Agboola (1983) found that 41% of the total P in 60 surface soils from the savanna region of Nigeria was in organic form.

The IFDC/IITA/ICRISAT Fertilizer Program for Africa

Although IFDC's involvement in Africa dates back to its early years (IFDC, 1976, West Africa Fertilizer Study, Vols. 1-7), a systematic program development was only started in 1981. At that time IFDC joined hands with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Institute of Tropical Agriculture (IITA) in building a fertilizer research program with the aim of involving as many tropical African countries as possible, representing environments ranging from desert-like to perhumid. Through coordinated research planning, it was anticipated that results in the program might be transferrable across the continent to allow various nations to benefit from the experience of others. The objectives of the project were as follows:

1. To evaluate the potential of indigenous phosphate deposits for direct application or production of P fertilizer at minimum cost. There are proven or suspected reserves of phosphate rock in at least 27 countries in sub-Saharan Africa. One of the ways to lower the cost of supplying the phosphate requirements is the direct application of phosphate rock. Factors that control the agronomic effectiveness of phosphate rock include the reactivity of the rock, soil reaction, soil moisture, and calcium (Ca) content of the soil. Where the reactivity of the rock does not promote immediate gains from directly applied phosphate rock, it has become necessary to find alternative, less expensive processes for converting these

phosphate rocks into chemical fertilizers. The production of partially acidulated phosphate rock (PAPR) by reacting phosphate rock with only a portion of the sulfuric acid required for the production of single superphosphate (SSP) is one such process.

2. To study the role and efficiency of N fertilizers applied to different crops and soils and seek fertilizer management techniques that maximize this efficiency in environments where N applications are a sound practice.

   Because of high energy requirements in their production, N fertilizers are extremely expensive. However, the efficiency of N fertilizer is often low in terms of nutrient recovery by the crop (Vlek and Craswell, 1979). The main avenues of loss of N from the soil-plant system are ammonia volatilization, denitrification, runoff, and leaching. The identification of the exact mechanisms by which N applied to different crops and soils is lost helps in the development of new fertilizer materials with more desirable properties. Recently, increased availability and decreased cost of the stable isotope ^{15}N have made it possible to use this tool to trace the fate of fertilizer N in the soil-plant system (Buresh et al., 1982).

3. To study the effect of cropping systems and farm management practices on the maintenance of soil productivity and the use and efficiency of fertilizers. The role of fertilizers needs to be assessed in the proper context. The farmer now has a range of cropping systems available to him--with and without fallow--which call for different levels of nutrient supplementation. However, regardless of the cropping system or nutrient source, fertilizer use efficiency can be significantly improved through better fertilizer management. Four major aspects of better fertilizer management are (1) right dose of fertilizer, (2) proper balance among nutrients, (3) right time of fertilizer application, and (4) right method of fertilizer application (Mudahar and Hignett, 1982). Fertilizer recommendations can be improved by making them more sensitive to rainfall and soil and crop management conditions, as well as to the farmer's socioeconomic status.

The farming systems programs of ICRISAT and IITA have the responsibility of developing sustained food crop production systems with acceptable input levels for the resource-poor farmers in the semiarid and humid parts of tropical Africa. The need for the development of better fertilizer use programs including higher fertilizer use efficiency in intercropping systems is recognized as an important aspect of the farming systems programs of both the international and national centers.

The extent of involvement of the program in tropical Africa is depicted in Figures 2-4. Aside from the collaborating international institutes, the program has entered into collaborative arrangements with research organizations listed in Table 1. The scope of phosphate research activities in these countries may range from strict P-resource evaluation (Benin) to full testing of the local deposit for agronomic use (Niger). Nitrogen research may involve simple comparison of N sources to in-depth evaluation of the fate of applied N by using ^{15}N. In addition, research on the interaction between cropping system and fertilizer use was initiated at some locations, whereas other countries collaborated in farm-level testing of fertilizer sources or surveying farmers' fertilization practices. The location of these activities is shown in Figures 2-4.

Research plans are determined through consultation among scientists from international and national institutes. The plans attempt to maintain some commonality across countries to allow evaluation of the effect of agroecological conditions on the research results and yet incorporate research aspects of interest to the countries involved. All data are assembled at IFDC for storage in a database, statistical analysis, and interpretation. Meetings are organized annually in different locations in tropical Africa where collaborators share the past year's experience and plan activities for the following year. The results from the past 3 years' experiments will be reviewed in a symposium scheduled for March 25-29 to be held in Lome, Togo. Some preliminary data are discussed below.

Nitrogen Fertilizer

Experiments to study the fate of applied N in sub-Saharan Africa were carried out in five key environments: humid tropics (Ikenne, Nigeria), subhumid tropics (Mokwa, Nigeria; Sefa, Senegal; and Kabete, Kenya), and semiarid tropics (Sadore, Niger). Table 2 summarizes the site characteristics and some preliminary estimates of fertilizer N lost from some of these soil/plant systems. Surprisingly, the results indicate that losses of N in the humid and subhumid regions are relatively low; this eliminates leaching loss as a suspected problem. On the other hand, in the semiarid tropics, N loss, presumably due to ammonia volatilization, appears to be substantial. Data collection and analysis for subsequent years and other sites are presently underway.

In environments with limited losses of N from urea, chances for improvement in fertilizer efficiency through modification of fertilizer source or management are limited. Our experimental data confirmed this notion. However, suspected loss of urea-N through volatilization in semiarid regions provides scope for improvement. Experimental results summarized for Niger are given in Figure 5. The use of calcium ammonium nitrate (CAN) tested against urea at Sadore in 1982 or 1983 did not show a significant improvement in millet grain yield (Figure 5). This is due in part to the great variability in the experimental data. In experiments conducted in other Niger locations, significantly better results were obtained with CAN. Research is being continued in the semiarid region to identify the mechanism of loss of urea-N and CAN-N in order to define management techniques that will improve the effectiveness of applied N.

Phosphate Fertilizer

Research on P has concentrated on the use of finely ground rock or PAPR as an intermediate product. Finely ground phosphate rocks from Togo, Burkina Faso, Senegal, and Niger have been evaluated in field trials. The response of millet to different phosphate fertilizer sources in Mai Gamji, Niger, is shown in Figure 6. Unmodified phosphate rock was economically and agronomically inferior to commercial fertilizers at most sites. Partial acidulation of phosphate rocks resulted in fertilizer products that could compete with commercial fertilizers. In trials in certain locations in Nigeria where sulfur deficiency was evident, PAPR performed better than diammonium phosphate (DAP) and compound fertilizer 15:15:15 (Table 3). Research is being continued in many other locations to evaluate the agronomic potential of local phosphate deposits or simple products made from these rocks.

Fertilizer Use Under Various Cropping Systems

In tropical Africa, it is vital to aim for improved food production on a sustained basis. Poorly buffered soils, such as exist in this region, are susceptible to degradation with continuous cropping and indiscriminate use of fertilizer. Long-term experiments have been initiated to evaluate the role of cropping system and fertilizer use on soil productivity. The effects of cropping system and soil fertility management on second season yields of maize and cowpea are presented in Figures 7 and 8 for a humid tropical site in Nigeria. Although continuous maize so far is being tolerated by the soil if fertilizer is applied, this system, in the absence of fertilizers, results in drastic yield reductions.

Drastic yield reductions also occur when a mixed crop of maize and cowpea is followed by sole crop maize in the absence of fertilizers. But with fertilizers, this cropping system produced the highest maize yield. Apparently, the net effect of a mixed crop is to increase nutrient harvest from the soil. In the absence of fertilizer supplementation, growth of a cereal on such depleted land is impaired. Sole crop maize following a cowpea crop did relatively well in the absence of fertilizers, but when fertilizer was applied, the cowpea contributed little to the maize crop. Continuous maize without fertilizer resulted in a yield decrease of 403 kg maize/ha. When maize was followed by cowpea-maize intercrop, the yield reduction, in the absence of fertilizer, was only 7 kg maize/ha. This would suggest that maize in the cowpea-maize mixture received some nutrition from the companion crop (cowpea). Indeed, it was observed that maize plants in this system were greener than maize plants in the continuous maize system without fertilizers.

In the presence of fertilizers, cowpea yields are generally depressed when grown with vigorously-growing maize because of shading. However, sole crop cowpea following a maize crop would do well by comparison. With or without fertilizers, the cropping system most productive for cowpea was maize followed by cowpea (Figure 8).

In the absence of fertilizer, it would be advisable for a farmer to begin with a sole crop of cowpea and follow this with a crop of maize. The residual fertility from cowpea would provide "decent" nutrition for the maize. Where fertilizer is available, a system beginning with a maize-cowpea intercrop followed by sole crop maize would be the best system. However, it must be borne in mind that these observations are only tentative. The experiment was designed to run for a number of years. It is hoped that by the time one cycle of cropping is completed in 1984, more concrete information will begin to emerge.

Although some of the information obtained to date gives credence to previous work done in the region, this collaborative program has helped to promote the establishment of a reliable data base on fertilizer efficiency that is unique for sub-Saharan Africa. In addition, the program is providing a better understanding of the kind of fertilizer to be used in various agroclimatic zones. Through collaboration with national and international centers in the region, a network structure of institutions in which technological innovations can be tested on a continent-wide basis has been put in place. A continent-wide interest in the development of alternative fertilizer products such as PAPR and urea supergranules has been generated. In some instances there are possibilities for further exploration of these fertilizer alternatives with outside donor assistance. In the long run the goal of IFDC and its collaborators is to increase food production in sub-Saharan Africa through judicious fertilizer use.

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Table 1. Collaborators in the IFDC/IITA/ICRISAT Africa Fertilizer Research Program

Country	Research Organization	Year Initiated
Benin	OBEMINES	1984
Burkina Faso	IBRAZ	1983
Cameroon	IRA	1983
Gambia	Department of Agriculture	1984
Ivory Coast	IDESSA	1984
Kenya	University of Nairobi	1983
Liberia	University of Liberia	1984
Malawi	Ministry of Agriculture	1983
Niger	INRAN	1981
Nigeria	IAR & T	1982
Nigeria	IAR	1984
Senegal	ISRA	1983
Sierra Leone	ACRE Project	1983
Togo	DEPEG	1983
Zambia	Department of Agriculture	1984
Zimbabwe	DRSS	1984

Table 2. Preliminary Estimate of N Loss From Fertilizer Urea in Different Soil-Plant Systems in Tropical Africa

Location	Ecological Zone	Rate of N Applied (kg/ha)	Timing	Mode	Fertilizer N Loss (%)
Ikenne	Humid	120	S	Br	10
Mokwa (1982)	Subhumid	120	S	Br	0
Mokwa (1983)	Subhumid	120	S	Br	27
Sefa[a]	Subhumid	100	S	Br	11
Sefa[a]	Subhumid	100	S	Bd	0
Sadore	Semiarid	30	Ba	Br	34

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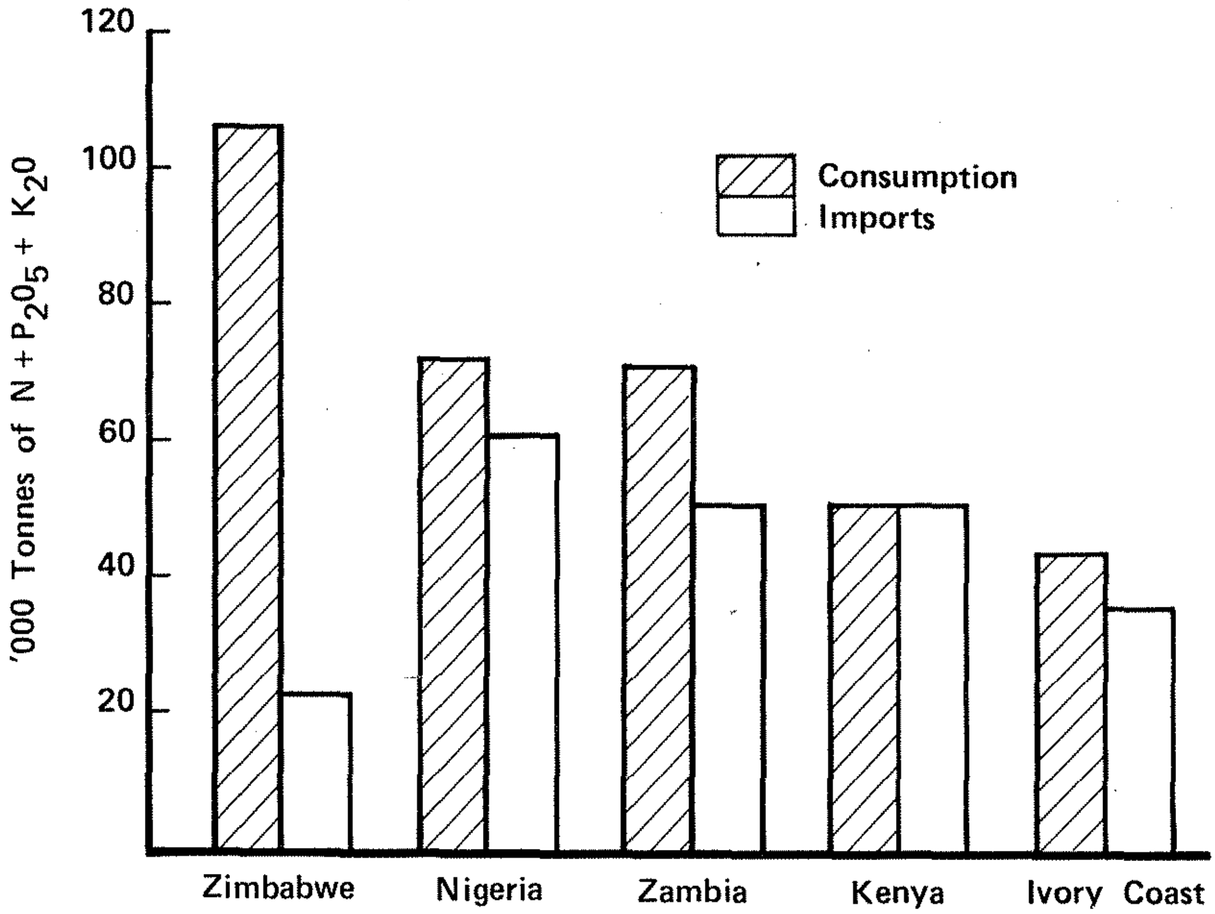
[a] F. Ganry, personal communication.

S = split application
Ba = basal application
Bd = banded
Br = broadcast and incorporated

Table 3. Response of Maize to Various Phosphorus Fertilizers in Southwestern Nigeria

P Source	P Rate	Maize Grain Yield		
		Ado-Ekiti	Ikare-Ekiti	Ikole-Ekiti
	(kg P/ha)	(kg/ha)		
Control	0	3,898	5,333	1,218
15:15:15	13	4,494	6,384	2,341
	26	3,821	5,803	2,937
DAP	13	3,814	6,209	1,842
	26	4,104	5,943	3,161
SSP	13	4,226	6,376	4,097
	26	4,077	6,737	4,711
PAPR	13	3,585	6,390	5,489
	26	3,613	7,609	4,909

Source: IFDC Annual Report, 1983.



Source: Data from *Fertilizer International,* 141,1981.

Figure 1. Fertilizer Consumption Versus Fertilizer Imports in Some Sub-Saharan African Countries.

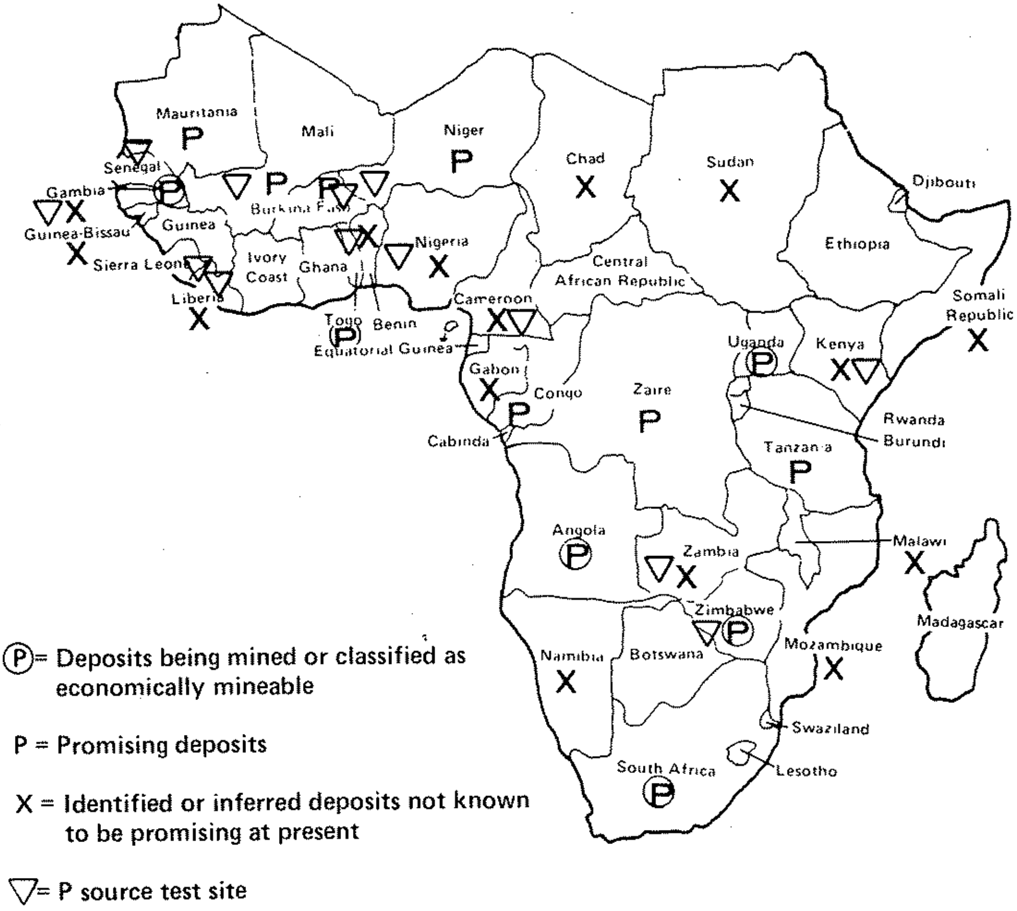


Figure 2. Phosphate Resources of Sub-Saharan Africa and Extent of IFDC's Research Program.

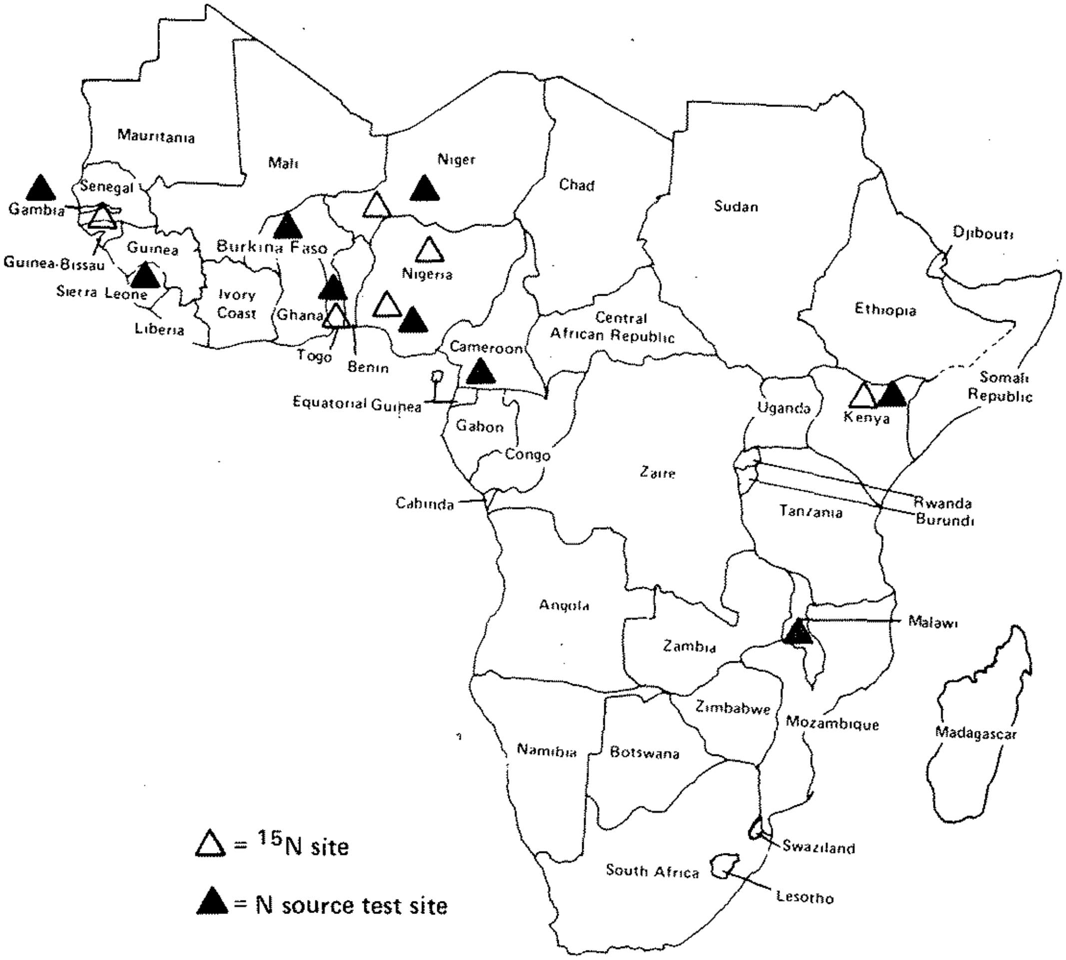
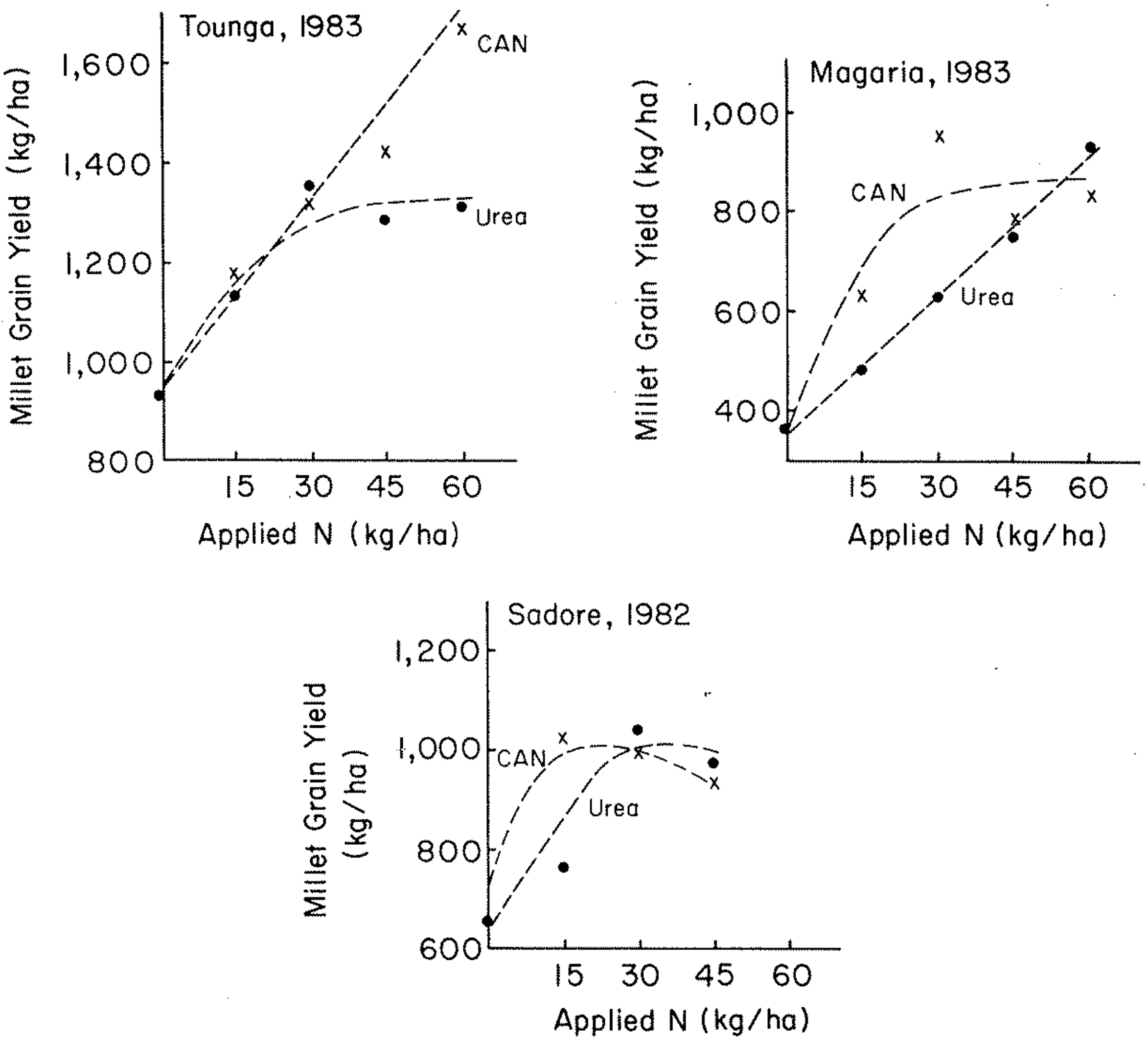


Figure 3. IFDC's Nitrogen Research Program in Sub-Saharan Africa.

Figure 4. Farm-Level Testing of Fertilizer Materials and Socioeconomic Research in Sub-Saharan Africa.



Source: Data from INRAN, 1984; IFDC, 1984.

Figure 5. Response Curves for Urea and Calcium Ammonium Nitrate in the Semiarid Environment of Niger.

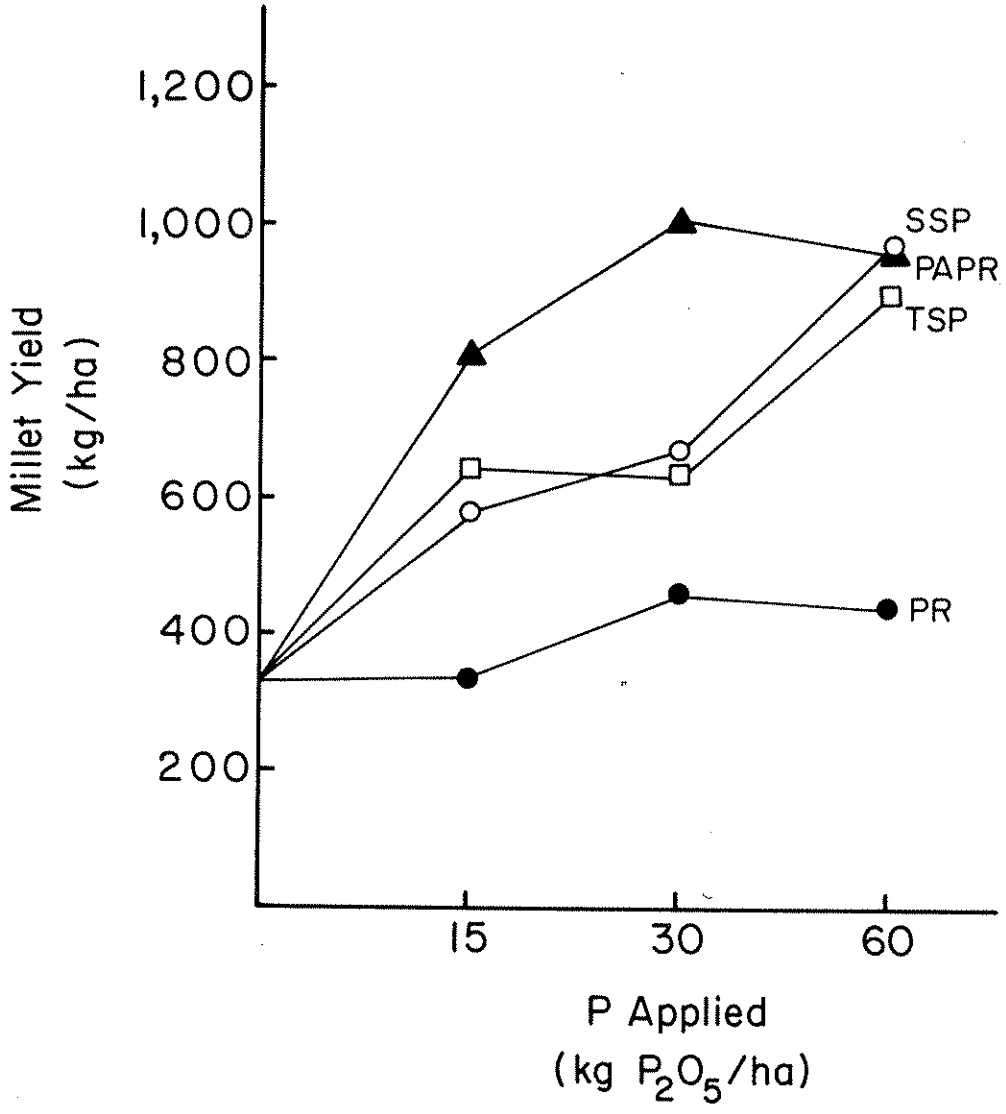
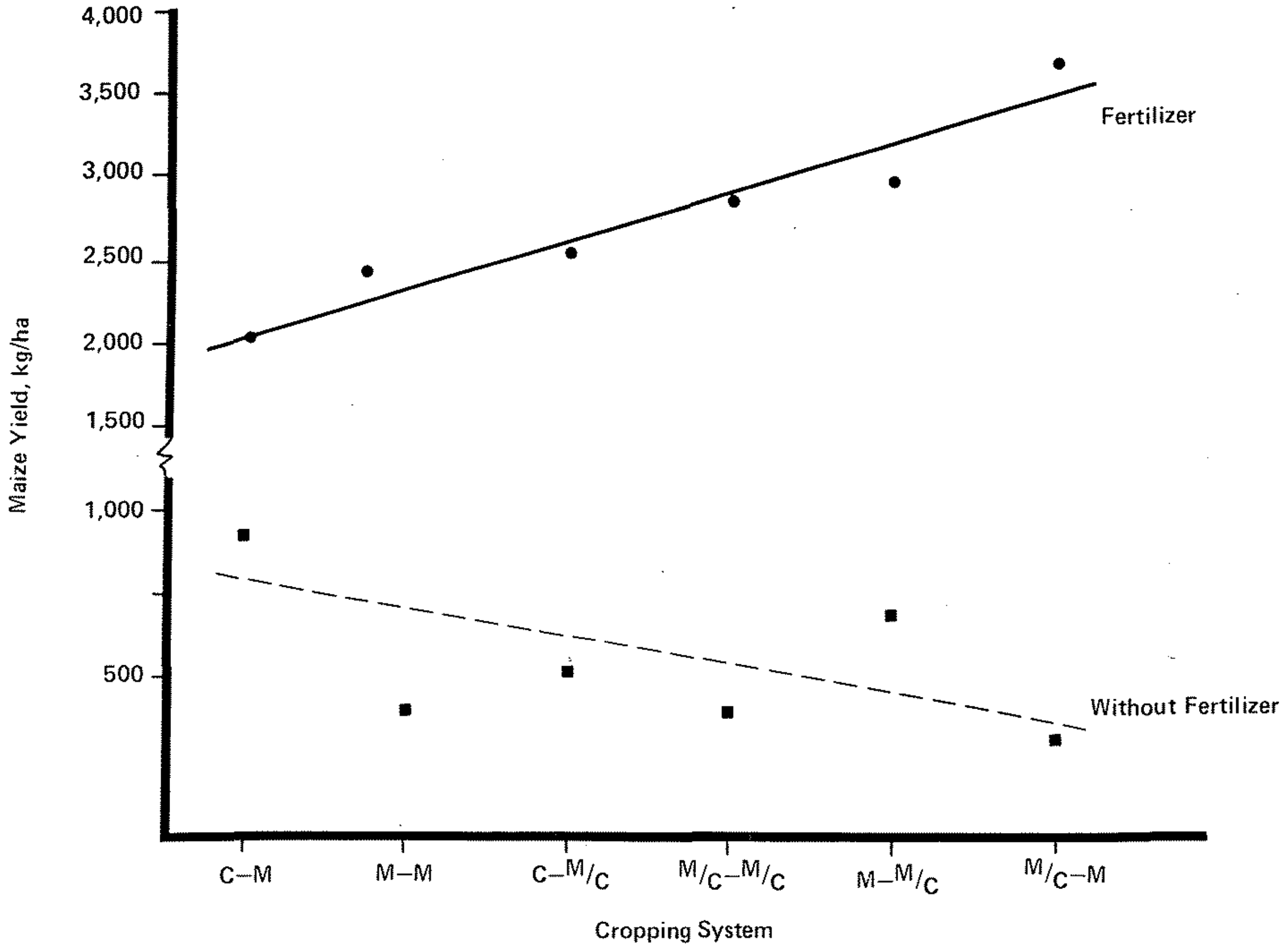
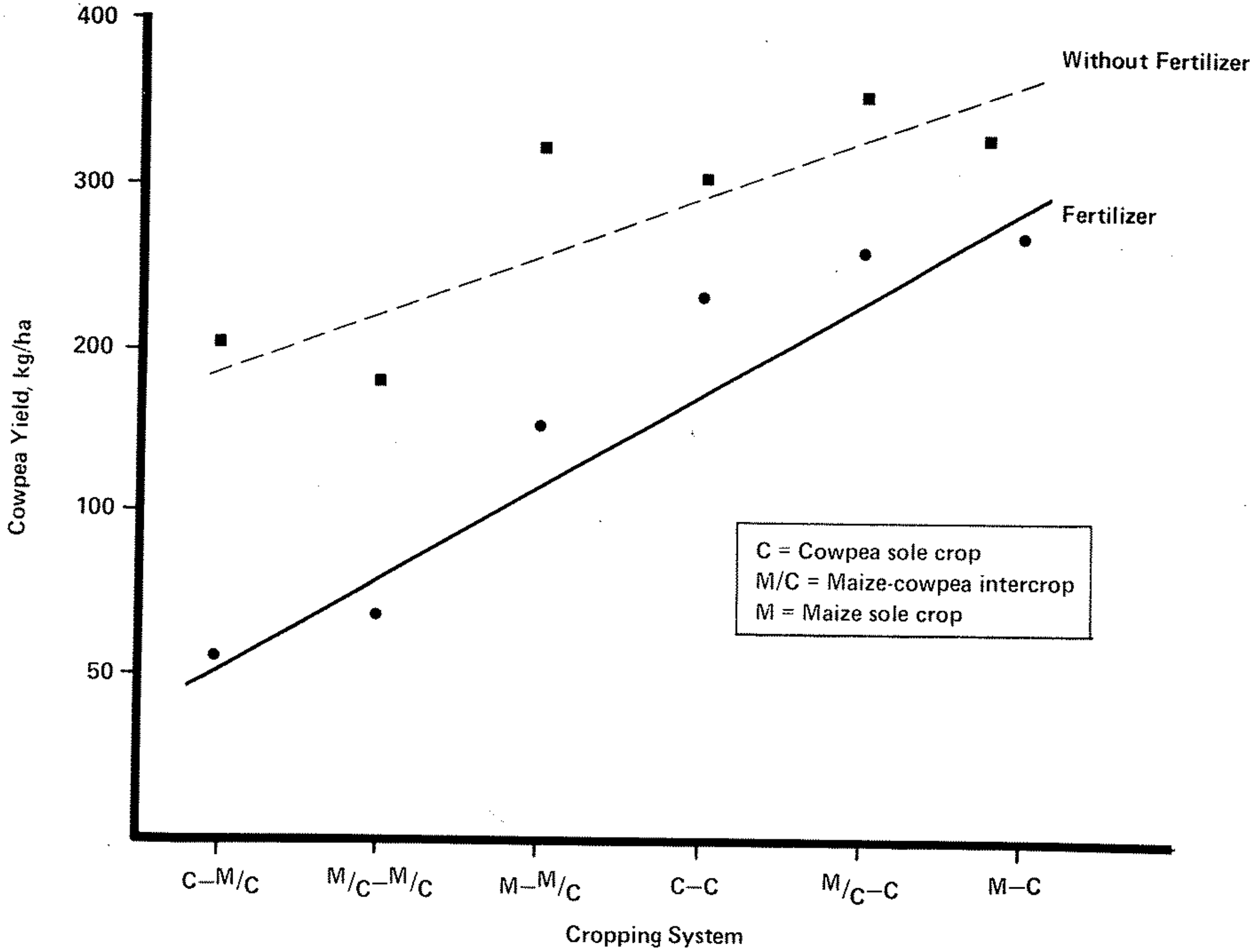


Figure 6. Response of Millet to Different Phosphorus Sources at Mai-Ganji, Niger.



Source: Data generated by Osiname, 1984.

Figure 7. Effect of Cropping System and Soil Fertility Management on Maize Yield.



Data generated by Osiname, 1984.

Figure 8. Effect of Cropping System and Soil Fertility Management on Cowpea Yield.

APPROCHES D'ETUDE POUR UNE UTILISATION OPTIMALE DU PHOSPHATE NATUREL DE TILEMSI PAR LES PAYSANS MALIENS

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English Summary

One of the objectives of the Club du Sahel is to increase food production in the Sahel region.

To achieve this goal a multidisciplinary approach is needed to ensure rapid adoption of:

1. New varieties,
2. Improved cultivation practices including mechanization, and
3. Sound crop management practices including fertilization and the necessary crop and produce protection measures.

Rural manpower in Mali is increasing at 1.5% per year while the total population is increasing much more rapidly at 2.5%. There is thus an increasing gap between the need for food and the capacity to produce that food unless steps are taken to increase yields.

Constraints to increased food production, other than a relative decrease in the labor force, are similar in many countries of Africa with Mali being no exception. Major development constraints are low crop prices, high input prices, and poor infrastructures, particularly as regards input and produce marketing.

Because the soils of Mali are not very fertile, the use of fertilizer nutrients is essential for high yields. Imported fertilizers are expensive and a drain on foreign exchange reserves. Therefore, full use must be made of local mineral resources which could partially substitute for imported fertilizers.

Phosphate is generally deficient in Malian soils and because Mali has a commercial-size deposit of phosphate rock, maximum agricultural use must be made of this national resource.

Past work has shown the agronomic value of this rock, but despite considerable investment, to date, use levels remain low and erratic.

Because of this fact, IFDC proposed an in-depth study of phosphate needs of Malian crops and the value of Tilemsi rock *per se* or of chemically modified Tilemsi rock more closely matching the phosphate used in the imported cotton fertilizer.

The program objective was to provide Malian decisionmakers with sound and relevant data on alternative phosphate fertilizers and to establish economically sound fertilizer recommendations adapted to each ecological zone in Mali.

Generally provided that nitrogen, potash, and sulfur fertilizers are applied to maize, average yield increases of 400-900 kg/ha can be sustained by annual phosphate applications. On the average, annual application rates for maximum yield tend to decrease as soil phosphorus status improves. In experiments where both basal phosphate rock and annual phosphates were applied, the annual application rate for maximum yield decreased with increasing basal phosphate rock applications.

In a cotton-maize rotation, the efficiency of the phosphate rock was at maximum when the fertilizer was basally applied to cotton at the time of plowing, rather than on the preceding maize crop as it is now recommended by the CMDT.

For sorghum and millet, crop response to annual soluble phosphate applications is usually better than the response to basal application. However, residual effects due to phosphate rock application exist and are more important when rainfall conditions improve.

For rice, basal applications of phosphate rock are very suitable; however, phosphate rock gives the best yields in the second year.

In 1984 farm-level experiments were installed on a north-south axis along a rainfall gradient ranging from 700 to 1,300 mm. Results show that in all but the driest zones, phosphate rock could replace the soluble phosphate contained in the complex fertilizer provided all other nutrients (N, K, S, B) are applied. It also appears that the current recommended application for phosphate is far beyond the optimum rate.

Results from both research stations and farmers' fields show that in Mali ground phosphate rock is the most promising fertilizer phosphate in today's agroeconomic environment. Its use should be strongly recommended and a proper production/marketing system established.

The program also showed the benefits to both researchers and extension agents of a strong and efficient collaborative program between research and extension services.

Introduction

Les problèmes de déficit alimentaire dans les pays Sahelliens deviennent plus dramatiques d'année en année, et ce malgré une aide internationale sans cesse plus importante. La croissance démographique, 2.7% par an dépasse de loin l'augmentation de la production alimentaire de 1% par an, retardant donc sans cesse l'autosuffisance alimentaire. La désertification et la dégradation des terres arables s'étend plus rapidement que les progrès des projets de reboisement. S'ajoute à cela l'exode rural et chaque année l'agriculture perd de précieuses superficies cultivables. Les terres cultivables perdues par dégradation sont estimées à 1.5 million d'hectares par an. Trois des objectifs principaux du Club du Sahel pour les années 1978 à 2000 (1) accroissement de l'aide au développement, (2) une meilleure compréhension des contraintes à l'épanouissement de cette région de la part de la communauté internationale, et (3) l'autosuffisance alimentaire et le retour à l'équilibre écologique pour l'an 2000; visent une mise en valeur harmonieuse du Sahel. Force est de constater cependant que peu de progrès fondamentaux ont été réalisés jusqu'à présent tant dans le domaine économique que celui du déséquilibre écologique. Toutefois les effets de tout programme de développement agricole important à l'échelle régionale ne se manifeste souvent qu'à moyen et à long terme. A long terme le développement agricole peut promouvoir la prospérité des états en assurant d'abord l'autosuffisance alimentaire et éventuellement l'exportation de denrées vivrières exédentaires, mais aussi en encourageant parallèlement la culture de plantes industrielles, assurant ainsi un revenu substantiel à l'agriculteur. Une telle politique sera aussi génératrice d'emploi principalement dans les industries de transformation telles que moulins, huileries, égraineuses de coton, filature, tissage, confection, etc... A court terme, une politique agricole doit se montrer efficace et administrativement bien structurée ce qui implique une étroite collaboration entre les différents départements du ministère compétent d'abord et ensuite entre différents ministères qui par leurs arrêtés affectent la prospérité des pays concernés voire de la région toute entière.

Le développement agricole est avant tout une action multidisciplinaire qui doit impliquer:

1. Les paysans qui assurent la production. Cependant leur comportement sera influencé par la politique nationale en matière de fixation des prix en amont et en aval, réglementation de la fiscalité, aménagement fonciers, etc...
2. La recherche agronomique qui détermine les technologies nouvelles à adopter.
3. Les services de vulgarisation qui seront chargés de la diffusion de ces nouvelles techniques, de la gestion des entreprises agricoles et de leur suivi par des enquêtes régulières.
4. Les structures de production ou d'importation des engrais et autres intrants agricoles, leur distribution, leur commercialisation, et les formules de crédits appropriées.
5. Les sociétés de commercialisation de la production elle-même en aval.
6. Le département qui assure les aménagements fonciers tels que périmètres irrigués, projet de drainage, la mise en place et le suivi de programmes de conservation de sol.
7. Les services de formation qui assureront le maintien de la compétence technique du personnel d'encadrement.

Le développement agricole doit intégrer les aspects économiques assurant à la fois l'intérêt national et l'intérêt individuel ainsi que celui du producteur et du consommateur. Vu sous cet angle, le ministère de l'agriculture, en assurant l'augmentation de la production agricole et gageant sur la prospérité nationale, agit comme un service public offert aux agriculteurs qui composent d'ailleurs la grande majorité de la population. La garantie de l'accessibilité par les paysans de services assurant la multiplication de semences améliorés, l'approvisionnement des engrais et des intrants agricoles en général, les marchés de produits agricoles, l'établissement de normes de qualité assurant la motivation et un revenu stable de l'agriculteur, à compétence des organismes de vulgarisation et leur information sur les résultats de la recherche agronomique sont des conditions indispensables pour un développement rapide et efficace des programmes agricoles.

Il est d'autre part souhaitable d'évaluer et de tenir compte des potentialités des différentes régions agricoles pour définir les ordres de priorités dans un programme cohérent de développement agricole national. Parmis les régions à potentiel élevé, on distingue celles où les projets de développement peuvent commencer ou s'intensifier immédiatement et celles où l'établissement d'une certaine infrastructure doit être préalablement mis en place. Dans les deux situations il est cependant souhaitable d'installer ou de développer une importante structure liant la recherche et la vulgarisation. Un développement agricole adapté pour les régions à faible potentiel est sûrement souhaitable mais l'assurance que les ressources investies ne compromettent pas le développement de régions à plus haut potentiel, ni retardent l'accomplissement de l'autosuffisance alimentaire, doit être préalablement acquise. Une planification appropriée assurant la complémentarité entre les services impliqués établissant un ordre de succession y compris une évaluation réaliste des temps de mise en place s'avère donc absolument indispensable pour un développement harmonieux et efficace du Sahel. L'action de développement intégré implique six éléments intimement liés: (1) la distribution efficace des intrants; (2) l'accessibilité des producteurs aux marchés extérieurs; (3) la recherche agronomique et la mise au point en milieu paysan de technologies nouvelles adaptées aux conditions du milieu; (4) la vulgarisation de ces techniques appropriées; (5) la disponibilité de crédits agricoles à tous les paysans; (6) la construction de routes et la mise en place de moyens de communications efficaces. L'absence ou la faiblesse d'un seul de ces éléments compromet le succès de toute la politique de développement agricole et il faut donc veiller à attribuer à chacun de ces maillons toute l'attention voulue de façon à assurer la réussite des programmes de développement intégrés.

Solutions Possibles au Déficit Alimentaire

Si les conditions de production agricole n'évoluent pas, le Sahel en l'an 2000 devra importer 3 millions de tonnes de céréales par an pour nourrir une population de 50 millions d'habitants. Les perspectives de ressources alimentaires alternatives ne sont pas encourageantes; d'une part la sécheresse refoule le bétail hors des parcours traditionnels vers les zones de culture céréaliaires. Dans ces conditions, le cheptel non seulement ne peut pas s'accroître mais de plus il est confiné dans les zones marginales où la végétation dégradée de faible qualité affecte gravement sa production. D'autre part, comme autre source de protéine, la pêche est loin d'être exploitée au maximum de sa capacité et, bien que potentiellement très productive, peu de travaux de recherche sont faits dans ce domaine.

Dans l'immédiat la production alimentaire peut s'accroître:

1. En utilisant les variétés améliorées répondant bien aux engrais, pour autant que les semences de qualité soient disponibles en quantités suffisantes. La sélection variétale progresse sans cesse, et dès à présent, de bonnes variétés de maïs, arachides, mils sont disponibles. En matière de sorgho et de Niébé certaines variétés améliorées existent et sont actuellement en cours d'évaluation. Les services des ministères de l'agriculture chargés de la production des semences améliorées doivent assurer leur disponibilité et leur distribution.
2. En utilisant les techniques culturales efficaces, y compris les fumures adéquates, adaptées aux contitions du milieu. Ces techniques ont été mises au point par la recherche agronomique et sont disponibles pour les services de vulgarisation.
3. Par l'intensification des cultures et l'augmentation des surfaces cultivées grâce à la mécanisation y compris la traction animale. Le manque de motivation du paysan est souvent le goulot d'étranglement qui limite la diffusion de ces techniques nouvelles.
4. Grâce à l'entretien phytosanitaire des cultures et des récoltes, l'utilisation de variétés résistantes ou tolérantes à certaines maladies, et le traitement des récoltes.
5. Par le maintien de la fertilité du sol voire même l'amélioration de ses propriétés physico-chimiques. L'utilisation d'une fumure bien adaptée et un recyclage des résidus de récoltes lorsque c'est possible permettent

souvent de réduire très sensiblement les doses d'engrais appliquées. De plus, vu les coûts très élevés des engrais importés, l'utilisation de ressources naturelles telles que le phosphate naturel permet d'importantes économies de devises.

La réduction du temps de la jachère et l'exportation des éléments nutritifs par les résidus de récolte induit la chute de la fertilité des sols. Le bétail forcé de quitter les parcours traditionnels surtout par manque d'eau et appauvrissement des pâturages vient gonfler un cheptel déjà trop abondant et accentue le surpâturage dans les zones cultivées tout en intensifiant encore davantage le processus de dégradation du sol.

Aux problèmes de dégradation de sol viennent se greffer les contraintes à l'utilisation des engrais et les facteurs limitant la réponse des cultures aux engrais. Comme on peut s'y attendre la plupart de ces contraintes rejoignent celles limitant la production agricole, et les solutions suivantes peuvent y être apportées:

1. La disponibilité de semences améliorées de bonne qualité, répondant mieux aux engrais pour autant que le "paquet technologique" qui les accompagne soit appliqué, augmenterait très significativement les rendements.
2. Pour assurer une réponse optimale aux engrais, les pratiques culturales adaptées, y compris la mécanisation et l'entretien phytosanitaire au sens général, mises au point par la recherche agronomique doivent être transmises aux paysans par les services de vulgarisation. Cependant, un manque de compréhension de la part du vulgarisateur de ces nouvelles pratiques de fertilisation limite souvent l'efficacité du transfert de nouvelles recommandations. Il appartient aux chercheurs, suite à la demande des responsables de la vulgarisation, d'organiser des stages de formation où les vulgarisateurs recevraient une information complète sur les tenants et aboutissants ayant conduits aux recommandations nouvelles. Bien comprise leur adoption par le paysan limiterait probablement les risques de variabilité de la réponse aux engrais et surtout l'imprédictabilité des récoltes.
3. Le coût très élevé des engrais minéraux importés freine sans aucun doute leur utilisation par le paysan et la disponibilité de ressources naturelles telles que le phosphate tricalcique et un recyclage des résidus de récoltes permet des économies importantes au niveau de l'Etat et de l'exploitation.

Des essais test conduits par la recherche agronomique chez des paysans d'une même zone écologique permet l'élaboration de recommandations spécifiques pour cette zone. L'implication des services de vulgarisation dans de tels essais aide les vulgarisateurs à mieux comprendre les résultats obtenus et les arme d'arguments pour faire passer le message plus efficacement.

4. Les enquêtes chez le paysan permet l'identification de contraintes à l'utilisation des engrais. Ces contraintes sont d'ordre agronomiques et d'ordre socio-économiques. Dans l'élaboration d'une politique de vulgarisation l'interprétation de ces contraintes conduit à la conception et la formulation d'arguments à présenter aux paysans pour faire face aux contraintes qu'il a lui-même énoncées. L'élaboration du questionnaire d'enquête et son dépouillement se fera de préférence conjointement en étroite collaboration entre les services de vulgarisation et la recherche agronomique.

L'efficience et l'application de nouvelles recommandations en matière de fumures est accrue lorsqu'on ne considère qu'une seule culture à la fois, comme c'est le cas dans les programmes de développement par production. Cette approche suscite une collaboration plus intense entre les services de vulgarisation et les chercheurs qui doivent répondre rapidement à des problèmes bien précis. Très souvent, même les projets de développement régionaux intégrés, dont l'objectif est d'exploiter simultanément un maximum de ressources dans une aire géographique donnée, oriente ses efforts vers une ou deux spéculations seulement, et, sans toutefois oublier l'aspect intégré du projet, agit en matière de recommandations de fumure comme un programme de développement par production. Simultanément à l'élaboration de recommandations par spéculation, des programmes étudiant les systèmes de production dans son entièreté se poursuivent pendant plusieurs années et conçoivent des recommandations pour l'ensemble des rotations présentes. Ces dernières sont souvent plus conservatrices et beaucoup moins onéreuses, mais leur application rationnelle nécessite une compréhension plus approfondie de principes d'agronomie et de pédologie. Ceci souligne encore une fois l'importance de programmes de formation pour les vulgarisateurs de façon à leur permettre de mieux pénétrer les concepts et recommandations mis au point par les chercheurs.

Cas Particulier du Mali

La population au Mali se chiffre à environ 7.5 millions d'habitants dont ±1.5 millions réside dans les centres urbains et ±6 millions constituent la population rurale. La croissance démographique nationale moyenne est de 2.5% par an, mais les taux de croissance urbaine et rurale sont de 6.06 et 1.51% par an respectivement. La force de travail rurale progresse donc moins vite que la population à nourrir menaçant donc gravement la sécurité alimentaire à moins que la production alimentaire ne soit encouragée.

Devant ce problème épineux, le Club du Sahel réuni au Mali en 1982 a identifié quelques lacunes de la stratégie alimentaire:

1. Le plan alimentaire conçu par les administrateurs et imposé aux paysans est voué à l'échec parce qu'il ne tient pas compte des objectifs du paysan.
2. Ces impositions créent un climat défavorable à l'éclosion des initiatives paysannes.
3. Le paysan n'est pas motivé à cause de:
    a. Faible prix à la production.
    b. Fourniture d'intrants mal organisée et tardive.
    c. Système de crédit très lourd et inabordable pour la plupart d'entre eux.
    d. Commercialisation difficile de sa production.

La nouvelle stratégie alimentaire entend non seulement combler le déficit alimentaire (aspect quantitatif) mais également diversifier la production (aspect qualitatif) pour assurer la sécurité alimentaire par la mise en place d'un système de production stable et efficace limitant les risques en conditions de culture moins favorable.

Malgré que les plus importantes opérations de développement rural soient axées sur une culture de rente, la composante vivrière de chacune d'elles doit se développer pour atteindre l'objectif de l'autosuffisance alimentaire. Bien que toutes les opérations fassent un effort dans ce sens en améliorant la politique de commercialisation qui a motivé les paysans, seul le projet Mali Sud avec des rendements moyens en maïs de 2.2t/ha a atteint cet objectif.

Le coût élevé des intrants et les difficultés de crédit face à la faible rentabilité des fumures sont probablement les contraintes limitant le plus la motivation des paysans. Au Mali cependant, la disponibilité de ressources naturelles en phosphates indigènes de très bonne qualité dans la vallée du Tilemsi au Nord de Bourem, et son utilisation permettrait des économies très importantes en devises.

Caractérisation et Potentiel d'Utilisation du Phosphate de Tilemsi

Les caractéristiques du phosphate de Tilemsi sont repris dans le Tableau 1 et 2. Les teneurs en phosphates varient de 25 à 32% P_2O_5, mais une valeur moyenne de 28.5% est généralement admise. Comparé à d'autres phosphates naturels d'Afrique de l'Ouest, avec une solubilité dans l'acide formique de 61%, le phosphate de Tilemsi est le seul qui, d'après les normes de la Commission des Communautés Européennes (solubilité dans l'acide formique = 55%), pourrait être exploité commercialement en vue d'une utilisation directe en agriculture (Truong Binh et al., 1978).

D'autre part des études faites à l'IFDC montrent que, par des moyens purement mécaniques, on peut enrichir le phosphate de Tilemsi en réduisant fortement la teneur en argiles, goethite et particules de quartz et ainsi augmenter la teneur en P_2O_5 jusqu'à 38% et abaisser la teneur en sesquioxides de $\underline{+}10$ à $\underline{+}4\%$. La plus faible teneur en sesquioxides de ce phosphate enricher le rend presque acceptable pour une utilisation industrielle et un affinement de la technique d'enrichissement le rendrait tout à fait utilisable pour la fabrication d'engrais. L'utilisation du phosphate de Tilemsi en application directe en agriculture en conjonction avec un labour d'enfouissement de jachère en fin de cycle et complémenté par une fumure d'entretien adaptée pour les céréales est recommandée depuis 1973, Tableau 3 (Pieri, 1973).

Dans une synthèse des recherches sur la fertilité des sols au Mali, J. F. Poulain, 1976, affirme que la carence phosphatée quasi générale des sols au Mali peut être corrigée rapidement par un apport unique de phosphate tricalcique de 140 kg P_2O_5/ha, soit 500 kg Tilemsi par hectare, complémenté par une fumure minérale adaptée contenant 50 kg P_2O_5/ha. Dans une synthèse ultérieure d'études plus spécifique sur le phosphate de Tilemsi (Thibout et al., 1980), des recommandations plus précises ont été élaborées: 80 kg P_2O_5/ha en fumure de fond appliqué sur jachères et enfouie par labour de fin de cycle, complémentée par une fumure d'entretien adaptée contenant 20 à 40 kg P_2O_5/ha suivant les cultures. Dans un document interne rédigé par la DRA (1982) à l'intention de la compagnie Malienne pour le Développement des Textiles (CMDT), la DRA synthétise les résultats obtenus dans la zone cotonnière et recommande, pour une rotation coton-maïs-sorgho-ou arachide, l'application de 200 kg de phosphate de Tilemsi sur la jachère incorporé par un labour de fin de cycle mais sans application complémentaire de phosphore dans la formule de fertilization ultérieure. Malgré qu'il ait été établi à maintes reprises que le phosphate naturel de Tilemsi pourrait économiquement améliorer la fertilité des sols du Mali et donc augmenter de façon très sensible la production alimentaire du pays, la consommation de phosphate naturel reste très faible, Tableau 4 (A. C. Cissé, 1984).

Programme de l'IFDC au Mali

Devant le faible intérêt de la part des paysans pour le phosphate naturel de Tilemsi dû surtout (1) à la réponse lente de cet engrais, (2) au temps d'application (labour de fin de cycle) qui sort des pratiques conventionnelles du paysan et ne rejoint pas les objectifs de son exploitation, (3) à l'état pulvérulent du phosphate naturel, l'IFDC propose de tester un nouvel engrais phosphaté, le phosphate naturel partiellement acidulé (PNPA), produit à partir du phosphate de Tilemsi et qui combinerait à la fois les propriétés du phosphate soluble (disponibilité immédiate du phosphate l'année de l'application) et les avantages du phosphate naturel (effet résiduel intéressant). De plus la fabrication de cet engrais nécessite des quantités beaucoup moins importantes de réactifs, et pour autant qu'une consommation suffisante soit assurée, pourrait être réalisée au Mali à moindre coût. Le Tableau 5 reprend les propriétés chimiques du phosphate partiellement acidulé. De plus la fabrication d'un engrais composé granulé pourrait également se concevoir.

L'objectif général du projet phosphate au Mali, subventionné par le Centre de Recherche pour le Développement International (CRDI) et l'International Fertilizer Development Center (IFDC) est la recherche d'un engrais phosphaté efficace produit directement à partir du phosphate naturel de Tilemsi et l'établissement de recommandations les plus économiques pour chaque zone écologique. L'exécution du programme permettra également de définir avec plus de précision, et pour chaque région étudiée, l'efficacité agronomique des différentes sources de phosphates et la mise au point de la méthode de leur application la plus efficace. Le projet permettra l'élaboration d'un modèle faisant intervenir les conditions climatiques et les propriétés pédologiques. L'effet des différents engrais phosphatés sur les propriétés du sol sera également évalué en fonction des cultures et des caractéristiques écologiques des régions.

Essais en Station

Le projet couvre l'ensemble des régions agro-pédo-climatiques du Mali puisque nous avons sélectionné 10 stations de recherches réparties sur l'ensemble du territoire national.

		Pluviométrie
1	Tiéourala	1,250
2	Dalabani	1,200
3	Samanko	1,050
4	Sotuba	1,000
5	Katibougou	800
6	N'Tarla	950
7	Massantola	800
8	Cinzana	800
9	Koporo Keniepe	600
10	Kogoni	Irrigation

Le Tableau 6 fournit quelques données pédologiques. Afin d'évaluer avec précision, l'effet des différentes sources de phosphate, toute fertilisation complémentaire N, K, S étant égale, quatre différents types d'expériences ont été conçues, et conduites sur le maïs, sorgho, mil, riz, arachide et cotonnier.

Expérience 1--Evaluation agronomique d'une application annuelle de trois différentes sources de phosphates (PN, TSP, PNPA 30)[1] à quatre différentes doses, complémentaire à une application de fond de phosphates naturels à trois différentes doses.

Expérience 2--Evaluation de la disponibilité initiale en phosphates et de l'effet résiduel d'une seule application de fond de quatre différentes sources de phosphates (PN, TSP, PNPA 15, PNPA 30) à cinq différentes doses.

Expérience 3--Evaluation des différences dans la réponse des cultures entre une application de fond de phosphates naturels et des applications annuelles de PN, TSP, PNPA 30 et PNPA 15 chaque engrais étant appliqué à cinq différentes doses.

Expérience 4--Evaluation de l'effet du placement des engrais phosphatés (PNPA 30, PNPA 15, TSP) épandus à la volée, placés en ligne ou en poquets. Sauf

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[1] PN = phosphate naturel, TSP = triple superphosphate, PNPA 15 = phosphate naturel partiellement acidulé; utilisation de 15% de l'acide nécessaire pour la fabrication de superphosphate simple, PNPA 30 = phosphate naturel partiellement acidulé; utilisation de 30% de l'acide nécessaire pour la fabrication de superphosphate simple.

pour l'expérience 4 les engrais phosphatés ont toujours été appliqués à la volée et enfouis avant le semis. Le phosphate de Tilemsi était dans la mesure du possible appliqué avant le labour. Les engrais complémentaires N, K, S, B étaient appliqués aux doses recommandées. En particulier le potassium était apporté sous forme de sulfate de façon à assurer une réponse réelle au phosphate et masquer une éventuelle réponse au soufre dans les traitements avec le phosphate partiellement acidulé.

Les différents traitements pour chacune des expériences sont repris en annexe. Les résultats de deux années d'expériences en station montrent que toutes les cultures sauf l'arachide répondent en général bien aux applications de phosphates. Dans les régions où la pluviométrie n'est pas un facteur limitant, bien que la réponse initiale soit plus lente, des rendements équivalents à ceux obtenus avec les phosphates solubles peuvent être atteint aux doses plus élevées. Pour le maïs en première année, en moyenne seule une combinaison phosphate naturel plus phosphate soluble permet des rendements maximums, mais dans les conditions pluviométriques les plus favorables ces apports de phosphates solubles sont superflues. Plus les pluies deviennent déficitaires, meilleure devient la réponse aux formes les plus solubles. Dans toutes les zones, néanmoins, la réponse aux applications de fond de phosphates, quelle que soit la source, est très marquée. Il faut cependant distinguer deux zones, celle avec une pluviométrie inférieure à 800 mm où une application supérieure à 60 kg P_2O_5/ha de phosphate naturel semble superflue et les zones mieux arrosées où une réponse est observée jusqu'aux doses de 120 kg P_2O_5/ha. Une forte interaction négative entre les applications de fond de phosphate naturel et les applications annuelles de tout phosphate montre qu'une fertilisation complémentaire au phosphatage de fond au moyen de phosphate soluble ne semble se justifier que dans les conditions de pluviométrie les moins favorables. L'effet résiduel des applications de phosphate (Expérience 2) est très marquée et on ne distingue souvent des différences significatives entre les sources que l'année d'application.

L'année 1983 a été marquée par des périodes de sécheresse prolongée dans beaucoup de zones, et on a pu constater surtout à Dalabani et à Tiéourala, que les cotonniers sont plus tolérants à la sécheresse sur les parcelles ayant reçu du phosphate naturel. Le phosphate naturel semble donc dans ces conditions favoriser la croissance du cotonnier, probablement grâce à un enfouissement plus profond et homogène de l'engrais par le labour qui favoriserait un meilleur enracinement.

En matière d'applications strictement annuelles, on ne met en évidence des différences significatives entre les sources que l'année d'application dans les zones les plus sèches, mais dès la deuxième année grace aux arrière-effets, même dans ces conditions sèches, on obtient des rendements équivalents quelle que soit la source de phosphate utilisée. En ce qui concerne les méthodes de placement, la localisation en ligne ne se justifie que dans le cas de la forme soluble (TSP) pour la quelle on obtient des rendements supérieur. Dans tous les autres cas un épandage à la volée suivi d'enfouissement est à recommander.

En riziculture à Kogoni l'irrigation induit un pH du sol proche de la neutralité peu favorable à la réaction dans le sol du phosphate naturel et une meilleure réponse aux formes solubles est observée la première année. Néanmoins, en deuxième année après drainage, l'acidité naturelle du sol (pH 4.9) permet au phosphate naturel de réagir dans le sol, et on observe une très bonne réponse du phosphate naturel équivalente à celle des phosphates solubles. Ces conditions plus favorables d'acidité solubilisent progressivement le phosphate naturel, le rendant donc plus accessible à la plante à partir de la deuxième année. En ce qui concerne les phosphates solubles les applications de fond de TSP, 120 kg P_2O_5/ha, donnent des rendements supérieurs à ceux obtenus avec deux apports annuels de 60 kg P_2O_5/ha.

Les Tableaux 7 à 10 reprennent les coefficients de régression par expérience et par culture.

Conclusion sur les Essais en Station

Les essais conduits sur un vaste réseau de stations de recherche aux structures bien établies, et couvrant la plupart des conditions pédo-climatiques, ont montré que (1) l'utilisation du phosphate de Tilemsi permettait d'atteindre des niveaux de rendement équivalent à ceux obtenus avec le phosphate soluble et ce dès la première année d'application dans des conditions de pluviométrie satisfaisante; (2) des applications annuelles de phosphates solubles complémentaires au phosphatage de fond parfois même en troisième année ne sont pas toujours justifiées et les doses d'application en tout cas réduites en fonction des apports de fond; (3) vu la très bonne réponse résiduelle des cultures au phosphate naturel, et l'estimation de coût actuellement très élevé pour la production au niveau national du phosphate naturel partiellement acidulé, la fabrication du PNPA ne se justifierait que si la consommation nationale d'engrais augmente de façon très sensible; (4) la finesse de mouture du phosphate naturel actuellement disponible, en augmentant la surface de contact, favorise sa réaction rapide dans le sol après son incorporation profonde, ce qui améliore fortement son efficacité et permet une révision des recommendations dans le sens d'un rapprochement entre la date d'application et la date de semis; (5) la bonification générale des terres peut se réaliser par un phosphatage de fond qui corrigera la carence en phosphore; (6) sur le riz irrigué, en première année on observe une supériorité incontestable des formes solubles et partiellement solubles, tandis qu'en deuxième année l'effet résiduel du phosphate naturel est spectaculaire, bien que non significativement différent des autres sources de phosphate.

La roche broyée actuellement disponible possède une granulométrie fondamentalement différente de celle sur laquelle sont basées les recommandations actuellement en vigueur (Figure 1). Sur base des expériences en cours on peut conclure que le phosphate naturel doit être appliqué avant le semis et incorporé au moment du labour. Dans ces conditions on peut atteindre des rendements équivalents à ceux obtenus par la fertilisation conventionnelle. Cet ajustement dans les recommandations répond bien aux préoccupations du paysan, car en fin de saison des pluies, il ne souhaite pas labourer une jachère ni les fanes de son champ qui servent de pâturage pour son bétail. De plus, le labour de fin de cycle ne peut se réaliser que dans des conditions favorables d'humidité du sol ce qui exclu des applications de phosphates naturels après une culture traditionnelle de sorgho ou de mil qui se récolte après l'installation de la saison sèche. La finesse de mouture permet donc une application au moment du labour tout en extériorisant pleinement les propriétés fertilisantes du phosphate naturel dès la première culture suivant l'application. Ceci également satisfait une des préoccupation majeures du paysan en assurant un revenu de son investissement dès la première année d'application. En riziculture irrigée on peut suggérer de tester l'efficacité de phosphate de Tilemsi suite à un labour de fin de fin de cycle. Ceci nécessitera toutefois une remise en eau des parcelles pour assurer de bonnes conditions de travail du sol.

Essais en Milieu Paysan

Suite à l'accumulation au fil des années, de résultats encourageants en matière d'utilisation du phosphate de Tilemsi, et l'entrevue de la possibilité de rentabiliser son utilisation par les paysans, la Banque Mondiale subventionne actuellement un projet sur l'utilisation du phosphate de Tilemsi par les paysans de la zone cotonnière. Bien que ce programme soit fondamentalement régional, les résultats pourraient être extrapolés dans des zones écologiquement semblables.

Un programme de recherche en milieu paysan implique une collaboration active entre chercheurs et vulgarisateurs et un partage des responsabilités. Si la conception des essais et l'analyse des résultats repose surtout sur les chercheurs, l'installation et le suivi des tests sera surtout la responsabilité des services de vulgarisation. Tout partage de responsabilités doit se faire sans équivoque, ce qui implique que chacune des parties soit bien informée sur les objectifs poursuivis et les moyens mis en oeuvre pour y parvenir. Pour cette raison, il est indispensable que dans ce genre de programme collaboratif, les agents de vulgarisation reçoivent une certaine formation de base concernant l'expérimentation et la mise en place d'expériences. Les plans d'expériences utilisés dans les essais en milieu paysans doivent rester simples et se limiter à quelques traitements seulement. De cette façon, les paysans eux-même, mais surtout les vulgarisateurs sont en mesure de différencier les traitements sans ambiguité. Il est en effet indispensable d'éviter toute confusion, et une formation complémentaire des vulgarisateurs sur les bases de l'analyse et de l'interprétation des résultats est pour cela essentiel. Ce sont en effet les vulgarisateurs qui auront pour mission de diffuser l'information parmi les paysans de leur zone, et cette diffusion sera d'autant plus efficaces que leur implication dans les programmes de recherche-développement aura été plus important.

Le programme en milieu paysan a débuté avec soixante paysans répartis dans trois régions et dix secteurs sur un axe Nord-Sud de SAN à SIKASSO couvrant les isohyètes 700-1,300 mm. Les services de vulgarisation ont identifié les paysans en tenant compte des caractéristiques pédologiques de leur champ et de leur niveau de technicité de façon à assurer leur représentativité au sein de la région. L'objectif de ces essais est non seulement de déterminer la dose optimale d'utilisation du phosphate de Tilemsi en milieu réel, mais aussi d'évaluer la possibilité de substituer le phosphate contenu dans l'engrais complexe par le phosphate naturel tout en maintenant les autres éléments nutritifs de la formule aux niveaux recommandés. Chez chaque paysan quatre traitements comparant deux doses de phosphate naturel (60 et 120 kg P_2O_5/ha) avec un témoin sans phosphate et la pratique actuellement vulgarisée, ont été répartis sur quatre parcelles adjencentes sans répétitions (Tableau 11).

De façon à quantifier la variabilité du champ du paysan quatre carrés de rendements sont prélevés dans le champ même du paysan, ce qui correspond également à un cinquième traitement, la pratique du paysan.

Du point de vue statistique, un tel schéma expérimental affecte la précision de l'essai par manque de répétition des différents traitements étudiés. D'autres part, l'élaboration au niveau de la région de recommendations concernant l'utilisation du phosphate de Tilemsi nécessite de multiplier les essais en milieu paysan de façon non seulement à amplifier leur représentativité et affermir leur pertinence, mais surtout à favoriser la crédibilité des résultats au niveau paysan. La perte de précision affecte la rigueur de l'expérimentation, qui est dans une certaine mesure compensée par un gain de représentativité et de crédibilité, deux conditions par ailleurs essentielles pour le transfert efficace de technologies nouvelles.

Les résultats de ces essais en milieu paysan ont montré que dans les zones à pluviométrie satisfaisante lorsqu'il y a réponse au phosphore, le phosphate naturel pouvait utilement remplacer le phosphate soluble contenu dans la formule de l'engrais complexe, pour autant que les engrais complémentaires soient apportés. Ceci confirme les essais en station qui montraient que des niveaux équivalents de rendements pouvaient souvent être obtenus quelle que soit la source de phosphate utilisée, y compris le phosphate naturel. Il apparait cependant qu'en milieu réel, celui du paysan, des doses d'application inférieures à celles recommandées par la recherche, 47-56 kg P_2O_5/ha suivant les cultures ou les régions au lieu de 85 kg P_2O_5/ha, peuvent être appliquées.

Il faut cependant aussi remarquer que la réponse du maïs au phosphate de Tilemsi n'est pas toujours observée parce que le maïs suit souvent le coton qui a reçu une fumure forte, et aussi parce que 1983 a été une année particulièrement difficile en matière de pluviométrie. Le coton par contre, venant en général après une culture vivrière peu fertilisée, répond mieux au phosphate de Tilemsi et, tout en maintenant la formule complémentaire au niveau recommandé, atteint des niveaux de rendements équivalents ou supérieurs à ceux obtenus avec l'engrais complexe.

Dans les zones à plus faible pluviométrie, comme pour les essais en station, on obtient une meilleure réponse avec le phosphate soluble (complexe coton) que le phosphate naturel. Pour chacune des régions, les essais implantés sont considérés comme des répétitions. Les coéfficients de variation assez élevés pour les regressions 17% à 30% nous conduisent à évaluer en termes économiques les risques encourus par les paysans en matière d'utilisation de l'une ou l'autre forme d'engrais. Les essais en station nous ont montré que les effets résiduels des engrais phosphatés, quelle que soit la source, sont équivalents. Les essais en milieu paysan montrent que les rendements équivalents sont atteint avec le phosphate naturel plus complément minéral et la formule complexe. L'apport des éléments complémentaires sous forme individuelle, urée, sulfate de potasse et boracine est très onéreuse, et il n'est pas certain, les résultats complets ne sont pas encore disponibles, qu'une fumure composée de phosphate naturel plus les engrais complémentaires apportés séparément soit la plus économique. L'étape suivante maintenant serait de déterminer l'opportunité d'appliquer tous les engrais complémentaires aux doses actuellement recommandées, et d'envisager éventuellement la possibilité de les réduires autant que possible.

Conclusions Générales

L'approche qui a été suivie au Mali dans le projet de recherche pour la maximisation de l'utilisation du phosphate naturel de Tilemsi par les paysans intègre bien les aspects de recherche en station et en milieu réel. Sur base de résultats de recherche antérieure et ceux obtenus récemment sur un plus vaste réseau de stations de recherche, le choix de la source de phosphate la plus prometteuse se porte sur le phosphate naturel qui est testé à grande échelle en milieu paysan. En vue d'assurer un maximum d'efficacité de programmes de recherche de ce genre, une étroite et intime collaboration entre les institutions de recherche et de vulgarisation est indispensable. La formation active d'agents de vulgarisation à certaines techniques de recherche est indispensable pour motiver les cadres des opérations de développement rural et installer un climat de confiance entre les chercheures et les vulgarisateurs surtout si l'ampleur du programme entraine un partage inévitable des responsabilités entre ces deux groupes. Sans collaboration étroite avec les services de vulgarisation, l'installation d'un programme important d'essais en milieu paysan devient difficile et entraine des dépenses surtout logistiques très importantes. Au contraire plutôt que la mise en place par les chercheurs seuls, une participation des services de vulgarisation, moyennant au besoin compensation financière, pourrait assurer un soutien logistique efficace certain. De plus, cette participation aiderait à établir un climat de confiance entre les paysans et les services de recherche ainsi qu'à assurer la crédibilité auprès des paysans des résultats obtenus. Par l'identification de contraintes à l'adoption par le paysan de technologies nouvelles, une composante socio-économique contribuerait sans aucun doute à adapter une politique de vulgarisation en fonction des contraintes définies par le paysan lui même. Le projet IFDC/IER au Mali peut servir d'exemple et de modèle à l'élaboration de programmes semblables dans d'autres pays en développement, mais une étroite et sincère collaboration entre les services de vulgarisation et la recherche agronomique est une condition préalable indispensable.

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Tableau 1. Analyses du Phosphate Naturel de Tilemsi (IFDC)

	Teneur			Moyenne
	(%)			
CaO	45.0	42.5	39.20	42.2
P_2O_5	31.3	28.9	27.60	29.3
F	2.9	3.0	2.5	2.8
CO_2	2.3	2.2	2.0	2.2
Na_2O	0.1	.14	.32	.19
MgO	0.31	.31	.44	.35
K_2O	0.11	.11	.13	.12
Al_2O_3	1.3	1.9	2.7	2.0
Fe_2O_3	5.3	6.0	7.1	6.1
SiO_2	3.5	-	13.9	8.7
Total S	0.36	-	.3	-
Sulfate S	0.36	.8	-	-
MnO	1.4	-	-	-
SrO	0.16	-	-	-
TiO_2	0.3	-	-	-
BaO	0.1	-	-	-
Cl	0.055	-	-	-
Total C	0.87	-	-	-
Solubilite dans lé citrate neutre	3.7	-	2.7	3.2

Tableau 2. Composition de la Roche

	Teneur (%)
Apatite	77
Quartz	8
Montmorillonite	7
Goethite	8
TOTAL	100

Tableau 3. Rendements Moyens (kg/ha) Au Cours de 7 Années D'Expérimentation (Pierri 1973)

	Traitements[a]				
	1	2	3	4	5
Coton	568	1,187	1,270	1,648	1,725
Sorgho	487	1,349	973	1,525	1,979
Arachide	919	1,477	1,128	1,613	1,770

a.

		Coton	Sorgho	Arachide
Traitement 1	Jachère Brûlée	-	-	-
Traitement 2	Jachère Brûlée	20-28-0	13-13-0	9-30-15
Traitement 3	Jachère Brûlée	15 t/ha fumier	-	-
Traitement 4	Jachère Brûlée	15 t/ha fumier+20-28-0	13-13-0	9-30-15
Traitement 5	Jachère Enfouie 500 kg/ha phosphate naturel	15 t/ha fumier+20 N	30 N	50 K_2O

Tableau 4. Project Phosphate du Mali Evolution de la Production et des Ventes (Cisse 1984)

Annee	Production (En tonnes)	Ventes (En tonnes)
1976	20	20
1977	500	500
1978	580	580
1979	1,400	1,400
1980	1,400	1,400
1981	4,800	1,050
1982	500	500
1983	450	1,000
1984	4,000	2,500

Tableau 5. Données Analytiques pour les Sources de Phosphate Partiellement Acidulé Utilisé dans le Projet

Source	P_2O_5 Total	Solubilité, Eau
PNPA 15NG	25.5	3.6
PNPA 15G	25.5	3.6
PNPA 30NG	23.0	5.0
PNPA 30G	23.0	6.6
PN	27.6	0

Tableau 6. Caractéristiques des Sols Horizons de Surface

Sites	pH Eau	% OM	Phosphore Disponsible Olsen	Phosphore Disponsible Bray 1	CEC	% Saturation
			- - - (ppm)	- -		
Tiéourala, 0-10	6.30	1.06	8.00	4.8	3.20	67
N'Tarla, 0-20	5.85	.46	5.00	2.7	1.75	59
Samanko, 0-20	5.75	.73	9.00	2.7	2.75	54
Katibougou, 0-25	5.95	.73	8.00	1.3	3.75	69
Massantola, 0-20	5.90	.89	8.00	3.3	4.20	75
Cinzana I, 0-20	5.90	.51	13.00	1.7	2.3	72
II, 0-20	6.80	1.22	6.00	2.3	7.2	71
Koporo, 0-20	6.70	.37	5.00	1.3	1.35	71
Kogoni, 0-20	4.90	1.19	-	-	14.9	81

Tableau 7. Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 1)

	Application de Fond	Intersection à l'Origine	PN		TSP		PNPA 30NG		R^2	CV
			Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique		
				MAIS						
Tieourala										
1982	0	1,220	15.13	-.087	54.61*	-.886+	11.96	-.020	30.3	22.5
	60	1,655	5.49*	-	15.25	-.292	6.52	-.085		
	120	1,559	17.48+	-.081	63.44**	-1.128*	27.01	-.413		
1983	0	424	27.7**	-.168**	41.15**	-.428	32.48**	-.247	50.3	22.0
	120	1,367	1.06	-	9.61	-.258	.31	-		
N'Tarla										
1982	0	1,191	15.43	-.064	33.90	-.341	9.31	-	18.3	26.5
	60	1,829	-.85	-	28.76	-.406	4.64	-		
	120	1,682	1.43	-	10.43	-	4.92	-		
1983	0	1,518	-.08	-	21.56	-.318	5.00	-	17.2	27.2
	60	1,475	2.91	-	23.04	-.416	1.86	-		
	120	1,671	6.91	-.061	73.00**	-1.735**	2.93	-		
Samanko										
1982	0	1,427	11.37	-.043	24.50	-.178	20.45	-.078	24.7	19.5
	60	2,017	11.79	-.083	9.46	-.091	6.71	-.138		
	120	1,963	8.81	-.067	64.39**	-1.442**	15.04**	-		
1983	0	1,232	21.86**	-.102	32.33+	-.237	38.09**	-.331	43.9	19.1
	60	1,870	3.53+	-	16.84*	-	16.55	-.119		
	120	2,192	2.99	-.027	10.99	-.255	8.33	-.075		
					SORGHO					
Massantola										
1982	0	2,090	10.02	-.029	28.35	-.314	11.88+	-	13.1	24.6
	60	2,451	3.10	-	7.85	-	.80	-		
	120	2,140	-2.30	-	1.32	-	3.27	-		

(Suite)

Tableau 7 (Suite). Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 1)

	Application de Fond	Intersection à l'Origine	PN		TSP		PNPA 30NG		R^2	CV
			Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique		
					MIL					
Cinzana										
1982	0	941	3.87	-.008	10.09*	-	5.33	-.010	21.4	16.8
	60	1,137	2.69	-.016	8.76	-.035	3.21	-		
	120	1,355	-.98	-	25.05+	-.493	-.45	-		
1983	0	1,266	7.26	-.028	33.35+	-.252	19.98	-.153	25.4	22.8
	60	1,736	-1.02	-	1.70	-	.39	-		
	120	1,746	-3.08+	-	28.24	-.606	8.89	-.126		
Koporo Keniepe										
1982	0	336	2.29**	-	11.23	-.070	.62	-	20.5	49.7
	60	308	1.58*	-	11.51+	-.180	.69	-		
	120	268	-.04	-	14.91*	-.272	1.65	-		
1983	0	354	8.06	-.042	16.22+	-.180	13.81+	-.197	8.8	46.5
	60	516	.72	-	1.05	-	2.3	-		
	120	408	3.70	-.022	13.77	-.329	1.19	-		
					COTON					
Tieourala										
1982	0	1,496	15.90**	-.078*	31.03*	-.280	18.66+	-.122	54.3	9.30
	120	2,397	2.15	-.031	.29	-	-.91	-		
1983	0	1,252	25.10**	-.152	29.66	-.291	31.46+	-.303	36.3	17.4
	60	2,089	3.07	-	1.85	-	2.80	-.137		
	120	2,452	2.02	-	3.00	-	.55	-		
N'Tarla										
1982	0	1,316	3.60	-.017	24.92	-.295	5.58	-.037	14.8	37.3
	60	1,216	3.47	-	46.42	-.828	12.33	-.266		
	120	1,477	20.33	-.200+	49.89	-.960	16.41	-.151		
1983	0	1,032	10.32	-.044	26.48	-.338	4.37	-	14.0	30.6
	60	1,101	2.25	-	32.41	-.500	9.25	-		
	120	1,031	12.8	.084	12.56+	-	9.15	-		

Tableau 8. Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 2)

	Intersection à l'Origine	PN		TSP		PNPA 15NG		PNPA 15 G		PNPA 30NG		PNPA 30G		R^2	CV
		Lin.	Quad.	Lin.	Quad.	Lin.	Quad.	Lin.	Quad.	Lin.	Quad.	Lin.	Quad.		
						MAIS									
Dalabani															
1982	1,755	12.56*	-.056*	11.79	-.082	9.42	-.036	5.28+	-	-	-	-	-	12.0	30.0
1983	1,950	14.55**	-.041	17.38	-.061	-	-	-	-	18.01	-.064	6.07+	-	26.9	69.3
						SORGHO									
Samanko															
1982	1,206	4.33	-.011	4.61*	-	3.12	-0.13	2.97	-	-	-	-	-	11.7	28.7
1983	892	6.43**	-.018+	10.97*	-.069+	-	-	-	-	4.83**	-	5.06	-.004	32.5	22.1
Katibougou															
1982	1,161	7.90*	-.033*	4.45**	-	4.31	-.045	-	-	7.49	-.063	-	-	13.5	27.8
1983	653	3.47	-.004	4.58+	-	7.42	-.026	-	-	5.75*	-	-	-	11.3	38.9
						RIZ									
Kogoni															
1982	5,457	3.48	-.002	14.21+	-.055	24.80**	-.186*	-	-	15.68+	-.091	-	-	21.4	7.0
1983	4,910	17.34**	-.047*	13.57	-.017	27.02**	-.161+	-	-	14.63	-.054	-	-	36.7	10.0
						COTON									
Dalabani															
1982	1,300	6.40*	-.016	5.76**	-	-	-	-	-	13.59*	-.073	2.69	-	23.6	29.0
1983	1,472	11.96*	-.044*	6.02*	-	2.32**	-	6.59*	-	-	-	-	-	15.9	39.8
Samanko															
1982	1,571	6.57*	-.018	7.12	-.019	-	-	-	-	3.43*	-	4.01**	-	22.1	22.0

Tableau 9. Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 3)

	Intersection à l'Origine	PN		TSP		PNPA 15NG		PNPA 30NG		PN (Fond)		R^2	CV
		Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique		
						MAIS							
Sotuba													
1982	1,202	19.22*	-.116+	44.56**	-.546+	30.20+	-.350	43.74*	-.569+	-	-	21.2	27.1
1983	930	15.92*	-.115+	11.08**	-	7.21+	-	10.15**	-	-	-	14.8	32.7
						SORGHO							
Cinzana													
1982	1,653	4.96	-.289	9.72**	-	-	-	2.63	-	-	-	24.6	14.1
1983	754	8.56*	-.083*	8.72	-.020	7.55	-.089	-	-	-	-	20.8	21.4
						RIZ							
Kogoni													
1982	4,480	1.66	-.006	27.04	-.423	7.34	-	13.28*	-	-	-	6.5	14.1
1983	5,107	18.98*	-.099	27.67	-.160	31.11+	-.234	34.82*	-.320	6.98	-.007	29.6	8.6
						COTON							
Cinzana													
1982	1,386	5.73	-.047	17.43*	-.225	7.11	-.104	-	-	-	-	18.9	13.9

Tableau 10. Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 4)

	Placement	Intersection à l'Origine	PN		TSP		PNPA 15NG		PNPA 30NG		R^2	CV
			Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique		
					MAIS							
Dalabani												
1982	A la volée	981.8	20.60*	-.156*	4.56	-	-	-	8.74	-.146	18.9	35.6
	En ligne		10.67	-.079	27.60+	-.378	-	-	47.22**	-.635		
1983	A la volée	942.1	15.26	-.084	32.56+	-.432	-	-	38.71*	-.56	21.7	40.5
	En ligne		8.87**	-	17.48**	-	-	-	16.79**	-		
N'Tarla												
1982	A la volée	1,301	-	-	25.85*	-.289	26.45*	-.335	27.87*	-.304	17.4	22.1
	En ligne		-	-	17.95	-.335	9.21+	-	8.83	-		
	En poquets		-	-	17.35	-.304	10.93	-.148	13.45	-.112		
1983	A la volée	1,817	-	-	22.99	-.228	10.96*	-	15.63	17.89	9.7	18.8
	En ligne		-	-	13.90	-.155	18.09	-.272	-.180	-.247		
					SORGHO							
Katibougou												
1982	A la volée	534	-	-	27.52**	-.040**	18.76**	-.270+	11.76	-.068	7.1	45.5
	En ligne		-	-	8.67	-.048	17.08+	-.223	17.42+	-.224		
	En poquets				11.97	-.120	10.13	-.091	16.04+	-.260+		

(Suite)

Tableau 10 (Suite). Coefficients de Régression, Niveau de Signification, Coefficients de Détermination (R^2) et Coefficients de Variation (CV) pour le Modèle de Régression Multiple (Expérience 4)

	Placement	Intersection à l'Origine	PN		TSP		PNPA 15NG		PNPA 30NG		R^2	CV
			Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique	Linéaire	Quadratique		
					COTON							
Dalabani												
1982	A la volée	1,119	2.02	-	2.66	-	-	-	1.92	-	7.1	26.2
	En ligne		2.84	-.011	3.94	-	-	-	10.42	-.042		
1983	A la volée	596	22.29**	-.142+	6.19	-	-	-	11.91	-.188	20.7	45.2
	En ligne		17.72*	-.131+	22.83	-.264	-	-	46.75**	-.596+		
N'Tarla												
1982	A la volée	1,802	-	-	7.53+	-	8.73*	-	-1.49	-	19.1	21.1
	En ligne		-	-	20.16	-.423+	-4.00	-	-2.46	-		
1983	A la volée	1,087	-	-	33.44*	-.339	38.54*	-.474	34.56*	-.345	24.4	33.5
	En ligne		-	-	15.36**	-	9.35*	-	6.35	-		
	En poquets		-	-	32.07+	-.235	7.75+	-	40.69*	-.509+		

Tableau 11. Traitements des Essais en Malieu Paysan dans les Zone Cotonnière

Objet	Traitement
1	Témoin
2	Pratique vulgarisée, 34 kg P_2O_5/ha
3	Phosphate naturel, 60 kg P_2O_5/ha
4	Phosphate naturel, 120 kg P_2O_5/ha

Annexe Tableau 1. Description des traitements des différentes expériences

Expérience No. 1

	Application de Fond Source	Application de Fond P_2O_5	Application Annuelle Source	Application Annuelle P_2O_5
1.	-	0	Té	0
2.	-	0	TSP	15
3.	-	0	TSP	30
4.	-	0	TSP	45
5.	-	0	PN	30
6.	-	0	PN	60
7.	-	0	PN	120
8.	-	0	PNPA-30	15
9.	-	0	PNPA-30	30
10.	-	0	PNPA-30	60
11.	PN	60	Té	0
12.	PN	60	TSP	15
13.	PN	60	TSP	30
14.	PN	60	TSP	45
15.	PN	60	PN	30
16.	PN	60	PN	60
17.	PN	60	PN	90
18.	PN	60	PNPA-30	15
19.	PN	60	PNPA-30	30
20	PN	60	PNPA-30	45
21.	PN	120	Té	0
22.	PN	120	TSP	15
23.	PN	120	TSP	30
24.	PN	120	TSP	45
25.	PN	120	PN	30
26.	PN	120	PN	60
27.	PN	120	PN	90
28.	PN	120	PNPA-30	15
29.	PN	120	PNPA-30	30
30.	PN	120	PNPA-30	45

Expérience No. 2

	Uniquement des Applications de Fond Source	Uniquement des Applications de Fond P_2O_5
1.	Té	0
2.	TSP	30
3.	TSP	60
4.	TSP	90
5.	TSP	120
6.	PN	60
7.	PN	120
8.	PN	180
9.	PN	240
10.	PNPA-30	30
11.	PNPA-30	60
12.	PNPA-30	90
13.	PNPA-30	120
14.	PNPA-15	30
15.	PNPA-15	60
16.	PNPA-15	90
17.	PNPA-15	120

Expérience No. 3

	Source	P_2O_5	Time
1.	Té	0	
2.	PN	60	Fond
3.	PN	120	Fond
4.	PN	180	Fond
5.	PN	240	Fond
6.	TSP	15	Annuel
7.	TSP	30	Annuel
8.	TSP	45	Annuel
9.	TSP	60	Annuel
10.	PN	30	Annuel
11.	PN	60	Annuel
12.	PN	90	Annuel
13.	PN	120	Annuel
14.	PNPA-30	15	Annuel
15.	PNPA-30	30	Annuel
16.	PNPA-30	45	Annuel
17.	PNPA-30	60	Annuel
18.	PNPA-15	15	Annuel
19.	PNPA-15	30	Annuel
20.	PNPA-15	45	Annuel
21.	PNPA-15	60	Annuel

Expérience No. 4

	Source	P_2O_5	Méthode d' Application
1.	Té	0	
2.	TSP	15	à la volée
3.	TSP	30	à la volée
4.	TSP	60	à la volée
5.	PNPA-30	15	à la volée
6.	PNPA-30	30	à la volée
7.	PNPA-30	60	à la volée
8.	PNPA-15	15	à la volée
9.	PNPA-15	30	à la volée
10.	PNPA-15	60	à la volée
11.	Té	0	en ligne/en poquets
12.	TSP	15	en ligne/en poquets
13.	TSP	30	en ligne/en poquets
14.	TSP	60	en ligne/en poquets
15.	PNPA-30	15	en ligne/en poquets
16.	PNPA-30	30	en ligne/en poquets
17.	PNPA-30	60	en ligne/en poquets
18.	PNPA-15	15	en ligne/en poquets
19.	PNPA-15	30	en ligne/en poquets
20.	PNPA-15	60	en ligne/en poquets

LEARNING FROM FARMERS:
METHODOLOGIES FOR IMPLEMENTING FARMER PARTICIPATION IN FERTILIZER TESTING

Jacqueline A. Ashby

Introduction

Methodology for increasing farmer participation in testing and evaluating new technology for small farm systems is especially pertinent to the development of fertilizer recommendations. The evidence on adoption of Green Revolution technologies shows that effective communication between farmers and researchers is essential in adapting fertility management techniques to specific soil conditions, which can vary enormously over small areas and which have a critical bearing on farmers' choices of other production techniques and on productivity. This diversity imposes severe limitations on the capacity of national research programs to exhaustively screen new recommendations for their suitability to every microenvironment.

Limited national program resources can lead to farmers being given blanket fertilizer recommendations which they still have to test and validate for local farming circumstances. As a result, small farmers must bear some of the risk of screening new fertilizer recommendations for their specific farm circumstances, which they do by conducting "experiments" on their own lands. The detailed information that farmers often develop about site-specific features of soils and fertilizers with this informal experimentation is often very costly to obtain with formal soil surveys.

Participatory research methods for farm-level testing that use farmers' expertise in local farming conditions are required to make this trial and experimentation by farmers more systematic and to improve the capacity of formal research systems to rapidly and reliably evaluate recommendations. Such methods are not intended to demonstrate correct practices to farmers, nor are they designed to achieve "instant" adoption of a recommendation. Their objective is to assist researchers in understanding farmers' goals, preferences, and criteria in making decisions about fertility management, and so to increase the probability of research that addresses problems relevant to farmers and develops recommendations tailored to their needs and resource constraints.

This paper discusses three participatory research methods for incorporating the indigenous knowledge of farmers into on-farm fertilizer testing and evaluation; these methods emphasize the role of the farmer as a partner in the research process for developing fertilizer recommendations.

Use of Indigenous Soil Classification Systems

Soil classification systems evolved by farmers represent a wealth of practical empirical information about crop-soil relationships on their own lands. This information is used by the farmers to make decisions about where and when to plant, what crops and intercropping practices are appropriate, and the need for fallowing and fertilizer applications. Studies of indigenous soil classification systems show that these exist in many cultures and involve often quite sophisticated criteria that farmers use for judging soil fertility management needs. For example, Netting's (1968) study of hill farmers in Nigeria shows that farmers use color to distinguish different degrees of soil fertility. In Northern Kenya, soil color is also used by Somalis to distinguish soil-vegetation associations (Chambers, 1983). Shifting cultivators in the Philippines use, in addition to color, six criteria to differentiate soils: moisture content, sandiness, rockiness, texture, firmness, and structure in the wet and dry seasons (Conklin, 1959). Malaysian farmers use vegetation and taste as a means of categorizing soils as "sweet," "neutral," or "sour," and these categories correlate significantly with pH levels (Thomasson, 1981). In Latin America farmers' classification of fallow periods, of ecological zones in which fields are located, and of soil color and moisture are of major importance for understanding their planting and fertilization practices (Johnson, 1974; Quiros et al., 1980). In relation to the study of African soils, Allen (1967) concluded:

> No approach to the problem could be made without some means of distinguishing and mapping soil or land units recognized by the cultivators and relating these to traditional agricultural practices. For this purpose ecological criteria have the great advantage that the units they define are recognizable to the African, and they enable us to see the habitat through the eyes of the inhabitants and to understand its potentialities and limitations for a people with no material resources but the hoe, the axe, and the labor of a small group of workers.

Interviews with a few local farmers about their local soil classification system in an area where on-farm fertilizer trials are to be established are a valuable starting point for understanding both the microvariation in soils and how farmers make decisions based on soil differences. In a collaborative phosphorus research project in Colombia, South America, undertaken by the International Fertilizer Development Center (IFDC) and Centro Internacional de Agricultura Tropical (CIAT), this approach is used by the project sociologist to assist soil scientists in the selection of sites for on-farm trials. The interviews take the form of unstructured conversation with farmers, often in the process of a short tour around the farm or the research area in the company of a local farmer, to identify the types of soils, fallow conditions, and location of plots considered suitable by local farmers for establishing different test crops included in the experimental program. Soil samples for analysis in the project laboratory are taken from the different types of soils and fields indicated by farmers.

Understanding how farmers classify their local soils has two important potential benefits for the on-farm testing of fertilizers. Familiarity with the indigenous soil classification system provides scientists with a reference point for how the local inhabitants are likely to perceive recommended practices for fertilization resulting from the experimental program. The process of learning from local farmers about their soils is also valuable in establishing rapport and mutual respect among farmers and scientists and, in turn, enhancing future cooperation in the management and evaluation of on-farm trials.

The IFDC/CIAT phosphorus project's study of local soil classification in a shifting cultivation system in Cauca, Colombia, showed, for example, that length of fallow period, soil color, and vegetation were important in whether farmers decided to apply fertilizer to cassava. Table 1 shows how farmers ranked expected productivity of four plots selected as sites for fertilizer trials with cassava and the criteria farmers used in ranking them. Economic analysis of the experimental results obtained from the trials comparing rates of application of two sources of P (triple superphosphate [TSP] and finely ground phosphate rock [PR]) showed that the zero fertilizer check was most profitable on the plot with longest fallow, which farmers ranked as most fertile. Indeed, this zero fertilizer treatment was more profitable than applying fertilizer on any of the other three plots except in the case of one treatment, an application of 50-25-50 NPK (with TSP) on the plot ranked as least fertile by farmers

(Table 1). In this example the local soil classification system provided insights into how to evaluate trial results. A recommendation based on aggregating fertilizer response across all types of fallow would have little validity for farmers who decide whether to apply fertilizer on the basis of their local system for classifying soils according to differences in fallow periods.

Integrating Farmer Experimentation With the Design of On-Farm Trials

In most small farm systems, conducting informal trials and experimentation is a common feature of the farmers' traditional practices (Biggs and Clay, 1981; Belloncle, 1979; Pachico and Ashby, 1983). This "informal research" is essential for farmers' specialized knowledge of microvariations in their environemnt and for them to identify acceptable, location-specific management techniques from blanket recommendations. The initative and specialized empirical knowledge of small farmers used in their informal research is a valuable resource seldom actively incorporated into on-farm research programs.

A focal point of decisionmaking in evaluating new fertilizers for use by farmers is the experimental design for testing under farm conditions. The experimental design of on-farm trials determines the criteria for recommending or rejecting technology. Enabling farmers to participate in determining some of the objectives in testing and evaluating fertilizers ensures that farmers' criteria for accepting or rejecting a recommendation are more likely to be considered in the experimental design. In 1982-84 the IFDC/CIAT phosphorus project in Colombia developed the following methodology for implementing farmer participation in the design of on-farm trials.

The project's social science research team consisted of a sociologist (Ph.D.), agronomist (B.S.), and a locally hired farmer assistant. This research team identified local farmers who were known to be experimental or innovative with new practices by members of the farming community in a potato farming system in Narino Department, Colombia. Farmers, either individuals or in groups, were asked to teach the agronomist and sociologist their local techniques for planting and fertilizing crops. The team had first developed an explanation of phosphate rock technology with the farmer assistant in local vocabulary. Once he understood the concepts, the farmer assistant was able to lead the discussion with farmers while other members of the research team took a secondary role. This approach was intended to reduce social distance, which inhibits free discussion among farmers and outsiders.

After an open-ended discussion had covered the basic concepts of the new technology, the farmers were asked by the research team to suggest how they themselves would try it out. The idea of applying fertilizer on only half a field to see its effect was quite familiar to farmers, and this provided a basis for dividing a hypothetical plot into treatments. Farmers suggested treatments, and the research team then tried to establish what information a farmer wanted to obtain from a given treatment. From these discussions a list of questions, objectives, and possible treatments was obtained for testing the technology.

Farmers' questions and suggested treatments were reviewed by the field research team with the project soil scientist, and he developed an experimental design to address some aspects of farmers' questions. This experimental design, termed the "Farmer Design," incorporated common elements of objectives or treatments suggested by farmers. The field research team returned for a second discussion with the same farmers, this time to review the Farmer Design and as a check to see if their interpretation of farmers' questions was consistent with what farmers wanted to know.

For example, discussions with potato farmers in Narino, Colombia, as they demonstrated to the research team how and why they usually applied fertilizers showed that farmers experimenting with fertilizers had two objectives. One concerned bringing down expenditure on fertilizers and using the recommended complex fertilizer 13-26-6 in mixtures with cheaper fertilizers. A second objective concerned the decline of potato yields over time and the perception that this required new potato varieties as well as new fertilizer formulas. Such farmers were experimenting with mixtures in an effort to arrive at a different formula.

From these discussions and demonstrations by farmers, the field research team outlined the following questions for developing a Farmer Design for on-farm potato trials:

1. How can expenditure on fertilizers be reduced?
2. Is a new potato variety available that will give higher yields with the same or less fertilizer than farmers are presently applying?
3. What effect would the mixing of PR with compound fertilizers have on potato yields and costs of fertilization?

4. What mixtures of PR with compound fertilizer are feasible? Is there a range, i.e., when cash for fertilizers is limited, can the proportion of the cheaper PR be increased and to what levels? When cash is more available can the proportion of PR be decreased?
5. When should PR be applied in relation to time of planting?

Drawing on farmers' questions, the project soil scientist developed an experimental design shown in Table 2. The design used farmers' criteria for mixing fertilizers according to their fertilizer:seed ratios and cost constraints to define treatments and rates and focused on these objectives:

a. To test different mixtures of complete fertilizer and PR with a newly-released potato variety.
b. To compare mixtures with the farmers' usual fertilizer practice and the recommended practice for application of complete fertilizer while the new variety was being used.
c. To compare economic returns to fertilizer applied in mixtures with different ratios of complete fertilizer and PR.

Ten on-farm trials with the Farmer Design were planted in addition to trials with a conventional agronomic design to compare rates of ground PR, TSP, and partially-acidulated phosphate rock (For further details of these trials see Ashby, 1984).

As a result of developing a Farmer Design, farmer experimentation was integrated systematically into formal fertilizer testing procedures. The Farmer Design required researchers to address location-specific issues of compatibility between new and current fertilizer technology in a way that ensured that criteria directly relevant to use of PR by farmers under local circumstances were included in its evaluation. Moreover, the questions farmers were addressing by making mixtures of fertilizers were clarified so that scientific conclusions could be drawn about them. New questions were raised about increasing the solubility of ground PR in mixtures, and they are being addressed in experimental station trials and greenhouse research by IFDC.

In summary, the methodology for involving farmers in the design of on-farm trials entailed four main steps:

1. Learning about farmer experiments and usual fertility management practices.
2. Developing a list of farmers' questions about new fertilizer practices and reviewing these with farmers.

3. Formalizing farmers' questions into objectives and designing an experiment to test them called the Farmer Design.
4. Establishing on-farm trials with the Farmer Design.

Evaluating Fertilizer Trials With Farmer Participation

An important objective of conducting on-farm testing with the participation of farmers is to enable technology designers to assess the potential acceptability of new practices to farmers. Often farmers' opinions are sought informally in the process of consultation about farm trials; occasionally a simple opinion survey may be conducted. Informal discussions with farmers who have managed on-farm fertilizer trials shows that soliciting casual opinions is seldom adequate for obtaining farmer evaluation of fertilizer treatments, even though a few outstanding treatments can be selected visually from an on-farm trial. Discussions with farmers have shown that information on the experimental results can be cast in terms of the criteria farmers themselves use to evaluate the crop and that this then makes possible an informed discussion.

To judge a potato crop, for example, farmers in Narino, Colombia, looked first at yield per unit of seed, a major item of value whether purchased or home produced. Although farmers did not keep written accounts, the absolute value of fertilizer expenses was a second criterion they used to judge a potato crop, expressed in terms of fertilizer expenses per unit of seed.

After a trial crop was harvested, yields per bag of potato seed were computed rapidly in the field, and these data were entered into a prepared data sheet that also showed fertilizer costs per bag of seed for each treatment. This information was discussed with each farmer for determining results from his individual trial site; with use of a pocket calculator, net profits at the current potato price were compared among treatments. The field researchers aimed to identify treatments which the farmer was interested in testing on another occasion. The evaluation did not try to elicit a commitment from the farmer to adopt a practice.

The main objective of this evaluation with farmers was not to select "a best technology" that farmers would adopt but to enable researchers to understand the concepts and values that farmers would bring to comparing different fertilizer practices. In the potato trials, neighbors and family members present at the harvest often took part in this discussion. One result of this process was that farmers often selected several treatments that they would be interested in trying under different circumstances. To conclude the evaluation, researchers asked farmers to indicate in order of preference the three most attractive results and explain why.

Results from evaluating the potato trials discussed earlier are shown in Table 3. No single treatment was preferred by a majority of farmers. Forty percent preferred the treatment with the lowest fertilizer cost per unit of seed (Treatment 1, a mixture of compound fertilizer and PR). This approach met conditions for extreme cash constraint in the Farmer Design although the yield was inferior to that of several other treatments. Other preferred treatments had higher yields and higher fertilizer costs: a farmer would prefer these when cash availability was more favorable. This evaluation reflected the need for flexible options in the technology of potato production of these farmers, in the face of extreme variability in potato prices.

In summary, the methodology for obtaining farmer participation in evaluating results of fertilizer trials involved the following steps:

1. Identifying the vocabulary and criteria farmers use to judge the test crop, such as yield per unit of seed.
2. Converting yield and input data from each fertilizer treatment into terms farmers use.
3. If farmers were illiterate, the development of visual symbols or actual quantities to express seed, fertilizer, and yield relationships.
4. Giving farmers the opportunity to select several rather than one "best" treatment they would like to see tested again.
5. Focusing the discussion on reasons for farmers' preferences among alternatives.
6. Using group discussions where possible.

Conclusions

The experiences with farmer participation discussed in this paper show that formal methodologies can be introduced into on-farm testing of fertilizers to ensure that farmers' knowledge of local soils, the constraints that farmers face, and their values and goals are included in the evaluation of fertilizers.

Three important guidelines should be observed when a program for developing fertilizer recommendations is implemented:

1. Researchers can learn from farmers and can use familiarity with idigenous soil classification systems to characterize local soil fertility conditions and to select sites for on-farm trials.
2. Farmers can contribute to defining objectives for on-farm trials that are consistent with their needs if the technology is reviewed with them before an experimental design is finalized.
3. Farmers can participate in evaluating apparently complex alternative fertilizer treatments if data are expressed in terms farmers themselves use to evaluate the test crop.

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Table 1. Characterization of Cassava Farm Trial Sites, El Socorro And Pescador, Cauca, Colombia

Farmer's[a] Ranking	Farmer Criteria for Classification of Plot			Soil Analysis								Total Mycorrhizal Spores Number/ 100 g Dry Soil
	Color-Texture	Vegetation	Fallow Period	Bray II P(ppm)	OM (%)	pH	Al	Ca	Mg	K	Al Sat.	
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1	"Negra parda y dura" (black hard soil).	"Rastrojo de pasto amargo" or "bitter pasture."	6 years fallow	1.1	17.3	5.1	1.5	0.06	0.16	0.14	80.6	7
2	"Colorada pegajosa" (red sticky soil)	0	"Soca" 2 cassava crops after 4 years fallow	4.1	7.6	4.7	2.3	1.0	0.22	0.12	63.2	0
3	"Mezcla" (mixed red and black)	"Rastrojo" bracken, secondary bush, pasture	1 cassava crop followed by 3 years fallow	1.0	10.4	5.4	1.4	1.0	0.28	0.31	46.8	12
4	"Colorada flojo y mezcla" (red powdery soil).	"Pasto puntero y yaragua Pasture for making cows	About 40 years fallow	2.1	8.9	4.9	2.4	1.2	0.55	0.23	54.8	20

a. 1 = worst, 4 = best fertility.

Source: Quiros et al., 1983.

Table 2. Farmer Design for Fertilizer Trials, Potatoes, Narino, Colombia, 1983

Treatment Number	Type of Practice	Fertilizers	Compound Fertilizer: Seed Ratio	Total Cost[a] Col. $/ha
11	Farmers' rate, no cash constraint	Compound	1:1	48,300
10	Farmers' rate with cash constraint	Compound	0.75:1	34,500
	Mixtures with extreme cash constraint			
1		Compound + PR Huila	0.25:1 (Rate 1)	16,500
2		Compound + PR Huila	0.25:1 (Rate 2)	21,500
3		Compound + PR Huila	0.25:1 (Rate 3)	26,500
	Mixtures with moderate cash constraint			
4		Compound + PR Huila	0.50:1 (Rate 1)	28,500
5		Compound + PR Huila	0.50:1 (Rate 2)	33,000
6		Compound + PR Huila	0.50:1 (Rate 3)	38,000
	Mixtures with moderate cash constraint			
7		Compound + PR Huila	0.75:1 (Rate 1)	39,500
8		Compound + PR Huila	0.75:1 (Rate 2)	44,500
9		Compound + PR Huila	0.75:1 (Rate 3)	49,500

a. Figures are rounded off.

Source: Ashby (1984).

Table 3. Farmer Evaluation of Fertilizer Treatments, Potato Trials, Narino, Colombia, 1983

Treatment Number	Fertilizers	Farmers' Evaluation Criteria Seed:Yield Ratio[a]	 Seed:Fertilizer Cost Ratio	Percent of Farmers Who Preferred
1	Compound + PR Huila	1:12	1:Col. $424	40
10	Compound	1:17.5	1:Col. $912	30
4	Compound + PR Huila	1:11	1:Col. $728	20
5	Compound + PR Huila	1:17.5	1:Col. $968	10

[a] Unit of 62.5 kg-bag of commercial potatoes.

Source: Ashby (1984).

TRANSFERRING TECHNOLOGY TO SMALL FARMERS: WHOSE JOB IS IT?

Bernard Woods

Introduction

Much has been written on ways to make extension workers more effective in the transfer of technology to farmers. Students of this subject are referred to Agricultural Extension: A Reference Manual (FAO, 1984), and the wealth of experience cited there. This paper makes no attempt to review that experience; instead, it focuses on a different but related topic: the role of extension workers in relation to supplementary and alternative means for developing among farmers the skills and understanding needed for agricultural development.

This paper examines the development objectives within which rapid expansion of extension services has taken place in the past 30 years; it concludes that in most developing countries the means are not yet in place to create the capability needed by whole rural populations to achieve and maintain the optimum agricultural development. Reasons are presented for the shortcomings, and the paper refers to individual initiatives that indicate directions in which solutions appear to lie. Generalizations are inevitable in a short paper of this kind, and none of my statements here should be inferred as detracting from the very real achievements in agricultural development around the world in recent years. The purpose of this paper is to contribute to thought and discussion of where to concentrate attention next to attain universal goals of achieving sustained development in the rural sector.[1]

Background

The overall objective of development in the rural sector has been, and continues to be, to improve the lot of the millions of people living in the rural areas. As agriculturalists, our role has been to promote agricultural production. We have been supported in this objective by scholars, economists, and planners who all saw the need to increase income at the local level and increase foreign exchange at the national level; by politicians whose constituents

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1. The opinions and conclusions expressed in this paper are those of the author and should not be assumed to be those of the World Bank.

were mostly farmers; and by humanitarians interested in food supply and self-sufficiency. Thus, increasing agricultural production has become a primary ingredient and objective in rural development theory.

The generally adopted approach for achieving this objective has concentrated on providing the following:

1. Farm access--by the construction of roads and tracks.
2. Research--to develop appropriate agricultural technology.
3. Extension services--to transfer that technology to farmers.
4. Input supply--to make available to farmers the recommended seed, fertilizer, insecticide, and so on.
5. Credit--to enable farmers to purchase the inputs.
6. Irrigation--where possible, to provide water.
7. Markets--for purchasing surplus production.
8. Pricing policies--to provide incentives to farmers.
9. Appropriate government authorities--to orchestrate the whole activity.

Worldwide, remarkable successes have been achieved, and world food production is now greater than at any time in history. But this global view contrasts starkly with (a) the reality in many developing countries where production has failed to keep pace with population increase--or has actually declined; (b) findings on all continents that the already better off have benefited disproportionately from investments to increase agricultural production, whereas the number of poor farmers is actually increasing; and (c) growing evidence that governments and intended beneficiaries are unable to sustain development initiatives. The persistency of these findings suggests a fundamental flaw in the thinking on which investment for agricultural development has been based. Some key ingredients seem to be missing. What are they? What now needs to be done differently from what we[2] have done so far?

Let us consider the approach outlined above. First, it is "top down." To some extent this is inevitable because governments have had to take a large part of the initiative for development in its early stages and take responsibility for establishing policies, infrastructure, and rural services. Second, if the objective is agricultural production, the most cost-effective means are needed: these favor large holdings, machinery for timely farm operations, low unit costs, and high levels of management. But in most developing countries,

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[2] We, meaning the entire fraternity of policymakers, planners, financiers, and practitioners of agricultural and rural development.

land is in small holdings, livestock have social as well as economic value, and the land is covered with people--mostly poor people with limited motivation to learn. The people are an impediment to the agricultural production objective. But the people are a reality, and the overall objective is to improve their lot. There is a conflict in practice between the overall objective and the agricultural production objective. Could it be that something is wrong with the agricultural production objective?

Let us adjust the production objective and see the effect this has on the approach outlined above.

An Amended Objective

Instead of the objective being to increase agricultural production, let us define it as follows: increasing agricultural production and developing the capability of people to do so. This objective has the same physical requirements: the development of farm access, input supply, credit, irrigation, and markets, etc., but it prescribes equal attention among the human, economic, and physical aspects of development. The development of the necessary human capability has always been implied in the agricultural production objective, but we can show that, in practice, this aspect of development has frequently been subordinate to the attention given to the physical and economic elements of agricultural and rural development--particularly in achieving the short-term goals of individual projects.

When focusing on developing the capability of people to increase agricultural production, the first question is: Which people? Clearly, whole farming populations are included in our new objective, not only those who qualify for credit or who can purchase recommended inputs. It includes farmers at subsistence level who, individually, are too disadvantaged to improve their own conditions and may have little expectation of doing so. These people need to form groups and clubs to overcome the social and physical disadvantages they suffer as individuals. They need to understand the benefits of groups and have the skills to manage them. They need help and guidance to do so. Certain factors affecting small farm production--such as erosion and grazing control, water management, land titling, and others--need the understanding, organization, and participation of whole communities. But most extension staff members are inadequately trained in group dynamics, leadership development, and community mobilization and may not have sufficient contact with individual communities to be able to form effective groups among poorer segments of communities. (Farmers' clubs and associations have generally been made up of wealthier rather than poorer farmers.) Most extension agents have been hard pressed to reach the more responsive farmers, and their impact on the poorer segments of farming populations in most countries has been low.

Our objective also includes ensuring the necessary capability of people involved in the provision and maintenance of access and irrigation and of people planning and operating research, input supply, markets, credit programs, pricing policies and so on--all needed for increasing production--and it also implies developing the capability to sustain increased production. This calls for skills in management, administration, training, financing practices, monitoring, and many others.

Increasing the ability of people to increase production involves enabling them to do things differently. This involves changing their attitudes, concepts, perceptions, understanding, motivation, knowledge, and practical skills before they will commit themselves to the new practices that are crucial for agricultural development. The means for achieving these changes are therefore critical in terms of both the means themselves and the responsibility for the activities involved. What are those means? And whose responsibility is it to provide them? Traditionally, ministries of education have held the primary responsibility for pre-employment education and training; responsibility and the means for all other aspects of human capital formation have been spread widely among other government agencies. As development proceeds, the private sector plays an increasing role in post-employment training. At the community level, private voluntary organizations have demonstrated that they can provide the means for developing essential skills for development which central governments cannot.

Ministries of Education

Ministries of education have been responsible for providing education by means of schools, universities, vocational centers, and other pre-employment institutions. These have concentrated on children and adolescents with the objective of achieving job entry qualifications. Ministries of education have given relatively little attention to the education of adults in the rural sector, and where they have, literacy and arithmetic have generally been the primary objectives. An economic value has been calculated for specific quantities of education, and establishing the means for providing education has become accepted as an objective of development.

Other Ministries

Ministries of agriculture, forestry, fisheries, health, population, water supply, transportation, and others have each become the authority for development in what have come to be thought of as their respective "sectors" and "sub-sectors." Recognizing the need for appropriate knowledge and skills for those involved in their programs, and in the absence of any other form of education and training for adults, each ministry has taken upon itself the responsibility for providing the education, training, and information dissemination needed for its own physical and economic objectives. Thus, responsibility for education and training for adults has been fragmented among a variety of technical ministries, managed mostly by technicians who are trained and employed to achieve technical and physical objectives. It has not been their role to develop the means for providing training in the "out-of-school" skills of practical management, administration, financial practices, equipment maintenance, leadership at local levels, and other skills essential for sustained development.

In the agricultural sector, governments have invested in extension services to develop the farming knowledge and skills of farmers to supplement whatever formal education they might have.[3] The number of government agricultural extension agents has increased dramatically in most developing countries during the last 15 years in full confidence that (a) they would be able to transfer the necessary technology to farmers and (b) farmers would adopt the new practices that researchers recommended.

Some of the worldwide increase in agricultural production that has taken place through adoption of new technology can be attributed directly or indirectly to extension workers. But evidence now available shows serious shortcomings in the performance of extension workers and difficulties with their

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[3] Jamison and Moock (1984), reporting on their research in Nepal and relating their findings to 37 earlier farm-level studies of education and crop production in low-income countries, conclude: "The clear suggestion in these studies, corroborated by the present study, is that an individual who completes 'just a few' years of school (fewer than four, or fewer than seven years, depending on the study) does not retain enough learning to benefit from it later as a farmer." These and other findings are a reflection on the form in which primary education is available in most low-income countries. Other data are available, e.g., Arbab (1980).

funding by central governments in the future. It also raises questions about the technology they have advocated and the role that is generally perceived for them. The evidence includes the following points:

1. Contact between extension agents and their intended beneficiaries has been low--ranging from highs of 25%-30% to lows of less than 5%--and contact has been heavily male-oriented, despite women being responsible for as much as 60% of farming operations in some countries.
2. Few governments now have the funds with which to pay sufficient extension staff to achieve a desirable intensity of agent-farmer contact. Costs of existing services are rising as (a) ratios of better qualified technical specialists to field workers increase;[4] (b) large numbers of young staff members move up their salary scales; and (c) support costs--transport, accommodation, materials, etc.--all grow. In many countries extension services are now severely handicapped by lack of operating funds; in some, field services are virtually at a standstill outside development areas.
3. The extension worker is widely perceived to be a deliverer of technical messages rather than an investigator who analyzes individual farmers' conditions and adjusts recommendations accordingly. Low-level extension staff personnel are not trained to be investigators, and their task is not commonly seen to be also that of organizing and teaching farmers to recognize and articulate their needs.

In summary, extension workers as they exist in most countries today cannot provide the means for increasing the capability of whole farming populations for improving their production. This is not to say that extension agents have no role. They have a role. But numbers of extension staff have been expanded without an adequate analysis or understanding of their logical

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[4] The increasing proportion of technical support staff in extension services as they mature and levels of technology rise is shown in data on national extension services analyzed by Swanson and Rassi (1981). They found the following percentages of administrative, technical support, and extension agents and assistants (data on extension assistance include paraprofessionals in some countries):

	Categories of Personnel, %			
	Administration	Technical Support	Extension Agents	Extension Assistants
Africa	5	6	51	38
Asia and Oceania	9	6	32	53
Latin America and Caribbean	7	13	66	14
Europe	13	18	61	8
North America	6	19	50.5	24.5

role within the total communication spectrum and, often, in ignorance of the conditions in which they have proved effective elsewhere. This expansion took place during a period of unprecedented economic growth, and the question of who should pay extension agents in the future has not been adequately addressed. In many of the most successful examples of effective extension, the field agents have been either partially or totally paid and controlled by the beneficiaries. But few extension services have, as an objective, the divestment of responsibility for their lowest level extension agents to groups, communities, and local authorities.

The Communication Spectrum

The means of delivering knowledge, skills, and information comprise an integrated communication spectrum extending from expensive forms of formal education and technical training, at one extreme, to the cheapest and most extensive forms of mass communication and traditional communication channels that have no cost to governments, at the other extreme. The spectrum is shown in Table 1.

Each item in the spectrum has a field in which it is the most cost-effective means of providing particular aspects of either education, training, or information.[5] It is therefore with the analysis and administration of this whole communication spectrum that governments now need to be concerned. Forms of education, training, and information dissemination on which developing countries have largely relied to date have mostly been adopted from models in developed economies that evolved decades or even centuries ago. Often no alternative was feasible at the time of their adoption--particularly in individual, area-specific projects that could not focus on national issues. But the longer governments rely on conventional, expensive forms of communication, and the more of their recurrent budgets they commit to those means, the harder it will be to change to more cost-effective, multimedia methods.

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[5] For example, research financed by the World Bank in Malawi and Cameroon (and supported by other data) compared the cost of 1 hour of extension agent: farmer contact with 1 hour of radio contact, taking investment and overhead costs of both into account, and found a ratio of 3000:1 (see also Perraton and Jamison, 1981). Clearly, radio and extension agents cannot perform all the same activities, but this finding and others raise the question: For what purposes are extension agents needed that cannot be achieved more cheaply by other means?

The Technology and Skills to Sustain Development

Policy statements by governments and development assistance agencies alike now call for greater attention to "human resource development," "institution building," "training," and the like. The underlying need is to develop the means for creating the out-of-school practical skills previously mentioned to achieve the necessary levels of performance in management, administration, financial practices, leadership, communication, etc. All these are technologies needed for agricultural development--and particularly sustained development--in addition to the agricultural technology with which agriculturalists have been naturally concerned. The means to transfer all these technologies are required for agricultural development. The absence of effective means is particularly acute at local levels where they are needed to enable individuals, groups, communities, and local governments to take over from central governments the initiative for their own development.

Here we find an anomoly.

As mentioned earlier, education is accepted as an objective of development in development thinking. It is given an economic value, and therefore the means for providing education (schools, universities, vocational training centers, etc.) can be justified in economic terms.

No equivalent value is given to the out-of-school skills referred to above; their provision is not regarded as an object of development in the same way that the provision of education has been, and the means for providing them have not been justified in their own right.[6] They have only been justified in terms of accepted physical objectives of development (tons of crops, miles of roads, volumes of drugs dispensed, and the like). Projects to achieve these physical objectives have generally been short term, scattered, and piecemeal, so it has seldom been the object of any one to provide the mechanisms for effective training in these nontechnical fields.

Programs around the world that have established effective training capability and communication channels in these nontechnical fields have demonstrated by their success that (a) the capability to provide these skills is essential for rapid development and (b) the means for doing so were previously missing. For example, the United Nations Development Program/Development Training and Communication Project in Bangkok has provided training for managers,

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[6] The historical reason for this is outlined in my paper, "The Role of People: A Paradigm for Achieving Sustainable Development in the Rural Sector," October 1984, World Bank, Internal Document.

trainers, and field workers in effective training and communication techniques. Its services have been sought by ministries of agriculture, forestry, irrigation, health, and population and by local government in a dozen different countries, which suggests that the means for providing the important skills involved were not available in their own countries. Many programs have demonstrated dramatically the potential of forms of mass communication, both individually and in combination with face-to-face contact, that we are just beginning to realize. Massangano 99 in the Philippines, the Village Education Project in Guatemala, Proderith in Mexico, health programs in Gambia and Honduras, and adult literacy in Tanzania are just a few of many examples. Open universities and "distance education" programs have pioneered new methods of distance learning that can be applied to the training of field staff, paraprofessionals, and leaders of interest groups at village level. The concept of village information centers is being tested in some countries, and the telephone is becoming a reality at village level (e.g., parts of India and Peru) with its potential for transforming rural communication. We now need to include these when considering the means for transferring technology.

At village level, many programs around the world have successfully mobilized whole communities by establishing the means for developing their capability to analyze, plan, organize, and manage their own development[7] by drawing on the agricultural and other expertise they need. These programs have all focused on developing the capability of people at local level, and they demonstrate that the means they have created to do so were previously missing from the approaches to development that were followed. Put differently, approaches to development that omit these critical ingredients can have little hope of achieving sustained development.

Thus, we need to be concerned with the means to develop all the skills required for lasting agricultural development and with the organizational responsibility for developing those means. At the same time, we need to remember that programs that have been successful in developing the capability of whole communities to take greater initiative for their own development have shown uniformly that village-level development is an integrated process and requires a balance between the many different aspects of development. Those responsible for promoting agricultural production, and for transferring the

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[7] See "Voices of Rural Practitioners" (1984); it summarizes findings of the International Exposition of Rural Development (IERD) which analyzed the key elements in over 2000 successful village-level projects.

technology to do so, need to understand that balance. Incentives and opportunities that continually favor only certain segments of the community will upset that balance; in the long run they will be, at worst, self-defeating and, at best, poor investments.

Conclusion

We can conclude from the above that a change in perception of the objective of agricultural development will allow different approaches for achieving agricultural development goals. Emphasis on creating the human capability on which sustainable development depends will focus attention on establishing the means for doing so, and it will place emphasis on reaching all members of farming communities. It will require more attention to human and social constraints on production than has been the case while economic and production objectives dominated; it will favor a farming system approach; and it will require mechanisms to enable information to flow from the field as well as to it.

So, whose job is it to transfer technology? We can conclude the following:

1. There is a job for educators to improve basic education systems so that those who leave school have the essential concepts for development on which understanding and acceptance of new technology can be based.
2. There is a need to develop efficient training and communication systems integrating the many different modes of communication so that each can be used in its most cost-effective role to create awareness, change attitudes, motivate, educate, and provide topical information that will influence behavior. At the same time, the systems must focus on improving two-way flows of information.
3. Face-to-face contact will continue to be necessary to help farmers find the best solutions to individual problems, but, by transferring their message delivery function to more efficient means, extension agents will be able to adopt a more investigatory role, seek and identify solutions to farmers' problems at village level, and feed the information into the larger communication system.
4. Training of most agriculturalists has focused heavily on "economic" crops and livestock and high-input approaches to maximizing production. Other crops and livestock with local market value are important to small farmers

and their wives, but extension staff are often poorly trained in these fields. Also, new technology is now available with widespread applications in agriculture-related fields, e.g., simple applications of solar energy; low-cost pumps, roofing materials, and implements; and many others. This technology has not been transferred to farmers because the means for doing so have been absent. The transfer of technology now needs to be approached on a broader front.

5. The need must be clearly seen to develop the out-of-school skills on which effective performance of organizations depends, so that providing the means for doing so can become an object of development. This is essential for the continuing generation and transfer of technology in the future.

We cannot hope to accomplish all these things immediately. They will require changes in perceptions of the priorities of development by planners and policymakers who have until now been content with economic and production objectives.

We know that governments were obliged to take responsibility for education, training, and information transfer at early stages of development, but only the richest will be able to do so on a continuing, country-wide basis. In the future, the role of governments will be to establish the essential framework; to oversee and manage the education, training, and communication processes; and to create the conditions in which commercial interests, local governments, and private voluntary organizations can each develop their responsibilities in these fields.

There is no quick and simple solution to the problems nor a single blueprint for development. (If there were, someone would have found it by now.) Pieces of the whole solution are demonstrated in the examples I have quoted--and in a host of other individual programs around the world. The way those pieces fit together will differ among countries. The first step in reaching any solution, however, is to recognize and accept the nature of the problem--that developing the means to transfer <u>all</u> the technologies and skills needed for sustained development has not received the same emphasis as the approaches to developments that have focused on the economic and physical aspects of production. Every one of us at this workshop has a role to play in the changes in perceptions that are required and the new plans that will follow from them. We at the World Bank are paying more and more attention to these issues and will be able to help in this process.

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Table 1. The Communication Spectrum in Human Development

Costs to Governments	Different Modes of Education, Training, and Information Transfer
High unit cost	Postprimary formal education and pre-employment vocational and technical training
	Farmer training centers
	Mobile education/training units
	Field extension agents
	Primary education
	Mobile information units
	"Formal" distance learning
	Telecommunication
	Broadcast technical programs
	Printed media: newspapers, magazines, etc.
	Paraprofessional communication agents
	Pamphlets/posters/cassettes
	Radio spots
	Communication through commercial channels
Low unit cost	Traditional informal communication channels

THE INDO-BRITISH APPROACH TO USING FERTILIZER IN VILLAGE-LEVEL DEVELOPMENT

S. P. Dhua

India has recently made remarkable progress in the field of agriculture. The first few years of the post-independence era saw a nearly stagnant agriculture. The strategies taken in the second 5-year plan started yielding good results, and the country witnessed a steep rise in agricultural production. In the year 1983/84, the food grain production reached a new high of 151.6 million tons. By the turn of the century, the country is expected to produce around 220 million tons of food grains.

The key factors contributing to the success of the new agricultural strategy in the mid-1960s were the development of new high-yielding varieties of crops and the transfer of an improved package of cultivation technology to the farmers. Even earlier, the country realized that the focus had to be on agricultural development when the Community Development Blocks Program was started. This helped to achieve some positive results. Because of the vastness of the problem and the lack of resources, emphasis was then laid on the Intensive Area Development Program. The 1970s saw implementation of crop-specific programs and special programs for small and marginal farmers (e.g., Small Farmers Development Agency and Marginal Farmers Development Agency). In the latter half of the 1970s, a massive extension program was launched in different states in India under the financing and guidance of the World Bank. This training and visitation (T&V) program was expected to accelerate agricultural productivity and production. With the multiplier effect that it was to generate, one would have expected a high rate of growth of agricultural production.

While this was the overall effort, in eastern India the Hindustan Fertilizer Corporation Ltd. (HFC), a Government of India undertaking, had been playing a vital role in agricultural extension work by transferring improved packages of cultivation technology to the farmers. Despite these efforts, the eastern states of India still had an overall low productivity and low and unbalanced use of fertilizer, the majority of farmers were small and marginal, and there was a predominance of poor peasantry. The scene needed to be changed radically. HFC started by having extensive promotional programs spread over three or four blocks for each extension worker. By the early 1970s, HFC realized that an intensive program dovetailed with an extensive program could achieve better results. With that aim in view, HFC launched the Indo-German Fertilizer Educational Project financed by the Government of the Federal Republic of Germany in the State of West Bengal. The central theme of the project was "to move sound fertilizer practices to the farmers." An agricultural graduate was posted to live in a key village and undertake crop improvement programs for the farmers of the village. In the surrounding villages, extensive promotional campaigns were undertaken. The favorable impact of the project, as evaluated by the National Council of Applied Economic Research, New Delhi (NCAER), in 1976, was evident in the movement toward the following:

1. Greater cropping intensity.
2. Increased area under fertilization.
3. Extensive use of high-yielding varieties of improved seeds.
4. Increased level of fertilizer consumption.
5. Better nutrient balance.
6. Improved yields.

In order to measure the welfare or distributional impact of the project on the population concerned, a second study was entrusted to NCAER in 1980. This study showed the tremendous benefits from the Indo-German Fertilizer Educational Project on the small and marginal farmers in West Bengal.

Experience gained in implementing this project showed that besides a knowledge of inputs, the whole service system for adequate and timely delivery to the farmers of requisite inputs, in the proper order, markedly influences both the crops produced and the productivity. Unless knowledge is accompanied by all the other requirements, efforts to teach and motivate farmers to use the improved technology will be futile. Any shortcoming in the intermediate stages of the input delivery system will cause an upset in the food production chain.

The experience of the T&V system, with its major thrust on knowledge input and without the support of an input delivery system, was not very encouraging, Milton J. Esnan and Norman T. Uphoff[1] note that "skepticism about the efficiency of the system has mounted, however, precisely because no basis for group communication and innovation has been established, and the farmer's contact with other farmers has been weak."

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[1] Local Organizations--Intermediaries in Rural Development by Milton J. Esman and Norman T. Uphoff, Cornell University Press.

The intense desire to help farmers by supplying them with knowledge as the first step in transferring technology to the marketplace and then arranging all the other required inputs of the farmers in a systematic manner led to the implementation of the Indo-British Fertilizer Educational Project (IBFEP), financed by the Government of the United Kingdom, in the six states of eastern India, viz, Assam, Bihar, Madhya Pradesh, Orissa, Uttar Pradesh, and West Bengal (Figure 1). The project was not considered to be a mere extension tool but also a philosophy. In terms of theory, the project was fairly close to the T&V system in the form of knowledge input but differed significantly in its emphasis on providing all the inputs to the farmers. The input requirements of the farmers were to be closely monitored, and the farmers were to be assisted in getting the supplies in time. As in the T&V system, a very high priority was given to training all the field staff on the latest technology available. Agronomists, soil scientists, and plant protection staff were given training to keep them abreast of the latest research work in the related fields. The project aimed at not only working with the farmers at the marketplace but also bringing the results of research right to their doorstep.

The objective of the present paper is to share our experience in implementing the Indo-British Fertilizer Education Project. The author hopes that this dynamic model will be tried and replicated in different countries with similar problems so that its benefits can be used for higher agricultural production.

The Project

In view of the slow process of agricultural development in the eastern states, HFC has been executing the IBFEP in 25 selected districts of Assam, Bihar, Orissa, Madhya Pradesh, Uttar Pradesh, and West Bengal since the 1981/82 Rabi season. The project aims at increased food production in these six states by educating farmers and demonstrating in their fields the profitability of scientific fertilizer use and adopting an improved package of practices and also concurrently ensuring timely availability of inputs. The project is financed by the Government of the United Kingdom for a period of 5 years under a bilateral agreement between the Government of India and the Government of the United Kingdom. Under the project program special emphasis has been placed on benefiting the small and marginal farmers.

With a view toward exploiting the production potential, districts with a fairly good irrigation potentiality have been selected by the Government of India in consultation with the concerned state governments. Nevertheless, some backward districts warranting immediate attention have also been included under the project program. In each of the selected districts four community development blocks and under each block two clusters of villages, each cluster consisting of 10 villages, have been included in the fertilizer education program. The project thus covers 2,000 villages spread over 100 blocks in 25 districts. A cluster of 10 villages constitutes the operational unit for one experienced agricultural graduate, designated as Cluster Agronomist, who is the resident of one of the villages of the cluster. The Cluster Agronomist is the key figure of the project, and he is responsible for undertaking a large-scale demonstration spread over two villages for 1 year supplemented with other extension aids and, more importantly, ensuring that the farmers get the required inputs. In addition to this grass-roots-level staff, an agronomist is posted at the block level. Besides guiding the implementation program of the Cluster Agronomist, he also undertakes the follow-up activities in post-demonstration villages when the demonstration site is shifted to other villages. The activities of eight clusters of villages in a district are supervised by the District Agronomist, posted at the district headquarters, and total activities of the state are supervised and monitored by the Regional Project Leader, posted at the state headquarters.

For proper planning and implementation of the action plan, the project is coordinated with the State Department of Agriculture very closely through duly constituted state, district, and village-level coordination committees under the Chairmanship of the Agricultural Production Commissioner, the District Magistrate, and the Block Development Officer, respectively. At the top level the project is administered through an All-India Level Committee with the representatives of the concerned Ministries of the Government of India and the Agricultural Production Commissioners of the concerned states. In order to get a comprehensive idea on the impact of the project, the NCAER and the Projects and Development India Limited have been entrusted with making a periodical assessment of the project and suggesting remedial measures from time to time.

Action Programs

In order to achieve the prime objectives of the project, educating farmers on scientific fertilizer use together with an improved package of practices and simultaneously ensuring a supply of requisite inputs for an effective use of the new knowledge, the following action programs are being implemented:

1. Establishment of a large-scale block demonstration of about 60 ha (in two villages) for 1 year.

2. Mobilization of organizational resources for ensuring arrangement of production inputs and associated services to the farmers in an integrated manner.
3. Arrangement of free soil testing and fertilizer recommendation service.
4. Supply of fertilizers and plant protection chemicals at subsidized rates to encourage participation of small and marginal farmers and also reduce their risks.
5. Reinforcement of the demonstration with adequate supplementary extension activities like group meetings, farmers' training, field days, crop seminars and workshops, farmers' tours, and distribution of technical literature.
6. Augmentation of infrastructure base for inputs supply and integrated agricultural development, namely, additional irrigation facilities, seed multiplication and exchange, land development, biogas plant, etc.

Implementation of Block Demonstration

The main thrust of the extension work done in the project for the transfer of technology in farmers' fields has been the implementation of large-scale demonstrations covering a large group of farmers. In order to encourage the participation of small and marginal farmers in the program, a 50% subsidy on fertilizers and a 30% subsidy on plant protection chemicals are allowed for 1 year with the expectation that additional income generated from higher yield in the demonstration would be recycled into furthering agricultural development. In order to render more benefit to small and marginal farmers through this project, fertilizer subsidy is restricted to a 1-ha area only for medium and big farmers but not for the small and marginal farmers. In ensuring better economy in production, farmers are encouraged to apply fertilizer in conjunction with organic manures on the basis of soil analysis of individual plots. On the basis of the soil test value, the agronomist issues a delivery order for the participating farmers to procure fertilizer at half price from the nearest retailers. The soil testing service of the project is rendered to the farmers through static and mobile soil testing laboratories established at district level. After selecting the demonstration area, listing participating farmers, issuing the fertilizer and mobilizing the other inputs, viz, seeds, credit, plant-protection chemicals, etc., the Cluster Agronomist makes an all-out effort to ensure the success of the block demonstration. During the harvesting time, the agronomist undertakes to sample the harvest for each 10-ha demonstration plot and explains with confidence and conviction at the farmers' gathering, the economic benefit achieved through adoption of modern technology. And this is the time when the farmers are apprised regarding the strength of technology pursued and demonstrated by the project. When the above plan of action is adopted systematically, step by step, and the farmers see for themselves the convincing input/output relationship, they become receptive to the innovation.

The data on the progress of block demonstrations for five seasons covering 25 districts in six states are summarized in Table 1. The data presented in Table 1 reveal that so far an area of 33,811 ha has been covered and 78,168 farmers have been involved, of which more than 80% belonged to the small and marginal farmer categories. Although the size of the block demonstrations varied in the states, the average size for the six states was about 40 ha/season/cluster. The area cultivated per individual ranged from 0.36 to 0.49 ha/season, and this is considered to be substantial.

Yield Increases

The average yield of the demonstrations in each district was a weighted average, taking into account the area covered by the demonstrations in the cluster and the average yield of the cluster, from the following equation:

$$\bar{Y} = \frac{wi \text{ x } \bar{y}_i}{yi}$$

where wi is the demonstration area of the ith cluster for the district and $\bar{y}_i$ is the average demonstration yield in the ith cluster.

The same methodology was adopted to arrive at the average yield of each state. Since there was no check plot in the block demonstration, the yield of the neighboring plot outside the demonstration was taken as the check plot; the yield of the check plot was worked out by taking crop cuttings from at least two rectangular plots of 10 m x 5 m in each cluster.

Increases in yields achieved in some of the important crops grown during the demonstrations are summarized in Tables 2a and 2b.

Kharif Paddy

In paddy altogether 11,717 ha was covered in the block demonstrations in six states during the 1982 and 1983 Kharif seasons. The data presented in Table 2a reveal that the mean yield of paddy in the demonstration, averaged over six states because the fertilizer was applied on the basis of soil test results, varied between 3.5 and 4.7 tons/ha as compared with 2.0-3.6 tons/ha outside demonstration areas even though there were considerable variations in yield among the states. It is of interest to note that mean value of yield increase was about 1.5 tons/ha. The comparison between yield obtained outside the demonstration area with normal fertilizer use and the yield obtained in the demonstration where the fertilizer use was based on soil test values showed a significant increase in yield of Kharif paddy in demonstration--as much as 60%.

Wheat

The data presented in Table 2a on wheat indicate that large-scale demonstrations covering a total area of 12,682 ha were carried out in six states during the Rabi seasons of 1981/82, 1982/83, and 1983/84. From a large coverage of area it was found that the mean yield of wheat ranged from 2.5 to 4.2 tons/ha against 1.5-2.8 tons/ha outside the demonstration area; the mean increase in yield was about 1.5 tons/ha. The increase of yield in demonstration was of the order of 80%, averaged over three seasons in six states.

Maize, Jowar, and Bajra

The data on the increase in yield for maize, jowar, and bajra presented in Table 2b show that with maize the mean increase in yield in two states, averaged over two seasons, was 13 quintals/ha, although there was considerable interstate variation. In jowar the yield in the demonstration areas increased by about two times, i.e., from 8.9 quintals/ha to 16.8 quintals/ha, and the yield increase was 7.9 quintals/ha. In demonstration areas covering 554 ha in Madhya Pradesh and Uttar Pradesh over two seasons, the yield of bajra increased about three times, i.e., from a level of 9.5 quintals/ha to 25.0 quintals/ha (15.5 quintals/ha).

Oilseeds

It is seen from the data in Table 2b that in an area of 1,978 ha with mustard demonstration over three seasons in Assam and West Bengal, the mean increase in yield was about 390 kg/ha and there was not much variation in the yield between the states. With groundnuts, however, the increase in yield, averaged over three seasons, was about 460 kg/ha, and in soybeans it was about 300 kg/ha.

Discussion

It is worth mentioning that the large-scale block demonstrations, the main thrust of the extension work adopted in the project, have been carried out under varied agroclimatic conditions in 25 districts spread over six states; thus, a large area has been covered under the program (Table 1). It has been said time and again that crop yields could be increased considerably even at the current level of technology provided field programs are suitably dovetailed and farmers'requirements are properly fulfilled. A close look at the increase in yields of crops presented in Table 2a shows that the yield of Kharif paddy and wheat, on an average, has gone up by 1.5 tons/ha. These significant yield increases, of the order of 60% in paddy and 80% in wheat, over a large area are very encouraging. In fact, of a total of 33,811 ha under large-scale demonstration by the project so far (Table 1), more than 80% of the area has been planted to cereal crops, and this works out to 27,049 ha for cereals alone. Considering production increases of about 1.5 tons/ha as mentioned above, the additional tonnage of cereals produced comes to about 40,570 tons in just 400 villages over five seasons of project implementation.

The results obtained in terms of the increase in yields of some of the crops grown under the demonstration conditions by the project compare favorably with the yields obtained in the country under the National Demonstrations Program (Table 3). For example, Table 3 shows that the yield of wheat was 34.0 quintals/ha during the National Demonstrations, similar to the mean yield of 34.0 quintals/ha during the present project. However, in the case of paddy, the project achievement fell short by about 12 quintals, probably because of a larger coverage under a varied agroclimatic situation. While looking at the yields of other cereals in the project, it may be observed that although bajra made an identical performance with wheat, the mean increase in yield of maize achieved by the project was greater. But with jowar the yield was lower. Although a yield comparison was not attempted for oilseeds, the level of yield increases in mustard, groundnuts, and soybeans has been on a lower side, probably because of low-scale technological developments on these crops. The above viewpoints on comparable yield achievement hold good when one considers separately the yield data on paddy and wheat for West Bengal and Uttar Pradesh presented in Table 4.

It may further be pointed out in this connection that the yields achieved in large-scale block demonstrations by this project are also similar to those obtained under the All-India Coordinated Agronomic Experiments of the Indian Council of Agricultural Research (ICAR) (Table 5). The compiled data from about 32,000 fertilizer trials carried out in cultivators' fields from 1969 to 1980 by ICAR show that increase in yield was about 56% in Kharif paddy and

114% in wheat, and these more or less conform to the achievements of 61% in Kharif paddy and 80% in wheat by the project. So far as the yields of other crops are concerned, the performances of jowar, bajra, and groundnuts have been quite favorable and are in agreement with those on the All-India basis.

The crop response to fertilizer application depends on a number of factors like crop variety, soil condition, water management, and growing season, as well as a host of agronomic techniques and, finally, proper management practices. The yield data even from cultivators' fields have shown that the return obtained from investment in fertilizer and other inputs will depend mainly on the efficiency of management practices at field level besides the actual yield-contributing factors. Whatever may be the case, for some reason the level of crop yields has not improved significantly on a wide scale; thus, there has been a low national average crop production. There are obviously some discrepancies and lack of effort in the technology transfer process and inputs management system under the situations of normal farming operations. Hence, there is a considerable gap between the yield achieved so far and achievable under ideal farm situations. In our attempts to narrow this potentiality gap, concerted and determined efforts are needed to improve the efficiency of the whole range of management factors so that productivity and production are brought to a higher level.

The higher yields obtained in the block demonstrations show that it is advantageous for the farmers to use fertilizer on the basis of soil tests. This relates to both quantitative and qualitative aspects of fertilizer application for optimum and balanced fertilization. In fact, farmers rate soil testing as one of the important components of the project for their motivation to use fertilizers. The significant point is that economy in fertilizer use is effected by educating and encouraging the farmers to apply fertilizers on the basis of soil analysis. While the data on fertilizer requirements were being computed on the basis of soil analysis for the area and crops covered under demonstration, comparison with the fertilizer required on the basis of standard crop recommendations showed that, in general, the fertilizer requirements based on a soil test were lower than the general crop recommendations (Table 6). The data compiled for five seasons over the area and crops covered revealed that in almost all cases fertilizer recommendations according to soil analysis were less by 12.6 to 23.0 kg/ha in Kharif and 13.5 to 35.3 kg/ha in Rabi season except for a marginal variation for Rabi season in Orissa and Madhya Pradesh. Although the details of cost/benefit analysis have not been presented here, fertilizer use based on soil tests was quite remunerative to farmers. Considering the cost of fertilizer at Rs 800-1,000/ha based on soil analysis and an additional yield of 15 quintals/ha, the net income accrued per hectare ranged from Rs 1,200 to Rs 1,400.

Once convinced of the benefit of improved technology demonstrated through the help and services of the project, farmers continued to adopt the package of technology in the post-demonstration period also. Realizing that the test of such an extension program is its performance in the following years, block agronomists strengthened followup activities in assisting farmers in crop planning and input arrangements. To support this program, a Farmers' Information Centre was established in each cluster to meet the needs of the followup program. The benefits accrued from increased yields were partly plowed back into the operation by the farmers after they met pressing family commitments, and this helped to improve the level of farming practices above the base level. In addition to increasing their yields, farmers are becoming enthusiastic about improving their agriculture as a whole by way of crop diversification, increased cropping intensity, varietal substitution, etc. The impact of the project has not remained confined within the project villages but has spread over to the surrounding villages also as a ripple effect.

As a result of project implementation, other significant developments have taken place in project areas, such as additional irrigation facilities, multiplication of quality seeds and their exchange among farmers, the opening of additional retail points for fertilizers and pesticides, and establishment of biogas plants. These results have been achieved with the help and cooperation of state governments and other developmental organizations at field level. Thus, the execution pattern of the project, which includes the posting of technically qualified experienced agronomists in interior villages to work in close association with the farmers and properly coordinate the activities with inputs supply agencies, is largely responsible for the success of this project. Because of their way of working, the agronomists are considered by the villagers not merely as their technical advisors for agricultural development but also as friends, guides, and philosophers among the rural folk.

Evaluation of the Project

The necessity of keeping a very close watch on the effectiveness of the project was felt from the beginning, and a decision was made to engage consultants specifically to monitor and evaluate this project. Two consultants were appointed, one from NCAER, with the responsibility for the States of Assam, Orissa, and West Bengal, and one from the Projects and Development India, Ltd., with the responsibility for the States of Bihar, Madhya Pradesh, and Uttar Pradesh.

It was decided to have a benchmark survey of all the villages covered under the project in order to have an idea of the situation prevailing at the start of the project. The reference period for this survey was agricultural year 1980/81 (April 1980 to March 1981). Samples of 13,266 households from key villages, 19,633 from cluster villages, and 2,085 from control villages, making a total of 34,984 households, were selected for the survey.

The first evaluation covered a sample of 2,631 households (1,076 in key villages, 1,045 in cluster villages, and 510 in control villages) and was conducted by repeat surveys of subsamples of households included in the benchmark study. This covered the period of Rabi 1981/82 and Kharif 1982 (i.e., October 1981 to September 1982).

Detailed reports are available concerning the project. A few relevant and important results are presented from Tables 7-17 to show the impact of a project like the IBFEP.

Economic Analysis of the Project

A thorough economic analysis of the project provided information on several points, which are discussed as follows.

Despite the lower than anticipated achievements in the block demonstration areas and the increased wage costs, the project continues to exhibit a healthy economic rate of return, even under conservative assumptions about the benefits of the project activities.

Models have been formulated that are representative of the two major irrigated cropping systems covered by the project: a Bihar Kharif paddy-Rabi wheat model and an Orissa Kharif paddy-Rabi paddy model. The critical assumptions are that yield increases of 1 ton/ha are achieved during the demonstration year on 50-ha blocks as a result of increased, and more balanced, fertilizer use under the influence of, among other things, a 50% subsidy. These yield increases are sustained for 40% of the block demonstration area in succeeding years, while in another 40% of the area an intermediate level of yields is maintained. Without the intensive extension advice provided by the project, it would take at least 8 years for these higher yields to be realized. Under these assumptions the economic rate of return for the project is 20% in Bihar with a net product value (NPV) of Rs 2.1 m and 34% in Orissa with a NPV of Rs 5.3 m.

The base case assumptions specified above are conservative in one additional respect, in that they take no account of ripple effects. If allowance is made for first-order ripple effects, i.e., the likelihood that farmers will continue to carry out recommended practices not only on their plots within the demonstration but also on the rest of their holdings, the economic rate of return increases to 44% for Bihar (NPV of Rs 13.7 m) and to 69% for Orissa (NPV of Rs 23.5 m).

The economic worth of the project is sensitive to increases in project overhead costs. A 25% increase in costs reduces the economic rate of return for the Bihar model to 2% and for the Orissa model to 1.5%. Rates of return maintain satisfactory levels if ripple effects are included.

A reduction in the area of the block demonstration from 50 ha to 40 ha (with a corresponding reduction in the number of farmer participants) causes the economic rate of return to fall sharply to 2% for the Bihar model and to 14% for Orissa, although satisfactory rates of return are maintained if ripple effects are included.

The rate of return is also sensitive to assumptions about the speed with which farmers would achieve higher yields in the absence of the project. If, for example, the period of adjustment is 7 years instead of 8, the initial rate of return falls to low levels. If allowance is made for first-order ripple effects, however, the project is still economically sound for a "without-project" adjustment period of 7 years. The World Bank experience indicates that it takes about 8 or 9 years for large numbers of farmers in irrigated areas to change from traditional to more intensive techniques.

The economic worth of the project is enhanced when its activities are focused in villages where irrigation has recently been introduced. Even if the demonstration size is only 40 ha and no allowance is made for ripple effects, the economic rate of return for a "new irrigation situation" is 29% in Bihar and 72% in Orissa.

To conclude, IBFEP passes the conventional economic tests under reasonable assumptions about its impact on farmer performance although the economic worth of the project is extremely sensitive to small changes in these assumptions.

Conclusions

The experiences of implementing the IBFEP in six eastern states in India have conclusively proved that an extension system works only when it is combined with a well-thought-out input delivery system with sound advisory support for modern agricultural practices.

With both the short-term and the long-term strategies for fertilizer extension and marketing, the experience has been that this program is necessary in order to establish sound fertilizer practices for the farmer and that research at the farm level is essential.

A fertilizer supplier must work in the marketplace and with the farmers if the desired growth is to be achieved. There is no short-cut method to reach the goal. The approach made with the IBFEP throws new light in the desired direction.

Table 1. Achievement of Block Demonstration During Rabi 1981/82 to Rabi 1983/84

State	Area of Block Demonstration (ha)	Average Size of Block Demonstration (ha)	Number of Farmers	Small and Marginal Farmers (%)	Average Area/ Farmer (ha)
Assam (4)	6,434.57	41.49	13,025	83.69	0.49
Bihar (4)	6,591.09	39.13	14,250	91.22	0.46
Madhya Pradesh (5)	4,548.17	33.24	9,428	64.73	0.48
Orissa (4)	6,784.34	39.64	15,058	80.41	0.45
Uttar Pradesh (4)[a]	4,367.86	45.23	9,890	91.42	0.44
West Bengal (4)	6,085.13	37.83	16,517	87.10	0.36
TOTAL/Average	33,811.16	39.43	78,168	83.10	0.44

a. Four seasons

Note: Figures in parentheses indicate number of districts covered.

Table 2a. Yield Increase in Block Demonstration

Crop/State	Total Demonstration Area ('00 ha)	Yield Outside Demonstration (q/ha)	Yield in Demonstration (q/ha)	Increase in Yield (%)
Paddy (2 Kharif)				
Assam	18.5	25.8	43.0	66.1
Bihar	28.7	19.8	38.5	94.8
Madhya Pradesh	11.5	23.1	42.4	83.5
Orissa	23.0	35.7	47.2	32.1
Uttar Pradesh	9.9	23.7	41.0	73.7
West Bengal	25.5	23.2	34.6	49.0
TOTAL/Average	117.1	25.2	40.7	61.3
Wheat (3 Rabi)				
Assam	12.3	14.6	25.4	74.3
Bihar	31.6	20.4	37.0	81.2
Madhya Pradesh	33.3	18.4	32.0	73.9
Orissa	6.5	15.5	25.5	64.6
Uttar Pradesh	30.5	27.7	42.0	51.9
West Bengal	12.6	16.7	25.0	49.2
TOTAL/Average	126.8	18.9	34.0	79.9

Table 2b. Yield Increase in Block Demonstration

Crop/State	Total Demonstration Area ('00 ha)	Yield Outside Demonstration (q/ha)	Yield in Demonstration (q/ha)	Increase in Yield (%)
Maize (2 Kharif)				
Bihar	1.2	27.7	44.3	59.8
West Bengal	0.9	30.6	39.2	28.2
TOTAL/Average	2.1	29.1	42.1	44.5
Jowar (2 Kharif)				
Madhya Pradesh	1.7	8.9	16.8	87.7
Bajra (2 Kharif)				
Madhya Pradesh	0.4	5.0	9.2	35.0
Uttar Pradesh	5.1	14.0	26.1	86.8
TOTAL/Average	5.5	9.5	25.0	162.7
Mustard (3 Rabi)				
Assam	17.0	5.1	9.1	78.6
West Bengal	2.8	5.4	9.3	72.1
TOTAL/Average	19.8	5.2	9.1	74.4
Groundnuts (3 Rabi)				
Orissa	3.2	11.3	15.9	40.5
Soybeans (2 Kharif)				
Madhya Pradesh	1.3	6.4	9.4	48.3

Table 3. Average Yields of Cereals in National Demonstration (1971/72 to 1979/80)

Crop	Country Average (q/ha)	National Demonstration Average (q/ha)
Paddy	17.45	40.7
Wheat	13.77	34.0
Maize	10.28	42.1
Jowar	6.12	16.0
Bajra	4.35	25.0

Table 4. Average Yield of Paddy and Wheat in National Demonstrations (1976/77 to 1979/80)

Crop/State	State Average (q/ha)	National Demonstration Average (q/ha)
Paddy		
Uttar Pradesh	22.8	41.0
West Bengal	21.5	34.6
Wheat		
Uttar Pradesh	16.34	42.0
West Bengal	22.13	25.0

Table 5. Average Yield of Some Major Crops Under the All-India Coordinated Agronomic Experiments (1969-80)

Crop	Yield in Control (q/ha)	Yield in Trial (q/ha)	Increase in Yield (%)
Paddy (Kharif)	29.6	46.1	56
Wheat	15.5	33.2	114
Maize	17.6	38.8	120
Jowar	10.5	23.3	122
Bajra	11.4	23.1	103
Groundnuts	16.2	26.7	65

Table 6. Fertilizer Application (N, P_2O_5, K_2O/kg/ha) According to Crop Recommendation and Soil Testing (Average of Five Seasons)

State	Crop Recommendation		Soil Test Recommendation		Difference Between Crop and Soil Test Recommendations	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Assam	118.0	122.6	98.1	87.3	-19.9	-35.3
Bihar	140.6	175.4	128.0	146.1	-12.6	-29.3
Madhya Pradesh	178.1	178.3	155.1	182.1	-23.0	+3.8
Orissa	159.0	188.3	144.8	199.0	-14.2	+10.7
Uttar Pradesh	189.2	191.2	173.2	166.8	-16.0	-24.4
West Bengal	119.0	205.5	96.3	192.0	-22.7	-13.5

Table 7. Average Yield: Key Villages

State	Season	Crop	Variety	Yield			Increase in Yield
				Demonstration Plot	Nondemonstration Plot	Average of All Plots	
				(kg/ha)	(kg/ha)	(kg/ha)	(%)
Bihar	Kharif	Paddy	HYV, Irrigated	2,457	1,609	1,621	52.7
	Rabi	Wheat	HYV, Irrigated	2,403	1,625	1,629	47.9
Madhya Pradesh	Kharif	Paddy	HYV, Irrigated	2,205	1,708	1,710	29.1
		Maize	HYV, Irrigated	2,340	1,423	1,425	64.4
		Jowar	HYV, Irrigated	1,436	980	982	46.5
	Rabi	Wheat	HYV, Irrigated	2,106	1,607	1,608	31.1
		Oilseeds	Irrigated	556	310	313	79.4
Uttar Pradesh	Kharif	Paddy	HYV, Irrigated	2,136	1,759	1,766	21.4
		Maize	HYV, Irrigated	3,022	1,382	1,393	118.7

Table 8. Fertilizer Application Rates to Cropped Area: Demonstration Versus Nondemonstration Crops

Type of Villages and State	Fertilizer Application Rate: Demonstration Crops N	P_2O_5	K_2O	Total	Nondemonstration Crops N	P_2O_5	K_2O	Total
	(kg/ha)							
Key Villages								
Assam	50.27	12.14	24.31	86.73	10.95	2.35	4.50	17.80
Orissa	83.15	20.13	31.28	134.56	10.92	2.29	3.57	16.78
West Bengal	62.47	13.47	30.24	106.18	20.90	3.27	4.89	29.06
Cluster Villages								
Assam	37.45	8.52	19.64	65.61	4.11	0.76	1.35	6.22
Orissa	77.11	16.22	30.57	123.90	18.61	2.57	4.95	26.13
West Bengal	61.53	10.56	26.17	98.26	9.59	1.14	2.00	12.73
Control Villages								
Assam	-	-	-	-	0.92	0.13	0.12	1.17
Orissa	-	-	-	-	12.45	1.63	2.79	16.87
West Bengal	-	-	-	-	6.27	0.67	1.23	8.17

Table 9. Farmers' Awareness of the IBFE Project and Their Adoption of Its Technology in Project Areas During a Benchmark Survey (BMS) and Evaluation

State/Category of Village	Farmers' Awareness of Program		Farmers Who Adopted Technology	
	BMS	Evaluation	BMS	Evaluation
	(%)		(%)	
Bihar				
Key	61	69	42	56
Cluster	48	55	39	43
Control	48	43	24	28
Madhya Pradesh				
Key	44	52	28	35
Cluster	46	50	29	31
Control	46	45	29	27
Uttar Pradesh				
Key	56	64	32	36
Cluster	51	53	31	32
Control	42	46	28	29

Table 10. Average Yield and Fertilizer Nutrient Application Rates--Assam Evaluation Study: Rabi, 1981/82 and Kharif, 1982--Key Villages

		Fertilizer Application Rate, kg/ha of Cropped Area				Fertilizer Application Rate, kg/ha of Fertilized Area			
Crop	Yield (kg/ha)	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
Crops Under Demonstration									
Kharif-paddy									
HYV-irrigated	3,606	49.05	12.71	23.33	85.06	49.03	12.71	23.33	85.06
All paddy	4,630	58.64	13.33	26.67	98.65	58.64	13.33	26.67	98.65
Jute									
HYV-irrigated	Not cultivated								
All jute	2,478	35.52	10.33	21.66	67.52	35.52	10.33	21.66	67.52
Rabi-oilseeds									
HYV-irrigated	Not cultivated								
All oilseeds	704	23.87	5.22	-	29.09	23.87	5.22	-	29.09
Crops Not Under Demonstration									
Kharif-paddy									
HYV-irrigated	3,528	34.25	12.85	21.75	68.85	34.25	12.85	21.75	66.85
All paddy	2,208	4.43	1.07	1.85	7.35	10.41	2.51	4.36	17.28
Jute									
HYV-irrigated	1,188	50.21	15.37	26.09	91.67	50.21	15.37	26.09	91.67
All jute	1,457	27.73	6.11	10.37	44.20	35.43	7.81	13.25	56.49
Rabi-oilseeds									
HYV-irrigated	741	27.49	7.82	18.45	68.77	37.49	7.82	18.45	63.77
All oilseeds	689	21.95	3.79	7.28	33.02	30.75	5.31	10.21	46.27

Table 11. Average Yield and Fertilizer Nutrient Application Rates--Orissa Evaluation Study: Rabi, 1981/82 and Kharif, 1982--Key Villages

Crop	Yield (kg/ha)	Fertilizer Application Rate, kg/ha of Cropped Area				Fertilizer Application Rate, kg/ha of Fertilized Area			
		N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
		Crops Under Demonstration							
Kharif-paddy									
HYV-irrigated	4,472	75.15	17.95	25.69	118.80	75.15	17.95	25.69	118.80
All paddy	4,367	73.42	17.55	25.08	116.06	73.42	17.55	25.08	116.06
Rabi-paddy									
HYV-irrigated	3,593	113.33	29.14	43.76	186.23	113.33	29.14	43.76	186.23
All paddy	3,593	113.33	29.14	43.76	186.23	113.33	29.14	43.76	186.23
Wheat									
HYV-irrigated	2,330	98.68	23.32	46.62	168.61	98.68	23.32	46.62	168.61
All wheat	2,330	98.63	23.32	46.62	168.57	98.63	23.32	46.62	168.57
		Crops Not Under Demonstration							
Kharif-paddy									
HYV-irrigated	2,408	38.74	10.23	13.92	62.00	50.62	13.37	18.19	82.19
All paddy	1,420	6.50	1.09	1.56	9.15	26.46	4.44	6.36	37.26
Rabi-paddy									
HYV-irrigated	3,231	91.39	24.66	34.36	150.41	91.39	24.66	34.36	150.41
All paddy	3,231	91.39	24.66	34.36	150.41	91.39	24.66	34.36	150.41
Wheat									
HYV-irrigated	395	113.67	6.96	-	120.63	113.67	6.96	-	120.63
All wheat	395	113.67	6.96	-	120.63	113.67	6.96	-	120.63

Table 12. Average Yield and Fertilizer Nutrient Application Rates--West Bengal Evaluation Study: Rabi, 1981/82 and Kharif, 1982--Key Villages

Crop	Yield (kg/ha)	Fertilizer Application Rate, kg/ha of Cropped Area				Fertilizer Application Rate, kg/ha of Fertilized Area			
		N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
		Crops Under Demonstration							
Kharif-paddy									
HYV-irrigated	3,417	72.00	14.92	34.91	121.85	72.00	14.92	34.91	121.83
All paddy	2,830	64.67	13.01	25.37	103.00	64.67	13.01	25.37	103.05
Wheat									
HYV-irrigated	2,385	58.35	13.21	46.76	118.33	58.35	13.21	46.76	118.33
All wheat	2,385	58.35	13.21	46.76	118.33	58.35	13.21	46.76	118.33
Jute									
HYV-irrigated	1,609	22.75	8.99	35.35	67.10	22.75	8.99	35.35	67.10
All jute	1,803	32.59	9.84	31.06	73.49	32.59	9.84	31.06	73.49
Potatoes									
HYV-irrigated	21,846	126.47	35.70	65.54	227.72	126.47	35.70	65.54	227.72
All potatoes	21,846	126.47	35.70	65.54	227.72	126.47	35.70	65.64	227.72
		Crops Not Under Demonstration							
Kharif-paddy									
HYV-irrigated	3,325	63.68	14.57	16.76	95.02	63.68	14.57	16.76	95.02
All paddy	1,721	17.27	2.40	3.01	22.67	26.36	3.66	4.60	34.62
Wheat									
HYV-irrigated	2,014	42.74	7.24	11.62	61.59	44.70	7.57	12.15	64.43
All wheat	1,937	38.13	6.43	10.32	54.88	42.56	7.17	11.52	61.26
Jute									
HYV-irrigated	1,285	14.78	-	-	14.78	14.78	-	-	14.78
All jute	1,349	7.07	1.48	3.64	12.20	16.88	3.54	8.71	29.13
Potatoes									
HYV-irrigated	15,223	268.88	44.42	56.52	369.82	268.88	44.42	56.52	369.82
All potatoes	15,223	257.75	42.58	54.18	354.51	268.87	44.41	56.52	369.80

Table 13. Quantity of Fertilizer Nutrient Applied on Fertilized Area in Project Areas of Bihar--Cropwise

Season/Crop	Fertilizer Nutrient Application Rate of Fertilized Area											
	Key Villages				Cluster Villages				Control Villages			
	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
	(kg/ha)											
Kharif												
Paddy												
HYV	16	3	3	22	12	3	2	17	13	2	1	16
HYV irrigated	16	3	3	22	14	4	1	19	13	2	1	16
All varieties	10	1	1	12	9	2	1	12	9	1	neg	10
Maize												
HYV	17	2	2	21	17	1	1	19	-	-	-	-
HYV irrigated	17	2	2	21	17	1	1	19	-	-	-	-
All varieties	5	neg	neg	5	8	1	neg	7	-	-	-	-
Potatoes												
Irrigated	-	-	-	-	25	neg	neg	25	-	-	-	-
Jute												
HYV irrigated	54	1	neg	55	39	neg	neg	39	-	-	-	-
All varieties	29	1	neg	30	26	neg	neg	26	-	-	-	-
Rabi												
Wheat												
HYV	14	1	1	16	13	1	1	15	12	1	neg	13
HYV irrigated	14	1	1	16	13	1	1	15	10	1	neg	13
All varieties	14	1	1	16	13	1	1	15	10	1	neg	11
Maize												
HYV	5	1	neg	6	5	neg	neg	5	4	neg	neg	4
HYV irrigated	6	1	neg	7	5	neg	neg	5	4	neg	neg	4
All varieties	5	1	neg	6	5	neg	neg	5	4	neg	neg	4
Potatoes												
Irrigated	31	1	1	33	31	2	1	34	-	-	-	-
Sugarcane												
Irrigated	92	2	2	96	78	1	1	80	-	-	-	-
Unirrigated	52	1	neg	53	67	3	neg	70	58	neg	-	58
Pulses												
Irrigated	14	1	1	16	12	1	neg	13	-	-	-	-
Unirrigated	-	-	-	-	-	-	-	-	-	-	-	-

Table 14. Quantity of Fertilizer Nutrient Applied on Fertilized Area in Project Areas of Madhya Pradesh

Season/Crop	Application Rate of Nutrient											
	Key Villages				Cluster Villages				Control Villages			
	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
	(kg/ha)											
						Kharif						
Paddy												
HYV	35	5	4	44	30	3	3	36	28	4	-	32
All varieties	18	4	3	25	15	3	3	21	12	3	-	15
Maize												
HYV	20	3	2	25	14	3	3	20	12	3	-	15
All varieties	15	2	1	18	12	2	1	15	10	2	-	12
Jowar												
HYV	16	2	-	18	10	1	-	11	10	1	-	11
All varieties	11	2	-	13	9	1	-	10	6	-	-	6
Sugarcane												
Irrigated	60	5	2	67	55	5	-	60	-	-	-	-
Pulses												
Irrigated	4	8	1	13	3	5	1	9	3	4	-	7
Unirrigated	3	6	1	10	2	3	-	5	2	3	-	5
Oilseeds												
Irrigated	6	6	2	14	6	5	1	12	4	4	-	8
Unirrigated	2	2	-	4	4	3	-	7	2	2	-	4
						Rabi						
Paddy												
HYV	35	5	4	44	30	4	4	38	-	-	-	-
All varieties	18	4	3	25	15	3	3	21	-	-	-	-
Wheat												
HYV	39	4	3	46	36	3	2	41	32	2	1	35
All varieties	37	4	2	43	30	2	1	33	25	2	0	27
Sugarcane												
Irrigated	60	6	1	67	55	4	-	59	50	3	-	53
Unirrigated	35	4	1	40	31	3	-	34	25	-	-	25
Pulses												
Irrigated	4	3	-	7	2	3	-	5	2	3	-	5
Unirrigated	1	2	-	3	1	2	-	3	1	2	-	3
Oilseeds												
Irrigated	6	6	2	14	6	5	1	12	4	4	-	8
Unirrigated	2	2	-	4	4	3	-	7	2	2	-	4
Potatoes												
Irrigated	-	-	-	-	46	3	3	52	-	-	-	-

Table 15. Quantity of Fertilizer Nutrient Applied in Project Area of Uttar Pradesh--Cropwise

Season/Crop	Fertilizer Nutrient Applied											
	Key Villages				Cluster Villages				Control Villages			
	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
	(kg/ha)											
					Kharif							
Paddy												
HYV	51	5	3	59	48	4	3	55	45	2	1	48
All varieties	44	4	2	50	39	3	2	44	40	2	1	43
Maize												
HYV	36	-	-	36	27	1	-	28	21	1	neg	22
All varieties	23	-	-	23	22	neg	neg	22	16	1	neg	17
Bajra												
HYV	35	1	-	36	28	neg	-	28	23	neg	-	23
All varieties	26	1	-	27	27	neg	-	27	13	neg	-	13
Sugarcane												
Irrigated	96	13	12	121	71	7	8	86	-	-	-	-
Pulses												
Irrigated	9	1	-	10	7	1	-	8	-	-	-	-
Unirrigated	1	1	-	2	1	-	-	1	-	-	-	-
					Rabi							
Wheat												
HYV	54	8	6	68	42	5	6	53	38	2	1	41
All varieties	53	7	5	65	41	5	5	51	35	1	neg	36
Sugarcane												
Irrigated	92	10	2	104	81	5	1	87	68	3	1	72
Pulses												
Irrigated	8	1	-	9	3	1	-	4	-	-	-	-
Unirrigated	1	1	-	2	1	-	-	1	-	-	-	-

Table 16. Fertilizer Application Rates in Fertilized Area: Key Villages

State	Crop Variety	Demonstration Plots N	Demonstration Plots P_2O_5	Demonstration Plots K_2O	Demonstration Plots Total	Nondemonstration Plots N	Nondemonstration Plots P_2O_5	Nondemonstration Plots K_2O	Nondemonstration Plots Total
		(kg/ha)							
Bihar	Kharif								
	Paddy HYV irrigated	65	12	13	90	19	4	4	27
	Rabi								
	Wheat HYV irrigated	82	20	21	123	15	2	2	19
Madhya Pradesh	Kharif								
	Paddy HYV irrigated	63	16	16	95	42	9	5	56
	Maize HYV irrigated	50	13	10	73	36	7	5	48
	Jowar HYV irrigated	45	10	8	63	27	6	4	37
	Rabi								
	Wheat HYV irrigated	78	20	20	118	43	7	4	54
	Oilseeds irrigated	20	30	-	50	8	8	-	16
Uttar Pradesh	Kharif								
	Paddy HYV irrigated	72	18	20	110	60	6	4	70
	Maize HYV irrigated	60	12	15	87	41	2	1	44

Table 17. Fertilizer Nutrients Recommended for Different Crops Compared With That Applied in the Demonstration Plots in Bihar, Madhya Pradesh, and Uttar Pradesh

		Nutrients							
		State-Level Recommendations				Quantity Applied in the Demonstration Plots as Found at the Time of Evaluation			
State	Crop (HYV)	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total
		(kg/ha)							
Bihar	Paddy	75	16	28	119	65	10	13	90
	Wheat	80	14	24	118	82	20	21	123
Madhya Pradesh	Paddy	65	17	18	100	63	16	16	95
	Wheat	80	24	20	124	78	20	20	118
	Maize	88	18	26	132	50	13	10	73
	Jowar	30	8	-	38	45	10	8	63
	Oilseeds	45	25	-	70	20	30	-	50
Uttar Pradesh	Paddy	80	16	32	128	72	18	20	110
	Wheat	80	20	32	132	60	12	15	87

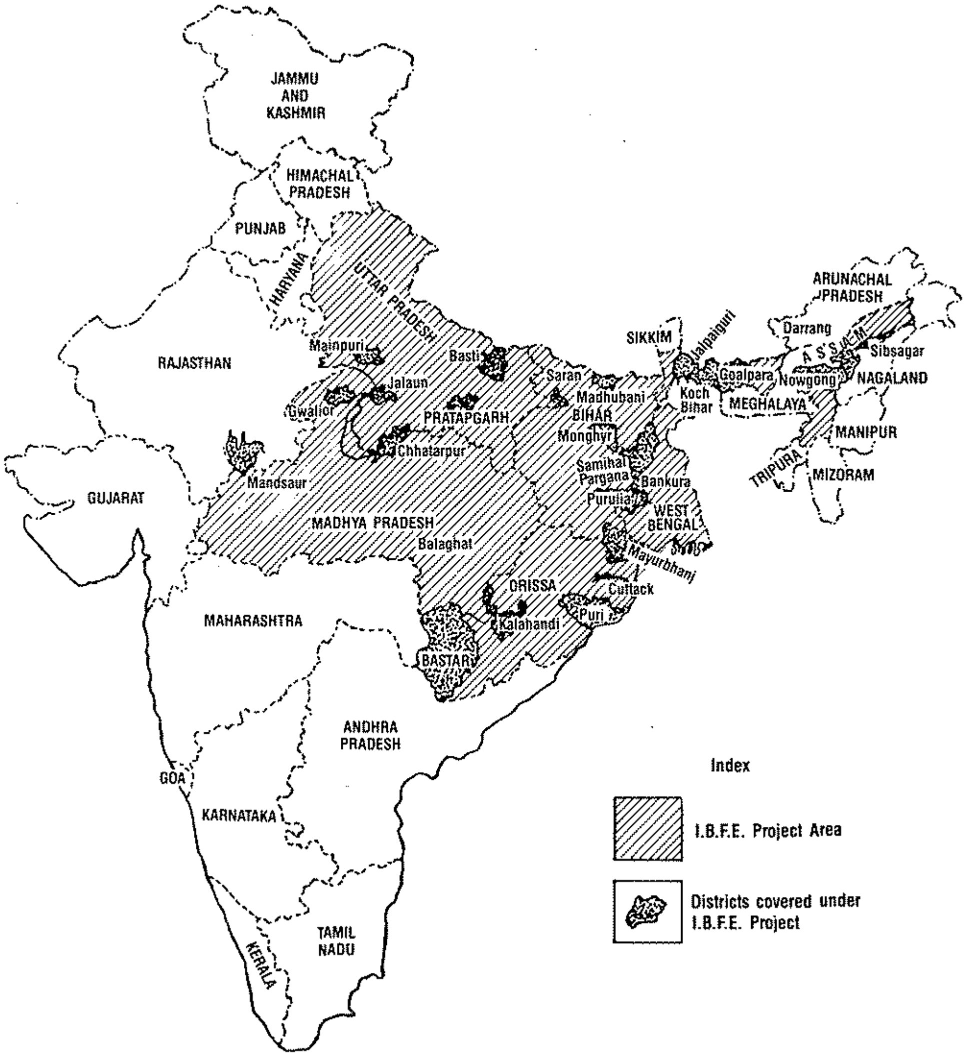

Figure 1. India: The Indo-British Fertilizer Education Project Area.

THE FAO FERTILIZER PROGRAMME IN AFRICA

C. Joly

Introduction

The Food and Agriculture Organization (FAO) study entitled Agriculture: Toward 2000 (FAO 1981) examines world agricultural perspectives and policy issues up to the year 2000 for 90 developing countries.

The production growth rates envisaged require a sustained and substantial expansion, not only in the land and water base but in the modernization of the production process itself. For the 90 developing countries, crops account for about four-fifths and livestock about one-fifth of additions to production during 1980-2000. Expansion of arable land provides 26% of the additional crop production, increased cropping intensity (the number of times that a hectare of land is cropped each year) 14%, and higher yields 60%. For Africa, these three values have been estimated to be 27%, 22%, and 51%, respectively (Table 1).

It is foreseen that the area cultivated per capita in the developing countries will fall from 0.9 ha in the middle of the 1970s to 0.5 ha of potentially arable land in the year 2000.

On the other hand, it is recognized that fertilizers have so far accounted for more than 50% of the increase in crop yields. It is also estimated that, to achieve the goal of meeting their food requirements, developing countries as a group will have to increase their use of fertilizers threefold to fourfold by the year 2000. This projection must be seen, however, in connection with the availability of raw materials and the rising cost of energy for fertilizer manufacturing.

In other words, the use of mineral fertilizers has to be considered in the global context of the "Integrated Systems of Plant Nutrition," which must increasingly include all other sources of plant nutrients available at farm level. These include the following:

1. Nutritive elements available in the soil.
2. Elements from organic matter resources.
3. Elements derived from crop residues.
4. Nitrogen from biological fixation of nitrogen.
5. Elements from applications of fertilizers and their residual effects.

Fertilizers and Crop Production

As stated before, fertilizers contribute up to 50% and more of yield increases. This has been proven by millions of fertilizer trials and demonstrations which have been carried out in practically all countries of the world.

It is evident that the effect of fertilizers on yields is influenced by climatic and soil conditions and greatly enhanced by the improvement in other factors, e.g., the use of irrigation, high-yielding varieties, and improved tilling practices.

The correlation between yields of cereals and fertilizer use is clearly shown by an analysis of yields and fertilizer consumption in 62 major cereal-growing countries, on the basis of data provided in FAO's Production Yearbook and Annual Review, respectively (1978 issues). See Figure 1.

Table 2 shows that the production index (kilograms of crop produced per kilogram of plant nutrients used, N, P_2O_5, K_2O) ranges from 5 to 30 and more, depending on crop, agroecological conditions, and management levels. The use of imported fertilizers makes less demand on foreign currency resources, costs, and transport volume than do food imports and, by improving the rural economy, helps to limit the rural exodus to urban centers.

The FAO Fertilizer Programme

The importance of fertilizers for agricultural development in developing countries was recognized some years ago by FAO, and the Fertilizer Programme was launched in 1961.

Under the technical and operational responsibility of FAO, cooperation has been established between donor governments, the United Nations Development Program, nongovernmental organizations, international institutions, and fertilizer producers on the one hand and, on the other, the governments of countries benefiting from the Fertilizer Programme. As a general principle, plans for varying spans of years are drawn up and adapted to the situation of the individual recipient country.

The basic feature of the Fertilizer Programme is the development of direct and repeated contacts with large numbers of small farmers growing mainly food crops. The field projects of the Programme have rapidly extended their scope to include all other production factors related to fertilizers (the use of improved varieties, improved practices, pesticides, etc.), pilot schemes for the production of fertilizer and other inputs of distribution and credit, and an enlarged training component.

Consequently, the Programme has focused on crop production and has become a spearhead of rural development that anticipates most of the principles for this development determined by the World Conference on Agrarian Reform and Rural Development, i.e.:

1. Access of rural population to resources.
2. People's participation in development.
3. Access to inputs, markets, and services.
4. Education and training.

The impact of Fertilizer Programme projects was substantially increased by the creation, in 1974, of the FAO International Fertilizer Supply Scheme. Following the "fertilizer crisis," the scheme was established to assist developing countries, particularly the least developed ones, to meet their fertilizer requirements.

Counterpart funds generated from the proceeds of the sales of fertilizer donations are, in agreement with the recipient governments, primarily directed to strengthening fertilizer use development and hence crop production in the countries concerned.

The FAO Fertilizer Programme in Africa

Since its creation, the Programme has been operational in Africa; the first three countries to benefit from it were Morocco, Nigeria (West and Mid-West), and Senegal where operations started in 1961. It has since provided assistance to 28 African countries.

At present, 12 projects are operational in Africa, in the following countries: Burkina Faso, Ethiopia, Gambia, Guinea Bissau, Madagascar, Niger, Rwanda, Somalia, Sudan, Tanzania, Zaire, and Zambia (see Table 3).

In the long run, a National Fertilizer Programme tends to become a specialized body for fertilizer use and plant nutrition in the Ministry of

Agriculture. As such, it coordinates the activities of the Ministry and contributes to the formulation of a national policy in this field.

The field activities are nevertheless the most visible portion of the activities of the Programme. They involve work in several areas.

Applied Research

In the general context of integrated plant nutrition systems and in close collaboration with national and international research institutions, the Fertilizer Programme tries to determine the most economical means to improve soil fertility and plant nutrition for main crops.

Where fertilizer recommendations have to be refined or confirmed, simple trials are laid out in order to determine rates of fertilizer application best suited to actual local crops. Response curves are analyzed from an economic point of view by determining the magnitude of the net profit and the value/cost ratio sufficiently attractive to farmers. (The value/cost ratio is the value of yield increase due to fertilizer use and other inputs divided by the additional cost incurred in obtaining such a yield increase.) See Figure 2. From worldwide experience, the value/cost ratio should be at least 2 to ensure that the new technology is adopted by farmers on a permanent basis.

In some specific cases and to obtain a solution to particular problems, the Fertilizer Programme carries out more complex trials, e.g., tests of new types of fertilizer (urea supergranules, organic fertilizer), tests of micronutrients, tests of local fertilizer material (phosphate rock, bat guano, lime) and tests of inoculation of legumes with Rhizobium strains of bacteria. When new varieties have to be tested together with fertilizers, split-plot trials (fertilizer rates x varieties) can be set up.

Residual Effects

Residual effects of applications of NPK fertilizers have been tested by the Programme in several countries, e.g., Burundi, Nigeria, and Zaire. Results have shown that fertilizers are not completely used in one growing season; part remains available in the soil for the crops grown during the following seasons and increases the natural fertility of the soil. In some cases, yield increases due to residual effects can amount to as much as 40% on the first crop grown after fertilizer applications, and residual effects on the next crop have been estimated at about 10%.

Consequently, the return due to the applications calculated on a 1-year basis (annual response) does not give a true picture of the benefit that farmers can expect. When clearly explained to farmers, residual effects can help the extension workers convince farmers of the profitability and usefulness of the application of fertilizers.

Concerning applications of ground phosphate, the Fertilizer Programme in Burkina Faso (Voltaphosphate) and in Niger (phosphate of Tahoua) has shown that full profit was not obtained during the first year of cropping and that residual effects are at least as important as the first annual response (Table 4).

Extension

On the basis of results from research, demonstrations are laid out in farmers' fields to disseminate economically sound recommendations. Demonstrations aim to familiarize the farmer with the use of fertilizers, showing him how to apply them and what results to expect.

Depending on the country and the crops, a demonstration comprises two to five plots; the design most currently used involves the following four plots:

1. The farmer's cultivation technique without fertilizer.
2. The farmer's cultivation technique with fertilizer.
3. Improved cultivation techniques without fertilizer.
4. Improved cultivation techniques with fertilizer.

Visits to demonstrations (field days) are organized at various times during the crop cycle. This makes it possible to point out the differences in growth between the control plot and the well-cultivated and fertilized plots.

However, it is at harvest time that the whole local agricultural population is invited to assess and appreciate the yield differences between the various treatments. Estimates made by the farmers themselves precede the calculation of the economic aspects of the results. Statistical information on the number of trials and demonstrations is given in Figure 3 and on the number of field days and field staff trained in Figure 4.

Distribution

When the demonstration work has created a demand for fertilizers in a country or a region, fertilizer distribution and credit pilot schemes are established, with a view to providing the types and amounts of fertilizer needed at the right time and to establishing conditions that enable the farmer to buy them. The first such pilot project took place in Ghana in 1963. Since that date, many other countries have benefited from this kind of activity (Table 5).

In general, a fertilizer distribution and credit pilot scheme starts with a fertilizer donation, through FAO, to the project. The fertilizer is sold on credit or for cash. The proceeds constitute a "revolving fund" managed by the government of the recipient country on the basis of the sale of the fertilizer. The revolving fund is used to buy fertilizers or other inputs (seeds, agricultural tools) in following years or sometimes to restore or build new stores and finance part of the training activities.

After a certain period--generally 3 years--fertilizer donations cease, and the recipient government is then responsible for continuing the operation. Public or private bodies take over the supply of fertilizer at this point.

Certain governments have linked the supply of fertilizers and other inputs to the marketing of crops produced (cotton, for example) or their procurement by government or private crop authorities.

The pilot schemes in general deal with the most important crops. In selecting participant farmers and in controlling their number and limiting credit to the amount of fertilizer needed for 0.5-2 ha, the FAO Fertilizer Programme aims to ensure the success of the operation.

An average repayment rate of at least 85% is expected. The main penalty for failure to repay is noneligibility for further credit.

Training

Training of a local staff at all levels has always been an essential component of every project under the Fertilizer Programme. A whole generation has been properly trained in matters relating to fertilizer use development by means of courses, seminars, and fellowships at specialized centers overseas (Table 6).

The Fertilizer Programme not only assumes responsibility for national training preceding the development of a project but also conducts training sessions at the regional (group of countries) level and assures in-service training courses as well as "on-the-job" training throughout the life of the project.

Uniformity of organization and procedures has been sought for the Programme and the training activities in order to enable organizers and participants to derive the most benefit from previous experience, to maximize the value of discussions, and to concentrate attention on the problems remaining to be solved. Numerous publications, often in local languages, and training aids have been prepared by FAO to achieve these objectives.

Other Activities

Data Processing and Establishment of a Data Bank--Results of field trials and demonstrations are analyzed by computers either at FAO Headquarters or at country level when information services are available (Table 7). For the last few years microcomputers have been supplied to projects.

The results of about 40,000 fertilizer trials and demonstrations from developing countries are stored in the computerized FAO Plant Nutrient Data Bank at Headquarters in Rome. Computer storage of field results was started in 1975. Results are stored by country, by year, by season, and by crop. For each site, the bank contains records of fertilizer treatments, crop varieties, yields, economic information, soil, and climate.

The data bank is being used for the following purposes:

1. To provide field projects with a summary of their results over a number of years under different economic conditions.
2. To compute the most favorable fertilizer treatments for given fertilizer and crop prices, according to specified economic criteria such as net return and value/cost ratio.
3. To provide field projects with sorted, analyzed data, e.g., to study the influence of agroecological zones or different soil parameters on the yield increase.
4. To provide annual summaries of results by country, by agroecological zones, or by crop.

The computer program used is the FAO DESFLEX. It is operational not only at FAO Headquarters but also in Burkina Faso, Madagascar, Niger, and Zaire. The data analysis capacity of the FAO Fertilizer and Plant Nutrition Service is available to all member nations and to institutions in these countries engaged in the development of agricultural production. The main objective of the data processing activities is to provide planners and decisionmakers with a reliable, easy-to-handle data base.

Biological Nitrogen Fixation--Inoculation of legumes with rhizobium strains of bacteria as well as tests of introduction of Azolla in rice fields are other activities of the Fertilizer Programme. Following preliminary tests of inoculation of legumes (mainly soya), FAO has financed the creation of pilot units for the production of inoculum for legumes in Madagascar, Rwanda, and Zaire. Two of them are already operational.

Use of National Resources--Through consultancies and tests of local fertilizer material, the Fertilizer Programme contributes to the development of national resources. The Programme has thus tested in recent years lime (Zaire, Zambia), phosphate rock (Voltaphosphate in Burkina Faso and phosphate of Tahoua in Niger), bat guano (Zaire), and all materials that could possibly be used as fertilizers to complement imported ones.

Post-Harvest Losses and Biogas--Conscious that post-harvest losses could be greatly reduced by the improvement of storage facilities, the Fertilizer Programme, through consultancies and in collaboration with the specialized service of FAO, has financed studies on this subject. In Zaire qualitative and quantitative estimates of losses have been followed by tests of village cribs and stores.

Regarding biogas, the Fertilizer Programme contributed in some cases to the development of biogas technology. The aims of this interest are to boost production of energy in remote areas, reduce deforestation, and use digester effluents as organic fertilizer.

These two types of activities must be considered as minor activities of the Fertilizer Programme, undertaken incidentally in order to contribute to solving important problems.

Conclusion

A Fertilizer Programme project generally culminates in the establishment of a fertilizer and related inputs unit within the government, usually within the Ministry of Agriculture. This unit is often responsible for fertilizer use policy on input price policy, taxes, and subsidies, as related to farm prices, and on sources of supply, either encouraging domestic production or purchase on the international market.

Through its field activities, the FAO Fertilizer Programme has been the initiator of several important rural development projects financed by such international institutions as the International Bank for Reconstruction and Development (IBRD), the International Fund for Agricultural Development (IFAD), and the Asian Development Bank (ADB). Examples of such projects are the Maize Project in Western Kasai and the Agricultural Development Project of Lulua, both in Zaire.

The FAO Fertilizer Programme, now in its 24th year of operation in Africa, has developed over the years into a technical assistance program to increase crop production, particularly of food crops grown by small farmers. This program is carried out through development of the judicious use of fertilizers and renewable sources of plant nutrients in the general context of the integrated plant nutrition systems. It takes into consideration other necessary inputs and the application of other improved and appropriate practices.

Without exaggeration the FAO Fertilizer Programme continues to be a success. This is illustrated by the continued confidence of donor countries and the fertilizer industry, represented in the FAO/Fertilizer Industry Advisory Committee which supports field projects. Its success is also demonstrated by the interest shown by countries collaborating with the Fertilizer Programme. In 1984, National Fertilizer Programmes were operating in 12 African countries.

Although past efforts have given impressive results, for many African countries the road to food self-sufficiency will still be long. Only the definition of a clear policy of intensification of agriculture, based on a greater use of agricultural inputs and the allocation of requested resources, will meet the challenge.

The FAO Fertilizer Programme, depending on its means, will continue to take up the challenge.

Table 1. Contribution to Increases in Agricultural Production (90 Developing Countries--1975 to 2000)

Region	Arable Land Growth	Changes in Cropping Intensity	Increases in Yields
	(%)		
90 countries	26	14	60
Africa	27	22	51
Far East	10	14	76
Latin America	55	14	31
Near East	6	25	69

Source: FAO 1981. Agriculture: Toward 2000, Food and Agriculture Organization of the United Nations, Rome, Italy.

Table 2. Productivity Index Per Country[a]

Country	Wheat	Maize	Sorghum	Millet	Rainfed Rice	Irrigated Rice	Crops	Legumes	Cotton
North Africa	7	6	-	-	-	-	23[b]	6[c]	3
Burkina Faso	6	11	6	5	-	10	-	5[d]	7
Burundi	7	13	6	-	6	-	56[b]	9[e]	5
Madagascar	4[f]	6	-	-	7	10	-	6	-
Nigeria (Sudan Savanna)	7[g]	-	5	8	-	-	-	12[d]	5
Nigeria (Guinean Savanna)	-	-	6	-	5	-	-	14[d]	6
Zaire	-	12	-	-	-	11	36[h]	10[d]	6

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a. Kilogram of agricultural product/kilogram of nutrients of recommended applications of fertilizer per hectare used in demonstrations. Average results from FAO Fertilizer Programme, Final or Interim Reports.
b. Potatoes.
c. Beans, chickpeas, lentils.
d. Groundnuts.
e. French beans, peas, groundnuts.
f. Dry season crop, partially irrigated.
g. Irrigated.
h. Cassava.

Table 3. Countries Participating in FAO Fertilizer Programme, 1961-83

Year of Entry	Country	Years in Program	Ongoing (1983)
1961	Lebanon	5	
	Morocco	10	
	Nigeria	18	
	Senegal	6	
	Syria	7	
	Turkey	8	
1962	Benin	2	
	Colombia	10	
	Costa Rica	12	
	Ecuador	12	
	El Salvador	8	
	Ghana	8	
	Honduras	6	
	Togo	5	
1963	Guatemala	7	
1964	Nicaragua	4	
	Gambia (1964-65)-1979	5	X
	Sri Lanka (1964-68)-1980	3	X
1965	Ivory Coast	6	
	Panama	5	
1966	Cameroon	8	
	Sierra Leone	5	
1967	Ethiopia	12	
	India (fertilizer and training)	16	
1968	Kenya	7	
	Indonesia (various Provinces)	15	X
	Tunisia	4	
1969	Botswana	7	
	Brazil	10	
	Lesotho	12	
	Paraguay	5	
	Swaziland	5	
1970	Algeria	5	
	Kampuchea	5	
	Tanzania (1970-77)-1979	5	X
1972	Burundi	11	X
	Philippines	7	
	Zaire	11	X
1973	Peru	8	

(Continued)

Table 3. Countries Participating in FAO Fertilizer Programme, 1961-83 (Continued)

Year of Entry	Country	Years in Program	Ongoing (1983)
1974	Thailand	5	X
	Burkina Faso	8	X
	Sudan	6	X
1978	Madagascar	5	X
1979	Afghanistan	1	
1980	Guinea-Bissau	3	X
	Niger	3	X
	Rwanda	3	X
1982	Nepal	1	X
1983	Zambia		X

Table 4. Residual Effects of Phosphate Applications on the Yields of Sorghum Followed by Groundnuts, 1975 and 1976, Guinean Savanna, Niger State, Nigeria

Treatment 1975 (kg P_2O_5/ha)[a]	Yield: Sorghum, 1975 (kg/ha)	Yield: Groundnuts, 1976 (kg/ha)	Yield Increase: Sorghum, 1975 (kg/ha)	Yield Increase: Groundnuts, 1976 (kg/ha)
Control plot	640	1,875	-	-
0	1,110	1,885	-	-
36	1,420	2,040	310	155
72	1,610	2,155	500	270

Treatment 1975 (kg P_2O_5/ha)[a]	Value of Yield Increase: Sorghum[b] (Naira/ha)	Value of Yield Increase: Groundnuts[b] (Naira/ha)	Total Value of Yield Increase 1975 + 1976 (Naira/ha)	Cost of Fertilizer[c] (Naira/ha)	Net Profit (Naira/ha)	Value/ Cost Ratio
0	-	-	-	-	-	-
36	77.5	42.6	120.1	5.8	114.3	20.7
72	125.0	74.3	199.3	11.6	187.7	17.2

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a. All plots were treated with 40 kg of N and 30 kg of K_2O/ha in addition to the phosphate

b. 1 kg of sorghum = 0.250 Naira (1977).
1 kg of groundnuts = 0.275 Naira (1977).

c. Subsidy for fertilizers = 85%.

Source: Terminal Report, Vol. 2, Project GCP/NIR/021/NOR, Fertilizer Demonstration and Distribution Programme, Niger State, Nigeria.

Table 5. Pilot Schemes for Distribution of Credit, 1983

Countries	Number of Pilot Schemes	Number of Participants	Number of Hectare	Tons of Fertilizers
Burkina Faso	6	1,500	700	300
Burundi	15	4,912	639	129
Gambia	-	-	-	-
Guinea Bissau	-	-	-	-
Madagascar	6	8,500	12,500	5,500
Niger	-	-	-	-
Rwanda	-	-	-	-
Somalia[a]	-	-	-	-
Sudan	3	1,116	1,488	437
Tanzania	7	316	252	137
Zaire[b]	3	1,497	783	226
Zambia	3	120	173	137
TOTAL AFRICA	43	17,961	16,535	6,856

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a. Projects established December 1, 1983.

b. Not including pilot schemes established by IBRD/ADB/IFAD Project "Maize Production in Western Kasai."

Table 6. In-Service Training Courses and Field Days, 1983

Countries	Training Courses[a]		Field Days[b]	
	Number Of Courses	Attendance	Number of Field Days	Attendance
Burkina Faso	36	770	825	21,100
Burundi	4	120	120	2,400
Gambia	36	545	1,050	14,430
Guinea Bissau	9	148	485	9,230
Madagascar	12	305	450	12,000
Niger	39	40	58	800
Rwanda	14	200	472	7,280
Somalia[c]	-	-	-	-
Sudan	31	510	959	11,780
Tanzania	48	910	1,375	35,370
Zaire	31	500	1,074	18,800
Zambia	24	380	10	200
TOTAL AFRICA	284	4,428	6,878	133,390

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a. Courses of not less than one full day on specific subjects such as fertilizer application or pilot schemes of distribution on credit.

b. Including multidisciplinary field days.

c. Project started December 1, 1983.

Table 7. Demonstrations and Trials, 1983

Countries	Main Crops	Demonstrations[a]		Trials[a]		
		Laid Out	Harvested	Laid Out	Harvested	Remarks
Burkina Faso	Sorghum, groundnuts, maize, millet, cotton	846	578	206	200	
Burundi	Beans, maize, cotton, groundnuts, wheat	900	700	57	57	
Gambia	Groundnuts, maize, millet, sorghum, rice	628	350	122	84	Drought
Guinea Bissau	Groundnuts, millet, maize, sorghum, rice	50	31	76	69	
Madagascar	Rice, soya, groundnuts, maize	382	86	94	34	
Niger	Millet, sorghum, groundnuts, cowpeas, maize	137	134	471	397	
Rwanda	Beans, maize, potatoes, sorghum	350	367	58	44	
Sudan	Wheat, sorghum, cotton, vegetables	905	735	87	57	
Tanzania	Maize, sorghum, rice	1,550	560	35	7	
Zaire	Maize, rice, cotton, cassava, groundnuts	1,313	729	8	7	
Zambia	Maize, groundnuts, sunflowers, rice	341	-	20	-	
TOTAL AFRICA		7,402	4,270	1,234	956	

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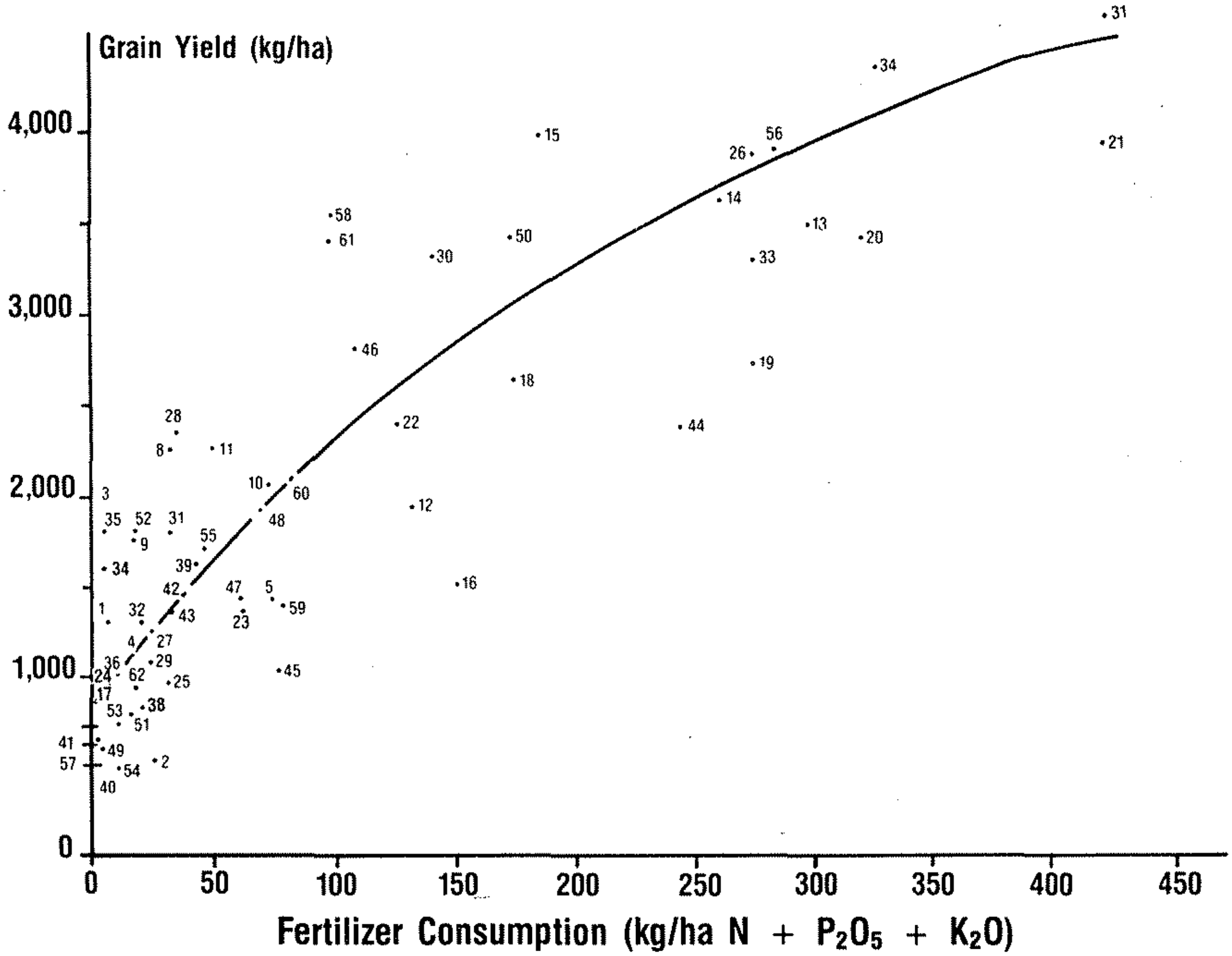
[a] Including trials and demonstrations laid out in 1982 but harvested in 1983 or laid out in 1983 and not recorded.



1 Afghanistan
2 Algeria
3 Argentina
4 Australia
5 Bangladesh
6 Brazil
7 Burma
8 Canada
9 Chile
10 China
11 Colombia
12 Cuba
13 Czechoslovakia
14 Denmark
15 Egypt
16 El Salvador
17 Ethiopia
18 Finland
19 France
20 Germany Dem R.
21 Germany Fed R.
22 Greece
23 Guatemala
24 Haiti
25 Honduras
26 Hungary
27 India
28 Indonesia
29 Iran
30 Italy
31 Japan
32 Kenya
33 Korea DPR
34 Korea REP
35 Madagascar
36 Malawi
37 Mali
38 Morocco
39 Mexico
40 Niger
41 Nigeria
42 Pakistan
43 Philippines
44 Poland
45 Portugal
46 Romania
47 South Africa
48 Spain
49 Sudan
50 Sweden
51 Syria
52 Thailand
53 Tanzania
54 Tunisia
55 Turkey
56 United Kingdom
57 Upper Volta
58 U.S.A.
59 U.S.S.R.
60 Vietnam
61 Yugoslavia
62 Zambia

Source: FAO, 1981. *Crop Production Levels and Fertilizer Use,* FAO Fertilizer and Plant Nutrition Bulletin, 2, FAO, Rome, Italy.

Figure 1. Cereal Yield and National Fertilizer Use in 62 Major Cereal-Growing Countries.

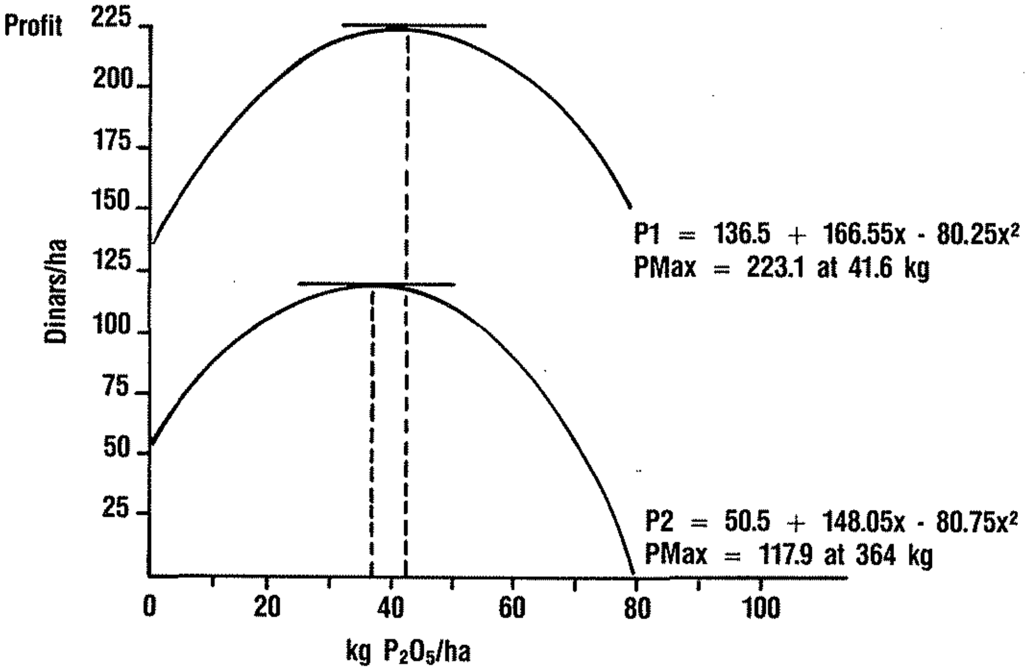


Figure 2. Profit Response Curves: Wheat Mean Results, Algeria, 1970, 1973; P1 = Normal Prices; P2 = High Prices.

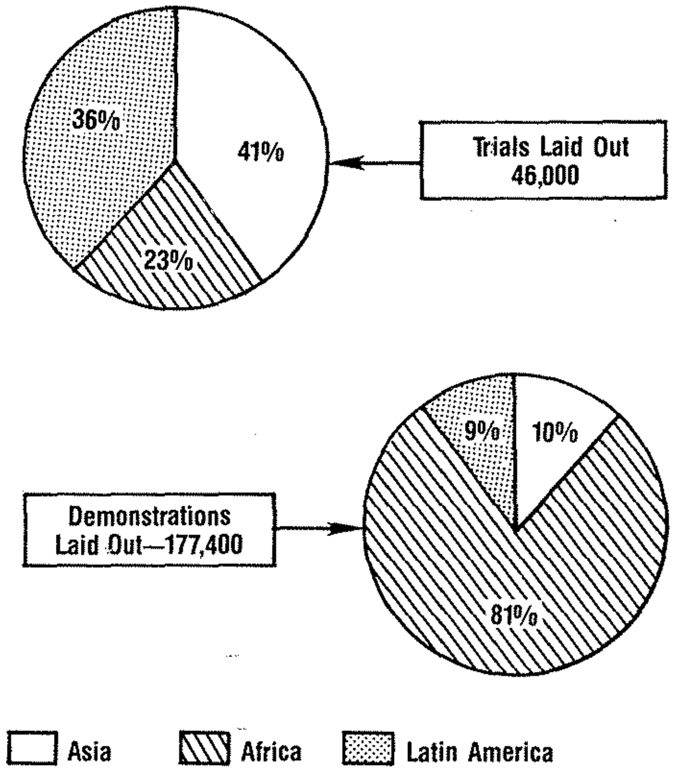


Figure 3. FAO Fertilizer Programme Field Trials and Demonstrations, 1961-82.

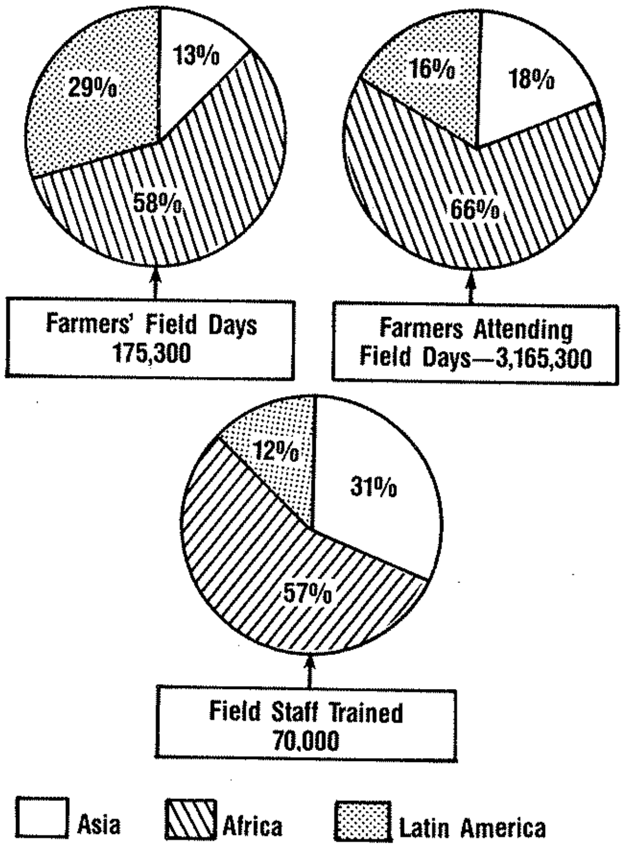


Figure 4. FAO Fertilizer Programme Field Days, 1961-82.

A LAND GRANT EXPERIENCE IN RESEARCH-EXTENSION LINKAGES

W. L. Pritchett

Conventional wisdom tells us that there are several ways for encouraging or improving fertilizer efficiency in a country with limited experience in fertilizer use. These include such practices as (a) making available the correct types of fertilizer materials at the correct time, (b) providing a widely available system of diagnosing nutrient deficiencies, such as a national program for testing farmers' soil samples and making recommendations; (c) conducting research into the kinds and amounts of fertilizers needed for prevailing soils, crops, and cropping systems, and (d) supplying an effective linkage between the researchers and the ultimate users of research information. I have been requested to relate some experiences of U.S. land grant colleges in research and extension linkages, with a comment on their possible application to conditions in Cameroon.

Experience With Land Grant Linkages

One of my first experiences with technology transfer occurred almost 40 years ago, when I was a graduate student at Iowa State University. I worked with an agricultural research scientist at the University to establish a series of NPK fertilizer test demonstrations on small grains in western Iowa, where fertilizers were essentially unknown at that time. The tests were simple 2 x 2 x 2 factorials, replicated in place, installed on farmers' fields, with the endorsement, and often the assistance, of the local county extension agents.

In preparation for the installation of large numbers of these tests, we would weigh and bag the fertilizer treatments for the individual plots in our laboratory over the weekend, and then take them to the field early Monday morning. We calculated, in advance, the approximate number of tests we felt were necessary to be installed on each major soil association in order to produce a reliable estimate of the yield responses one might expect from a given fertilizer treatment on a given soil.

Government of Cameroon and the U.S. Agency for International Development specifies the establishment at Dschang of an agricultural education and research institution modeled on the "land grant" agricultural university system, as practiced in the United States. In order to better understand what this mandate entails and the constraints to its implementation, let us first briefly examine the land grant concept.

The Land Grant Concept

The U.S. land grant universities are state-supported institutions of higher learning, in which agriculture and the mechanical arts are an integral part. They were established by an act of Congress and signed into law by President Abraham Lincoln in 1862. This law authorized a grant of public lands in each state for the establishment of an agricultural college.

It soon became apparent that, in order to teach improved farming techniques, there had to be more research and experimentation to provide information for dealing with the problems. Accordingly, in 1887 (almost a century ago), legislation was passed authorizing the establishment of agricultural experiment stations to be associated with each land grant college.

In a short time, these university experiment stations were developing valuable research results, but there were no adequate means of getting the new technology to the farmers so that it could be put to effective use. This was a situation not too different from that of Cameroon today. Fortunately, a third piece of legislation passed the U.S. Congress in 1913 to correct this problem. Agricultural extension services were created to be affiliated with the land grant college in each state. It should be noted that these extension services acquired a certain creditability and effectiveness from the beginning as integral parts of well-established colleges of agriculture.

These land grant colleges have grown into large, diverse universities which are sometimes difficult to distinguish from other universities. However, the unique feature of each of these institutions is the presence of the three highly complementary functions of agricultural teaching, research, and extension, and their strong orientation toward development and service.

The basic administrative unit of most land grant universities is the academic department through which all faculty are appointed. The departments are organized into the three functional areas, with individual faculty members responsible for one, two, or all three of the functions of teaching, research, and extension. Having all three functions in the same administrative and budgetary unit, and under a single administrator, makes it much easier to achieve the close, complementary relationship that has been a major factor in the success of these programs. No one of these functions would be as effective standing alone or operating as part of a separate administrative organization.

Constraints in Cameroon

The major constraint in developing the land grant model in Cameroon is that responsibilities for the three major functions of an agricultural university--teaching, research, and extension--have historically been placed under different administrative agencies. As a result, there has been little communication and cooperation and few viable linkages among the agencies charged with these functions.

The first step toward correcting part of this problem was taken in 1984 with the creation of the Ministry of Higher Education and Scientific Research. This brought together for the first time agricultural training and research under the same Ministry and created a framework for closer cooperation and communication between the institutions of higher education and the research institutions. The benefits expected from the creation of this Ministry have yet to be fully realized, but the potential certainly exists for cooperative research projects, sharing of equipment and facilities, and rapid incorporation of research results into teaching programs.

The major remaining constraint may well be the administration of the extension service within the Ministry of Agriculture, completely separate from the other two functions. The present organizational structure does not provide adequate communication links between the research and education institutions and the extension workers. The general lack of resources and low level of training of its agents further limits the effectiveness of the extension service. A reorganization to place the extension function under the new University Center of Dschang would appear to be highly recommended and in keeping with the mandate of the project agreement, but this would require action at a high level of government which could take considerable time to achieve. In the meantime, alternative linkages between these agencies must be explored.

Alternative Linkages

The organizational framework presently exists for developing the agricultural university at Dschang into the principal agricultural research organization in Cameroon. This could be accomplished by closer cooperation between the agricultural research centers and the University Center of Dschang or, better yet, by placing the administration of the agricultural research institutions under a director of research and extension at the university. Such a transfer would create a network of research and education centers in the different agricultural zones of the country. This network would be composed of the present research centers and stations, plus the present and proposed university antennae. These research and education centers would be intimately linked to the main campus with its library, laboratories, media center, and university faculty. Scientists at these centers could be given faculty status; joint, multidisciplinary research projects would then be developed between scientists at the main campus and those at the centers, and the research scientists at the centers could be given the opportunity to teach courses at the university.

The more pressing problem of creating an effective linkage between the university research activities and the Ministry of Agriculture Extension Service might best be accomplished by the addition of another function to the present organization. For example, in addition to the present service function of the Extension Service, a rural education program could be developed by the use of an extension subject-matter specialist staff located in their respective departments at the University Center of Dschang as well as at the research and education centers in the provinces. These subject-matter specialists should be capable of developing recommendations on improved production practices, in collaboration with their research colleagues, and they could provide a linkage between the university, the research institutions, and the Ministry of Agriculture field extension services. Such linkages should enhance the effectiveness of these institutions and help them better meet the needs of agricultural development in Cameroon. The subject-matter specialists in agronomy and soil science could provide leadership in the establishment of test demonstrations, as mentioned above, and training and visitation systems, now widely advocated, to help past extension workers teach farmers new skills and practices, particularly those relating to efficient use of fertilizers.

EFFECT OF NATIONAL POLICIES ON FERTILIZER USE

A. O. Falusi

Introduction

The seed- and fertilizer-induced production technology, which revolutionized the production practices and led to significant production increases for millions of farmers in the rice and wheat fields of Asia and Latin America, has yet to make any meaningful impact on the African continent.

The tragedy of the contemporary African scene is the fact that many African countries that were self-sufficient in food 20 years ago even though technologically backward agriculturally and industrially have become chronically food deficient today and still remain technologically backward.

The sub-Saharan African food scene has attracted a lot of attention from researchers, policymakers, and international donor agencies in recent years. The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the Organisation of African Unity (OAU), the United States Agency for International Development (USAID), the International Food Policy Research Institute (IFPRI), and the general research community have all been active in creating awareness about the deteriorating situation and in offering both explanations and policy prescriptions.

The aim of this discussion is not to provide a treatise on the policy failures of African agriculture but rather to highlight the potential role of fertilizers in helping to solve Africa's food problem. In this paper, an attempt will be made to provide answers to the following three questions:

1. Why have fertilizers not featured prominently in the solution to the African food problem?
2. What are the prerequisites to a seed-fertilizer revolution?
3. What policies need to be instituted to promote and sustain widespread use of fertilizers?

The paper is structured as follows. In the first section, the contemporary sub-Saharan African food scene is briefly discussed. This will be followed by an assessment of the fertilizer situation, drawing heavily from the Nigerian experience. Policies to promote accelerated growth in fertilizer use will be put forward in the third section of the paper. The last section contains the summary and conclusions of the paper.

Contemporary Sub-Saharan Africa Food Scene

The food production situation in sub-Saharan Africa has continued to deteriorate. Per capita food production in the subregion fell by 8 percentage points between 1973-75 and 1980-82 (Table 1). Although rate of growth of production almost matched rate of population growth in the 1960s, a higher population growth rate coupled with either little or no growth in food production led to a negative growth rate in per capita food production in the seventies in many African countries, as shown in Table 2. Thus it is not just that per capita food production is low but that it has continued to fall. A look at the food production situation will also reveal that unlike central, east, and southern Africa, which recorded modest increases in cereal production in the last decade, other regions experienced low and in some cases a negative growth rate. Production increases came about principally through area expansion rather than yield increases (Table 3). The implication of this for fertilizer use will be discussed later.

Food imports continued to soar. Cereal imports into the region doubled from 1.1 million tons in 1978 to 2.2 million tons in 1982 (Table 4). An increasing proportion of food imports coming in as aid is shown for selected countries in Table 4. It has been estimated that imports provided 20% of the region's cereal requirement in 1982 (FAO, Trade Yearbook).

The food situation is likely to be further aggravated as a result of the global economic recession facing the world, the decrease in the net availability of external assistance, and the tightening of food supplies in the world market as well as in many donor countries. In trying to reverse the gloomy trend, the World Bank has drawn up a joint program of action toward sustained development in sub-Saharan Africa, and OAU at its last summit of heads of states in 1984 in Addis Ababa, Ethiopia, endorsed the recommendation for an economic summit in Nigeria in 1985.

Given the physical and policy environment under which agricultural (particularly food) production takes place in the sub-Sahara, what is the potential role of fertilizers in helping to solve the food problem? This is the focus of attention in the next section.

An Assessment of the Fertilizer Situation in Sub-Saharan Africa

Agricultural production takes place in most sub-Saharan areas under poor or stagnant technology even though some farmers use improved technology.[1] The extent of this is shown in Table 5. Plant nutrient consumption per hectare in the continent in 1980 was less than 15% of that used in the Asian continent (FAO, Fertilizer Yearbook). Africa currently consumes about 3% of the total world consumption (Table 6). Between 1979/80 and 1982/83, Africa experienced an annual growth rate of 7.3%. This growth rate appears modestly impressive; however, because of the low base per hectare, consumption is still the lowest in the world.

Tables 7 and 8 bring this point home more vividly. Although consumption of plant nutrients increased in many sub-Saharan African countries between 1969/70 and 1981/82, the per hectare use is very low. As Table 7 shows, even though fertilizer use increased fourteenfold in Nigeria, the estimated plant nutrient use per hectare in Japan is 56 times more than in Nigeria. Nigeria's estimated plant nutrient use per hectare of arable land was less than half of the continent's average. Only one of the 39 sub-Saharan African countries uses more than 20 kg of plant nutrients per ha of cultivated land.

What factors are responsible for the low level of plant nutrient use in Africa? A number of reasons have been put forward:

1. The favorable land/man ratio in many African countries and the traditional practice of shifting cultivation. Indeed, production increases in African agriculture could be attributed mainly to extension of the area cultivated (Table 3).
2. The limited knowledge of the soil fertility conditions. In many African countries, soil fertility maps and land-use capability ratings are either nonexistent or completely outdated where they exist.[2]
3. Inadequate funding and support of research and crop technology development programs. Improved varieties of seeds that are highly fertilizer responsive are available in limited quantities in many African countries. Viable seed industries are yet to be developed.

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[1] In the Agricultural Development Projects (ADPs) areas of Nigeria, evidence abounds that farmers are adopting improved production technology. However, the total arable area under the ADPs in Nigeria in 1980 was less than 15% of total area.

[2] In Nigeria, land-use capability ratings are still based on the soil map prepared by FAO in 1964. Attempts have been made to update this, but the revised soil map is still not widely available.

4. Limited irrigated area. There is a high correlation between land under irrigation and fertilizer use. Unfortunately, the percentage of land under irrigation remains extremely low as pointed out in Table 5.
5. Unfavorable price relationships. A favorable price relationship is a necessary though not a sufficient condition to encourage fertilizer use. In many African countries, a combination of low farm-gate prices for produce and trade policies that encourage imports have turned the terms of trade against farmers. Low staple food prices do not provide the farmer much incentive to use fertilizer.
6. Limited credit. Farmers in general are unquestionably short of working capital, especially during the planting season, and this affects their ability to purchase the modern farm inputs made off the farm.
7. Lack of adequate information concerning results of on-farm crop demonstrations and trials that demonstrate the profitability of fertilizer use at current price relationships. The dissemination of information on the technical and economic aspects of fertilizer use to the farming community has been partly hindered by the limited extension personnel available and the grossly inadequate facilities available to them. In many African countries the number of farmers for each extension worker exceeds 2,000. With this low ratio, it should not be surprising that the use of fertilizer on previously unfertilized land would be extremely low even when the land is planted with crops that could be profitably fertilized.
8. Deficiencies in the procurement and delivery system. Fertilizers not being available at the right time and in sufficient quantity hinders the growth of fertilizer use among the farming community. There are noticeable deficiencies in the procurement and delivery systems for fertilizers in many African countries (IFDC, 1980).
9. Foreign exchange constraints. As a result of worsening balance of payments and the increasing burden of debt servicing, many African countries are having to ration their foreign exchange allocations. In almost all cases, foreign exchange provisions for fertilizer imports and/or imports of raw materials and spare parts (when there is a domestic production facility) get cut off or are seriously delayed. Consequently, when the fertilizers finally arrive, they are too late for the particular cropping season.

Policy Measures to Promote Fertilizer Use

Opportunities exist in many African countries for rapidly increasing the use of fertilizers within the farming community. This is because of the following factors:

1. The low fertility status of the soils and the need to replenish their nutrients.
2. The current low levels of fertilizer use.
3. The possibility of rapidly increasing production in the short run without undertaking the necessary long-term structural reforms, e.g., land reform.
4. The scale-neutrality of the seed-fertilizer technology (i.e., it has the potential to benefit the small as well as the big farmers equally).
5. The crucial role of fertilizer in import substitution (i.e., importation of fertilizers could replace cereal imports).

The policy measures that could be used to stimulate and sustain growth in fertilizer use will now be examined by using Nigeria as a case study.

Features of Agricultural Policy in Nigeria

Nigeria's agricultural policy rests essentially on three pillars:

1. The production of food adequate in quantity and quality to meet the needs of the population at reasonable prices.
2. The production of raw materials for local agroindustries and for export to earn foreign exchange.
3. The provision of gainful employment for the majority of the rural population, which will thereby enhance their income and welfare.

The ADP approach favors a philosophy of development that emphasizes the ongoing action of and assistance to smallholder farmers as the centerpiece of development activities. In this regard, smallholder farmers are encouraged to increase their productivity, expand production, generate more marketable surplus, and thereby earn higher incomes. The major thrust of activity is, therefore, the evolvement of operational strategies and programs to ensure that credit, modern inputs, intensive extension service production and marketing incentives, and various infrastructural facilities are provided. The key policies provide for the following:

1. Agricultural credit.
2. Farm input supply.

3. Mechanization.
4. Input price subsidy.
5. Agricultural product pricing and marketing.
6. Agricultural extension.
7. Research and technology development.

Assessment of the effectiveness of this array of policy measures in bringing about the desired changes in agricultural production is beyond the scope of this paper.

Main Elements of Fertilizer Policy in Nigeria

Nigeria's fertilizer policy derives directly from the country's general agricultural development policies. The goal of its fertilizer policy is to encourage widespread use of fertilizers by small landholders as a means of increasing agricultural production and raising rural incomes.

The main elements of the policy are as follows:

1. Expansion of fertilizer supplies through allocation of foreign exchange for imports, centralization of procurement, and creation of domestic production capacity.
2. Nationally fixed uniform retail price for fertilizers.
3. Federal and state subsidies of fertilizer price.
4. Fertilizer distribution primarily through public channels.
5. Promotion of fertilizer use through the operations of the agricultural extension machinery as well as project authorities in integrated ADPs.

Other ancillary agricultural development policies that influence fertilizer use include crop price supports, development of irrigation facilities, provision of agricultural credit, agricultural research (including soil fertility research and development of fertilizer-responsive varieties of seeds), development of rural infrastructures, and crop marketing improvements. However, fertilizer supplies and price subsidy schemes have received by far the greatest attention.

The effectiveness of the policy measures has been evaluated in previous studies carried out by the author (Falusi, 1981; Falusi and Williams, 1981).

Policy Implications

The policy implications of the discussion in the preceding paragraphs for accelerating the growth in fertilizer use in Nigeria as well as in any other country (African or other) are considered in the following section.

Three important factors influence the pace at which the full potential of fertilizer use is to be realized in any country:

1. The rate and the level at which effective demand can be generated for fertilizer by farmers.
2. The rate at which supplies can be increased to keep pace with increasing demand.
3. The creation of an adequate and efficient marketing system for distribution of supplies.

Although each of these factors is important, the interaction among them is even more important in understanding fully the process and the forces generating growth in fertilizer use in any country. Growth in fertilizer consumption in a country results from the conversion of viable potential into actual fertilizer use. The viable potential is determined by the environment with respect to physical responses of crops to fertilizer and prices of crops as well as fertilizer. Actual fertilizer use invariably begins very much below the viable potential. The pace of growth in fertilizer use over time does not depend only on the fertilizer response functions and prices or changes in them. The rate at which fertilizer consumption grows is also affected by the following factors: overall availability and distribution arrangements; farmers' effective demand for fertilizer (as governed by their perception of net returns from its use on different crops); support systems of research (which besides developing new technology also generates knowledge about the response function; extension (which spreads this knowledge among farmers); and credit (which facilitates the flow of fertilizer from factories and ports to farmers' fields).

The influence of aggregate supply on effective demand extends beyond the usual price effects alone. It has impact on the geographical expansion of the distribution system and the efforts to generate effective demand for fertilizers where its use is potentially profitable to farmers.

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Table 1. Average Index of Per Capita Food Production in Selected Sub-Saharan African Countries (1969-71 = 100)

Country	Year 1973-75	 1977-79	 1980-82
Cameroon	99	110	102
Ethiopia	67	84	82
Ghana	88	82	72
Guinea	91	86	89
Ivory Coast	110	102	107
Kenya	101	92	88
Mali	88	85	83
Niger	91	89	88
Nigeria	96	87	92
Somalia	91	89	88
Tanzania	101	94	88
Zambia	110	99	87
Sub-Saharan Africa	96	91	88

Source: The World Bank. *World Development Report* (various issues).

Table 2. Growth in Agriculture in Selected Sub-Saharan African Countries

	Average Annual Growth Rate in Production				Average Annual Growth Rate of Per Capita Total Production			
	Food		Total Agriculture		Food		Total Agriculture	
Country	1960 to 1970	1970 to 1982	1960 to 1970	1970 to 1982	1960 to 1970	1970 to 1982	1960 to 1970	1970 to 1982
					(%)			
Cameroon	4.6	2.1	4.8	2.0	2.5	-0.9	2.7	-1.0
Ethiopia	2.9	1.7	3.0	1.5	0.5	-0.3	0.6	-0.5
Ghana	2.6	-0.2	2.6	-0.2	0.3	-3.1	0.3	-3.1
Guinea	2.7	1.5	2.7	1.4	1.2	-0.5	1.2	-0.6
Ivory Coast	5.2	6.0	5.5	5.0	1.4	1.0	1.7	0.1
Kenya	3.6	2.0	3.3	2.7	0.4	-1.9	0.1	-1.2
Mali	1.3	2.5	1.6	2.7	-1.2	-0.2	-0.9	0.0
Niger	2.7	4.1	2.7	4.0	-0.7	0.8	-0.7	0.7
Nigeria	0.5	2.5	0.4	2.4	-2.0	-0.1	-2.0	-0.2
Somalia	2.8	1.0	2.8	1.0	0.0	-1.8	0.0	-1.8
Tanzania	5.5	2.1	5.0	1.0	2.7	-1.3	2.2	-2.3
Zambia	3.5	1.8	3.1	1.7	0.9	-1.3	0.5	-1.4
Sub-Saharan Africa	2.5	1.7	2.5	1.4	0.2	-0.9	0.2	-1.1

Source: The World Bank. 1984. Toward Sustained Development in Sub-Saharan Africa, p. 77.

Table 3. Area, Yield, and Production: Average Annual Growth Rates in Selected Sub-Saharan Africa, 1969-71 to 1977-79

Crop, Community, and Region	Production	Yield	Area
	(%)		
Cereal			
The Sahel	-1.8	-1.4	-0.4
West Africa	0.9	-0.2	1.1
Central Africa	3.5	0.6	2.9
East and Southern Africa	2.6	1.4	1.2
Roots and Tubers			
The Sahel	-1.7	-1.2	0.5
West Africa	1.9	0.3	1.6
Central Africa	1.4	-1.8	3.2
East and Southern Africa	1.7	2.6	-0.9
Pulses			
The Sahel	1.6	-1.9	3.5
West Africa	2.0	-1.6	4.8
Central Africa	1.9	-2.0	4.0
East and Southern Africa	1.9	-0.2	2.1

Source: FAO. Production Yearbook (various issues).

Table 5. Modern Input Use: Africa, Asia, and South America, 1980

Area	Percentage of Irrigated Land (%)	Tractors per 10,000 ha	Fertilizer Used (kg/ha)
Africa	2.1	8	6.2
Asia	31.0	48	45.4
South America	7.5	57	38.8

Source: FAO. 1981. Production Yearbook and Fertilizer Yearbook.

Table 6. Estimate of Plant Nutrient (N + P_2O_5 + K_2O) Consumption, 1979/80-1982/83

Region	Quantity				Percentage			
	1979/80	1980/81	1981/82	1982/83	1979/80	1980/81	1981/82	1982/83
	('000 tons)				(%)			
1. Africa	2,782.4	3,266.0	3,587.2	3,438.4	3.0	3.4	3.7	4.5
2. North and Central America	24,803.7	25,637.1	14,053.1	11,324.3	26.2	26.1	25.1	13.4
3. South America	4,663.3	5,290.3	3,694.3	3,652.4	5.0	5.5	3.9	3.8
4. Asia	28,054.9	30,684.0	31,373.6	33,052.5	29.6	32.0	32.7	39.1
5. Europe	32,683.4	31,191.1	31,410.4	31,518.8	34.5	32.0	32.8	37.3
6. Oceania	1,854.7	1,717.2	1,705.7	1,567.0	1.7	1.0	1.8	1.9
7. World	94,842.4	96,068.5	95,824.3	84,553.4	100.0	100.0	100.0	100.0

Source: FAO. Monthly Bulletin of Statistics, March 1984.

Table 7. Consumption of Fertilizer Per Hectare of Arable Land in 20 Selected Countries

Country	Year 1969/70	 1981/82
	(kg $[N + P_2O_5 + K_2O]$/ha)	
Argentina	2.4	2.7
Brazil	17.0	35.0
Cameroon	3.0	6.5
Canada	19.2	50.0
Chile	31.0	20.0
Egypt	128.0	247.5
Ghana	1.0	7.2
India	11.4	34.0
Ivory Coast	7.0	13.2
Japan	315.0	389.0
Kenya	22.0	35.0
Nigeria	0.5	7.0
Pakistan	17.0	53.0
Philippines	21.0	32.0
Senegal	2.0	5.0
Thailand	8.0	18.0
United Kingdom	252.0	330.0
United States	80.0	102.0
Western Germany	418.0	420.0
Zambia	7.0	17.0
Africa	5.0	16.0
North America	78.0	101.0
Western Europe	239.0	446.0
Near East	14.0	35.0
Far East	24.0	50.0

Source: FAO. Fertilizer Yearbook (various issues).

Table 8. Distribution of 39 Sub-Saharan Countries in Terms of Fertilizer Consumption in 1981/82

Plant Nutrient ($N + P_2O_5 + K_2O$) Consumption, kg/ha	Number of Countries	Percentage Distribution
Less than 5	11	28.0
5-10	16	41.0
11-15	7	18.0
16-20	4	20.0
Over 20	1	3.0
	39	100.0

Source: The World Bank. World Development Report 1984.

FERTILIZER MARKETING FOR DEVELOPING COUNTRIES

Lewis B. Williams

Introduction

There is an urgent need to change the course of events relating to food production and fertilizer consumption in Africa. The October 1984 issue of African Business states: "Africa stagnates as agriculture fails...per capita income grew at less than 1% in 11 sub-Saharan countries...food output per person has declined in 25 countries." An increasing population and a reduction in food production can only lead to a disastrous situation. Why should Africa not be self-sufficient in food production? Africa has 210 million ha of arable and permanent cropland and another 800 million ha of permanent grassland. Many soils are highly fertile; according to agronomists, with the application of good management practice, they have the ability to produce several times as much as their current output. Yet, Africa is the only continent where food production per capita has decreased in the last 20 years.

The FAO 1982 Production Yearbook shows that cereal production in Africa is basically flat or slightly down from 72.2 million tons in 1980 to 71.4 million tons in 1982. In the mid-1970s Africa was producing 70 million tons of cereals and was importing only one-third of the 23.8 million tons imported in 1982 (FAO 1982 Trade Yearbook).

During the period 1981-83 developing countries as a group increased fertilizer consumption by 3.7%. In Africa during the same period, fertilizer consumption declined by 9%. The role of fertilizers in food production has been established. High yields per unit of area cannot be sustained over time without the use of fertilizers. A reduction in fertilizer consumption in Africa inevitably results in reduced food production.

The reasons given for the decline in fertilizer consumption in Africa include the usual constraints caused by an inefficient marketing system and unfavorable economic environment, i.e., reduction of farmer incentives, lack of attention to the farmers' input needs, etc. These are real constraints to farmers. However, in a country with low productivity, these constraints can be overcome by the development of an effective marketing system that will make conditions favorable for increased food production.

Several market researchers (Drucker, 1958 and Shapiro, 1965, cited in Barksdale and Anderson, 1982) and others have emphasized the positive relationship between efficient marketing and economic development. It is interesting to note that so-called developed countries where food supplies and per capita income appear to be adequate employ a private-sector philosophy toward marketing. The developing countries where food is often in short supply and per capita incomes are low have a tendency to employ government-planned and government-managed marketing systems. Inefficient crop production in Africa can be directly related to inefficient marketing, including that for fertilizers. Marketing therefore should be defined.

There are three broad-based marketing concepts--public sector, cooperative, and private sector. The private-sector approach will best supply the African farmers the right product, at the right time, in the right place, and in the most cost-efficient manner. The private-sector concept of fertilizer marketing can be compatible with the philosophies of different governments. It provides an opportunity to have an efficient fertilizer marketing system that will help accomplish national goals of increased food production. The purpose of this paper is to describe the basic fertilizer system and concepts used by the private sector. A limited discussion of the public-sector and cooperative marketing concepts is necessary for comparison and in establishing the private-sector approach to fertilizer marketing.

Definition of Terms

Fertilizer Marketing

The definition and meaning of fertilizer marketing is widely misunderstood and misused. Definitions used seem to coincide with goals established by different philosophies. In many countries distribution of fertilizer is called marketing; in others selling is called marketing. In some, marketing may suggest a stockist role of making fertilizers available. On some occasions we hear the wholesaler's function referred to as a marketing system.

The definition of fertilizer marketing used by the private sector is the same as that given by marketing academicians. It is as follows:

> Fertilizer marketing embraces all business activities involved in the flow of goods and services from production to consumer including the elements of forecasting the need for and deciding the product, providing place utility, product pricing, and promotion. These activities are

viewed from the position of satisfying the end user's (consumer's) demand for fertilizers.

The structured performance of these functions constitutes a marketing system.

Ownership

Ownership of a fertilizer marketing system appears to be highly important in many developing countries because of the power it provides. It will be shown in the last section of this paper that methods of ownership do not have to influence the efficiency of operation. The organizational structure, philosophies, management techniques, and goals are the all-important components of an efficient marketing system. The methods of ownership and goals for the three basic approaches to fertilizer marketing are shown as follows:

Ownership	Goal
Public sector (government)	National/social benefits and control
Cooperative	Member benefits
Private sector	Profit oriented

There are different methods by which governments own fertilizer marketing organizations. Quasi-government organizations are joint ventures between private interests and government. The ownership ratio can be set at any desired level. A parastatal is an autonomous government-owned organization. The goals established for these organizations would be determined by the governments involved.

Public Sector--The main objective of these centrally planned systems is to promote the national best interest; whether the marketing of the product generates a profit or loses money is incidental to the planned objective. Some public-sector marketing systems have objectives of:

1. Using a product such as fertilizer as a means of increasing domestic crop production. In these instances increased crop production may have a greater value to the nation than any losses that may occur in fertilizer marketing. From the national viewpoint "the end justifies the means." Price controls, regulations, quotas, product allocations, and subsidies are used to reach the national or social objective.
2. Providing a product at a cost that is low enough to induce its introduction or continued use, regardless of marketing costs.

3. Providing a product at the same price to all consumers regardless of cost to serve each consumer.

The public-sector marketing concept is not based on a principle of competition.

Cooperatives--The cooperative marketing system is designed to serve and benefit members. The system is owned and operated by members and is planned and managed to serve members with products and services at lower prices; any profits are returned to members through lower prices or patronage dividends. The products marketed must provide a benefit for the owner members. When a cooperative system is controlled by government, it is not a cooperative in the true meaning and should be classified under the public-sector method of ownership.

Cooperative systems are usually formed to offer competition to the public or private sectors. Once a monopoly position is gained, cooperatives seldom offer competition among themselves. True farmer agricultural cooperatives often use the integrated marketing management concept.

Private Sector--The goal of this basic system is to make a profit by the marketing of a product. In some instances marketing may be a way to maximize profit built into the product at the point of production or the declared value of the raw material that the producer owns. In the private-sector system, the costs at each step of marketing may determine whether or not a profit can be produced.

Private-sector marketing systems are designed to make a profit. Some products are high volume and low profit, whereas others may be low volume and high profit. In order to survive, each product marketed must generate a profit.

Goals of the private-sector marketing system complement those of the governments. The private-sector approach is to encourage as many farmers as possible to use fertilizers judiciously and increase food production. Profits created in one area may be used in educational programs to encourage sales in areas of low use. These marketing systems are designed to satisfy the customer in the most cost-efficient manner, keep farm-gate fertilizer prices as low as possible, and ensure a continued growing demand. The private-sector concept is based on having competition to keep the system efficient.

Marketing System Normally Used--In actual practice, national marketing systems seldom use one pure basic system. Most often they use variations of and/or combinations of one or more basic systems.

The degree to which the different elements of a marketing system are used will vary from organization to organization and country to country. It will depend to a great extent on an organization's objective and the national environment in which the organization will be operating.

The Total Marketing System

Public-sector and cooperative marketing concepts can best be compared with the private-sector approach in the areas of controllable and noncontrollable factors, integrated and unintegrated systems, and the role of dealers and government. As the definition implies, fertilizer marketing involves the functions of deciding the products, providing place utility (distribution), product pricing, and promotion of the products. In fertilizer marketing this is referred to as the four Ps. The marketing system is responsible for the four Ps. Therefore, a total marketing system is a combined effort of all organizations and their people who perform the marketing functions. These functions may be performed by several organizations or by a single one. To illustrate, some of the functions are supply--product, transportation--place, warehousing--place, subsidies--price, agronomic research--promotion, soil testing--promotion, and educational meetings--promotion.

Controllable and Uncontrollable Factors

The four Ps are the controllable factors in a fertilizer marketing system. The four Ps are controlled in a marketing mix designed to satisfy the customers' needs while accomplishing the marketing goal. Figure 1 illustrates the controllable factors and the role of the marketing system while operating in an environment of uncontrollable factors. The uncontrollable factors that the marketing system has little influence over are Economic Environment, Political and Legal Environment, Cultural and Social Environment, Resources and Objectives of the Organization, and the Existing Business Situation. The private-sector approach is to recognize the uncontrollable factors and operate the controllable factors as efficiently as possible. Cost effectiveness and efficiency of operation are the key management tools.

The private-sector concept is management oriented--to determine needs and wants of markets and adapt itself to delivering satisfaction efficiently and more effectively than its competitors. The public-sector and cooperative marketing systems are not management oriented, and cost effectiveness is not always an objective. For this reason there are many examples of developing-country marketing costs equaling c. & f. port cost of fertilizers. For example, in Nigeria in 1980 the c. & f. port cost of urea, single superphosphate, and muriate of potash was 59%, 45%, and 50%, respectively, of the retail price. In Zambia, a country with long supply lines, it was found that marketing costs were equal to c. & f. port prices of fertilizer. In Cameroon in 1983 the farm-gate cost in Bafoussan of 20-10-10 and ammonium sulfate was 65% and 58%, respectively, of the c.i.f. Douala port price. Long supply lines heavily influence marketing cost, and marketing cost guidelines cannot be exact; however, in the private sector in developed countries, the cost of an efficient fertilizer marketing system should not exceed 20% of the product cost.

Integrated and Unintegrated Systems

As discussed above, a marketing system is the total effort of the people performing the marketing functions, and it encompasses the organizations that perform these functions. The private-sector approach is to have one single autonomous marketing-oriented organization perform all of the marketing functions. Its management-oriented concept is to delegate authority, responsibility, and accountability at the lowest possible level. Figure 2 shows an integrated marketing system. Principal characteristics of an integrated marketing system used by the private sector are the following:

1. One autonomous organization has authority, responsibility, and accountability for all marketing activities.
2. Authority, responsibility, and accountability are vested in the lowest level employee responsible for the activity.
3. Marketing objectives are specified.
4. Detailed job descriptions with scheduled objectives are implemented.
5. The organization has the right to hire, dismiss, and promote personnel on the basis of job performance.
6. Cost-effective programs (budgets) generate a desired profit level.
7. The system is self-supporting through profits generated.
8. The retail dealer satisfies his customer's needs on an on-going basis.
9. Intensive programs of employee training and development are carried out.

An unintegrated marketing system similar to that used by public-sector marketing systems is shown in Figure 3. Marketing functions are carried out by different organizations as shown. For example, the Ministry of Agriculture is responsible for ordering fertilizers and carrying out research and extension activities. The Ministry of Communications is responsible for publicizing the use of fertilizer. The Ministry of Finance sets fertilizer prices. The Ministry of Transportation does the shipping, and the Ministry of Industries carries out domestic production of fertilizers. Planning and execution of the marketing functions are usually not well coordinated. It is almost impossible for an unintegrated marketing system to function efficiently. If the volume of fertilizer handled is small and demand is low and does not need to be increased, and if the cost of marketing is not an issue, an unintegrated system might do the marketing job. But when the fertilizer volume handled is large and marketing costs need to be kept to a minimum, an unintegrated marketing system cannot perform the expected task efficiently. The principal characteristics of an unintegrated marketing system would include the following:

1. Marketing functions are usually not well coordinated.
2. Functions are not coordinated by a manager whose sole interest is fertilizer marketing.
3. Authority and responsibility for carrying out functions are often divided among personnel.
4. Accountability is often not assigned to personnel having responsibility for functions.
5. Responsibility, authority, and accountability are not delegated to the people at the lowest possible level having responsibility for each function.
6. Job descriptions are usually not specific, and often employees have other time-consuming responsibilities.
7. Hiring, promoting, and dismissing employees are usually controlled by civil service regulations and not controlled by the marketing system.
8. Cost effectiveness is usually not a major concern.
9. The system is usually not self-supporting and is made operational through subsidies.
10. Marketing objectives are not usually defined because of the monopolistic nature of the system.
11. Retail dealers are usually stockist and do not offer a continuous feedback of information on the market requirements.

Retail Dealers

In the public-sector marketing system, the dealer plays a very insignificant role. The dealer is usually nothing more than a stockist. Under the private-sector approach, the dealer plays an important role. The dealer is the all-important connecting link that ties the farmer to the system that is designed to serve him. The dealer is sensitive to the customers' needs and gathers information that will help in satisfying the farmers' needs. The private dealer is an important component in a marketing system that is designed to understand the marketplace and to develop a strategy for obtaining a share of the fertilizer business and protecting it against competition. The private-sector marketing system encourages competition at the dealer level to ensure quality of service.

With the private-sector approach, the dealer sells a crop production program--not just a product. He has seed, crop protection chemicals, fertilizers, equipment, and knowledge on their best use. He often buys farmers'produce, operates a sales development program for his customers, and assists them in obtaining production credit. The dealer has storage for products and a place for displaying the products that he has for sale. Most importantly, he is a salesman. He calls on farmers to tell them of the advantages of the crop production program that he can provide. For these purposes he is assisted by agronomists and field representatives of the marketing system. Their job is to help him become a successful agricultural businessman. In the private-sector approach, the marketing system supports and intensifies the efforts of the existing extension network.

Getting customers at the retail dealer level to understand what is offered and how to use it is one of the most critical elements of getting and keeping customers. Selling is very much an educational process. The private-sector approach allows the marketing organization to encourage and assist its dealers in assuming responsibility for dissemination and interpretation of technical research of value to their customers. The complexity of agricultural technology makes it increasingly difficult for the extension agent to provide all the information necessary to today's farmers. With the private-sector approach, the dealer is able to advise his customers on the proper use of the products sold; he does not rely exclusively on the extension service to provide this information.

In choosing dealers the private sector looks for the following qualities:

1. Ability to sell.
2. Community respect.
3. Favorable credit rating.

4. Adequate storage capacity.
5. Desire and ability to purchase farmers' products.
6. Sale of other essential crop production inputs.
7. Ability to make farm visits.
8. Ability to participate in demonstrations, field days, advertising programs, and forecasting of sales.
9. A place of business within his market area.
10. Knowledge of agriculture.
11. A reasonable sales volume within his area.

The private-sector approach to fertilizer marketing is for the dealer to provide a connecting link between the agricultural research organizations and the farmer for whom most of the research is intended. The dealers in the marketing system are a key link in disseminating information on fertilizer use. The dealers are also an important link in the feedback of farmers' information to the researchers on the need for additional research.

The public-sector marketing systems referred to take an entirely different approach toward retail dealers. They do not have dealers according to the modern definition of marketing and the role of dealers. Their dealers are more similar to stockists. If a customer knows what he wants, the stockist may provide it. He is usually not equipped to advise on product use, cost of nutrients by sources, and the benefits of different products. The stockist does not carry out any educational programs or provide any service other than a supply of product. The stockist most often does not operate a place of business and usually will not offer a market for crop produce. In many situations, the agricultural extension officer or a government officer has the responsibility of dispatching fertilizers to farmers from a government-controlled store house. This seriously jeopardizes his role of carrying out educational programs with farmers.

Role of Government in Private-Sector System

In the private-sector approach, government involvement in fertilizer marketing is limited to the role of regulator. One role of government is to safeguard competition. Competition is good for a country, and it is good for the marketing systems. It keeps the cost of marketing down, and it helps to keep the marketing system sharp and creative in developing fertilizer sales.

Another role of government is to have quality control legislation and to enforce the laws. The laws should protect the farmer from any fraudulent activities by anyone in the supply and marketing chain and should establish penalties for those indulging in such activities. It must ensure that the farmer gets proper weights and guaranteed analysis.

Still another role of government is to establish policies that will allow the efficient functioning of a fertilizer marketing system. The government through favorable policies should promote the availability of a fertilizer supply to the marketing system. It is necessary for the marketing system to cover cost and make a suitable marketing margin. Government should establish favorable policies toward crop price supports, fertilizer prices, subsidies, taxation, crop produce, marketing, and credit.

The private-sector approach to government in fertilizer marketing is that government should help but not hinder. Although the private sector does not expect a preferred treatment by government, it does want a fair and equal opportunity for developing an efficient and competitive fertilizer marketing system.

Government-Owned Integrated Systems

There is a way for governments to own and control a successful integrated fertilizer marketing system and not be directly involved in the marketing implementation. Many times governments nationalize fertilizer production and marketing operations to gain control of the fertilizer industry in their countries. They take over an efficient integrated marketing system and immediately convert it to an unintegrated, inefficient system. In a limited time, fertilizer marketing becomes chaotic and expensive, and fertilizer consumption begins to decline.

It is very simple and easy for governments to employ the private-sector concept in fertilizer marketing and enjoy the benefits and at the same time own and control the system. Figure 4 illustrates how a board of directors can control such an organization. The government controls the organization by appointing the board of directors from its principal ministry staff. The board of directors elects a chairman from among its members, or the chairman may be selected by government. The board determines all policy issues. A general manager is hired by the board of directors and is responsible for implementing the policy. The general manager is normally a board member and is responsible only to the board of directors.

The private-sector approach to management must be installed at the board of directors' level. The board makes policy, and the general manager carries it out. The board does not get involved in execution of policy. The marketing organization is an autonomous organization having specific responsibilities, authority, and accountability for the operations as outlined under the integrated marketing system.

Governments often want to employ some of the principles and guidelines used by the private sector but not all of them. This is when the system begins to collapse. Governments may install the autonomous organization concept and assign responsibilities but not give authority to management for execution.

Government most often imposes the civil service procedure for hiring, promoting, and firing employees. The marketing system is faced with taking government employees who do not have the necessary skills for performing marketing tasks. The marketing organization is handicapped with a procedure where good employees cannot be promoted until they have been in service for a certain length of time. Worst of all, it is difficult for the marketing organization to fire an employee for an inadequate job performance.

Figure 5 depicts stages of the development of fertilizer use. The stages or classifications are based on quantities of fertilizer consumed per hectare of cultivated land and are Introduction Stage I, Take-Off Stage II, and Maturity Stage III. During the introductory stage total tonnage consumed in a country may be small, i.e., Tanzania--3,000, Sierra Leone--3,000, Nepal--22,000, Afghanistan--37,000, and Burma--166,000 tons of product in 1982. During the introductory stage and even during the early portion of the take-off stage, marketing costs may not be a burden since the fertilizer tonnage is small. During this period two situations may exist. First, a country may elect to keep fertilizer marketing in the public sector and have large educational and promotional programs to encourage increased consumption. Second, the tonnage of fertilizer consumed is small, and it may be difficult to find a private company that will be willing to develop fertilizer use for several years prior to reaching a self-supporting level of sales. If a government wants the private sector to develop fertilizer sales, most likely it will have to subsidize a company until the profitable level of sales is reached. During this period usually one organization having a monopoly position can do the marketing. Even with a subsidy payment the private sector can be less costly than many of the public-sector marketing systems.

When countries consume large tonnages of fertilizer, it is advisable to have several organizations involved in fertilizer marketing. Competition helps to keep the marketing organizations sharp, effective, and efficient. In a complex marketing situation, the private dealer is more sensitive to the farmers' needs and can provide marketing intelligence to management for decisionmaking. The private-sector approach to fertilizer marketing is applicable in this stage.

In many cases it would be advisable for governments to try the private-sector approach to marketing in stages. Stage I could be to commercialize or privatize the dealer operations. Stage II could be to commercialize the warehouse portion of the marketing system. Stage III could be the privatization of the autonomous organization to manage the entire system. The changing of a public-sector marketing system to a private-sector system should be designed and planned to meet the needs of the specific country involved. Another approach would be to set up an experiment or trial and learn how to manage a small marketing organization in a small section of the country prior to installing a country-wide private-sector marketing system. An IFDC publication, _A Seeding Program for Fertilizer Marketing_, explains the advantages of learning how to manage a program in a small area before undertaking a country-wide marketing program.

The private-sector approach offers governments the opportunity of owning and controlling an efficient fertilizer marketing system. Regardless of whether this approach is called the private-sector approach or something else, the principles remain the same. This approach is working in India, Korea, Japan, Australia, and many countries with organizations like Indian Farmers' Fertilizer Cooperative, International Minerals Chemical Company, Gulf Chemical Company, and many more. In developing countries, however, the private sector and the value of market forces as a source of guidance in establishing efficient fertilizer marketing systems have not been utilized. This source of technical assistance needs to be used. Crop produce marketing in Africa has been developed largely by the private sector. Even with the handicaps of bureaucracy, the private sector has rewarded countries with a good market. Positive policy support will help the private sector to do an even better job in crop produce marketing. Experiences from the private sector in crop produce marketing can be used in fertilizer marketing. For the private-sector concept to work, however, the whole package of concepts must be used. A private-sector approach to fertilizer marketing offers Africa an opportunity to avoid a repetition of the failures of marketing systems of the past.

Conclusions

There is an urgent need to increase food production in most African countries. Fertilizers are an essential input for increasing food supplies. Constraints caused by an inefficient fertilizer marketing system can be eliminated with an efficient system.

The private-sector approach to fertilizer marketing is used in most so-called developed agricultural economies and offers an opportunity for a developing country to own and control its own efficient system. The entire package of management principles must be installed in an autonomous organization having responsibility, authority, and accountability for success.

Many countries having centrally planned economies are now employing the private-sector approach not only to fertilizer marketing but also to crop produce marketing as well. If governments are unsure about shifting to a private-sector approach on a country-wide scale, phasing in the system and small experiments with an autonomous marketing organization in a test area may be tried.

The private-sector approach to fertilizer marketing is a proven system. It will make the right fertilizer available to farmers at the right time, in the right place, in the right quantity, and in the most crop-efficient manner. It can make the difference in having an adequate future food supply.

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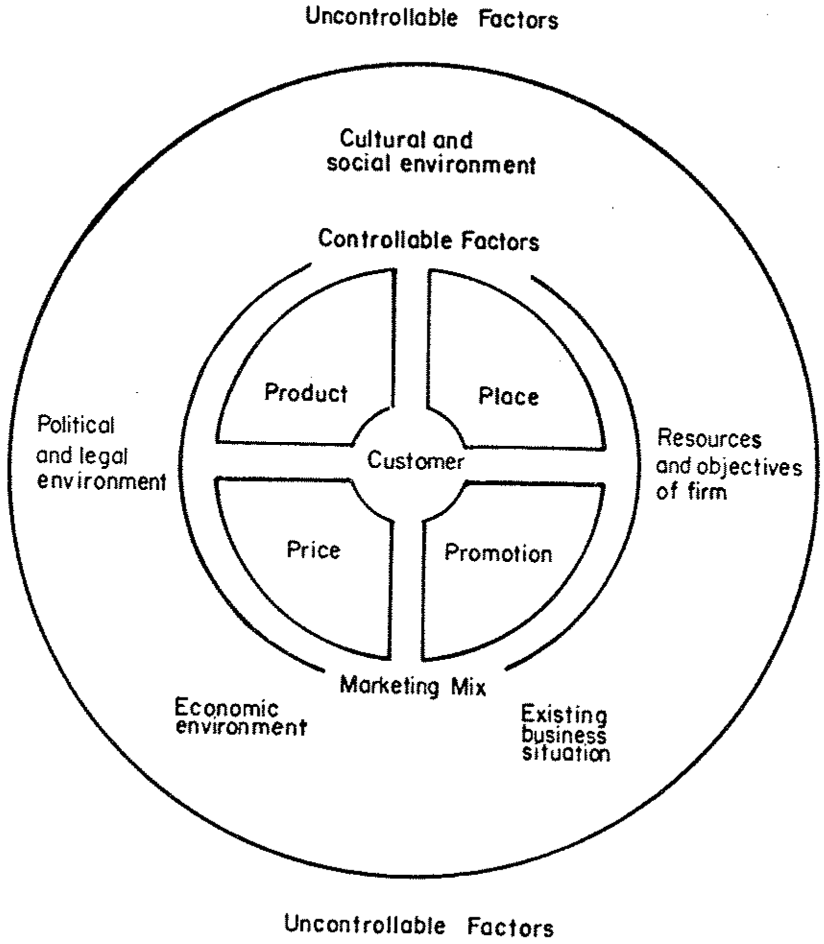


Figure 1. Marketing Management Focuses on Satisfying the Farmer Using the Controllable Factors Within an Uncontrollable Environment.

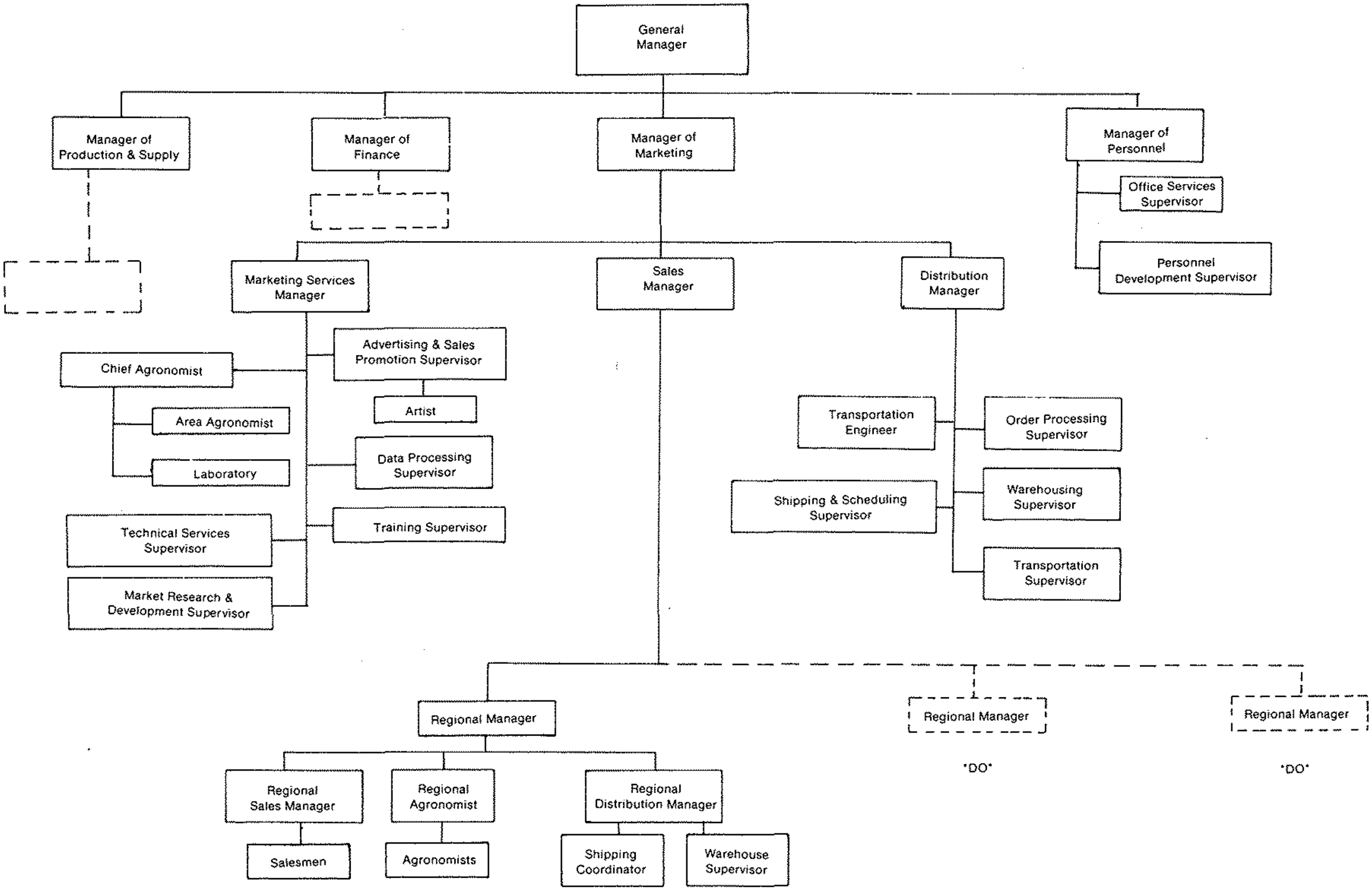


Figure 2. Organizational Chart of an Integrated Fertilizer Marketing System.

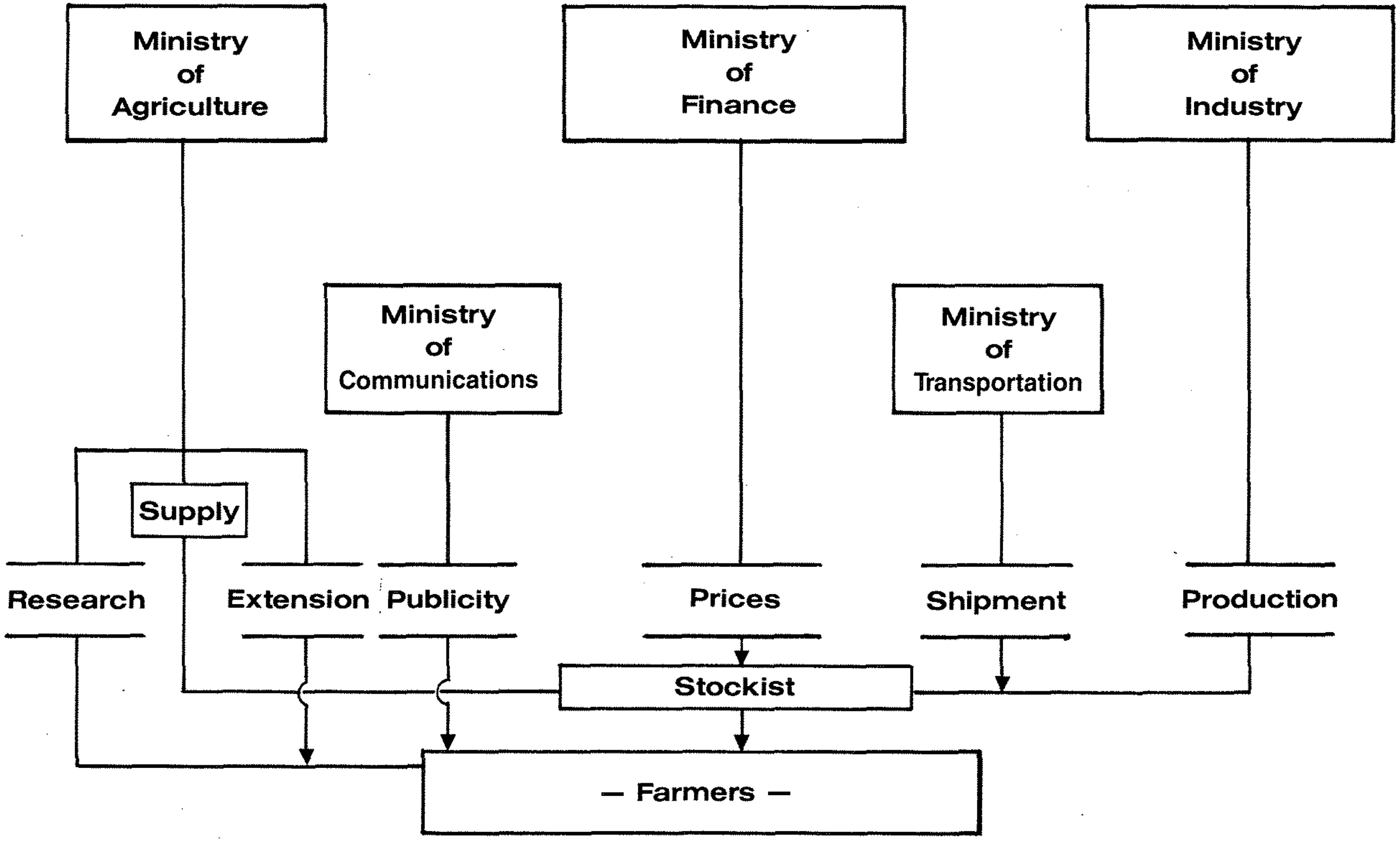


Figure 3. Organizational Chart of an Unintegrated Fertilizer Marketing System.

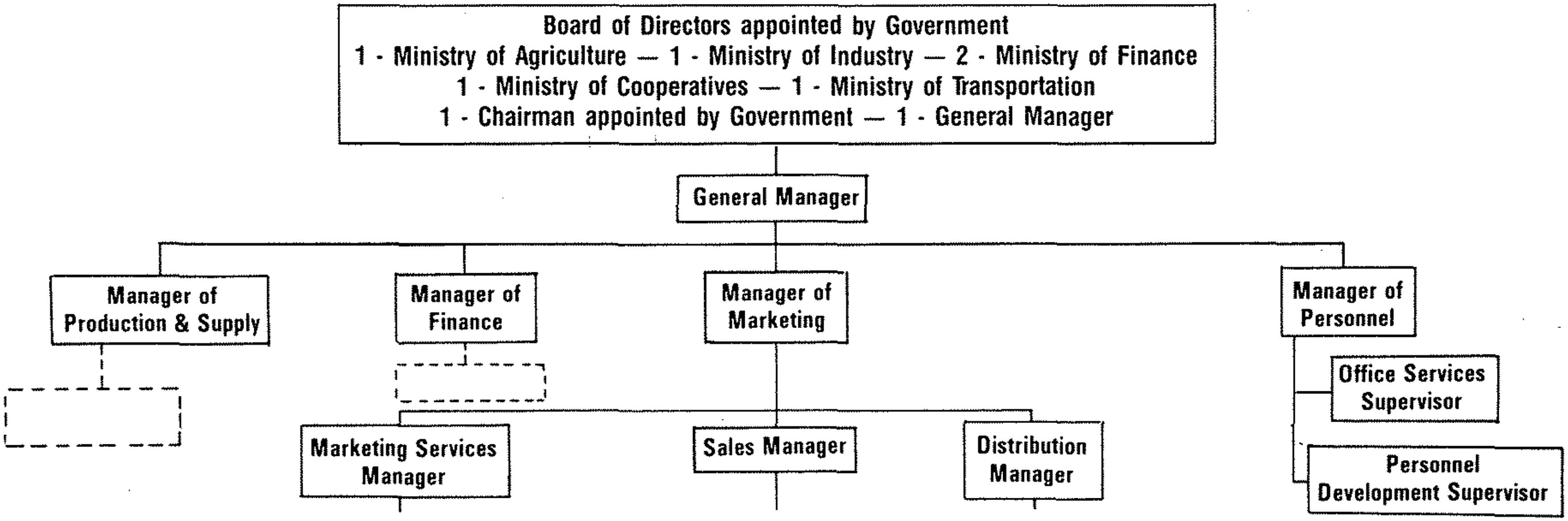
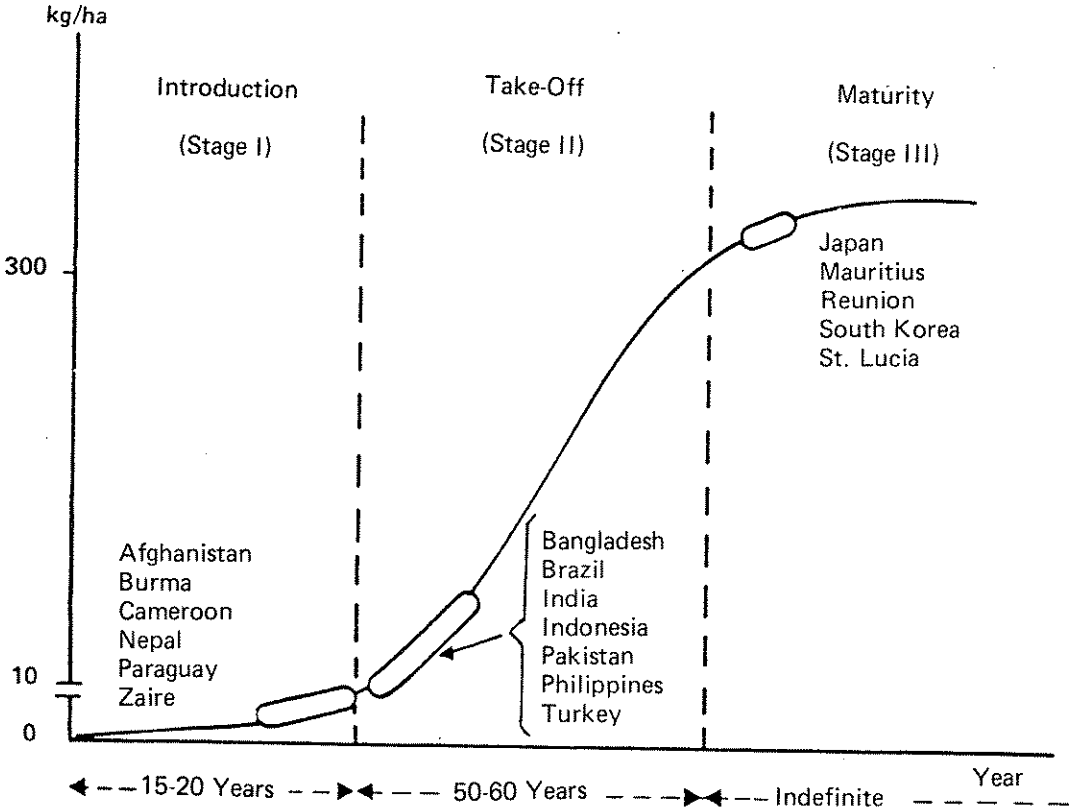


Figure 4. Organizational Chart of a Government-Owned and Controlled, Integrated Fertilizer Marketing System.



Source: C. Y. Lee. 1980. "Stages of Fertilizer Use Development and Marketing Policy," FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. (mimeo)

Figure 5. Stages of Development of Fertilizer Use in Selected Countries.

Country Papers

THE EXTENSION SYSTEM AND FERTILIZER RESEARCH IN LIBERIA

Alton Johnson

Liberia is a country bounded on the east by the Republic of Ivory Coast, the west by the Republic of Sierra Leone, the north by the Republic of Guinea, and the South by the Atlantic Ocean. This nation, which is predominantly evergreen forest, receives annually 110-160 inches of rain along the coastal plains and 80 inches about 80 miles north of the coast. Liberia has a bimodal rainfall pattern: the rainy season commences in May and ends in October, and the dry season is from November to April.

Topographically, Liberia contains farming soils on slopes ranging from 1%-45%. Parent materials from which Liberian soils are derived are mostly granite and granitic gneiss. Soils found at the base of slopes or stream terraces are sediments of granitic gneiss. Wetland soils are derived mainly from alluvial materials. There are 22 series of soils and 3 soil orders. Eighteen of the series are Ultisols, two are Inceptisols, and two are Entisols. The soils have a pH range from 3.5 to 5.8. The high level of acidity makes them infertile; as a result, the optimum yield cannot be obtained without fertilization.

Approximately 80% of the farming population engages in shifting cultivation or the bush fallow system, a pragmatic agricultural solution for people who live in primitive conditions and pay a high price in human endeavor.

In that a very high number of the farming population does not have an agricultural education (whether formal education or "learn by doing") and those with an agricultural education are not engaged in farming, the situation becomes complex. Most graduates in agriculture have found themselves in research institutions or in high places in agricultural projects throughout the country; this has compounded the problem, for it has left very few to carry contemporary agriculture to the illiterate farmers.

During the last decade, the Ministry of Agriculture decided to extend itself into every region of the country. The effort resulted in the creation of Agricultural Development Projects (ADPs). The primary objective of the projects is to promote improved agricultural practices to the farmers engaged in food and cash crop production. Even though agricultural extension emerged in the Liberian society about 28 years ago, the program had little focus.

The ADPs triggered the process for providing some of the farmers with some level of improved farming methods today. This extension work provides farmers not only with improved cultural practices or technology in food and cash crop production, but also with roads, wells, latrines, improved sanitary conditions, child care, and nutritional education. (The last three are in the embryonic stage.) These make the Liberian extension system an "Integrated Rural Development Program."

While it is true that the ADPs provide extension service to the farmers, they depend greatly on the extension agents to send the message of modern agriculture throughout the country. Therefore, training divisions of the projects provided basic technical skills to selected individuals as extension agents. Their shortcoming, however, was a lack of experience in interpreting research results for the farmers.

In response to the need for training, the Episcopal Church of Liberia, the Ministry of Agriculture, the United States Agency for International Development, and the Cuttington University College agreed to cooperate in providing a 2-year technical education program in the field of agricultural extension. The intention was to bridge the gap between the researchers and the farmers. The program commenced in 1978 with the establishment of the Rural Development Institute (RDI).

Since 1978, at the beginning of each year a group of young men and women has been enrolled in RDI's 2-year agricultural training program. Students are drawn from each of the major geographic regions in Liberia and are exposed to basic courses such as Plant Science, Animal Science, Soil Science, Agricultural Economics, Farm Management, Agricultural Engineering, and others during the first year of study. Students have the option of selecting Plant Science or Animal Science as their area of specialization during the second year. Agricultural Extension is compulsory for all second year students, with Land Surveying, Soil Taxonomy, Soil Survey, etc. as electives.

Since RDI is an extension institution and its paramount objective is to create a breed of young men and women to carry modern agriculture to the farming population, it becomes imperative to transfer technology to the surrounding villages in order to strengthen the practical abilities of the students and the rural human resources in that area.

The Division of Technology Transfer, realizing the involvement of both farmers and students in this process, chose the name Farmer Involvement Program (FIP). The program seeks to provide "on-farm" practical training to the students and at the same time seeks to improve the farmer's welfare by demonstrating to him, first hand, improved methods of crop and animal production.

In setting up the FIP, it became essential that effective linkages be established and maintained between the regionally focused agricultural extension program, the experiment station-based research program, and the implementing and planning institutions. This has been facilitated through such approaches as meetings and visits of staff to other programs. The program, which was established in March 1984, maintains linkages between itself and such organizations as the Bong Country Agricultural Development Project, Central Agricultural Research Institute (CARI), Nimba Country Rural Development Project, Partnership For Productivity, and Smallholder Rice Seed Project.

The objectives of the farmer and his family are directly incorporated into the FIP. The farmer is the central unit in the on-farm practical training exercise. Involvement of farmers gives them a voice in the design of on-farm exercises. Technical feasibility and social acceptability of the practical exercises determine whether the farmer is able to adopt the improved practices.

A few of the benefits the farmer derives from participating in the FIP are (1) increased cash income--the result of the on-farm practical exercises is to produce a substantial surplus of marketable commodities, (2) an increase in the family food supply, and (3) a move from shifting cultivation to continuous use of land or rotations that result in a substantial increase in per acre returns.

The FIP began with the identification of farmers from the nearby villages within a 10-mile radius of RDI. A multidisciplinary team, herein called the Monitoring and Evaluation Committee (M&E Committee), consisting of an agroengineer, a soil scientist, an economist, an animal scientist, and a plant scientist were involved in the identification process.

A farmer is selected to participate in the FIP on the basis of the following criteria: (1) he must have demonstrated his competence in managing a small agricultural enterprise (e.g., rice farm, coffee/cocoa farm, swine/poultry farm, etc.), (2) he must have ownership or guaranteeable rights to an area of farm land located within 10 miles of the RDI campus, (3) he must be willing to sign a contract with RDI obligating him to reimburse the FIP for any recurrent costs incurred upon his behalf (e.g., seed, fertilizer, insecticide, etc.). Payment in kind is accepted.

When a potential farmer is identified by the M&E Committee, another team, consisting of RDI technical assistants from various disciplines, makes an onsite inspection of the farm to describe and interpret the farmer's situation and identify management problems and possible development opportunities.

On the basis of the finding of the Technical Assistants Team, the M&E Committee identifies improved animal/crop production practical exercises and farming methods that have a potential for improving the welfare of the farmer.

Next, the Technical Assistants Team conducts on-farm practical exercises selected by the M&E Committee as relevant and feasible for the farmer, given the conditions he faces in production.

Following the completion of the on-farm practical exercise, the M&E Committee identifies unsolved technical problems the farmer faces and recommends alternative strategies in conducting on-farm practical exercises to the Technical Assistants Team.

The various stages of the FIP can be summarized as follows:

1. Identification of the farmer.
2. Survey of farmers' priorities and resources and diagnosis of environment and development problems.
3. Identification and evaluation of materials and techniques offering potential for problem solution.
4. Conducting on-farm practical exercises relevant and feasible under farmers' conditions.
5. Identification of unsolved technical problems and possible new practices and materials relevant to farmers' development opportunities.

As a supplement to the FIP, an on-campus Demonstration Farm has been constructed. RDI will conduct practical exercises for freshmen on the Demonstration Farm. Participating and other interested farmers will be brought in to view recent advances in crop/animal production.

The site selected for the Demonstration Farm is adjacent to a river and is within a 10-minute walk from the RDI classroom building. The area of the farm is approximately 4.0 acres. Three soil types occur on the farm, with the

Kpatawee series being predominant. The Kpatawee soil is suitable for a variety of crops including bananas, cashew, citrus, coffee, cocoa, oil palm, rubber, rice, and others.

It is a well-drained, moderately permeable, and gravel-free soil. The others are the Balam clay and the Sinyea sandy clay loam, which is very gravelly. Some of the features of the Demonstration Farm are as follows:

1. Mixed cropping demonstration: growing peanuts and maize.
2. Rotation cropping demonstration: the use of legumes or leguminous trees to maintain soil fertility.
3. Mulch demonstration: the use of a selected living or dead mulch to suppress weeds, conserve moisture, and minimize erosion.
4. Low-cost animal house demonstration: the use of indigenous materials to construct pig pens, chicken coops, and rabbit hutches.
5. Improved post-harvest technology demonstration: the use of indigenous materials to construct improved food crop storage structures.

Fertilizer use may account for most of our agricultural production in Liberia. One main reason for the necessity of fertilization is the high intensity of rainfall in that region of Africa. Almost all of the soils are deficient in one or more of the 16 essential nutrient elements needed to sustain plant growth. These nutrient elements may be lost through plant removal, leaching, erosion, volatilization, denitrification, fixation, or any combination of these loss processes. Such losses alter soil fertility; as a result, a fertilizer management program is needed in Liberia to supplement the original soil minerals or replace the natural soil nutrients that have been lost. However, before the establishment of a fertilizer program, it is necessary to make a quantitative evaluation of existing soil fertility levels.

The method best qualified to assay the soil and develop profitable fertilizer recommendations is that of measured crop response to fertilizer in field experiments on all appropriate soil types and under all possible cultural practices. However, even to the casual observer, it is obvious that measured crop response to fertilizer in the field cannot be obtained for every field, for every crop, for every year, and for every climatic and cultural condition although this ideal is our ultimate objective.

In addition to soil fertility evaluation provided by the field fertilizer experiment, other evaluation methods are being seriously considered. Among other methods are nutrient deficiency symptoms, nutrient analysis of plant tissue, chemical analysis of the soils, and measured plant response to nutrients in greenhouses and growth chambers.

Although not all of the evaluation methods can be carried out fully, the experiment on crop response to fertilizers is the primary approach used at the University of Liberia, CARI, and RDI.

We at RDI work in collaboration with the International Network on Soil Fertility and Fertilizer Evaluation for Rice, based in the International Rice Research Institute.

Last July we started with an experiment on the efficiency of different sources of N-fertilizers for upland rice during the wet season.

Our aim was to measure the response of a single variety of rice to six sources of N-fertilizers. We were also interested in the rates and methods of application. This would help us to identify efficient fertilizers and transfer that information to the farmers.

Soils vary in the amounts of nutrients that they supply to growing plants. The amounts of nutrient elements available depend greatly on the plant's need and ability to compete for nutrients, the amounts and kinds of nutrient reservoirs present, and environmental parameters such as temperature, water, and aeration. Because of the diversity in the properties of our soils (both physical and chemical), these factors are considered in predicting the fertilizer needs.

All of our research work on fertilizers consists of preliminary investigations. The fertilizer rates used in Liberia are recommendations from other tropical countries with established fertilizer management and evaluation programs. Our hope is to obtain a sound fertilizer evaluation progrm in the years to come, for we are aware that a knowledge of soil-plant relations is important if determination and interpretation of the quantities of nutrients recommended are to be meaningful.

RAPPORT DU PAYS SUR LES PROGRAMMES DE RECHERCHE A COURT OU A LONG TERME

Kotto - Same

GENERALITE: L'économie du Cameroun est essentiellement basée sur l'agriculture qui emploie plus de 70% de la population active totale. La contribution de l'agriculture au PIB est évaluée à plus de 30%, 50% aux recettes nationales, 40% aux ressources budgétaires nationales. Nous pouvons donc voir à travers ces taux, la place, on ne peut plus prioritaire qu'occupe notre agriculture dans la promotion de l'économie nationale en général et dans l'amélioration du niveau de vie des citoyens en particulier.

Si pour le gouvernement Camerounais la réalisation de ce but, constitue un pari à gagner à tout prix, un deuxième pari reste cependant un souci permanent; celui de maintenir notre auto-suffisance alimentaire sous toutes ses formes et dans tous les coins du Cameroun.

Pour atteindre cet objectif, 3 voies sont souvent suivies

- La première consiste à augmenter la superficie cultivable.
- La deuxième vise à l'augmentation de l'intensité culturale
- La troisième est liée à l'augmentation de rendements;
  Tout ceci implique l'utilisation rationelle des engrais organiques et minéraux.

Utilisation des Fertilisants au Cameroun; l'Historique des Engrais

L'utilisation des engrais pour l'augmentation de la productivité alimentaire dans le monde actuellement ne peut plus être trop soulignée. De tous les facteurs d'intensification de l'agriculture, c'est-à-dire mécanisation, production de variétés à haut rendement, méthode intégrées de contrôle antiparasitaire etc, l'emploi des engrais minéraux et autres, seuls contribuent à environ 50 à 65% à l'accroissement de la production agricole.

Bien que les engrais soient utilisés de longue date, cette utilisation n'a pris de l'essor, qu'à partir de 1973, terme du programme engrais FAO exécute au Cameroun de Septembre 1966 à Décembre 1973.

Les objectifs de ce programme visaient entre autres la mise au point des méthodes de vulgarisation et d'utilisation efficace des engrais. Diverses recommandations ont alors été retenues correspondant à des formulations moyennes adaptées à diverses cultures vivrières.

Pour donner suite à ces recommandations la FAO se propose une fois de plus d'apporter son appui pour le lancement d'un second projet engrais dont les objectifs immédiats sont multiples.

Le programme national des engrais vise en priorité l'approvisionnement des petits producteurs grâce au processus des marchés publics. Certains facteurs limitants tels que lenteur administrative, déblocage tardif des crédits, enchères au niveau des prix etc... font que de plus en plus, il est envisagé la libéralisation de l'approvisionnement et de la distribution des intrants dans leur ensemble. Mais leur importation reste cependant règlementée.

- La Recherche Agronomique et le rôle des Engrais

Si l'utilisation rationnelle des engrais est recommandée par la politique agricole du Cameroun, il importe de rechercher des doses efficientes d'engrais et d'en proposer des formulations recommendables dans diférentes zones Agro-Eco-Pédologiques et sur les différentes cultures. Aussi cette charge incombe t-elle à l'Institut de la Recherche Agronomique en général et au Centre National des Sols en particulier.

- Le Centre National des sols (CNC) (voir organigramme page 2)

- Role et Objectifs

Cré eu 1983 au sein de l'IRA le Centre National des Sols a pour rôle et objectifs:

- La centralisation, la programmation, la coordination, la réalisation directe ou indirecte de l'ensemble des études (recherches et inventaires) concernant les sols sur tout le territoire national.

- L'acquisition et la diffusion de l'information pédologique en utilisant toutes les méthodes utiles de collecte et de traitement et de coopération avec les systèmes nationaux et internationaux d'information.

- La formation des cadres à tous le niveaux du CNS et la participation aux décisions prises par les responsables de l'aménagement et de la planification en vue de la conservation des ressources naturelles.

Le Centre National des Sols a une vocation interdisciplinaire Etude de la pédologie et de ces applications à des problemes concrets liés au développement.

Bref le Centre National des Sols constitue un outil priviligié dont s'est doté le governement Camerounais pour promouvoir le développement économique du pays sur la base des acquis scientifiques et techniques. Il est par conséquent soutenu par l'Etat.

Composition Structurales du CNS

L'organigramme de la page 2 nous montre d'une manière claire les quatre sections qui composent le CNS. Dans ce séminaire la section qui nous intéresse est celle de l'utilisation et de la mise en valeur des sols; cette section détermine la fertilité actuelle des sols, recherche, expérimente et recommande des méthodes d'utilisation optimale des ressources en sol disponibles.

Les opérations de recherche au CNS exécutées par la section de l'utilisation et de la mise en valeur des sols, sont multiples. Elles concernent la recherche sur le comportement physique et mécanique des sols en relations avec l'utilisation du matériel agricole lourd.

Cette opération a commencé en 1984 et les premières observations faites sur une culture d'arachide, indiquent que les moyennes des rendements entre les pratiques de non labour, travail minimum du sol et mécanisation conventionnelle ne sont pas significativement différentes. On note cependant au regard des profils racinaires, une colonisation de plus en plus forte de l'horizon Ap par les racines à mesure que l'intensité de la préparation du sol croît. Il faudra poursuivre cette opération pour confirmer ou infirmer ces premières observations.

La deuxième opération concerne l'évolution des sols sous cultures vivrières continues en relation avec l'utilisation de la matière organique: il s'agit du recyclage de la parche de café. Dans cette opération la parche de café a été utilisée comme matière organique dans la culture du maïs et du manioc sous des formes combineés. Les premierès observations sont mentionnées dans ce tableau.

L'analyse des sols montre une augmentation du potassium échangeable de 0,10 meq/100g à 0,50 meq/100g en moyenne pour les parcelles sans pache et avec pache respectivement. L'enfouissement de la pache semble plus bénéfiques pour le rendement que son apport en surface.

- La troisième opération concerne l'évolution sous culture de la fertilité des sols en relation avec le chaulage. L'objectif de cette opération est de déterminer la dose optimale de chaux à apporter sur les sols acides rouges ferrallitiques à l'ouest du Cameroun.

Des traitements combinés chaux/engrais ont été appliqués sur les dispositifs de blocs de FISHER à 4 répetitions Randomisées.

Résultats Dans les conditions de notre expérimentation, la chaux se confirme comme l'un des factures limitant du rendement de maïs. L'apport combiné chaux/NPK s'avère très récessaire pour obtenir du haut rendement 1000 kg/ha de chaux pourrait faire l'objet de recommandation aux vulgarisateurs de cette localité.

Quatrième Opération: Etude de disponibilité des éléments fertilisants sous cultures vivrières.

Cette étude est en cours et nous attendons les résultats. Comme vous le voyez nous n'avons cité que quelques opérations parmi une vaste série de thèmes de recherche que le CNS est en train d'entreprendre.

- Opérations en Perspective Dans le domaine des opérations futures le CNS entend réaliser les études sur la valorisation agricole des déchets des poulets de ferme et des boues résiduelles collectées localement.

Vous trouverez dans la petite brochure d'autres projets nationaux dont la réalisation est en étroite collaboration avec le PNUD-FAO.

COUNTRY PAPER ON AGRICULTURAL EXTENSION AND RESEARCH LINKAGES

N. E. Mumba and M. R. Mulele

Introduction

Agricultural extension in Zambia is largely carried out by the Department of Agriculture in the Ministry of Agriculture and Water Development (MAWD).

The basic function of the Extension Branch, under the Department of Agriculture is to provide technical and managerial advice, information, and skills to agricultural producers. The ultimate goal is to improve husbandry practices and farmer efficiency with a view to increasing output and in the long run create a large pool of self-reliant and viable farmers, especially from the rural populace.

Free extension services to farmers are provided through farm visits to both individuals and groups, training courses at farm institutes and farmer training centers, radio broadcasts of topical information, and publications distributed at field days.

Currently the nature of the extension effort, through its programs, is largely directed toward advising farmers to improve on existing husbandry practices in order to increase agricultural production and their own productivity. In the case of crop production this takes the form of teaching the farmer and demonstrating to him the results of adapting improved cultural practices. New technology is introduced as it becomes available.

Although, ideally, the Extension Branch is obliged to serve all types of farmers (large-scale commercial, medium-scale commercial, small-scale commercial, and traditional), the emphasis is now more on the small-scale farmers in the rural areas. This is because they form the vast majority of the farming population and clearly lag behind in terms of improved knowledge and technology.

Prior to 1970, the emphasis of the extension program was mainly on a few crops such as maize, cotton, tobacco, and rice. In fact, the policy then encouraged specialization by extension agents. Thus, there were Cotton and Tobacco Assistants, dealing only with farmers growing those crops. However, specialization by Extension staff at field level has been phased out owing to the country's desire to be self-sufficient in many agricultural products.

With emphasis being placed on reaching more farmers through extension contact, the approach now is to interact with groups of farmers rather than with individuals. Thus, efforts are currently being made to develop an intensive system of extension based on the training and visit system of extension methodology.

Organization Structure

The Department of Agriculture is one of the four departments in the MAWD, headed by the Permanent Secretary.

The organization chart which follows summarizes the structure of the Department of Agriculture and its three branches. As can be seen from the chart, the Director of Agriculture is supported by three assistants, each of whom is in charge of a branch: Research, Extension, or Land Use.

The Extension Branch is organized on a national, provincial, district, and field level. At the national level, the Assistant Director (Extension) is supported by seven sectional heads, i.e., Senior Subject Matter Specialists. This setup is replicated at the provincial headquarters where Subject Matter Specialists are under the administration of the Provincial Agricultural Officer who is the defacto director of agriculture in the province.

At the district level, the Extension Branch operates (through the District Agricultural Officer) a network of agricultural stations and camps where field-level extension workers are based. These are the staff who work directly with farmers and are in constant touch with them.

Staffing

The Extension Branch has a total of 80 posts for professional officers (i.e., degree holders) and 1,500 posts for the technical staff (holders of diplomas and certificates in agriculture).

Extension agents who work directly with farmers number approximately 800, and the ratio of extension agents to farmers is 1:800. Although this ratio may appear ideal, the average agent's area of more than 600 km^2 tends to limit effective extension coverage.

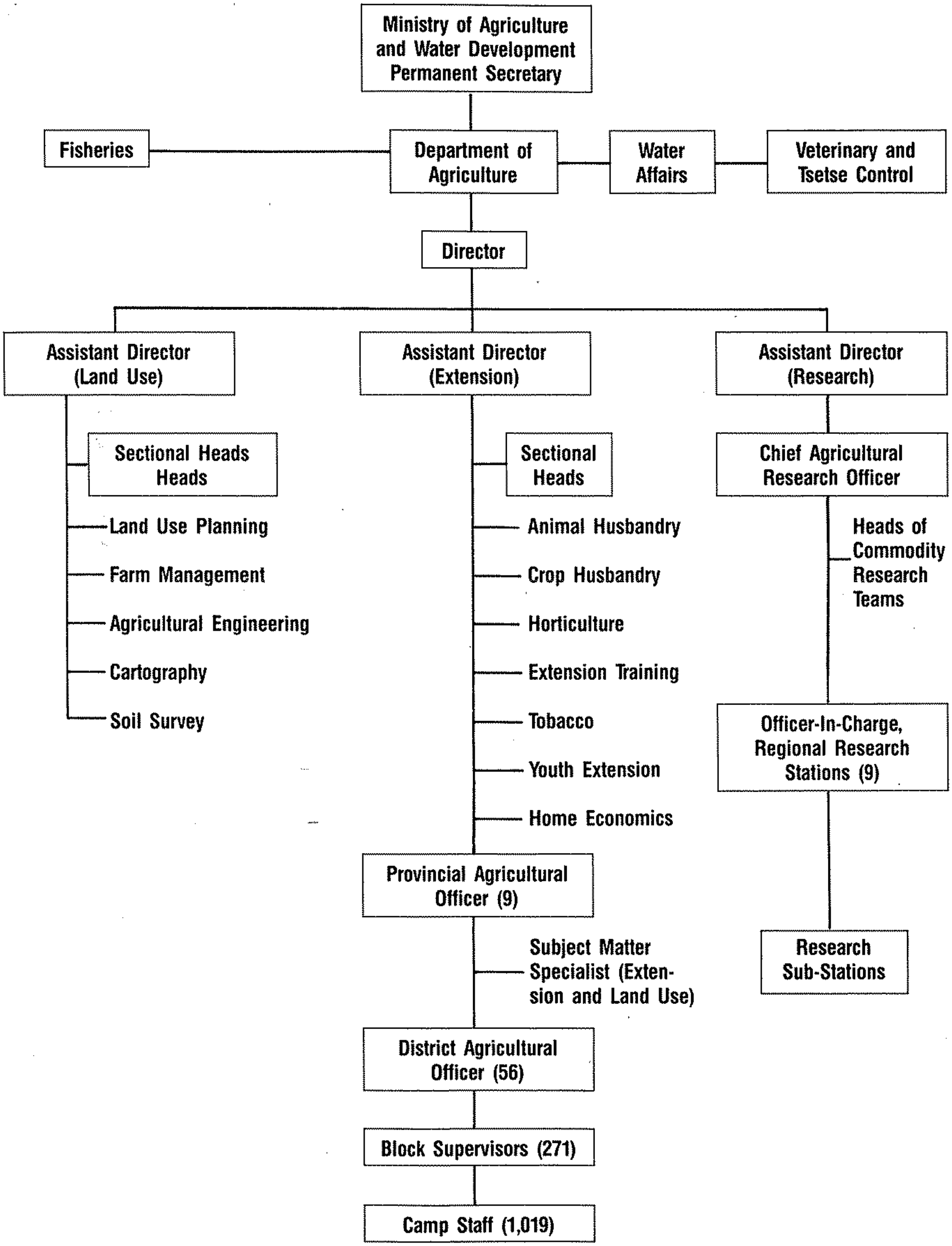


Figure 1. Organizational Structure of the Department of Agriculture.

Links With Research

Formal links between the Research and Extension Branches exist through various committees, notable ones being the annual commodity research meetings (e.g., oilseeds, cereals, livestock, etc.) which are attended by Extension Subject Matter Specialists. In addition, there are a number of coordination committees, whose membership is made up of Research and Extension personnel and staff from other relevant organizations. Until recently, the senior Research and Extension personnel took annual tours of provinces at the beginning of the cropping season to obtain firsthand information about the farmers' problems in the field. These were called Provincial Experiments Committee (PEXCO) meetings. Proceedings from PEXCO meetings were then discussed at the commodity research meetings later in the year. Such an arrangement helped to focus research in the direction of field problems faced by farmers.

Over the years PEXCO meetings became somewhat ineffective because the problems that were surfacing had little relevance to research--e.g., delayed input supplies and late payment for produce. This, coupled with restrictive budgetary allocations for recurrent expenditure, has resulted in the temporary shelving of the annual research extension provincial tours and the PEXCO meetings.

The establishment of the position of a Research-Extension Liaison Officer (RELO) at the Headquarters of Agricultural Research and in all Adaptive Research Planning Teams (ARPTs) based at the provincial level is aimed at strengthening the linkage between Research and Extension and getting information flowing between the two branches.

Furthermore, the establishment of ARPTs in 1980 was aimed at ensuring incorporation of both Extension staff and Research workers into the process of generating technology. An ARPT essentially consists of a Farming Systems Agronomist, one Farming Systems Economist, and an RELO in each province.

Technology Generation

To ensure the generation of appropriate and relevant farmer technology requires strong linkage and coordination mechanisms between the Research and Extension Branches. The establishment of the ARPT in 1980 in the Research Branch of the Department of Agriculture to conduct farming systems research can be viewed as a principal effort to strengthen this linkage. The ARPT has the overall objective of helping the Research Branch to produce more relevant recommendations for the majority of the country's traditional and small-scale commercial farmers. The ARPT complements the technical research undertaken by 16 commodity and specialist research teams in the Research Branch by examining the socioeconomic circumstances of farmers and conditions of the whole farming system with all its interactions and by conducting on-farm trials.

Thus, in the process of generating technology, farmers' technological needs are identified through the process of conducting diagnostic farm surveys. These needs are then incorporated into the research programs by provincial ARPT committees which discuss research proposals outlined in diagnostic survey reports as well as the results of ongoing trial programs. In principle, adaptive trials aim to see whether a proposed technology fits the farming system under farmers' conditions.

The "packaging" of extension messages is the responsibility of the RELO, Subject Matter Specialists, and the District Agricultural Officer who oversees the work of all field staff in the district. The guidelines, issued as extension messages from time to time, are based on available research recommendations.

Research With Fertilizers

Much research work has been done in Zambia with the major nutrients: nitrogen, phosphorus, potassium, sulfur, and calcium (lime). A lot of this work was done to assess the response to fertilizers of a variety of crops throughout the country, although maize, the principal staple crop, was the test crop in most cases. Much has been learned from this research work. Although most of the soils have adequate amounts of potash, it appears that in the absence of large amounts of nitrogen satisfactory crop yields can hardly be obtained. Some of the experimental results have shown that in the majority of the high-rainfall areas, sulfur is the limiting factor. On the basis of this finding, specific fertilizer compounds were formulated so that they all contain at least 10% sulfur. This is in addition to the major nutrients NPK. Another important finding was the need to apply boron in fields intended for cotton.

However, in spite of all this research, farmers' yields are not remarkably high. In the case of maize it has been shown that yields of more than 10 tons/ha can be achieved by using fertilizers and existing varieties. But even then, large-scale commercial farmers do not average more than 4 tons/ha over the whole country. On the other hand, small-scale farmers, who are in the majority (600,000 plus farm families), average just over a ton per hectare of shelled maize.

It is therefore clear that the gap between what could be achieved (as indicated by research results and verification trials) and what farmers are presently obtaining constitutes a major area of concern to both the Research and Extension Branches. Could it be that the technology of better crop husbandry has not been properly transferred to the farmer? Or that the technology itself is not quite appropriate for the farmer? Better still, might it not be that no one really knows or understands what the farmers are doing or how they are employing the technology which is reportedly the result of years of research work?

To try and overcome these uncertainties and develop technologies deemed appropriate, Zambia has initiated the Adaptive Research Planning methodology which has already been referred to above. Thus, by integrating social scientists with biological scientists it is hoped that farmers' problems can be properly understood and tackled in a manner likely to provide relevant solutions.

Extension on Fertilizers

Before chemical fertilizers were used for crop production, farmers used various methods to raise or maintain the nutrient status of soils. These methods included the use of organic manures, crop rotations, and various forms of shifting cultivation.

Since the introduction of chemical fertilizer, the use of various forms of organic manures has declined. When chemical fertilizers were readily available in the country (in the 1950s) their widespread use was promoted through extension work. Thus, many demonstrations, field days, and meetings, etc., were hosted to teach farmers about the effects of fertilizer on increasing crop yields, and in addition to show them the advantages of good cultural practices. Government supported the move by subsidizing fertilizer prices heavily, thereby increasing consumption of the commodity. For instance, the total consumption of fertilizer (NPK) rose from 8,000 tons in 1965 to 45,000 tons in 1975. Over the last 9 years, 1975-84, consumption has almost doubled to 80,000 tons of NPK per year.

Although extension work has promoted the wide use of fertilizer, there is still the question of efficient and economical utilization especially among small-scale farmers.

It is in this regard that the "Lima" approach was initiated to try to correct the inefficient use of crop inputs (particularly seed and fertilizer) in the small-scale farming sector. The Lima approach carried a package of recommendations based on the Lima, which is a land unit equal to one-fourth of a hectare, i.e., 2,500 m^2. Through this approach, some very encouraging crop yields have been obtained, especially with maize.

Thus, whereas farmers have known that fertilizers will increase crop yields, most of them are unable to use them in a satisfactory manner. The Extension Service has the difficult task of rectifying this situation.

EXPERIENCE CAMEROUNAISE EN MATIERE DE PROMOTION DE L'UTILISATION DES ENGRAIS EN MILIEU PAYSAN

F. Nkonabang

Le Cameroun est un Pays dont l'économie est à essence agricole. La population est à majorité rurale et l'Agriculture occupe plus de 70% de la population active totale, contribue pour plus de 30% au PIB et pour plus de 50% aux recettes nationales en dévises, avec 40% des ressources budgetaires nationales.

Compte tenu des données qui précèdent, lesquelles sont suffisemment éloquentes, le Gouvernement, dans le souci d'augmenter la production agricole et la productivité des paysans, d'assurer l'autosuffisance alimentaire, et d'accroître le revenu des paysans et leur promotion sociale, a engagé un train de mesures au niveau des structures d'encadrement, de gestion et de financement de certaines opérations qui sont déterminantes dans l'accroissement des rendements et de la production.

Parmi ces opérations, le programme Engrais revêt une haute priorité puisqu'elle est déterminante dans l'amélioration et l'augmentation des récoltes tout en réduisant les coûts de production.

Compte tenu cependant du coût élevé de cet intrant, et du faible pouvoir d'achat des petits exploitants du Secteur dit "traditionnel" qui est de loin le plus important, puisqu'il comprend 950.000 exploitants, soit 90% du total, couvre 1.500.000 ha et occupe 3.200.000 actifs agricoles.

Le Gouvernement a institué depuis la campagne 1974/75 une politique de subvention aux engrais, donnant ainsi suite aux recommandations de la FAO, et suite au programme de sensibilisation et de promotion conduit par cette institution dans notre pays de 1966 à 1973.

Au départ la subvention ne concernait que les principales cultures d'exploitation, à savoir Café Arabica et Robusta, ainsi que le Coton.

Progressivement elle s'est étendue aux cultures vivrières, et le taux de subvention a parallèlement augmenté, passant de 30% à plus de 70%, comme nous le verrons plus loin.

I. Etablissement des Formules de Fertilisation/Rôle du 1er Projet "Programme Engrais FAO"

La détermination des formules-types d'engrais a été entreprise grâce au projet Engrais FAO qui de 1966 à 1973 a permis de récolter des données et d'élaborer des recommandations rationnelles spécifiques par culture et par région sur l'emploi de fertilisants par les agriculteurs.

Parallèlement il a été mis au point des méthodes de vulgarisation et d'utilisation efficaces des engrais, une politique et un système pilote dans les zones où l'expérimentation et la vulgarisation ont suscité de l'engouement.

Des essais conduits dans le pays ont abouti à des recommandations de fumure.

Le programme a réalisé par la suite des démonstrations d'engrais qui ont vulgarisé les recommandations en question.

Des centres de vente ont été créés et au terme de 7 années, plus de 20 000 planteurs avaient été sensibilisés.

Parallèlement la formation des encadreurs et des cadres à l'action de promotion des engrais a été entreprise dans le cadre d'un programme de recyclage systématique.

Un fonds de roulement a aussi été mis sur pied à travers une institution financière de promotion rurale, le FONADER.

II. Evolution de la Consommation des Engrais au Cameroun

Au terme de ce projet, l'utilisation des engrais a connu un essor fantastique, passant de 3 000 tonnes en 1973 à plus de 150 000 tonnes en 1984 toutes formules confondues.

Les tableaux en annexe présentent l'évolution de la consommation des Engrais au cours des 5 dernières années, ainsi que l'évolution de la consommation des Sociétés.

III. Structures d'Intervention dans le Processus

Elles sont nombreuses, les plus importantes étant:

- Le MINAGRI dont l'organe d'exécution est la Direction de l'Agriculture;
- Les Services Extérieurs du MINAGRI (DPA et DDA);
- Les Coopératives, Sociétés, Projets et mission de Développement;
- Le FONADER, Fonds National de Développement Rural, assure la Gestion des opérations (achat, transport, opérations diverses, etc.);
- Les Fournisseurs;
- La Direction de l'Agriculture intervient dans:
    - La determination des besoins, le contrôle des Stocks et la fixation des quotas en relation avec le FONADER et les Services Extérieurs du MINAGRI, ainsi que l'élaboration des appels d'offres;
    - La réception des échantillons et l'organisation de la Commission Technique d'Analyse des intrants, etc.;
    - Elle participe au dépouillement et à l'analyse des offres et apporte à la Commission Centrale des Marchés toutes les indications Techniques nécessaires pour le bon choix des Commissionnaires;
- La Commission Centrale des Marchés attribue les quotations et passe les Marchés.

IV. Fixation de la Subvention sur Engrais

Il y a lieu de rappeler une fois de plus la subvention est principalement destinée aux petits agriculteurs qui dans notre système de production assure plus de 90% de la production des cultures de rente et toutes les productions vivrières.

Il faut aussi noter que depuis quelques années la subvention ne provient plus de l'ex-Caisse de stabilisation des Prix des Cafés et Cacao (Caistab), remplacée par l'Office National de Commercialisation des Produits de Base (OCNPB), mais du compte hors-budget.

La subvention est donc réservée au groupe qui assure la rentrée de la plus grosse part des dévises étrangères et surtout assurent à 100% l'autosuffisance alimentaire.

Mais de plus en plus toutes les Sociétés, projets, Missions et organismes de Développement, voire Entreprises privées, sollicitent le bénéfice de la subvention.

Il va sans dire que compte tenu des quantités actuellement consommées par les Sociétés, soit

57,246.625 T en 1982-1983
59,653.360 T en 1983-1984

Il est hors de question de pouvoir subventionner les Agro-industries. Il a donc été admis que seules les Sociétés de développement telles que (SODECOTON, PROJET NORD-EST BENOUE, ZAPI, SODENKAM, PROJET HAUTS PLATEAUX DE L'OUEST, SEMRY, etc...) peuvent prétendre et bénéficier de cet avantage dès lors qu'elles assurent l'encadrement des paysans.

Cela étant, je dois dire que le montant de la subvention n'est pas déterminée d'avance. Par contre le prix de vente des engrais est fixé par les autorités et uniformisé pour toutes les formules.

Le calcul du coût se fonde sur les paramètres suivants:

- Prix d'achat des engrais:
- Transport,
- Frais de gestion (stockage, manutention) 10%,
- Assurance 0,70%
- ,..

A partir de ces éléments on peut déterminer le montant de la subvention par la déduction du prix de vente aux planteurs.

V. Engrais et Accroissement de la Production

Au regard des potentialités de notre système de production (ressources humaines et Ressources en sol qui sont abondantes), il faut dire que la Consommation actuelle des engrais ne permet pas encore d'atteindre le niveau de production auquel on est en droit de s'attendre.

Pourquoi? Parce que cette Consommation est encore loin d'atteindre l'optimum en vue d'une production économiquement rentable.

A titre d'exemple si tous les engrais consommés étaient consacrés aux Cafés Arabica (150.000 ha) et Robusta (25.000 ha), il faudrait à peu près 160.000 t pour un seuil de 400 kg/ha. Actuellement la Consommation est de l'ordre de 80.000 T.

Ces engrais sont surtout consommés par les cafés et les cultures vivrières ne font que bénéficier des effets résiduels de ceux-ci. Ce qui explique les faibles rendements des cultures vivrières et ceux plutôt moyens des caféiers. Il y a par ailleurs des conditions liées aux autres facteurs de production et intrants tels que:

- Etat sanitaire et pesticides
- Entretien adéquat
- Fourniture de variétés saines et à hauts rendements,
- Climatologie et autres conditions écologiques,
- Prix de vente et autres facteurs incitatifs,
- Technologie proposée et technicité du paysan,
- etc...

En conclusion, l'introduction d'un programme d'engrais à prix subventionné constitue à coup sûr un des facteurs qui devrait permettre une nette amélioration de certaines productions. Mais il ne saurait être le seul. Leur optimisation est certainement liée à d'autres opérations telles que

- La lutte contre l'exode rural qui doit permettre le rajeunissement des exploitants et des exploitations, ce qui suppose un train de mesures sociales,
- Les aides à l'installation des jeunes Agriculteurs,
- Le crédit agricole
- La réduction de la pénibilité du travail manuel par l'introduction de la mécanisation et de technologie nouvelles,
- L'application de prix incitatifs,
- etc...

J'ai fait exprès de passer sous-silence les divers problèmes liés au financement et à la gestion des engrais, à la politique de la subvention aux engrais, etc...

J'ai tout simplement voulu situer ce programme dans notre stratégie de développement, où il constitue un des volets les plus déterminants, dans la mesure où il est le plus lié à l'accroissement de la production, condition de l'autosuffisance alimentaire qui ne doit pas être un état d'équilibre instable, mais permanent.

EVOLUTION DE LA CONSOMMATION DES ENGRAIS AU COURS DES CINQ DERNIERES ANNEES

Annees	Type d'engrais	Besoins exprimés en (tonnes)	Quantités commandées en (tonnes)	% qtés subventionnées	Prix achat/ tonne	Prix subventionné/ tonne
79/80	S.A.	52 520	24 500	46,7	41 500	20 200
	12-6-20	6 060	-			
	20-20-10	37 460	10 000	26,7	63 800	28 000
	Urée	2 330				
	Sulfate potasse	1 010				
	Superphosphate simple	320	-			
Total		99 700	34 500			
80/81	S.A.	50 000	30 000	60	51 000	28 000
	20-10-10	35 000	19 000	25,7	74 500	32 000
	Divers	20 000	5 000	25	76 530	32 000
Total		105 000	44 000			
	Kiéserite	20				
	S.A.	90 000	22 000	24,5	57 700	35 000
	Kcl	40				
	20-10-10 ou 19-9-9	58 950	20 000	33,8	77 500 76 000	40 000
	Urée	1 000				
	16-6-20 ou 12-8-20	20				
	Total	150 000	42 000			
82/83	S.A.	85 000	38 000		52 900	35 000
	20-10-10	81 000	40 000		79 730	35 000
	Divers	-	7 000			
Total		166 000	85 000			
83/84	S.A.	93 400	35 000		55 250	35 000
	20-10-10	79 100	45 000		89 000	35 000
	Urée	-	2 828		-	35 000
	Divers	-	-	-	-	-
Total		172 500	82 828			
84/85 (Prévisions)	Divers	2 000				
	20-10-10	29 333	20 000			
	12-6-20	15 000	15 000			
	Urée	17 332	15 000			
	S.A.	24 538	20 000			
	Sulfate de Potasse + Chlorure de Potasse	5 000	-			
Total		93 203	70 000			

CONSOMMATION DES ENGRAIS AU CAMEROUN
CAMPAGNE 74/75 à 83/84 (tonnes)

SOCIETES AGRO-INDUSTRIELLES

Années Organismes	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84
PAMOL	2 003,5	2 079,0	1 341,3	1 998,1	2 256,5	2 163,0	2 231,8	2 787,3	2 222,8	2 344,0
WADA	102,7	86,0	161,55	-	146,45	51,0	39,0	65,0	241,45	133,85
SOCAPALM	610	766	1 171	1 831	2 230,0	5 000,0	4 130,0	3 405,0	3 405,0	3 615
SPDEBLE	-	-	-	1 292	9 233,05	-	1 775	-	-	3 400
MIDEVIV	15	56,0	15,0	168,5	246,5	311,0	314,0	292,0	392,0	-
HEVECAM	-	1,0	52,0	400,0	1 250,0	950,0	1 750,0	2 360,0	3 020,0	2 627,0
MIDO	20	3,75	15,0	30,0	39,5	37	33,5	18,75	43,0	28,75
S C T										
SODECOTON	-	6 000	77 000	2 000	9 800	13 500	15 000	15 015	14 100	20 250
SODERIM	46,650	47,950	53,850	420,950	314,800	202,000	200,150	229,700	123,835	110,150
ZAPI EST	NPK = 126	69	243,8	402,5	337,65	337,65	1 147	-	773,45	1 054,25
	SSA			20	105,85	80,4	30,6		84,1	240
INVDA	-	-	-	-	350	-	125	525	626	-
UCCAO	12 000	8 403	8 896	14 957	24 638	15 000	20 516	30 276	27 000	30 000

RESEARCH AND EXTENSION AT IAR

O. O. Ologunde

Introduction

The Institute for Agricultural Research (IAR) was established in 1924 as the research division of the Department of Agriculture for the then Northern Provinces of Nigeria. The Institute was formally transferred by law to the Ahmadu Bello University in 1962 when the University was established. Two of the broad functions of the Institute involve research and extension.

One important research program of the Institute is directed toward the development of farming systems that involve crops of the savanna ecological zones and result in the maintenance or improvement of soil resources. The mandated crops are sorghum, millet, maize, wheat, and barley; cowpeas and soybeans; groundnuts, sesame, and other oil seeds of economic importance; cotton and other vegetable fibers of economic importance; and tree and horticultural crops. In particular, research should focus on the following:

1. Improvement of agronomic and husbandry practices.
2. Improvement of the genetic potential of the specified crops.
3. Mechanization and improvement of the methods of cultivating, harvesting, processing, and storing the specified crops.
4. Improvement of the utilization of byproducts.
5. Ecology of pests, diseases, and improved methods for their control in specified crops.
6. Technical, social, and economic integration of the cultivation of the crops into the farming systems in different ecological zones and their impact on the economy.
7. Irrigated agriculture.
8. Other crop problems related to the specified crop.

Another important function is to cooperate with other bodies in the dissemination of knowledge of agricultural matters and the results of the research program conducted by the Institute (Extension).

In carrying out these research and extension functions, the Institute operates within the guidelines of national policies and priorities for agricutural research as outlined by the National Council for Science and Technology in December 1975.

Funding of Research at IAR

The Federal Ministry of Education, Science, and Technology, created in 1979 as the Federal Ministry of Science and Technology, is charged with the promotion and coordination of scientific and technological research and the dissemination of research results. This Ministry almost wholly funds scientific research at the IAR and other institutes of its type in Nigeria.

The Board of Governors directs research activity at IAR and prescribes policy guidelines within the specified functions of the Institute. It assigns priorities for research activities and approves the IAR budget before it is forwarded to the Ministry of Education, Science, and Technology.

Research Methods

Research into the various crops of the mandated ecological zone takes the form of a multidisciplinary approach under the five different crop research programs. There are five other supporting programs. Each research program has a committee which is headed by a leader. A committee consists of at least a breeder, an agronomist, a soil scientist, a crop protectionist, an agricultural engineer, an agricultural economist/rural ecologist, and an extension specialist. Attendance at the committee meetings is open to all other members of IAR and the sister extension institute, the Agricultural Extension and Research Liaison Services (AERLS).

Each research program comprises several subprograms under which several projects can be formulated. A project can have one or more subprojects each with one or more experiments designed to answer stated objectives.

Research Sites

Research activities of the Institute are centered at the headquarters in Zaria. Outstations include the Mokwa Agricultural Research Station and Yandev Research Station in the southern Guinea savanna ecological zone, Kano Research Station in the Sudan savanna zone, and the Kadawa and Bakura Irrigation Research Stations which specifically deal with research into irrigation and water management problems. Apart from these research stations, many other sites are located in various states on farms belonging to the Ministry of Agriculture of the state, the River Basin Authority, and individual farmers.

Dissemination of Research Results

Results from research conducted in the various locations within a season are compiled and analyzed by the researchers. Reports of these are then given in the annual Cropping Scheme Meeting where all of the individuals concerned--researchers, State Ministry officials, and other agricultural experts--have the chance to examine these results.

After some years of reliable data collection, a researcher might decide to write up his results in the form of draft recommendations for the farmers. This report is critically reviewed by the program concerned, the Professional and Academic Board, and finally the Board of Governors. When it is accepted, the report is finally passed to AERLS which makes the report available in forms suitable to the farmers and other agricultural establishments.

Reports on the research activities of IAR are also presented in various international and national scientific journals. The Institute also produces an annual report which contains highlights of the various research activities of the current season.

Copies of all these reports and articles are available in the Publication Unit of the Institute at Samaru Zaria, Nigeria.

FERTILIZER RECOMMENDATIONS AND TECHNOLOGY TRANSFER TO FARMERS IN NORTHERN NIGERIA
THE AERLS EXPERIENCE

Enoch A. Salako and Ndanusa B. Mijindadi

Abstract

Fertilizer use holds the key to increased food production in developing countries, especially in those areas where soils of low nutrient status abound. The research efforts of the agricultural research institutes in Nigeria have been concentrated on development of a 'package' of improved production practices including fertilizer recommendations.

Various channels of communications are employed by the Agricultural Extension and Research Liaison Services (AERLS) to transmit improved recommended practices to the farmers to enhance their adoption. However, selective adoption of the composites of the package has been observed, with the fertilizer component being the most popular with farmers.

There is great need for tailored fertilizer recommendations based on soil and plant analyses.

Introduction

Nigerian farmers, like most farmers in Africa, have always recognized the need for improved soil fertility. Thus, the practices of shifting cultivation, which allows for periods of bush fallow for fertility regeneration, and the application of farmyard manure and household refuse to farmers' fields were in use long before farmers were aware of inorganic fertilizer recommendations. It is therefore no surprise that of all farm recommendations passed on to farmers in the northern states the one on fertilizer use has been most easily accepted and widely adopted.

The first recorded recognition of the potential value of inorganic fertilizer in Nigeria was in 1937 when it was found that superphosphate fertilizer applied to cereal crops gave yield increases commensurate with what was obtained from use of farmyard manure of similar phosphate content (Yayock et al., 1980). However, the basis of most of the current fertilizer recommendations on major crops in the northern parts of the country is in agronomic research carried out by various workers in the late 1950s and early 1960s (Mijindadi, 1984).

The Agricultural Extension and Research Liaison Services and the Technology Transfer Process

The Regional Research Station at Samaru was established in the 1920s. Within the first 30-40 years (i.e., by 1960) it was recognized that most of the useful research information already accumulated was not reaching the intended beneficiaries--the farmers. This prompted the Ministry of Agriculture of the now defunct Northern Region to establish the Extension and Research Liaison Section (ERLS) in 1963 as part of the Field Services Division stationed at Samaru. Its primary function then was to act as a link between research efforts and the Ministry's extension services. By this time, the Regional Research Station at Samaru was appropriately transferred to the newly established Ahmadu Bello University (ABU) and given the title of the Institute for Agricultural Research and Special Services (IAR). Consequent to the dissolution of the Regional Ministry of Agriculture, as a result of the creation of states, ERLS was merged with IAR in 1968. ERLS was completely integrated with IAR in 1969 when its staff members were transferred to the University.

As a link between IAR and the Ministry's extension services in the states, the ERLS staff was required to critically evaluate research before recommendations were released for use by farmers. Failure of ERLS to do this effectively might result in release of unadoptable recommendations to the states while the consequent blame would be entirely on ERLS and not IAR. Therefore, some measure of autonomy was required by ERLS. Statute 19, the University Council on October 15, 1975, separated ERLS from IAR as the Agricultural Extension and Research Liaison Services (AERLS) within the agricultural complex of ABU.

Figure 1 is an illustration of the structure of AERLS within the agricultural complex of ABU. AERLS initially had two sections, the Subject-Matter Specialist and the Audiovisual. In 1980, the Subject-Matter

Specialist Section gave birth to four sections: Extension Agronomy Section (consisting of agronomy, horticulture, home economics, agricultural engineering, and forestry); Livestock Section (consisting of poultry, animal sciences, and veterinary services); Irrigation Section (consisting of irrigation, agronomy, and engineering); and Farm Management and Crop Protection Section.

In 1982, the sections were upgraded to departments as illustrated in the following outline.

The constituent units of each department at present are as follows:

1. Extension Agronomy Department
    a. Agronomy
    b. Horticulture
    c. Forestry
2. Extension Audiovisual Department
    a. Audiovisuals
    b. Graphics
    c. Photography
    d. Farm broadcasting (radio and television) programs
3. Agriculture Extension Economics Department
    a. Farm management-extension
    b. Marketing
    c. Home economics
    d. Rural youth
4. Extension Crop Protection Department
    a. Entomology
    b. Pathology
    c. Nematology
5. Extension Irrigation and Mechanical Engineering Department
    a. Irrigation agronomy
    b. Irrigation engineering
    c. Mechanization
6. Extension Livestock Department
    a. Poultry science
    b. Animal science
    c. Veterinary services

Major Functions of AERLS, Samaru-Zaria

AERLS is charged with the primary responsibility of assisting the Guinea, Sudan, and Sahel States of Nigeria in their agricultural extension programs; specifically the functions may be summarized as follows:

1. Interpretation, publication, and dissemination of research results to the farmer. The application of these research results must take into account the existing farming systems.
2. Identification of field problems needing research and communication of these to the appropriate crop research institutions.
3. Serving as an information center on agriculture for industries, banks, and other organizations.
4. Training of states' extension staffs on a systematic basis through regular in-service training courses and specialized shortcourses or workshops.
5. Providing advisory and consultancy services.
6. Assisting states in organizing and conducting agricultural shows. The activities and contributions of ABU to rural development are usually publicized during such shows.
7. Assisting in the organization of states' extension demonstration units. This includes training of field extension staff in preparation and use of audiovisual aids and servicing and repair of audiovisual equipment in use by the states.
8. Conducting applied research especially where the need is urgent and staff is not available in the research institutes to undertake it.
9. Organizing seminars/conferences for the solution of common problems.

Although AERLS Samaru is an autonomous body as indicated earlier, a definite relationship exists between it, IAR and the National Animal Products Research Institute (NAPRI). In its liaison role, it usually transmits identified field problems on crops from the states to IAR; problems pertaining to livestock are appropriately transmitted to NAPRI. Progress reports on these problems are usually discussed annually, and any recommendations are critically examined to ensure practicability in the field and enhance adoption by farmers. The research committees are responsible for this, and an AERLS representative attends such meetings in his own area of discipline. Recommendations approved by such committees are passed to the IAR Professional and Academic Board meeting for ratification.

At this stage, the IAR leader of the relevant committee formally transmits the recommendations to AERLS for official release to the relevant ecological zones to which such recommendations apply. The relevant specialist in AERLS is then responsible for interpretation and simplification of the recommendation for ease of comprehension by the state extension staff. The recommendations are written in simplified form and sent to the Ministry of Agriculture in relevant states and to various agricultural institutions in the area. Other channels of communications are also used to inform farmers and extension workers of the new recommendations.

Fertilizer Recommendation and Mode of Technology Transfer

Although research programs are based on individual factors of production, the available recommendations on the various factors are put together for each crop and disseminated as a package for farmers' use by various research committees. However, recommendations by various research committees do not necessarily evolve at the same time, and this warrants periodic revision of any part of the package of recommendations.

The plant nutrient recommendations for major crops grown in northern Nigeria are indicated in Table 1. Recommendations indicated for sorghum, maize, millet, groundnuts, wheat, cotton, and cowpeas have resulted from the efforts of the Soil and Crop Environment Research Committee of the IAR in Zaria; those for the other crops in the table were released by the other research institutes in the country who have mandates for major work on those crops.

It may be noted that the recommended nutrient rates are not necessarily aimed at the production of maximum crop yields. The recommended rates consider the ease of adoption by farmers as related to resources available. For example, many farmers are financially unable to use the total recommended nutrient rates.

The nutrient recommendations are, to the degree possible, specific for various ecological conditions. They are revised as often as new findings become available.

Because of the low literacy level of the farmers, the recommended nutrient levels are converted to bags of the fertilizer used.

Channels Used for Technology Transfer

Effectiveness of transfer of improved technologies to farmers is highly dependent on the channels of communication used.

Several major channels of communication are used by AERLS. All of these are regularly evaluated for impact.

Use of Radio and Television

Radio releases on the information contained in recommendations already sent to the states are immediately prepared to keep farmers aware of the new findings.

Radio releases are prepared in their simplest forms to answer some basic questions that farmers might ask and to ensure, as much as possible, that farmers understand how to use the specific recommendations correctly.

Radio is one of the most effective channels of communications used by AERLS, and a study on effectiveness of various communication channels confirmed its superiority over all others in the northern states. The availability of a radio in most family homes was found to greatly enhance its effectiveness. In addition to the releases on newly improved technologies, regular radio releases on timely farm operations are made slightly before such operations are usually executed for particular crops. This approach recognizes the need for timely farm operations and solicits farmers' cooperation to ensure good field establishment of the various crops during the particular season. Television programs are also popular but are more restricted in terms of household access. Table 2 gives some details.

In-Service Training Courses

These courses are organized for field agricultural extension workers in the various disciplines. The courses were designed to update and to improve specific skills on key farming practices.

It is impossible to overemphasize the major objectives of these training courses and the usefulness of field extension workers as demonstrators of improved farming practices and of feedback through personal contacts with farmers. The field extension workers should be the most effective means of agricultural technology transfer, but numbers are very low as shown in Table 3. Observations also revealed that the very few available extension workers also perform much below expectation partly because of the poor organization in the Ministry of

Agriculture but mostly because of the deplorably poor working conditions in the agricultural sector. Table 4 gives some information on some of the training conducted over the years.

Pre- and post-course evaluations of participants are usually conducted at each training course to measure the knowledge or skill gained by the participants. Overall, the general performance of field staff is still much below expectation largely because of a lax work attitude. Course evaluation, usually conducted at the end of each training period, serves to help AERLS staff identify necessary areas of improvements in future training for greater effectiveness or achievement of predetermined, specified objectives.

Agricultural Publications

Agricultural publications form the major channel of transfer of information on improved farming practices from the researchers to the field extension workers and literate farmers. The publications are designed primarily for the field extension workers who, in turn, transmit such information to the illiterate farmers in the local language. Some of the publications are also produced in some major local languages such as Hausa, Yoruba, Nupe, Tiv, and a few others for those farmers who can read and write.

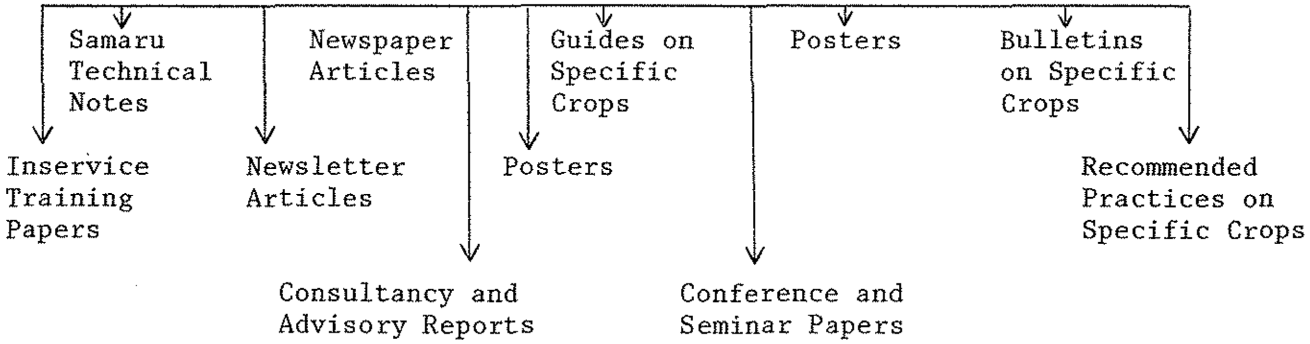
The relevant research information supplied to the farmers is usually simplified as much as possible to enhance comprehension and practicability of adoption of specified practices.

Samaru Technical Notes

These "notes" usually contain interpreted and simplified new findings from research to improve the farmers' specific farming practices. They are sent directly to the Ministry of Agriculture in the states concerned as soon as such recommendations are released. The Chief Agricultural Officers of the particular states are responsible for the transmission of such information to their agricultural extension staff in the field.

A very effective extension system uses a variety of publications for the transmission of the same information to the farmers. This variety is necessary because of the varying preferences of the target audience and their ability to grasp information much faster in some types of publications than in others. Such publications have varying characteristic simplifications, and brevity of information thus ensures greater coverage of the target audience under normal conditions such as adequate quantities and efficient distribution systems. The following chart indicates the various types of publications produced by AERLS.

Agricultural Publication Types



The difference between a "guide" and the "recommended practices" publications for the production of specific crops lies in the fact that the latter contain information confirmed by research, while the former advises on essential production practices for a good crop. The "bulletins" contain more detailed information on research-proven practices for the specific crops already summarized in "recommended practices." Both are updated or revised periodically as more findings on particular practices become available. The posters transmit one specific piece of information at a time with appropriate illustrations, while the leaflets transmit illustrated information in definite characteristic stages on particular practices, e.g., methods of application of fertilizer or comparison of a specific fertilized crop with the unfertilized one.

Feedback from the states indicates varying degrees of usefulness of the publications. Such reports indicate the need to further simplify the contents of guides, recommended practices, and bulletins. Availability of the relevant publications to the field extension workers and literate farmers needs to be improved.

An evaluation of the effectiveness of the system was conducted to determine the major problems affecting availability of such publications to the intended beneficiaries. The findings revealed the inefficiency of the state headquarters in the distribution of the publications to the various parts of the state due partly to the nonchalant attitudes of the headquarters staff but very largely to unavailability of sufficient serviceable transportation. The states occasionally send their vehicles for the collection of agricultural publications from AERLS Centre in Samaru.

The guides, recommended practices, and bulletins have been the most popular and have recently been requested in large numbers from various parts of the country other than the northern states covered. Table 5 provides some data on several publications sent to various states over a period of time. More than 200 newspaper articles were also supplied by IAR in 1982.

Consultancy and Advisory Services

The Institute provides these services to small- and large-scale farmers on request. Such services cover proper observation by farmers of the major agronomic practices influencing crop performance and crop combinations in proposed farms by prospective farmers.

The Institute responds promptly to farmers' field problems. All services traditionally are rendered free of charge to farmers; however, firms requesting consultancy services are charged. Hundreds of requests for advisory services by mail from small-scale farmers are received daily. Response is given over the radio and by mail.

Agricultural Shows

Agricultural shows serve as an invaluable medium for technology transfer, especially if widely publicized. Their effectiveness conforms with the adage 'seeing is believing' since farmers have the opportunity of comparing crop products produced through improved farming practices with those under traditional methods. The very inquisitive nonadopters have the opportunity for dialogues with field extension workers, researchers, and the adopters who have benefitted from the improved technologies. New available technologies can also be transmitted to the farmers through necessary method demonstrations.

Such state agricultural shows are regularly attended by agents of AERLS. The AERLS team seizes the opportunity to educate the audience on its roles as well as to transmit any currently released improved technology through demonstrations, relevant agricultural publications, and personal discussions. Increasing requests for AERLS personnel to attend is a testimony of the impact of the Institute in this respect.

Campaigns

Campaigns must be very purposeful and directed at the identified problems experienced by the farmers, if they are to have any impact in revitalizing their interests. A typical example is the case of groundnut production; it was seriously threatened by rosette disease in 1975 with consequent drastic reduction in production levels by farmers. Farmers had to be educated on preventive and control measures as well as given free seeds by the Groundnut Board in order to maintain farmer interest in growing this crop.

Farmers had to be informed by AERLS of the availability of free seeds from the Groundnut Board and to be convinced of the importance of timely planting, close spacing, and other relevant practices as measures to prevent any recurrence. Although the previous production level has not been attained since the catastrophe, an appreciable increase in production levels has been recorded.

Evaluation Visits and Field Days

The efforts of AERLS and state extension services are meaningless if newly developed improved agricultural technologies do not reach the farmers or reach them but are not adopted. If farmers receive the information or master the skills necessary and adopt them on their farms, the impact will obviously be visible in the farmers' fields. Visits to farmers' fields in the states allow AERLS personnel to accomplish the following tasks:

1. Check on farmers receiving such information through the various channels used and if the farmers do not receive such information, determine and correct the reasons for this situation.
2. Confirm the practicability of adoption of the specific improved practices. Identification of factors influencing any impracticability is essential in achieving practicable practices.
3. Confirm adoption of the relevant improved practices on farmers' lands and secure information on associated problems for more critical evaluation by the research teams.
4. Play advisory roles in situations where farmers require more details on particular practices, especially where field extension workers are unavailable.

Observations taken during field visits provide on-the-spot assessments of some problems confronting adoption of improved practices and help to review the extension program as necessary. These visits are conducted during production seasons to sampled areas of each of the ten northern states, and they help AERLS to provide some information on crop-weather forecasts for each season.

The field days are usually organized by the individual states and conducted during the cropping season and prior to harvesting. This gives farmers the opportunity to assess the effectiveness of particular recommended practices and to encourage other farmers to adopt them. Farmers who adopt these practices are usually given the opportunity to explain the methodologies of the particular recommendations to their colleagues in order to have greater impact on them.

AERLS staff members attend as many such field days as possible to confirm that the farmer-adopters derive the expected benefits from such practices and to provide any necessary advisory services.

The year 1982 was the most inactive in this respect since most states did not organize such field days because of financial handicaps.

The National Accelerated Food Production Project

NAFPP was introduced by the Federal Government as a new extension approach to replace an existing ineffective one. The difference between the new approach and the old one is the involvement of the farmers in the demonstrations and decisionmaking in the final release of the improved technology. In addition, this method does not wait for final recommendations from research to be released but evaluates the technologies almost ready for release by allowing the farmers to identify actual and possible problems before final release of the technology. If no major problems are encountered, the particular technology can be adopted by the farmers much earlier than in the existing approach. Thus, the NAFPP provides a short-cut in the adoption of recommendations from research.

Guidelines for a More Effective Transfer of Fertilizer Recommendations

Application Method

Feedback on farmers' reactions to recommended practices released over a period of time has been observed to be invaluable in identifying areas of improvement for specific practices. Many farmers have found the recommended fertilizer application methods very tedious; the exceptions are the very few who are able to mechanize production of their crops. For example, the ring method of applying fertilizers is recommended for small land areas (small gardens), whereas the farmers have found the broadcast method most convenient under the prevailing high labor cost. It is therefore important that simple fertilizer applications be developed to ease the drudgery involved in the recommended ring method of fertilizer application.

Soil Testing

In Nigeria soil testing facilities are not available outside universities and research institutes. Thus, most fertilizer recommendations tend to be 'blanket' recommendations rather than specific to a given area. It is suggested that a soil testing laboratory be established in each Agricultural Development Project (ADP) and in the River Basin Development Authorities.

Timely Availability of Fertilizers

This is primarily a function of the distribution system. Distribution tends to be politicized, e.g., on the basis of population. Distribution should be based on need--need of the soil of the area, types of crops, form and extent of irrigation practiced, the returns to fertilizer use, etc. For the farmer to get fertilizer without much trouble, the input delivery system must be improved.

Package of Recommendations

The provision of fertilizer with other agricultural inputs, high-yielding variety seeds, and pesticides can aid the effective transfer of fertilizer recommendations.

Developing Fertilizer-Responsive Varieties

This can be made a research objective for key crops like maize and cowpeas so that farmers can better appreciate the need to adopt recommendations.

Field Extension Support

Constraints on field extension staff must be removed. These include the problem of incentives for extension staff, transportation, payment of claims, and a salary difference between ADP extension staff and Ministry staff, etc.

Conclusions

Fertilizer use greatly influences plant productivity. Research efforts have proved that food production is increased through the use of fertilizers.

Fertilizer recommendations have always been included in the package of recommendations released to farmers in the northern states of Nigeria. Various channels of communication are employed to enhance adoption of these recommendations by farmers. Selective adoption of the components of the package have been observed by farmers, with fertilizer recommendations receiving the greatest attention and adoption by the farmers. The fertilizer recommendations need to be more meaningful, and a more effective transfer approach needs to be developed. Suggestions have been made as follows:

1. Improved and acceptable methods of application are needed.
2. A well-organized soil and plant testing service for farmers is needed.
3. Timely availability of fertilizers should be given serious consideration.
4. Farmers need to be advised to observe the package of recommendations for better and more profitable results.
5. Development of fertilizer-responsive varieties is very important to an increase in food production.
6. A more effective extension service is only possible through removal of the major constraints on the field extension staff.

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Table 1. Recommended Nutrient Rates for Some Crops Grown by Farmers in the Northern States of Nigeria

Crops	Recommended Nutrient Rates N	 P_2O_5	 K_2O
		(kg/ha)	
Sorghum	64	32	-
Millet	60	30	30
Groundnuts	-	54	25
Rice			
Shallow swamp	75	30	30
Deep flooded	50	30	30
Upland	30	20	20
Maize	100	-	50
Wheat	100	45	-
Cowpeas	-	12	-
Cotton			
June sown	22.5	22.5	Plus boron
July sown	-	12	-
Yams	26.25	-	-
Cassava	30	15	90

Table 2. Radio Programs

Type of Program	Language	Number of Programs 1979/80	1980/81	1981/82
Nu Koma Gona	Hausa	48	52	52
Noman Zamani	Hausa	48	52	52
Noman Karkara Magajin Garba	Hausa	-	-	52
Fillin Manoma	Hausa	-	-	52
Filin Kungiyoyin Samari Manoma	Hausa	-	-	52
Down to Earth	English	48	54	53

Television Programs

Type of Program	Language	Number of Programs 1979/80	1980/81	1981/82
Farming in the 1980s	English	9	-	-
Noman Yanke Talauci	Hausa	41	52	53

Table 3. Farm Families Per Junior Technical Agricultural Staff[a] by States, 1975/76

States	Farm Families Per Extension Worker
Kwara	994
Niger/Sokoto	3,006
Benue/Plateau	3,140
Kaduna	3,528
Bauchi/Borno/Gongola	3,828
Kano	6,315
State average	2,313

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a. Refers to Agricultural Assistant and the equivalent grades.

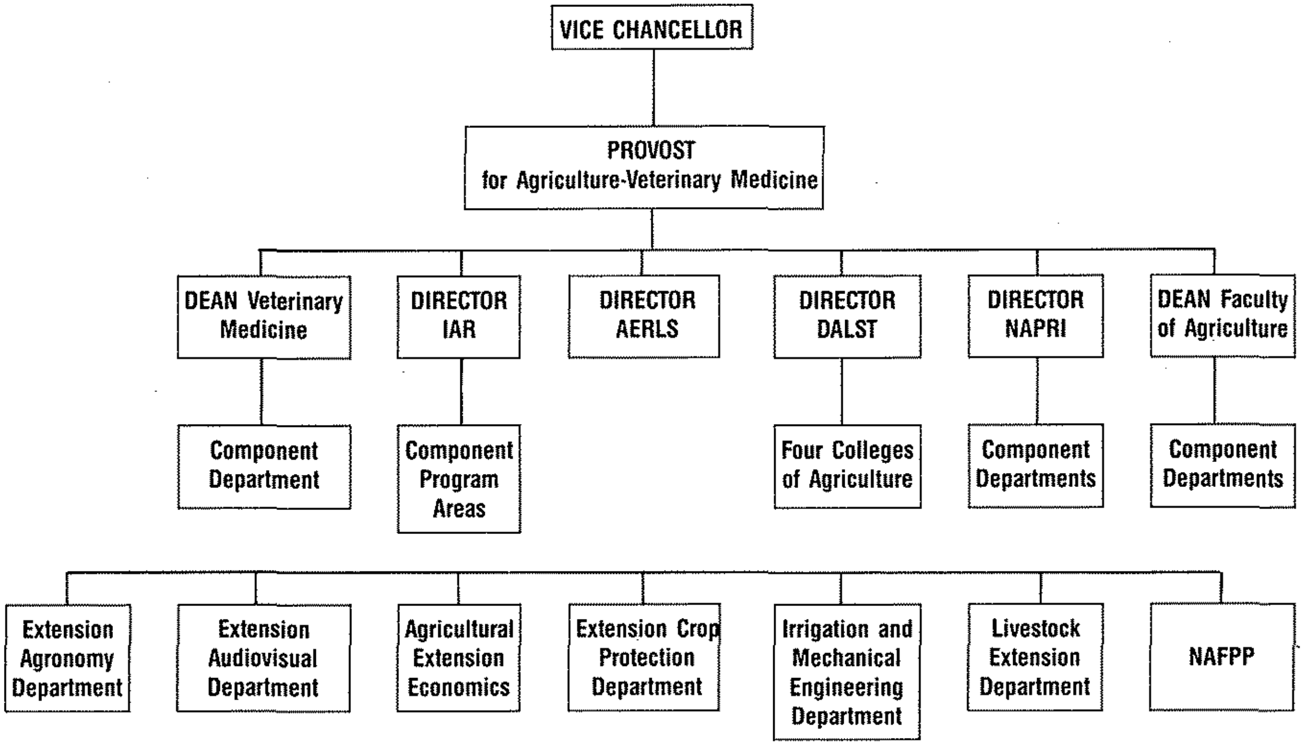
Source: Countrywide Study, Nigeria Manpower Planning and Utilization, FAO, Rome, 1978.

Table 4. Specialized In-Service Training Courses

Course		Number of Participants	Year
1.	Crop protection	305	1978
2.	Young farmers clubs	14	1973
3.	Irrigation agronomy	117	1976
4.	Irrigation engineering	97	1975
5.	Farm management	109	1974
6.	Audiovisuals	100	1975
7.	Home economics	80	1979
8.	Livestock/veterinary	233	1979
9.	Horticulture	76	1979
10.	Agronomy	115	1979
11.	Requested	?	?
12.	General	856	1982

Table 5. Publications Produced and Distributed, 1979-82

Publications	1979/80		1980/81		1981/82	
	Types	Quantity	Types	Quantity	Types	Quantity
Recommended practices	-	-	3	30,000	-	-
Guides	25	145,000	85	472	38	295,000
Bulletins	2	10,000	13	54,000	13	66,000
Flipbooks	-	-	9	9,000	10	13,500
Posters	11	724,000	13	143,000	25	788,000
Leaflets	3	260,000	13	434,000	2	120,000
Newsletter	-	-	1	400	2	805
Extension journal	-	-	-	-	1	5,000
Handbills	4	249,000	1	62,000	-	-



Notes: IAR - Institute for Agricultural Research.
DALST - Division of Agricultural Livestock Services Training.
NAPRI - National Animal Products Research Institute.
NAFPP - National Accelerated Food Production Project.

Figure 1. Structure of AERLS Within the Agricultural Complex of the Ahmadu Bello University - Zaria.

AGRICULTURAL RESEARCH AND EXTENSION IN SIERRA LEONE

Willie E. Taylor

History of Agricultural Research and Extension in Sierra Leone

Organized agricultural research in Sierra Leone began about 1910 with the establishment of the Department of Agriculture and a Training College, both at Njala. The department in those days carried out research mainly on the export crops such as coffee, cocoa, and to a certain extent rice and with livestock, including pigs, poultry, and cattle. The teacher training college that was within the same area trained teachers as well as agricultural workers to be extension agents in the rural areas.

During the period before Sierra Leone achieved its independence in 1960 research became regional in orientation. There were the West African Rice Research Station with headquarters in Sierra Leone, the West African Institute for Oil Palm Research in Nigeria, and the Cocoa Research Institute in Ghana. Each of these had stations in all the then British West African colonies. The emphasis on research was to increase the productivity of the cash/export crops to meet the demands of the colonial manufacturers.

After independence, there was a full-scale dismantling of these research structures in an attempt to help in the realization of an image of independence. In this regard very nearly all the former colonies began to establish their own national research institutions. This was, in our own experience, an era that spelled doom for research. The linkage between research and extension became progressively weaker to the point of being nonexistent. The direction of research thus became very diffuse so that the possible benefits that it could bring were often not realized. To the politicians and policymakers, a research institution was another of those appendages that were liabilities rather than assets. They were regarded only as institutions for disbursement of the Government funds, which were beginning to become very scarce.

Organization of Research and Extension in Sierra Leone

Research is presently a function that is being carried out within the University of Sierra Leone and other institutions that were developed for research. As far as agricultural research is concerned, this is done by Njala University College (NUC), which is one of the two constituent colleges, and the Rice Research Station at Rokupr (once the headquarters of the West African Rice Research Station). These institutions carry out their work to a certain extent quite independently of each other. They have their own staff and are largely supported financially by the Central Government. A certain amount of external funds for research is received by such international organizations as International Institute of Tropical Agriculture (IITA), International Maize and Wheat Improvement Center (CIMMYT), International Development Research Centre (IDRC), etc. However, these funds constitute only a small percentage of what is spent on agricultural research.

Presently, there has been established a research/extension model which is the Adaptive Crop Research and Extension (ACRE) Model. This will be discussed later.

Extension in agriculture is a function of the Ministry of Agriculture and Natural Resources (MANR). However, there are a number of agencies such as rural development projects that also have their own extension support programs.

In such a research and extension setting, we are familiar with the many defects that have made the process of technology transfer ineffective. The two major weaknesses are that (a) research is not coordinated and does not address the real issues that affect productivity and (b) extension work does not have a research support base and therefore has nothing much to extend.

Suggested Improvement of Agricultural Research Structure in Sierra Leone

Research in agriculture should be multidisciplinary in approach. The problems that limit agricultural production include agronomic, sociocultural, and economic issues. Where these are addressed in a team approach, the result is that packages can be developed that are appropriate, responsive to, and acceptable by the farmers. At the present, we talk of a farming system approach to agricultural research because it embraces a consideration of all the various facets that influence the farmer's performance in the rural setting. It is not surprising, therefore, that this kind of approach is beginning to receive the recognition it deserves by our agricultural research institutions.

The university has a corps of highly trained personnel whose full potential energies still remain untapped. This group of people should be used in investigating the many constraints to agricultural productivity.

Research should be coordinated to avoid unnecessary duplication of both materials and manpower resources. It must also have an advisory role to be able to influence policies in the right direction. Thus, in Sierra Leone we are in the process of forming a National Agricultural Coordinating Council to take over these and many other functions.

Suggested Improvement of Agricultural Extension Structure in Sierra Leone

One of the deficiencies in our system has been the complete lack of a linkage between research and extension. In order to achieve linkage, there is a need to have a regular means of communications between these two sectors so that the idea of mutual interdependence for "survival" is established and extended in all activities. In our situation, there is a need for appropriate training of the extension workers and for recognition equal to that of the researchers. This, where properly done, puts both the extension workers and the researchers on the same level for easy communication.

In addition, there are other supports that must be adequately provided for the extension staff so that they can perform effectively. These are mobility and improved conditions of service, as well as suitable means of award for excellent performance.

In terms of decisionmaking, there is a need to decentralize authority so that the extension agents can be more responsive to the demands on their judgment in the field and not be made ineffective by the usual bureaucratic and cumbersome situation that exists within the Ministry of Agriculture.

Technology Identification and Transfer--The ACRE's Experience

Background Information on the ACRE Project

As a result of the ineffectiveness of applied technical and socioeconomic research and extension in the country, the Sierra Leone Government approached the United States Agency for International Development for assistance in this direction. ACRE was the outcome of this request and subsequent negotiations. Its location close to the NUC Campus was deliberate and was meant to:

1. Provide a strong working relationship between MANR and NUC.
2. Maximize the use of college expertise and reduce costs on the implementation of the project.
3. Remove the constraints of logistic support for the NUC staff by providing funds that will enable them to carry out effective applied research.
4. Link the Ministry of Agriculture and Forestry (MAF) extension staff with research so that the results can be known, appreciated, and usefully applied in extension.
5. Establish a model for cooperative research and extension that will be sustained after the project funding period.
6. Test the feasibility of cooperative extension between MAF and NUC.

The special features of the ACRE Project are as follows:

1. It has an almost countrywide coverage; NUC's extension is limited to the four neighboring chiefdoms.
2. It covers all food crops generally intercropped with rice on the uplands; it does not deal with rice per se.
3. The research emphasis is on applied research and testing on the farmers' fields.
4. Considerable emphasis is put on collecting basic socioeconomic information as a guide to the best approach in helping farmers.

Objectives of the ACRE Project

The ACRE Project has a number of objectives, which are listed as follows:

1. Increase the agricultural productivity in terms of food crop production by the small farmers in Sierra Leone through on-farm research and extension activities. In this the researchers, the extension workers, and the farmers work as a team with a common objective.
2. Establish a linkage between agricultural research and extension with appropriate feedback machinery.
3. Establish local links with agricultural agencies as well as with the international agricultural research institutions such as West African Rice Development Association (WARDA), IITA, CIMMYT, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and IDRC.

4. Reach a target of 20,000 farm families in terms of making available to them improved seeds and planting materials, improved production techniques, and storage/marketing techniques.
5. Establish a long-range food crop research and extension plan.
6. Provide adequately trained local staff in relevant areas of adaptive research and extension.
7. Develop, through on-farm trials, a replicable and reliable technology delivery system in terms of food crop production.
8. Help improve the nutritional status of the farm families through the introduction of more nutritious and acceptable food crops accompanied by appropriate technology and management practices.

Project Output

Since the commencement of activities of the ACRE Project in 1980, the following achievements have been noted:

1. Constant delivery of improved, adaptable, and acceptable technology in terms of seeds, planting materials, and management practices.
2. The successful demonstration that extension and farmers' activities benefit from appropriate research support.
3. Increased farmer participation in deciding the nature of the problems that are to be investigated.
4. Completion of a benchmark survey on socioeconomic, agronomic, and appropriate technology status of representative groups of the farming population.
5. Establishment of long- and short-term training to provide the local counterpart skills needed in all relevant areas of the ACRE Project activities.
6. Provision of information and materials relevant to the needs of the extension workers, i.e., bulletins and planting materials.
7. Demonstration of the need for closer collaboration between NUC and MAF in terms of improvement in the country's research and extension activities.

International Research and Training Relationships

The following is a summary of the links that have already been established:

1. WARDA--Consultancy services, conduct of rice trials, and more recently attempts to enable ACRE's extension staff to benefit from WARDA's training activities.

2. IITA--Consultancy services, training, participation in international food crop trials (maize, cowpeas, roots, and tubers). Proposal for a joint project on farming system research.
3. CIMMYT--Consultancy services and participation in international maize trials as source of new materials for Sierra Leone conditions.
4. ICRISAT--Source of planting materials for sorghum, groundnuts, and pigeon peas.
5. IDRC--Support to ACRE/NUC for farming system research.
6. Universities--Ife in Nigeria, Louisiana State University in the United States, and others provide training of graduate staff of ACRE.

Technology Identification

A major assumption of the ACRE Project is that food crop production is limited mainly by the characteristics of the crop cultivars and the management practices. However, experience has shown that other factors, such as labor availability, and economic constraints, such as marketing of produce and the costs of recommended technology, are very important in influencing the farmer's response to the technology. The kinds of technology that we have tried include the following:

1. Identification, screening, and release of improved crop cultivars together with simple management practices. These management practices include fertilizer application, row planting, timely weeding, application of insecticide, and the selection of sites to suit the crop that is being grown.
2. In terms of increasing the efficiency of fertilizer application, the use of fertilizer-impregnated mudballs to be placed near the rice stand that will benefit from the slow release of fertilizer in the swamp ecology.
3. In terms of improving the crop stand, dibbling for uplands where rice is normally broadcast. For the swamp, an increase in the number of plants transplanted per hill is recommended for higher crop yields.

In general, surveys carried out have shown that farmers will adopt the technology that is within their reach. For example, experience has shown that in an improved crop cultivar management demonstration, the farmers will first adopt the crop cultivars and later, in succession, the components of the package that are within their reach.

Fertilizer Technology, Recommendations, and Adoption

The ACRE experience has shown that a sound basis is needed for fertilizer use recommendations to farmers. The recommendations must be based on actual soil fertility/crop response studies of the various elements that are necessary for good and economic crop performance. This is a very time-consuming and expensive exercise that is not always accepted.

For farmers to accept and benefit from recommendations, there must be a means of testing soil and advice on appropriate fertilizer requirements well before the cropping season begins. However, with our predominantly shifting cultivation, where the farmer may not always decide early on the site for his new farm, this may not be possible.

In economic terms, fertilizers are necessary but expensive farm inputs. Except for high-value cash crops and, to a certain extent, the staple food crops, farmers may not be able to make use of this recommended technology.

The efficiency of fertilizer can be increased by such practices as split application, mudball fertilizer placement, and band placement. These are technologies that require extra labor and are therefore not usually welcomed by the farmer.

The use of biological and organic fertilizer needs to be given greater consideration. It is generally felt that this kind of soil treatment may have an important role in subsistence agriculture.

Conclusions

I have tried to give a historic sketch of the status of agriculture research and extension before and after independence in Sierra Leone. This has been followed by a discussion of the efforts to introduce corrective measures by the establishment of the ACRE Model. In this model for food crop research, the two components--i.e., research and extension--are retained in the University (research institution) and the Ministry of Agriculture respectively. Linkage is established through extension specialists that provide the necessary two-way communication between the researcher and the extension worker.

In terms of technology identification, transfer, and diffusion, farmers would in general adopt the components of a package one item at a time. Usually they would first adopt a cultivar and later, depending on the socioeconomic and cultural demands, would adopt the others.

In terms of fertilizer use, much needs to be done in providing soil fertility/crop response curves for the various agroecologies. This will form a basis for more accurate and economic recommendations to the farmers. Fertilizer use is widely accepted as a worthwhile technology for increased productivity; yet such factors as cost, availability and distribution, and special demands on labor as well as the fertilizer's interaction with weeds, pests, and disease need to be considered by the researchers. In addition, more attention is needed to develop farming practices that will help in the efficient use of fertilizer, be it organic or inorganic.

ISSUES AND POLICY OPTIONS IDENTIFIED AT THE WORKSHOP

Group I--National Policy Issues

1. Issue--National agricultural development plans are often overgeneralized; lacking specificity, they fail to guide research and extension planning adequately.

   Policy Option--National agricultural development can be accelerated if it is based on clearly defined policies and priorities with action plans for the development of specific areas and crops. Knowing which areas and crops are priorities will enable research and extension staff to focus on the particular problems of these areas and crops.

2. Issue--National research and extension organizations are either not involved in developing or are not fully informed of national policy decisions affecting crop and input procurement and marketing strategies.

   Policy Option--Information on government plans to produce or procure and market food and fertilizer products should be directed to research and extension organizations so that research and farmer assistance activities and farmer recommendations can be tailored to the changing situation. Particularly, changes in fertilizer products to be imported or produced nationally should be fully discussed, and needed programs of research and farmer education on the use of the new products should be given priority. Crop and input price changes must be made well ahead of the start of the crop season as these may well affect fertilizer recommendations and farmer plans.[1]

3. Issue--Food should not be imported into a country when it can be grown economically.

   Policy Option--Fertilizers are a key item in food crop self-sufficiency plans, but they must be used effectively. National fertilizer policies should be aimed at increasing the cost effectiveness of fertilizers by maximizing crop response to applied nutrients and by reducing the cost of fertilizer through efficient procurement, production, and distribution

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[1] The whole area of efficient fertilizer procurement, production, distribution, storage and handling, and sales requires a considerable degree of expertise. These are areas in which a nonprofit organization like IFDC can play a key role in preinvestment studies and training, technical assistance, and research support.

schemes. Potential use of national mineral resources directly as fertilizers or for converting into fertilizers products should be evaluated and exploited where feasible. Fertilizer efficiency research in terms of improved products and application practices--form, rate, timing, and placement--integrated with good soil fertility management practices is needed.

4. Issue--Farmers exploit the land and the natural fertility of the soil for gain (food or profit). Long-term adverse effects of agricultural exploitation on soil productivity are of major concern.

   Policy Option--Farm ownership patterns and the returns from farming should be such as to encourage good farming practices. Sound soil and water management practices, including drainage and erosion control measures, must be developed and applied as nationally supported programs. Strong research and extension programs are also needed to ensure increasingly better crop yields based on improved soil fertility.

5. Issue--The soils of Africa are of generally low fertility status. Increased crop production is possible by increasing crop areas and yield per unit area. In either case, it is essential to maintain and if possible increase soil productivity.

   Policy Option--Effective use of organic materials, biologically fixed nitrogen, and fertilizers is needed to achieve these two objectives. Only sound government agricultural policies will encourage the farmer to maintain or increase the fertility of his fields.

6. Issue--Adverse soil conditions due to soil acidity and low base status are endemic in many parts of Africa. These adverse conditions can reduce the efficiency of applied fertilizers, while fertilizers themselves may aggravate the acidity problem.

   Policy Option--National programs are needed to ensure that the adverse effects of soil acidity and base depletion associated with fertilizer use do not reduce crop yields or decrease soil productivity. These programs must be based on research aimed at the economic use of basic materials, particularly those of local origin. Unless innovative and practicable solutions are found to the acidity problem, governments may be forced into large-scale, subsidized national liming programs.

7. Issue--Both researchers and extension workers often feel that they are undertrained or underpaid and underbudgeted as regards support funds; however, a prime concern is for more efficient utilization of existing resources, both human and material.

Policy Option--Effective management, including better definition of priorities, and collaborative work with the international centers and with countries with similar ecological zones and problems can reduce costs and increase effectiveness.

International and bilateral donor funds and staff support should be seen to be incorporated into a logical development niche in the overall national effort.

More in-service training with a strong practical component is needed.

8. Issue--The desired level of integration of research, extension, and farmer knowledge is rarely achieved.

Policy Option--Institutional structures and linkages and individual attitudes must be changed so that farm-level development is clearly seen as the ultimate objective of both research and extension organizations.

9. Issue--Even when institutional linkages exist between research and extension, these are generally weak.

Policy Option--Both research and extension must be involved jointly when programs of work and budget are being established for integrated activities. Financial, organizational, and material requirements and responsibilities must be clearly defined before the start of such programs.

Farming systems research teams, where they exist, can be used to guide both researchers and extension staff on an integrated approach to the solution of farm-level problems.

Trials and demonstrations in farmers' fields, although the responsibility of research and extension, respectively, must be seen as steps in the same process, namely, the transferrence of sound advice to the farmer.

10. Issue--Farmer education is generally regarded as a monopoly of some government department.

Policy Option--The commercial sector is capable of supporting, in a complementary way, extension activities aimed at the dissemination of product knowledge, e.g., the types, rates, and application methodologies for efficient fertilizer use when used as a component of a crop production package. Demonstrations, mini-kit schemes, and publicity campaigns run by the commercial sector can strengthen the impact of the government extension service.

Group II--Research-Related Issues

11. Issue--Adverse moisture regimes, particularly drought conditions, reduce crop yields in an unpredictable way and thus expose the farmer to severe risks.

    Policy Option--Research is needed on yield stabilization under adverse moisture regimes and on the role and effectiveness of fertilizers in stabilizing crop yields under these conditions.

12. Issue--Agricultural research programs are often developed without reference to sources of expertise other than that of peer group researchers.

    Policy Option--In developing research programs, emphasis must be placed on achieving results that are relevant to the agronomic, economic, and sociological needs of the farmer. Such an approach will require changes in the perception of the role of the extension worker and farmer, both of whom should be used in investigative and two-way communication functions.

13. Issue--Although the food problem is currently being highlighted, increased biomass production to cover not only food but fodder, litter, building materials, and fuel needs must be achieved.

    Policy Option--The development of improved agricultural production systems is an urgent need. Improved soil fertility must be a component of these systems.

14. Issue--Organic matter recycling and the use of organic manures, while proven to be desirable in maintaining and improving soil fertility, are not farming techniques achievable by sedentary farmers, particularly in the drier areas. Organic materials either do not exist in the required quantities or their transfer to the field is too labor intensive, unless associated with livestock movement.

    Policy Option--In problem areas, biomass production must be increased over the short term. Research should be directed toward shifting soil organic matter and plant nutrient dynamics of farmers' fields in a positive direction and in an economic and practically acceptable way.

15. Issue--Biologically fixed nitrogen is widely recognized as having major potential for improving the fertility of soils; this effect is indirect, however, because leguminous crop residues must be incorporated into the soil either directly or through animal waste recycling.

    Policy Option--As with organic matter recycling, the growth of leguminous plants specifically for incorporation as sources of nitrogen and organic matter is unacceptable to most farmers; farmers produce crops that they can use, not crops to be plowed back into the ground. Therefore research leading to economical and practical ways of increasing the role of legumes in cropping systems is needed. Research on soil microorganisms as factors in soil nutrient dynamics is also needed.

16. Issue--Farming systems and cropping systems research is complex and long term. Short-term increases in farm-level productivity are needed.

    Policy Option--If low levels of soil fertility are holding down productivity, then research must identify or develop a point in the system where the introduction of fertilizer treatments can be seen by the farmer to be of value.

17. Issue--Fertilizer use recommendations must become more site and situation specific in order to be cost effective.

    Policy Option--On-farm research is still generally the monopoly of the cropping systems research teams. More awareness of farm-level fertility problems and the role of fertilizers in correcting these problems can be achieved by actively involving soil fertility researchers with the cropping systems research fieldwork.

    Land capability maps, field experimentation, and supporting analytical services are needed to refine fertilizer recommendations. In the development of such recommendations, economic and sociological factors must be taken into account, particularly in terms of investment risk and land ownership patterns.

    The effects of adverse moisture regimes both excessive and deficit are of particular interest in establishing sound fertilization practices.

18. Issue--Fertilizer research is generally aimed at increasing the yield of only a portion of the total crop; this is particularly true in the case of grain crops.

    Policy Option--The effect of fertilizers on the components of yield and the vegetative composition of the crop must be more fully understood. Fertilizer response work must integrate both the crop physiology and soil fertility aspects of crop yields.

Group III--Extension-Related Issues

19. Issue--The education levels of even senior extension staff may compare unfavorably with those of the research staff leading to lack of two-way communication.

    Policy Option--Standards of recruitment to the extension service must be raised; quality should override quantity considerations. Extension staff at all levels should participate in regular training courses and advanced courses organized jointly by the agricultural research and higher education institutes. Links between research and extension should be strengthened by the incorporation into the extension service of highly qualified subject matter personnel who should be involved in both defining national research priorities in respect to farm-level needs and in working with research personnel to upgrade the knowledge and skills of field extension staff.

20. Issue--Extension staff have a low status in the technical hierarchy.
Policy Option--Salaries, terms of service, promotional prospects, etc., should be raised to a level adequate to give the extension worker a feeling of improved career prospects.

21. Issue--Irrespective of career prospects, immediate job satisfaction is often low because of lack of funds to adequately carry out allocated tasks. Budget constraints not only reduce the level of activity but adversely affect the value of the limited activities undertaken.
Policy Option--Job descriptions and the program of work and budget must be matched so that productivity is not only possible but is also demanded.

22. Issue--Extension staff are often heavily involved in activities unrelated to farmer education.
Policy Option--Nonextension work, such as data collection, is usually gladly shed, but activities involving the distribution of inputs (sales, credit ratings, cash reimbursement, etc.) are often considered desirable. Extension staff should transfer only knowledge. They should not engage in any task involving the actual advance or transfer of funds or products to or from the farmer. Such activities may give the aura of authority but can be damaging to good farmer-extension staff relationships in the long run.

23. Issue--Communications support units, even where they exist, are often short of farm-level facts for use as educational material.
Policy Option--Communications support units are needed and should be involved with successful field plots (both research and demonstration). These field plots should be used for field days with research and extension staff and farmers present. Communications support units must exploit these occasions to develop farmer information items for publication, radio, video, and TV use. Research and extension staff and farmers should also be used for panel discussions of farmer problems at fertilizer sales points or produce delivery centers.

Notre continent a des ressources très limitées. Et comme le disait le Ministre de l'Enseignement Supérieur et de la Recherche Scientifique lors de l'ouverture de cet atelier, "il faut faire de l'argent avec l'Agriculture et non faire l'Agriculture avec l'argent".

Nous devons donc déployer des efforts supplémentaires pour que l'autosuffisance alimentaire que nous appelons de tous nos voeux puisse intervenir à très court terme et à moindre coût.

Le Cameroun, en dépit des contraintes écologiques et des aléas climatiques qui peuvent affecter certains de nos Etats, croît, quant à lui, qu'il est possible à l'Afrique Sub-Saharienne de produire ce dont elle a besoin pour se nourrir, à condition toutefois que nos divers Etats mettent sur pied de véritables politiques de production vivrière.

Les observateurs objectifs et les responsables politiques de nos Etats sont aujourd'hui d'accord pour reconnaître que, bien que la situation catastrophique que connaît de nos jours l'Agriculture africaine soit pour l'essentiel due aux mauvaises conditions climatiques, notamment la sécheresse persistante qui a perturbé pendant plusieurs années consécutives toute pratique agricole dans bon nombre d'Etats, cette situation aurait pu être moins dramatique si des politiques adéquates de développement privilégiant notamment la promotion et la modernisation de l'agriculture avaient été mises en oeuvre dès nos indépendances.

Madame,
Messieurs,

Permettez-moi de féliciter et de remercier les promoteurs et les organisateurs de cette rencontre, notamment le Centre International pour le Développement des Engrais (IFDC) pour cette heureuse initiative qui a permis aux Représentants de nos pays de se réunir pour travailler ensemble dans le cadre de ce Séminaire. Cette initiative constitue une contribution décisive à l'effort entrepris par nos pays pour sortir leur population de la faim et de la misère.

Permettez-moi aussi de dire combien mon pays se sent honoré d'avoir été choisi pour héberger votre Séminaire. C'est là je le crois bien, une marque d'estime vis à vis du Cameroun, et un hommage rendu à son peuple, à son gouvernement, et à son Chef, le Président Paul BIYA, pour l'intérêt tout particulier qu'ils accordent à la promotion de l'Agriculture.

La Politique de développement Agricole de notre pays, sous l'égide de son Excellence le Président Paul BIYA, a en effet permis au CAMEROUN d'atteindre son Auto-Suffisance alimentaire et de mettre ainsi à l'abri du spectre de la famine la majeure partie de notre population.

Je peux dire que malgré les effets de la Sécheresse qui a frappé l'année dernière notre pays, et qui persiste encore cette année dans la Province de l'Extrême-Nord, l'Agriculture Camerounaise, grâce aux efforts appréciables consentis par le Gouvernement, continuera à tenir ce cap, car, nous sommes convaincus, comme l'a déclaré le Président Paul BIYA lors de l'ouverture du Comité Agro-Pastoral le 13 Décembre dernier à BAMENDA, que je le cite "l'Agriculture et l'Elevage, tout en assurant l'auto-suffisance alimentaire à tous les Camerounais, représentent la source la plus sûre de devises nécessaires à nos efforts de développement", fin de citation.

Monsieur le Représentant de l'IFDC, Madame et Messieurs, permettez-moi de vous féliciter une fois de plus pour les résultats élogieux de vos travaux.

Je souhaite un bon retour à chacun de vous dans vos pays et déclare clos le Séminaire IFDC-IRA sur l'efficacité des Engrais et le transfert de Technologie en Afrique.

Vive la Coopération Internationale...

CLOSING REMARKS

Mr. Kouessen Benjamin

The Honorable Governor of Littoral Province, the Representatives of IFDC, Ladies, and Gentlemen,

In view of the importance of this workshop, the Minister of Agriculture wished to preside personally over this closing session; unfortunately he has been called away on urgent business and has asked me to speak on his behalf.

It is with pleasure therefore that I take this opportunity to speak to this gathering of scientists. The theme of the workshop is Fertilizer Efficiency Research and Technology Transfer. For 5 days researchers and extension workers from Europe, North America, and Africa have been able to exchange their experience concerning the important problem of fertilizer use in Africa south of the Sahara.

I am pleased to congratulate you on the serious manner in which you have approached the problems and the pertinent conclusions which you have derived. My hope is that these final conclusions will act as a guide for your future work on fertilizers.

At the time of the opening of the workshop, the Minister of Higher Education and of Scientific Research underlined the necessity for the states of Africa to make profitable investments in agriculture and expressed the wish that this workshop could serve as a framework in defining realistic fertilizer policies. These policies should lead to increased agricultural production through a better understanding of our soils and the judicious use of fertilizers.

It is not necessary to stress the importance of the theme of the workshop at a time when many of the countries of Africa represented here have to face an almost unprecedented calamity in their food production.

Not a day passes without the media drawing our attention to the large population movements away from the stricken areas and even into neighboring countries, looking for food to survive on.

Whether we are talking about

--Research themes and programs which must take into account the problems of the small farmers and zonal development,

--Or the training of extension agents, particularly concerning their introduction to research techniques suitable for guiding the farmers correctly,

--Or the improvement of communications between research and extension so that research results can reach the small farmers,

--Or improvements in the supply, storage, and distribution of fertilizers to the farmers by creating a structure relevent to the tasks in each country,

--Or the strengthening of subregional cooperation for the supply or production of fertilizer,

the solutions to these problems are important to us.

Needless to say, without clearly defined policies in each country and without close subregional cooperation, the procurement or production of fertilizers will become increasingly difficult and this in spite of the willingness of our governments to get fertilizers to those small farmers who need it for increased crop production.

More than ever, it is necessary that fertilizer use be developed in a rational way so that all the various necessary investments become profitable. Recycling of organic matter, the use of improved seeds, and sound plant protection practices will allow us to maximize the profit that can come from the correct use of fertilizers.

Our continent has very limited resources. As the Minister of Higher Education and Scientific Research said in his opening address to this workshop, "We must make money from agriculture and not make agriculture with money."

We must therefore make extra efforts so that the food self-sufficiency that we all wish for will be achieved soon and at the least cost. Cameroon believes that sub-Sahara Africa can feed itself in spite of the ecological constraints and the climatic hazards which affect certain countries, provided that our various countries establish sound food production policies.

Objective observers and responsible politicians of Africa agree that although the catastropic agricultural situation in Africa is due principally to adverse climatic conditions and particularly to the drought, which for several years running has severely damaged agricultural production in many countries, nevertheless, if sound agricultural modernization schemes had been initiated at the time of independence, the situation today would possibly be much less grave.

Ladies and Gentlemen, allow me to thank the sponsors and organizers of this workshop, particularly IFDC, for creating the opportunity which has allowed representatives of our African countries to meet and work together.

This initiative is a decisive contribution to the efforts being undertaken by our countries to lead the population away from hunger and poverty.

Allow me also to say that my country feels honored to have been chosen as a base for the workshop. This is, I believe, a mark of the esteem in which Cameroon, its people, its government, and its President Paul Biya are held, and also for the great interest shown here in the promotion of agricultural production.

The agricultural development policies of our country under the guidance of his Excellency President Paul Biya have in effect permitted Cameroon to achieve self-sufficiency in food and thereby sheltered most of our population from the spectre of famine.

I am able to say that despite the effects of the drought that hit our country last year and that still persists this year in the extreme north we have been able to surmount the difficulties because of the efforts of the Government.

I repeat President Paul Biya's words at the opening of the Agro-Pastoral Committee, December 13, 1984, at Bamenda, "Crop production and livestock rearing while ensuring food self-sufficiency also represents the source of capital that we need for our development."

The Representatives of IFDC, Ladies and Gentlemen, permit me to congratulate you once more for your praiseworthy efforts.

I wish each of you a safe return to your home country and declare the IFDC IRA Workshop closed.

Long live international cooperation.

APPENDIX I

Program Schedule for
Fertilizer Efficiency Research and Technology Transfer Workshop for Africa

Douala, Cameroon
January 21-25, 1985
International Fertilizer Development Center
and
Institute of Agronomic Research
Ministry of Higher Education and Scientific Research

Date	Time	Activity	Responsibility
1/21 Mon.	0830-0900	Registration	
	0900-0915	Welcome Address by His Excellency the Minister of Higher Education and Scientific Research Dr. Gibering Bal Alima	J. Eckebil
	0915-0945	Coffee break	
	0945-1015	Introduction to Workshop	D. H. Parish/ J. Eckebil
		Session I: The Farmer and the Land	C. Pieri, Chairman
	1015-1130	African Farm Practices and Potential for Change	D. Norman
	1130-1230	Soil Resources of Sub-Saharan Africa	R. Sant Anna
	1230-1400	Lunch	
		Session II: Dynamics of Soil Fertility	D. Norman, Chairman
	1400-1450	Integrated Soil Fertility Management in Africa: IRAT's Experience	C. Pieri
	1450-1540	IITA's Farming System Research and Soil Fertility Dynamics	B. Okigbo
	1540-1610	Coffee break	
	1610-1700	Organic Matter Recycling and Biological Nitrogen Fixation in Africa (Verbal presentation only)	R. Sant Anna

(Continued)

Date	Time	Activity	Responsibility
1/21 Mon.	1700-1730	Review and Summary--Issues and Options	
		Session I	C. Pieri
		Session II	D. Norman
		Rapporteurs	U. Mokwunye/ P. Rosseau
	1900-2000	Reception for Delegates	Ministry of Higher Education and Scientific Research, Cameroon

(Continued)

Date	Time	Activity	Responsibility
1/22 Tues.		Session III: Fertilizers and Soil Fertility	B. Okigbo, Chairman
	0830-0915	1. Fertilizers and Sub-Saharan Africa 2. Appropriate Fertilizer Technology for Sub-Saharan Africa	D. H. Parish D. H. Parish
	0915-1000	Fertilizer Research in India (Verbal presentation only)	D. H. Parish
	1000-1030	Coffee break	
	1030-1115	Cooperative Research on Management of Phosphate and Nitrogen in Sub-Saharan Africa	U. Mokwunye
	1115-1215	Approches d'Etude Pour Une Utilisation Optimale du Phosphate Naturel de Tilemsi par les Paysans	P. Rosseau/Z. Sanogo
	1215-1400	Lunch	
	1400-1445	Learning From Farmers: Methodologies for Implementing Farmer Participation in Fertilizer Testing (J. Ashby)	D. Norman
		Session IV: National Fertilizer Research Programs	U. Mokwunye, Chairman
	1445-1545	Country Presentations	
	1545-1615	Coffee break	
	1615-1645	Country Presentations	
	1645-1730	Review and Summary--Issues and Options	
		Session III	B. Okigbo
		Session IV	U. Mokwunye
		Rapporteurs	A. Bationo/ W. L. Pritchett
	1800	Sightseeing	

(Continued)

Date	Time	Activity	Responsibility
1/23 Wed.		Session V: Extension Alternatives for Transfer of Improved Fertilization Practices	R. Sant Anna
	0830-0915	Transferring Technology to Small Farmers: Whose Job is It?	B. Woods
	0915-1000	The Indo/British Fertilizer Program (S. P. Dhua)	G. Sohbti
	1000-1045	Coffee break	
	1045-1130	The FAO Fertilizer Programme in Africa	C. Joly
	1130-1215	Research and Technology Transfer--The U.S. Land Grant University Approach	W. L. Pritchett
	1215-1400	Lunch	
		Session VI: National Fertilizer Extension Programs	B. Woods, Chairman
	1400-1530	Country Presentations	
	1530-1600	Coffee break	
	1600-1700	Panel on Approaches to Fertilizer Technology Transfer	G. Sohbti/C. Joly/ W. L. Pritchett/ L. Williams
	1700-1730	Review and Summary: Issues and Options	
		Session V	R. Sant Anna
		Session VI	B. Woods
		Rapporteurs	E. A. Salako/ P. Rosseau
	1900	Reception for Delegates	IFDC

(Continued)

Date	Time	Activity	Responsibility
1/24 Thur.		Session VII: National Policies and Fertilizer Marketing	G. Sohbti
	0830-0930	National Policies and Their Effect on Fertilizer Use	A. Falusi
	0930-1030	Fertilizer Marketing in Developing Countries	L. Williams
	1030-1100	Coffee break	
	1100-1215	Session VIII: National Policy Issues and Fertilizer Use Development	A. Falusi, Chairman G. Sohbti/L. Williams/ D. H. Parish/B. Woods
	1215-1400	Lunch	
	1400-1830	Formulation of Recommendations of the Workshop by Working Groups	
		Item I--Improving Fertilizer Efficiency Research	Francophone sub-group Anglophone sub-group
		Item II--Improving Fertilizer Technology Transfer	Francophone sub-group Anglophone sub-group
		Item III--Integrating Fertilizer Research and Technology Transfer	Francophone group Anglophone group

(Continued)

Date	Time	Activity	Responsibility
1/25 Fri.		Closing Session: Conclusions and Recommendations of Workshop	D. H. Parish/J. Eckebil Chairmen
	0830-0915	Recommendations and Discussions--Item I Chairman	U. Mokwunye
	0915-1000	Recommendations and Discussions--Item II Chairman	M. R. Mulele
	1030-1045	Recommendations and Discussions--Item III Chairman	E. A. Salako
	1045-1130	Coffee break	
	1130-1200	Conclusions and Recommendations	D. H. Parish/J. Eckebil
	1200-1230	Closing Address by Mr. Kouasseu Benjamin, The Secretary General, The Ministry of Agriculture	J. Eckebil
		Vote of Thanks	D. H. Parish
	1230-1400	Lunch	
	1400-1730	Field Trip to Jhamba Research Station	

APPENDIX II

RESOURCE DOCUMENTS DISTRIBUTED

1. Chemistry and World Food Supplies: Research Priorities for Development. 1983. Report of a Workshop. "Soil Fertility and Plant Nutrition," National Academy Press, Washington, D.C.

2. Toward Sustained Development in Sub-Saharan Africa. 1984. The World Bank, Washington, D.C.

3. Lofchie, Michael F. and Stephen K. Commins. Number 2, September 1984. Food Deficits and Agricultural Policies in Sub-Saharan Africa, The Hunger Project, 2015 Steiner Street, San Francisco, California 94115.

4. Organic and Conventional Farming Compared. October 1980. Council for Agricultural Science and Technology Report No. 84.

5. World Agriculture - Review and Prospects into the 1990s. December 1983. Winrock International Livestock Research and Training Center, Route 3, Morrilton, Arkansas 72110-9537.

6. Frederick, M. T. 1983. Pollution Control and Environmental Protection, International Fertilizer Development Center, Muscle Shoals, Alabama.

7. Kanwar, J. S., and M. S. Mudahar. 1983. Fertilizer Sulfur and Food Production (Executive Brief), International Fertilizer Development Center, Muscle Shoals, Alabama.

8. Martinez, A., and R. B. Diamond. 1982. Fertilizer Use Statistics In Crop Production, International Fertilizer Development Center, Muscle Shoals, Alabama.

9. Mudahar, M. S., and T. P. Hignett. 1981. Energy and Fertilizer Policy Implications and Options For Developing Countries, International Fertilizer Development Center, Muscle Shoals, Alabama.

10. Clayton, W. E. 1984. Humidity Factors Affecting Storage and Handling of Fertilizers, International Fertilizer Development Center, Muscle Shoals, Alabama.

11. Kaddar, T., D. A. Russel, and G. W. Cooke. 1984. The Vital Role of Potassium Fertilizers in Tropical Agriculture, International Fertilizer Development Center, Muscle Shoals, Alabama.

12. McClellan, G. H. 1984. "Fertilizer Raw Material Resources and Fertilizer Products," unpublished paper, International Fertilizer Development Center, Muscle Shoals, Alabama.

13. Eicher, C. K. "International Technology Transfer and the African Farmer: Theory and Practice," University of Zimbabwe, Harare, Zimbabwe.

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15. "International Spot Market Prices of Key Fertilizer Materials and Crops, 1982 to Date." 1984. Computer Printouts. International Fertilizer Development Center, Muscle Shoals, Alabama.

16. "African Workshop on Extension and Research." 1984. Unpublished paper. The World Bank, Washington, D.C.

17. Mellor, J. W. 1984. "The Changing World Food Situation - A CGIAR Perspective," unpublished paper, International Food Policy Research Institute, Washington, D.C.

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