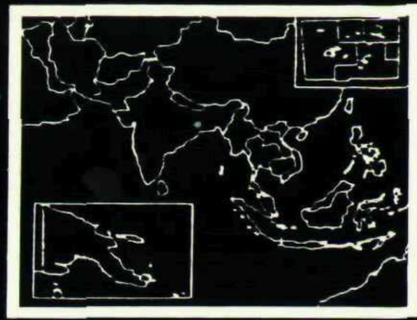
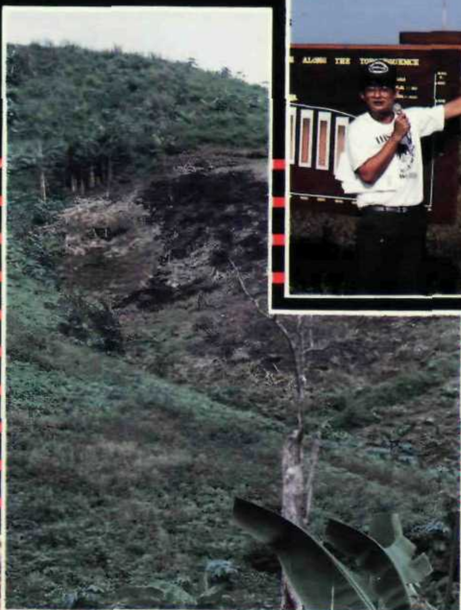
SOIL MANAGEMENT UNDER HUMID CONDITIONS IN ASIA AND PACIFIC





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SOIL MANAGEMENT UNDER HUMID CONDITIONS IN ASIA

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Proceedings of the

First Regional Seminar on

Soil Management Under Humid Conditions in Asia

ASIALAND

October 13-20, 1986

Edited by

M. Latham

IBSRAM International Board for Soil Research and Management
P.O. Box 9-109, Bangkhen, Bangkok 10900, THAILAND

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Foreword

Soil management under humid conditions, the adaptation and use of new cost-saving technologies in order to increase food and other agricultural production, while at the same time minimizing environmental damage, is becoming more and more urgent in Asia and the Pacific. Forest clearing is increasing at a very rapid rate - where there still is some forest - and reaches lands which are extremely marginal for crop production. Clearing methodologies are often not adapted to the area, and hence land clearing creates problems for plant growth. Whereas clearing is sometimes a necessity due to high population pressure, on the whole management technologies used on lands after they have been cleared remain rather poor. Increasingly intensive land use under poor conditions has created extended areas of degraded land.

To address these problems, IBSRAM has created three global soil management networks:

- Tropical land clearing for sustainable agriculture
- Management of acid tropical soils
- Management of Vertisols.

The seminar addressed these three topics in order to establish a regional soil management network. In this endeavour, IBSRAM was supported by the Asian Development Bank (ADB) and the Australian Centre for International Agricultural Research. Other organizations, and notably the Swedish Agency for Research Cooperation with Developing Countries (SAREC), the Technical Centre for Rural Cooperation Program of the European Economic Community, the US Soil Management Support Service (SMSS) and TropSoils, the International Rice Research Institute (IRRI), and the International Crop Research Institute in the Semi-Arid Tropics (ICRISAT), joined in this effort.

These proceedings include the formal opening and closing addresses, twenty-seven papers which were presented during the plenary session, the recommendations, program, and the list of participants of the seminar.

The participants concluded that they were ready to form a regional network on "Land Development and Soil Management in Asia and the Pacific (ASIALAND)" under the guidance of IBSRAM. It is hoped that this network will provide solutions to the problems raised during this seminar and also form a framework within which such issues can be addressed.

M. Latham
IBSRAM Director

Opening Addresses

OPENING ADDRESS

by Sakda Orpong
Governor of Khon Kaen

Your Excellency, distinguished guests:

It is an honour for the province of Khon Kaen to host this seminar on Soil Management under Humid Conditions in Asia. Khon Kaen province, as you will see, is essentially an agricultural region. Farmers form the bulk of the population. They grow rice, sugarcane, cassava, kenaf, peanuts and a lot of vegetables, which makes the food of the northeast one of the most famous in the country. I hope that during your stay here, you will have the opportunity, apart from your work, to try some of our specialities.

Agriculture is our major activity, and you will see the efforts which are being made to improve our technology base - in the regional stations of the Department of Land Development, in the Department of Agriculture, and in the university. Khon Kaen has had a university since 1964, and this has given an opportunity for our youth to be trained in new techniques. Many specific development projects have been established in the region in recent years. However, we still need further knowledge to help us to diversify our cropping systems and to increase the production of our main crops - cassava, sugarcane, and rice - which have been very difficult to produce commercially in recent years.

We have confidence in the processing of the commodities of the region by agroindustry, and we hope that in the future this will be a solution to the marketing of our products. In the meantime, we have to cope with the present situation. Farmers are poor but cheerful, and are prepared to learn. You should also be aware of our two tourist specialities - umbrella design and sericulture. Chonabot silk is very famous in Thailand and is probably one of the best quality silks in the country. And finally, after your working sessions, you may have a chance to enjoy some aspects of Khon Kaen nightlife, and that, as you will see, is a real experience in itself.

Your Excellency, distinguished guests. Welcome to the province of Khon Kaen. I wish you every success for this seminar, and I hope that you will take back to your respective countries a warm image of this part of northeast Thailand.

OPENING STATEMENT

by Dr. Marc Latham

Director, International Board for Soil Research and Management (IBSRAM)

Your Excellency, distinguished guests, and participants:

It is a great honour for IBSRAM to organize, with the help of the Asian Development Bank, the Australian Centre for International Agricultural Research, and the Thai Ministry of Agriculture and Cooperatives, this first regional seminar on Soil Management under Humid Conditions in Asia. I am pleased to see all of you here and I am sure that we will have a fruitful week. Let me present IBSRAM in a few words and situate this seminar in our overall strategy.

The International Board for Soil Research and Management (IBSRAM) is a new international organization. It was created in 1983 in Townsville, Australia, and has been functioning in a practical way since 1985. Now we have our headquarters at the Department of Land Development in Bangkok, Thailand. The basic ideas behind the formation of IBSRAM were that:

- By the end of the century an extra two billion people will be living on this planet. Yet farmers cannot produce, at present, the quantity and the quality of crops necessary to feed this growing population. It is in the tropics that this deficiency is most acute and widespread.

- In order to increase their production, farmers have extended their cultivation to marginal areas for agriculture, creating soil erosion and environmental degradation.

- New technologies have been produced by international and local agricultural research centers. However their adaptation to marginal lands and their extension to farmers has proved to be difficult.

- Soil management needs to concentrate on a better use of soil resources by employing adapted technologies. In this respect, farming systems have proved to be the most successful way of achieving an increased yield with low- to medium-input technologies.

So IBSRAM was created to promote sustainable soil management technologies in order to remove soil constraints to food and other agriculture production in developing countries. More specifically its objectives are:

- To validate the existing knowledge on soil management, and to promote new soil management research through networks of national agronomic institutions.

- To disseminate information on validated technologies widely through newsletters, publications, training courses, a computerized data bank, and workshops.

- To strengthen national agronomic institutions by network and information activities, and by providing technical support.

With this scope as its mandate, the IBSRAM approach could be defined as a four-stage strategy:

- Stage 1 was concerned with a review of past research, the identification of priority areas of research, and with the approach to be taken. In 1984/1985, four inaugural workshops were held on the following subjects: the physical aspects of the management of rice-based cropping systems, the management of Vertisols, the management of acid tropical soils, and tropical land clearing for sustainable agriculture.

- Stage 2 is concerned with conducting regional seminars, in which potential cooperators' project proposals are reviewed and in which the methodology to implement the programs will be defined. We are now in stage 2.

- Stage 3 is concerned with the implementation of the approved soil management program with IBSRAM coordination. We hope that, in view of the results of the present seminar, coordination activities for the Asian network will be possible by next year.

- Stage 4 deals with the development of appropriate technologies based on the results of the research projects and their extension to the farmers. The main achievements in stage 4 are not expected before two to three years, but hopefully as soon as there are some solid results to work with they will be disseminated to farmers so that practical benefits can be obtained.

Your Excellency, distinguished guests, ladies and gentlemen. As you can see, we are at an optimum stage for the establishment of the IBSRAM Asian Network on Soil Management under Humid Conditions in Asia. We have to work together during this week to clarify the ways in which we can cooperate as a network. Please do not hesitate to ask questions. We need your inputs in order to make this network a successful venture.

FORMAL ADDRESS

by Sanarn Rimwanich

Director General, Department of Land Development, and Chairman of the Organizing Committee

Your Excellency, distinguished guests, honorable participants:

It is an honour for me, as chairman of the Organizing Committee, to introduce you to this seminar on soil management under humid conditions in Asia. I would like on this occasion to thank the sponsors of this seminar: the Australian Centre for International

Agriculture Research, (represented here by Dr. Eric Craswell), and the Asian Development Bank (represented at the seminar by Dr. Dimyati Nangju), and also to acknowledge the work done by the members of the Organizing Committee. In this short introduction, I would like to put into perspective our involvement in soil management, the reasons why IBSRAM was invited to establish its headquarters in Thailand, and the outcome that we expect from this meeting.

Soil management is one of the major aims of the Department of Land Development that I have the privilege to guide. Our divisions on soil survey and classification, soil conservation, land-use planning, soil analysis, and engineering and policy planning are all more or less related to soil management. Our friends from the Departments of Agriculture and Agricultural Extension and Forestry have similar preoccupations. Our agricultural universities of Kasetsart, Khon Kaen, Chiangmai and Prince Songkhla provide the educational formation of our officers. A great effort is directed in Thailand toward agriculture and soil management. Yet, due to the importance of the problems faced and to the economic targets which are set, agricultural development and soil management come to be our main priorities. However, to improve the effectiveness of our operations we need help, information, and contact with other countries facing similar problems. Clear objectives, coordinated research, and the exchange of experience may help us to avoid expensive and long duplication.

These needs motivated my predecessor, Dr. Anunt Komes, to extend, through Dr. Samarn Panichapong, an invitation to host the headquarters of the International Board for Soil Research and Management. The establishment of this organization in our buildings in Bangkok has been effective since last year. Since then, we have been working in close cooperation, and some of our staff have participated in the major IBSRAM activities. This seminar may open a new cooperative phase with the effective inclusion of some of our programs in the IBSRAM network.

From this seminar we expect guidelines to conduct our soil management experiments, assistance to present our project proposals, and further backstopping to conduct our programs. Thailand participates in many international programs in cooperation with FAO, ESCAP, the international centers IRRI, CIMMYT and SMSS, and in networks like the IBSNAT benchmark network of the University of Hawaii. We welcome the opportunity to participate in the IBSRAM network, especially as this organization has established its headquarters in the DLD. We fully back the IBSRAM approach, which has been presented many times. However, we need further details on the objectives of the proposed Asian network, on the methodology to be adopted, and on the procedure for integrating into the network. We count on this seminar to make things clearer and to open the way to a second step in our cooperation with IBSRAM, which will be our participation in the Asian network.

Your Excellency, ladies and gentlemen, this Khon Kaen seminar is the occasion to clarify the details and to gain more insight into our possible involvement in the IBSRAM Asian Soil Management Network. We have eight days ahead to present project discussions, see some facts in the field, and finalize our network. The program is heavily loaded, but I am sure you will put all your energy into this exercise - which, unlike most conferences, requires work from all the participants.

Let me now call on the Deputy Minister of Agriculture, His Excellency Prayuth Siripanich, to officially open this seminar.

INAUGURAL ADDRESS

by H.E. Prayuth Siripanich

Deputy Minister of Agriculture and Cooperatives

Ladies and gentlemen:

It is a great honour for me to preside at the official opening of this First Regional Seminar on Soil Management under Humid Conditions in Asia. Thailand is an agricultural country. More than 70% of its population live directly or indirectly on agriculture, and about two-thirds of our total exports come from the land. You may have seen the importance of our cultivated areas when you flew from Bangkok to Khon Kaen. Thais are farmers, and even if - as in many countries - they tend to migrate towards the urban centers, agricultural development will remain as our first national priority for the foreseeable future.

However, this strength hides a great fragility. The world market for our main agricultural products - rice, cassava, rubber and sugar - has been very difficult in the past few years. Competition on the world market by our neighbours or even by developed countries, has created very harsh conditions for our exports. Prices for these major commodities are less and less rewarding for the farmers. So we need to diversify our production and adopt better management techniques in order to lower our production costs and at the same time to decrease the pressure on our environment which, if allowed to continue unabated, could create serious problems in the future.

Diversification is the key-word in our effort to achieve agricultural development. In reality, it is not an easy target. Let us take the example of the northeast where you are holding this seminar. Rice and cassava are the main agricultural products. Farmers are used to rice, and this is the main traditional crop in the lowlands: there are few alternatives to this well-adapted crop. Exports, mainly for animal feed in developed countries, has boosted our cassava production. Cassava is mainly grown on our upland sandy soils and is well adapted to their low fertility. However, threats are presently placed on these exports by developed countries, who would like to replace cassava in their animal feed by their surplus of cereals. Big efforts have been conducted by European and American specialists to find alternative crops, but the results are still unimpressive. So diversification is the target, but it still needs practical, adaptable, and acceptable solutions.

The lowering of production costs is our second aim. It can be obtained by an increase of inputs which, while increasing our yield, will lower our cost per unit. This in the long term is obviously one major avenue. However, in the shorter term, increasing the yield will boost our production and our surpluses and will create new problems for our exports. Increasing yields and decreasing the planted areas may generate employment problems that our present industry and tertiary sector cannot help to solve. So our present policy is to encourage diversification by the use of adapted cropping systems using low- to medium-input adapted technologies.

Our third aim is to decrease the pressure on the environment. Few forests are left in Thailand. Farmers have cleared low undulating areas like this Khon Kaen region. Unfortunately, due to the population pressure, they have also cleared steeplands, creating soil erosion and degradation. You will see one example in Khao Kho during your field tour. The extension of cropping to these steep slopes creates a real concern in terms of environmental conservation, as well as in terms of the sustainability of the crops which are introduced. Solutions to these problems have to be found as well. They range from reafforestation of the steepest slopes to anti-erosive practices on the lower slopes. A large project backed by the World Bank has given some solutions. These and others need to be tested and applied.

So, ladies and gentlemen, agriculture in Thailand, and Thailand as a whole, faces the end of this century with winning cards in its hand - but also with major weaknesses. We need to find solutions to the diversification of our crops, to the lowering of our cost of production, to a less environmentally damaging use of our lands. I address your seminar on these points. We do need more than recommendations which will be quickly forgotten. We need practical adapted programs on soil management which will help to solve some of our farmers' problems. I hope the Asian Development Bank, ACIAR, and IBSRAM will help us through international cooperation in this high priority task which will condition the life of our children.

Ladies and gentlemen, I have pleasure in declaring this seminar on Soil Management under Humid Conditions open.

First Session: IBSRAM and its networks

Chairmen: R.J. Millington
S. Panichapong

THE IBSRAM LAND DEVELOPMENT AND SOIL MANAGEMENT NETWORK PROGRAM IN MONSOON ASIA

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ABSTRACT

The IBSRAM soil management approach is reviewed, emphasizing the multidisciplinary strategy which has been adopted, with interactions involving soil scientists, agronomists and socioeconomists. The three global networks which are part of the regional network on land development and soil management in monsoon Asia are presented consecutively: (i) tropical land clearing for sustainable agriculture, (ii) management of acid tropical soils, and (iii) management of Vertisols. An account is also given of the organization of the proposed regional network, the mechanism of approval of the national project proposals, and the objectives of the seminar.

INTRODUCTION

IBSRAM was set up three years ago in September 1983, which was when the first Board was elected. At the time it was decided, as a first priority, to promote four soil management networks. After four inaugural workshops from December 1984 to September 1985, three soil management networks were considered to be of special interest in their great potential for developing agricultural resources:

- Management of Vertisols (IBSRAM, 1985a)
- Management of Acid Tropical Soils (IBSRAM, 1985b)
- Tropical Land Clearing for Sustainable Agriculture (IBSRAM, 1985c).

In order to implement these networks on a realistic base, three regional network programs have since been proposed. They are:

- Land Development and Management of Acid Tropical Soils in Africa, for which a regional seminar took place in Douala, Cameroon, in January;
- Land Development and Soil Management in Monsoon Asia, which is the object of this meeting; and
- Management of Vertisols under Semi-Arid Conditions in Africa and Southwest Asia.

The objective of this meeting is to establish a regional internetwork program for Land Development and Soil Management in Monsoon Asia.

IBSRAM SOIL MANAGEMENT NETWORK APPROACH

The IBSRAM soil management network approach has been described earlier (IBSRAM 1985d, 1985e, and 1986b, 1986c),but it may need to be restated for those who are not yet familiar with it.

The overall goal of IBSRAM is to promote sustainable improved soil management technologies in order to remove soil constraints to food and other agricultural production. To implement this goal, the IBSRAM approach is to help cooperators, through soil management networks, to conduct the investigations necessary for the practical adaptation and validation of improved soil management and land-use practices.

Soil management, in the IBSRAM view, should be based on a multidisciplinary approach, which must combine inputs from soil science, agronomy and socioeconomics.

Soil knowledge for soil management has to envisage the soil as a whole and classify it comprehensively in order to have international viability. However, it must focus on the layers prospected by roots, in the lateral variations of their characteristics, and on the dynamics of their most mobile components: air, water, ions, fauna and flora. The latter components are related to the climate and the seasons, since they are controlled by rainfall and temperature. They are also the direct cause of erosion, taken in conjunction with the slope and the land use. For proper application to management, a good soil knowledge must be comprehensive so that a sound interpretation of experimental data can be made and the results can be promulgated extensively.

New technologies have been produced by agronomists. International agriculture centers and other research organizations have found new germplasms, improved phytosanitary protection, and appropriate tillage and fertilizer practices which have led to what has been called the green revolution. Unfortunately, these techniques, which can be applied successfully on good agricultural soils, have been difficult to extend on the more marginal lands, which is where the current pressure for agricultural development is becoming more intense. Also, more complexity is involved in marginal lands, Ultisols, Oxisols, Vertisols, and steepland Inceptisols than there is in good agricultural lands such as alluvial Inceptisols and Entisols or Mollisols. This means that there is a great deal of work to be done in adapting and testing these new improved technologies, taking into account the variability of the environments involved.

Socioeconomic inputs are necessary because they are the means by which these new technologies can be applied. A knowledge of the farmers and of their traditional practices is essential in the search for acceptable technologies. Agricultural habits, derived from long experience, represent a very rich source of information. The attempt to integrate familiar habits into the proposed technologies, and at the same time to improve them, will save time and will make them more acceptable. Finally, soil management technologies must adapt to the farmers' possibilities and to national priorities regarding the lands and crops to be developed.

Individual efforts are long and costly in agricultural research. The use of the existing knowledge, the sharing of new findings by national institutions working on the same subject, and the coordination of these efforts, are the most cost-effective ways of tackling these problems. IBSRAM has chosen a collaborative research approach to achieve its objectives.

NETWORK PROGRAM ON LAND DEVELOPMENT AND SOIL MANAGEMENT IN MONSOON ASIA

The network regional program on Land Development and Soil Management in Monsoon Asia will regroup the cooperators of our three networks:

- Tropical land clearing for sustainable agriculture will be one of the major points of this regional program. Technologies for post-clearing management and for the rehabilitation of degraded land are badly needed in the region. Post-clearing management technologies are urgently in demand in countries where big resettlement schemes are under way - mainly Indonesia, Malaysia and the Philippines. They have to be directed towards the establishment of sustainable cropping systems, and especially food crops. Monitoring of the fertility parameters of erosion, of soil moisture, and of crop parameters are the main operations which have to be tackled. Rehabilitation of degraded land, whether it is under *Imperata cylindrica* or under any other type of grasses or bracken, is also a very high priority in the region. In particular, Indonesia, China, and Thailand are gravely in need of more intensive rehabilitation programs, but they are not the only countries which would benefit from such efforts. The use of pioneer plants or of initial high inputs should be adopted and put into effect over wide areas in order to restore the soil fertility of degraded lands and to give them a reasonable agricultural or agroforestry status.

- Management of acid tropical soils is often linked with the land clearing network, since forest is often cleared on acid tropical soils. This network will focus more particularly on the management of acidity and aluminium toxicity and deal with the problems linked with phosphorus fertilization and with the dynamic of the nutrient in general. An important aspect of the work will be to compare technologies at different levels of inputs. The general idea is to test different packages of technologies, alley cropping, ley farming systems, multiple cropping, etc., and to monitor the dynamics of the acidity, of the nutrient, of the soil loss, and other relevant factors. A good deal of experience has already been gained; but this experience now needs to be evaluated in a comparative way and to be extended for the benefit of as many regions as possible.

- The same questions arise in connection with the management of Vertisols, though the Vertisols of Southeast Asia are largely restricted to those which are flooded and which normally support one crop of rice. Farmers would like to have a second crop, preferably an upland crop, as there is not enough water for two crops of rice. Some irrigation may be possible, as shown by a project being carried out in Thailand. The main problems in using Vertisols for a second crop concern physical and mechanical issues - though there is also the question of the soil moisture management and problems regarding nutrients and micronutrients.

The proposed Asian network program will, then, bind together programs linked to the three IBSRAM global networks. It is hoped that this program, rather than destroying the integrity of the original networks - which should link participants from different regional programs through global activities such as specific meetings or training courses - will help to foster links between networks on a regional basis.

ORGANIZATION OF THE REGIONAL PROGRAM

The proposed organization of this network regional program will be similar to that envisaged for the initial networks. It will comprise three components, namely:

- Cooperators, who will initiate and operate the soil management program activities. Four types of participation are possible:
  * simple participation in the different program activities, mainly with a view to sharing information;

* active participation - both by having an accepted program, and by participating in all the various program activities;
* basic participation - by having an approved program, some basic research related to the objectives of the network, and also participation in all the program activities;
* support participation by international and other agencies, by undertaking some part of the basic research related to the objective of the network, either alone or in conjunction with other cooperators.

- IBSRAM, which through a Program Coordinator, backed by the Network Coordinating Committee, will catalyze, coordinate, and assist cooperators in conducting their activities. IBSRAM provides assistance in the preparation and in the presentation of the projects to donor agencies. The coordinator acts as a link between the cooperators and IBSRAM. He helps strengthen the national cooperators' programs by regular visits and consultations and by backstopping the following network activities:
  * site characterization;
  * exchange of control soil samples and analytical methods;
  * design of experiments, analyses and interpretation of data arising from these experiments;
  * technical assistance;
  * regular meetings during which programs will be reviewed and eventually revised;
  * monitoring;
  * training courses;
  * creation of a data base;
  * review of past and ongoing research and bibliographic information services;
  * program newsletter, publications, and documentation.

- Donors, who will fund the program coordination and, in part, the activities of the individual national cooperators.

MECHANISM OF APPROVAL OF NATIONAL PROJECT PROPOSALS

One of the main objectives of this meeting is to revise and approve national project proposals in order to establish the regional network program.

The mechanism of approval, which is already being applied, consists of the following steps:

- A project proposal on soil management is presented to IBSRAM by a national institution. Coordination between national organizations is favoured. More than ten projects have been presented for this Asian program.

- The project is reviewed by the Network Coordinating Committee (NCC). Until now, the initial interim NCC formed during the inaugural workshops has been used. During this meeting, one question to be discussed is the formation of an NCC for this Asian program. The NCC will consist of the active, basic and support cooperators, the main donors, and the IBSRAM coordinator. The IBSRAM Board must then endorse this acceptance of the project proposals.

- After approval, an official letter of acceptance will be sent to the cooperators, who may use it as a letter of support for fund seeking. During the regular meetings of the network, cooperators will present their results, and these will be discussed and reviewed by the participants in order to maintain high scientific and development standards in the program.

The criteria for the approval of a national project proposal are as follows:

- The project must fulfill the network objectives as defined during the inaugural workshops and as clarified during the present seminar.

- The project must be technically acceptable, i.e. it follows the approach and methodology to be defined during this seminar. An example is given by the results of the Cameroon seminar that you have to hand (IBSRAM 1986a).

- The project is thought to be economically acceptable.

- The country is already involved in research of the type proposed, or is willing to invest in training for its personnel to achieve worthwhile participation.

OBJECTIVES OF THIS SEMINAR

This seminar then, will have three major objectives:

- To define a common approach and methodology. The review papers presented in the first part and the following discussion are designed to help the working groups to design this common methodology and approach - without which no exchange amongst cooperators can function. The results of these working groups will be discussed and provisionally approved on the last day of the seminar. They will be the basis of our future work. In order to harmonize the work of the three regional network programs and of the future ones, the Board will review these results and those of the other regional programs during its meeting in March 1987. However, the results obtained here can serve as a basis to start the projects.

- To revise the national project proposals. An exchange of correspondence has already taken place with regard to the national project proposals received. Improvements have been made, but further discussions and revisions will be conducted during two full days, when it is hoped to finalize some of these projects. Others, which have not yet been discussed, will be reviewed during these two days. Finalized projects will be submitted to the Board immediately after the seminar in order to get their final approval before the end of the year. They will be published separately as the basis of the regional program.

- To establish the regional network program on Land Development and Soil Management in Monsoon Asia. Discussions will take place during this seminar. Some donors have expressed their interest in this network and we hope that a coordination plan will be funded by the beginning of 1987. Your requests will be discussed and finalized on the last day of this meeting. This network must be yours. So in addition to your national project proposal, we must work out in more detail the rules governing the functioning of the network and the common activities which can be implemented. A regional Network Coordinating Committee (NCC) must be formed which will serve as an advisor to the coordinator.

A record of these various activities will be retained in the form of three publications, which will be produced after this seminar.

- A report of the seminar in the format of the report of the Cameroon seminar. This will be ready before the end of the year and will be widely distributed.

- A document including the approved projects, to be circulated internally in the network as a base document and for donor support purposes.

- Proceedings of the seminar, which will include the presented papers of the first two days and the results of the working groups. In order to keep a standard level of these proceedings, we will form an editorial committee which will look at the scientific aspects of the papers, and Dr. Colin Elliott will help you in the language editing of your paper during this meeting and afterwards.

CONCLUSION

In conclusion, we have seven full days of seminar. The program is heavily loaded but I am sure of your cooperation as we are building your network. We will have two days of lectures - Monday and Tuesday; three days of full discussion on Wednesday, Thursday and Friday. On Saturday and Sunday you will have the chance to visit some of the beautiful countryside in this part of Thailand during the field trip, with some soil management concerns in mind; and next Monday we will finalize our discussions. Your enthusiasm in the seminar will be the best start for this Asian network program.

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STATUS OF IBSRAM'S ACID TROPICAL SOILS NETWORK

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ABSTRACT

The IBSRAM soil management network on the management of acid tropical soils is the result of an inaugural workshop which took place in Yurimaguas, Peru, and in Manaus and Brasilia, Brazil, from April 24 to May 3, 1985. This paper gives an account of the goals and objectives, the research validation activities and the support activities envisaged for the network, and also describes the results of the Cameroon seminar where eight countries indicated their intention to join a regional African network on this subject.

INTRODUCTION

Representatives from thirteen developing countries (Brazil, Cameroon, China, Congo, Ivory Coast, Madagascar, Malaysia, Mexico, Panama, Peru, Thailand, Venezuela, and Zambia) have decided to form the Acid Tropcial Soils Management Network with a defined target area, six principal research-validation activities, and several supporting services. The network, which will be coordinated by IBSRAM, will focus on increased use and improved management of the acid tropical soils, classified mainly as Oxisols and Ultisols or as ferrallitic soils, in the humid tropical and acid savanna ecosystems.

The inaugural workshop of IBSRAM's Management of Acid Tropical Soils Network was held in Yurimaguas, Peru, and in Manaus and Brasilia, Brazil, from April 24 to May 3, 1985, and was co-hosted by the Instituto Nacional de Investigacion y Promocion Agropecuaria (INIPA) and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). Other co-sponsoring institutions included the Australian Centre for International Agricultural Research (ACIAR), North Carolina State University (NCSU), the Institut Français de Recherche pour le Développement en Coopération (ORSTOM), Soil Management Support Services (SMSS), and the U.S. Agency for International Development (USAID). During the first six days, workshop participants visited INIPA and EMBRAPA research stations and nearby farmers' fields in the humid tropics and acid savannas. In the remaining four days, they took part in presentation of regional and subject-matter reviews, working group discussions, and expressions of country interest. A total of 67 individuals, representing 13 national research institutions, 7 donor agencies, and various research institutes and universities, attended the workshop.

Based on expressed country representative interest, the network will concentrate its technology-validation activities on (1) pedology-fertility interactions, (2) soil acidity, (3) phosphorus fertilization, (4) management of the soil surface, (5) rehabilitation of degraded acid tropical lands, and (6) soil dynamics. The level of interest in specific activities varied among countries, as a function of their ecosystems, resources, and levels of technology development. The principal network support services will include training, experimental design, common methodologies, reference laboratories, workshops, monitoring tours, data bases, and documentation.

GOALS AND OBJECTIVES

Goal

The overall goal of the Acid Tropical Soil Management Network is to serve as an international means to coordinate research on acid tropical soils, validate and transfer improved technnologies, and foster their adaptation for sustained food production by farmers in developing countries.

Objectives of the Network

1. To strengthen agricultural research on acid tropical soils for the purpose of:
   a. Validating and/or developing principles of pedological characterization and their linkages to fertility evaluations.
   b. Validating and/or developing soil-management components of farming systems for the efficient management of soil acidity for sustained production.
   c. Validating and transferring soil-management technologies developed for efficient use of phosphorus fertilizers.
   d. Developing improved management of the soil surface by physical or biological means.
   e. Validating and/or developing technologies that reduce degradation of soils through use and which, when necessary, rehabilitate the soil for sustained production.
   f. Developing and testing research methodologies for the evaluation and dynamics of nutrients, toxic elements, and physical and biological soil properties.

2. To exchange information on validated technologies by:
   a. Conducting training programs for research and extension staff of national institutions.
   b. Publications, newsletters, and audio-visuals.
   c. Computerized interactive systems.
   d. Workshops and seminars on specialized subject-matter areas.

3. To strengthen national institutions by providing technical support services for problem solving, including experimental design, statistical and soil analyses, and data base design and development.

RESEARCH-VALIDATION ACTIVITIES

From the reports of the six working groups, the major areas for research-validation activities of the Acid Tropical Soils Management Network were determined to be (a) pedology and soil fertility, (b) soil acidity, (c) phosphorus fertilization, (d) management of the soil surface, (e) rehabilitation of degraded lands, and (f) soil dynamics.

The reports of the working groups provided guidelines for specific research needs and priorities within each of these areas. It was agreed that network activity should focus on the working group reports, and that these reports should serve as the basis for proposals for potential country participation. The following is a summary of research-validation activities suggested for each major area.

Summary of

Working Group A:

Pedology and Soil Fertility

The network should:

- Establish an international reference base for soil characterization and soil fertility parameters.
- Establish and collect minimum data sets for the major experimental stations and on-farm research sites.
- Examine present coverage of acid tropical soils by existing research stations and recommend new stations if necessary.
- Promote research to establish better relationships between pedological characteristics and management behavior of acid soils, as well as to develop fertility capability groupings based on farming-systems information.
- Develop expert systems or other interactive computer systems that incorporate available information and use them as a tool for technology transfer.

Summary of

Working Group B:

Soil Acidity

The network should:

- Assess the current status of knowledge of soil acidity and foster consolidation and interchange of information among netork scientists.
- Develop standardized methodologies for characterization of soil acidity in relation to plant growth.
  * Direct attention toward assessment of charge characteristics and determination of species and activities of ions in the soil solution.
  * Focus on aluminum. The characterization of soil solutions can best address the question of whether aluminum toxicity or calcium deficiency limits plant growth, or, if both, under what conditions one is a larger constraint than the other.
- Promote an experimental program to ameliorate soil acidity.
  * Determine management considerations for soil amendments and develop management practices for both surface horizons.
  * Determine implications of liming for legume nodulation, nitrogen fixation, organic-matter mineralization, nitrification, and mycorrhizal activity.
  * Determine management practices for use when liming materials are not available or are noneconomic.
- Develop a methodology for characterizing plant adaptability to soil acidity and selection of tolerant species and cultivars.
  * Establish reference collections of germplasm for both pot trials and field experiments.
  * Evaluate plant indices as indicators of tolerance to soil acidity.

Summary of

Working Group C:

Phosphorus Fertilization

The network should:

- Produce a state-of-the-art review on phosphorus fertilization in acid tropical soils.
- Validate concepts on rates and methods of phosphorus applications.
  * Conduct field plot experiments to obtain response curves on representative soils.
  * Compare band and broadcast methods of application.
  * Assess residual effects.
  * Calibrate field results with standard laboratory procedures.
- Determine the interactions of phosphorus with lime, organic manures, and green manuring.
  * Measure interactions in field plot experiments.
  * Assess the practical value and residual effects of liming and manuring based on local conditions and availability.
- Promote the use of cheaper sources of phosphorus.
  * Characterize locally available phosphate rock materials.
  * Compare the agronomic efficiency of these materials.
  * Assess the calcium-supplying properties of available materials.
  * Assess transformation technologies of available rock phosphate materials in relation to agronomic and economic efficiency.
- Monitor nutrient balance interactions of phosphorus with macro- and micronutrients.
- Evaluate phosphate use in different farming systems through on-farm trials, and assess the socioeconomic factors involved.
- Encourage research on mycorrhiza where facilities are already available.

Summary of

Working Group D:

Management of the Soil Surface

The network should:

- Validate tillage practices that result in minimum surface compaction and practices to overcome existing physical impediments (deep ripping) while also providing for possible necessary incorporation of amendments.
- Validate the existing knowledge and evolution of new technology in both the humid tropics and the savannas, where appropriate, with emphasis on:
  * Residue by tillage interactions.
  * Pasture-crop rotations.
  * Legume understory in perennial crops.
  * Alley cropping and managed fallows.
- Give emphasis to cover crops or mulch that have food, economic, or forage value.

Summary of

Working Group E:

Rehabilitation of Degraded Lands

The network should:

- Assess various degradation features of acid soils.
  * Compare basic relationships between degradation features and soil properties.
  * Study relationships between soil erodibility and rainfall erosivity.
- Develop methodologies for rehabilitation of degraded lands.
  * Evaluate management practices to eradicate undersirable weeds.
  * Compare conservation-oriented tillage practices.

* Study fertilizer use and legume-based pastures.
* Study the efficiency of agroforestry, wooded pastures, and other cover crops, especially on steep lands.

- Evaluate the socioeconomic aspects of reclaiming degraded lands, including the cost of rehabilitation and extension methods and their effectiveness.

Summary of

Working Group F:

Soil Dynamics

The network should:

- Produce state-of-the-art reviews on soil physical, biological, and chemical dynamics from currently available studies on acid soils in the humid tropics and savannas.
- Establish trials to evaluate soil dynamics under different tillage practices.
- Establish trials to evaluate soil dynamics under different cropping systems, such as arable and permanent crops, pastures, agroforestry, and fallow systems.
- Establish trials to evaluate soil dynamics under different organic-matter management systems.

SUPPORT ACTIVITIES

IBSRAM will support the technology-validation activities undertaken by specific national research institutions through a series on networkwide activities. These will enable research collaboration and transfer of results and promote data and information exchange. Networkwide supporting activities are to include:

Training. Training deserves priority attention to enable national cooperator personnel to participate more effectively in various networkwide activities. Because of the diversity of research capabilities in national cooperators' staffs, some people will need to undertake further training for the benefit of the network and the national program. Also, from time to time, it will be necessary to conduct training in new technological advances and state-of-the-art techniques to maximize the effectiveness of the network.

Literature reviews, state-of-the-art analyses, maintenance of documentation centers, and other information services (including publications and translation services). During the workshop, all the working groups and several of the potential national cooperator reports identified the need for initial literature reviews for the activities to be undertaken. Periodic state-of-the-art analyses and maintenance of documentation centers with some translation capability will also be needed to keep participants well informed. Many participants indicated concern that they did not know about soil management research conducted in other countries and reported in languages other than their own.

Experimental design and statistical analyses. Several potential national cooperator representatives expressed the need for technical assistance with experimental design (for both pot and field trials) and statistical analyses of data. Not only will such support increase the quality of networkwide results, but also it will improve the standardization, compatibility, and comparability of data.

Establishment and maintenance of computerized data bases and databanks. Accessibility of data throughout the network will increase the sharing and, hence, the effectiveness of the results being obtained. Wide availability of data throughout the network will also increase the capability for statistical analysis and the early detection of problems in incompatibility and wide variance of specific sets of data.

Computer-based interactive information systems and expert systems. Microcomputers are increasingly available in developing countries, and could become effective tools in the transfer of soil management technologies. The desire is that each national cooperator will have immediately available the experience and advice of leading experts in the fields of interest through computer-based, interactive query systems and knowledge-experience data bases proposed by expert system techniques.

Assistance in site characterization and reference sample exchange. For some network activities, assistance from developed countries or other projects will be needed for characterization of some pedology and soil fertility parameters at reference sites. Exchanges of reference samples or standards and checks on methodology and procedures will be needed to ensure comparability of analyses throughout the network.

Travel, workshops, and monitoring tours. Network participants will need support for intercountry travel so that personnel can attend network workshops. Especially they will need support for participation in monitoring tours to observe field plots and discuss results together outside their countries, in agroecological zones similar to those in which they are working.

CAMEROON SEMINAR

Eight countries joined the African network. Their framework for collaboration is outlined in Table 1.

Table 1. Management of acid tropical soils in Africa.

Country	Lead institution	Site	Ecosystem	Annual rainfall	Main soils	Focus
Burundi	Univ. Burundi	Bututsi	Highland	1400	Oxisols	Al toxicity, fertility soil erosion
		Kirimiro	Savanna	1200	Oxi-Ultisol	Al toxicity, fertility
Cameroon	IRA	Nkolbisson	Forest	1600	Ultisol	Shifting cultivation stable systems
Congo	DGRST	Mantsoumba	Savanna	1200	Ferrallitic pH 5.5	Savanna cassava production
		Dimonika	Forest	1800	Ferrallitic pH 5.5	Shifting cultivation stable systems
Ivory Coast	ORSTOM	Djimini	Forest	2100	Ferrallitic sandy	Fertility maintenance and improvement
		Bandama V.	Savanna	1200	Ferrallitic non-acid	
Madagascar	Min. Rech.	N. Plateau	Savanna	1400	Ferrallitic	Stable food production
		S. Plateau	Savanna	1400	Ferrallitic	Stable food production
		East Coast	Forest	2500	Ferrallitic	Shifting cultiv. - rice
Nigeria	Univ. Ife	Mokwa	Savanna	1500	Sedimentary	Fill gaps in charact., fertility
		Epe	Forest	3000		
Rwanda	Univ. Rwanda CPR	Crete Zaire-Nil (2000 m+)	Savanna	1400-2000	Ultisols	Soil deterioration, data management, fertility improvement
		Low Plains (1400 m)	Savanna	900	Oxisols	
Zambia	SPRP + SSU	Misamfu	Savanna	1300	Ultisols + Oxisols	Chitemene sustained agriculture Applied soil + plant residue

NETWORK ON LAND CLEARING FOR SUSTAINABLE AGRICULTURE IN TROPICAL ASIA

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ABSTRACT

Land clearing is the first step in bringing new land under cultivation. Although the first priority lies in improving production from existing lands and restoring productivity of degraded lands, it is also important to develop guidelines for new land development. These guidelines are to be developed on the basis of regional validation of technologies. Objectives of the land clearing network are discussed. Also outlined are possible technological options for validation in the network.

INTRODUCTION

Conversion of tropical rainforest for food crop production is a major concern of agriculturists, ecologists, and environmentalists because of its possible environmental effects. For some, the conversion of tropical rainforest is a moral issue. For example, environmentalists advocate that it is unethical to destroy the storehouse of a diverse gene-pool, the sanctuary of a vast number of unknown species of plants and animals, and the regulator of global climate. They warn of the disastrous consequences of deforestation by citing examples of environmental bankruptcy of the kind seen in Nepal, Haiti, Dominican

Republic, Andes, Ethiopia, and sub-Saharan Africa. Deforestation by improper methods, for an unsuitable land use, without prior knowledge of the land-use capability and without proper planning can no doubt lead to serious environmental consequences. However, others consider tropical rainforests to be unexploited wealth that awaits development for agriculture, forestry, and related industries. In fact, there are others that wish to develop their forest reserves for strategic reasons.

There are no reliable estimates of the existing reserves of tropical rainforest and the rate of their conversion. The available statistics often vary by a factor of 2 or 3, depending on the criteria used in defining "forest" and "forest conversion". Sweeping statements made to dramatize the issue by stating gigantic per-minute conversion rates may lead to more harm than good and may also severely erode scientific credibility. One must also be careful not to "cry wolf" without an adequate data base to back up the environmental claims.

There is no question that the first priority lies in improving agricultural production from existing lands and in restoring the productivity of lands that have been rendered unproductive, e.g., eroded and compacted lands, lands infested with *Imperata* and other noxious weeds, and lands with problems of severe nutrient imbalance. These measures are necessary to lessen the pressure of bringing new land under cultivation and to lessen the adverse effects of these "waste lands" on environments.

As far as IBSRAM is concerned, the issue is not whether to remove the forest. Neither does IBSRAM or anyone else support the needless and indiscriminate removal of tropical rainforest. The major objective is to develop and provide guidelines to those national and regional organizations that have sound reasons for expanding agriculture into existing forested lands. These guidelines are to be developed on the basis of local or regional adaptation and validation of the best-guess technologies that may have been tested and found promising in a similar agroecological region elsewhere in the tropics. Although it is not a major objective, some basic research on monitoring alterations caused by deforestation and changes in land use on soil, hydrology, microclimate, etc. may be carried out by those interested.

NETWORK OBJECTIVES

The First International Symposium on Land Clearing and Development in the Tropics was held at the International Institute of Tropical Agriculture (IITA) in November 1982 (Lal *et al.*, 1986). The Symposium established a working group called the International Committee on Land Clearing and Development (ICLCD). One of the responsibilities of this committee was to suggest research priorities applicable at the international and national levels, to establish and coordinate a research network, and to seek funding for suitable research proposals (IITA, 1983). Subsequently, the functions of this committee were effectively taken over by IBSRAM.

The IBSRAM-sponsored inaugural workshop held in Sumatra in September 1985 outlined the general goals of the network: to encourage the use of appropriate technologies for new land clearing and for restoring degraded lands, to evaluate the ecological effects of such practices, and to identify and adapt sustainable soil and crop management systems. More specifically the objectives were grouped into three categories:

- Technology validation:

  The network will develop criteria to choose new lands for sustained agricultural production and will validate promising technologies for ecologically compatible methods of land clearing and development, for optimal post-clearing land utilization, and for rehabilitation of degraded lands.

- Technology dissemination:

  The network will disseminate tested and proven technologies by periodically organizing regional workshops and training courses.

- Institutional strengthening:

  IBSRAM will seek support to strengthen the collaborating institutions by providing the facilities or services needed to meet the objectives.

TECHNOLOGIES AVAILABLE FOR DIFFERENT SOILS

These objectives will be achieved through validating existing land development and soil management technologies. The technological components chosen for testing will be those that have proved to be useful for similar agroecological regions. Technological packages available are different for different soils, agroecological regions, and farm sizes. It is therefore essential that the network should be designed to evaluate technical production potential under different methods of land clearing and development for different soils in different agroecological regions. While validating potentially useful technologies, it is important to obtain data on soils and environments so that technological responses can be related to important production determinants. The emphasis is to transform resource-based agriculture to scientifically-based agriculture. For smallholders with less than 5 ha, the soil and crop management systems tested should be those that minimize the use of agrochemicals, e.g., fertilizers, herbicides and pesticides. The productive potential of different technological options should be evaluated in terms of more than just crop output per unit area per unit time. In regions where resource degradation is a critical issue, productivity should be assessed in terms of output per unit of input and per unit of resource degraded, e.g. per unit of soil lost, per unit reduction in organic matter content or available water-holding capacity, or per unit change in any other factor that may be critical to crop production. Sustainability should also be assessed in terms of agronomic, economic or ecological factors. All variables must be quantified so that results are comparable across soils and ecological regions.

Alfisols

Land clearing and post-clearing management

Some examples of potentially useful technological options for land clearing and post-clearing soil and crop management for Alfisols in the humid and subhumid tropics are shown in Table 1. Whereas in subhumid Africa animal traction is not yet feasible due to the tse-tse fly and the high incidence of trypanosomiasis,

Table 1. Land clearing, land development, and soil and crop management: options for Alfisols in subhumid Asia (1000-15000 mm rainfall where $P > ET$ for 6 to 8 months in a year).

Land clearing and development	Soil and water conservation	Cropping system	Fertility maintenance	Farm tools and implements	Weed control
(a) < 5 hectare					
1. Manual clearing and in-situ burning 2. Partial mechanization using chainsaw 3. Manual underbrushing, no burning, immediate sowing of a cover crop, chemical poisoning of large trees and felling them	1. Mulch farming 2. No-till/minimum tillage 3. Cover crops 4. Tied contour ridges with mulch in between 5. Cropping systems	1. Maize + cassava mixed cropping 2. Maize-cowpea sequential 3. Cassava + cowpea mixed cropping 4. Yam + maize intercropping 5. Maize-soybean sequential cropping	1. Planted fallow once every 3 or 4 years 2. Alley cropping with woody perennials 3. Compost 4. Strip cropping with cover crops	1. Chainsaw 2. Jab planter 3. Rolling injection planter 4. Cassava lifter 5. Animal traction	1. Rotational control 2. Manual weeding 3. Supplemental use of herbicides 4. Cover crops
(b) 5-15 hectare					
1. Clearing with chainsaw and in-situ burning 2. Shearblade clearing, burning in wind rows, and immediately growing a cover crop 3. Manual underbrushing, no burning, immediate sowing of a cover crop, chemical poisoning of large trees and felling them	1. Mulch farming 2. No-till/Minimum tillage 3. Cover crops 4. Tied contour ridges 5. Cropping systems 6. Supplementary engineering structures	1. Maize-cowpea sequential cropping 2. Maize-soybean sequential cropping 3. Maize + cassava mixed cropping	1. Planted fallow once every 2 or 3 years 2. Supplemental chemical fertilizers: (60:20:20) 3. Farmyard manure and compost	1. Chainsaw 2. Two-wheel tractor 3. Animal traction 4. Farmobile	1. Interrow cultivation 2. Rotation and cover crop 3. Herbicides
(c) 15-50 hectare					
1. Chainsaw clearing followed by burning 2. Shear blade clearing followed by cover crop	1. Minimum tillage 2. Strip cropping 3. Periodic chiselling 4. Periodic chiselling engineering structures	1. Maize-cowpea 2. Maize-soybean	1. Planted fallows once every other year 2. Farmyard manure and compost 3. Chemical fertilizers for maize (100:30:30), inoculation for soybean and application of P	1. Four-wheel tractor (30-60 MP) 2. Animal traction	1. Rotational control 2. Interrow cultivation 3. Herbicides

it is an important technological consideration for tropical Asia, especially for the farm-size range of 5 to 10 ha. In accord with the principles in Table 1, Von Uexkull (1984) indicated that improved methods of land clearing should minimize the use of heavy equipment and should not involve burning. He suggested the following sequence of steps as an improved technique for land clearing:

- underbrushing at the start of the rainy season to keep the cut biomass moist;
- stacking the cut biomass to facilitate farm operations;
- sowing a cover crop while the big trees are still standing;
- applying a basal dose of fertilizer (particularly P) to help establish the cover crop;
- killing the big trees by chemical means and/or by ring barking; and
- felling the trees manually.

The land is kept under planted fallows for 2 or 3 years, by which time the hardwood has decayed. During this period, the cover crop has replaced the forest canopy by a thick layer of mulch and has prevented weed infestation. Soil organic matter and fertility are either maintained or enhanced. Soil structure and tilth are improved by the enhanced biotic activity, earthworms, and other soil fauna. After 2 or 3 years, food crops can be grown through the mulch by a no-till system.

Similarly, a literature survey should be carried out to seek other packages of land clearing techniques developed in the region. These packages or components should be tested in the proposed network for their adaptation.

Restoration of Degraded Lands

Technological options for the rehabilitation of degraded lands depend on the processes responsible for causing soil degradation. Some important technological options are listed in Table 2. Regardless of the major processes involved, improvement of soil organic matter content and of soil structure are important considerations in making the choice among the technological options suggested.

Table 2. Technological options for restoration of degraded lands.

Imperata control	Compaction alleviation	Restoration of eroded lands	Nutrient imbalance
1. Mechanical techniques (depth and time of plowing, soil inversion)	1. Planted fallows (i) woody perennials (ii) seasonal and annual (grasses and legumes)	(a) Sheet/rill erosion 1. Improving soil structure (i) Addition of organic matter (ii) Planted fallows and cover crops (iii) No-till farming	(a) Species selection, Growing tolerant species/cultivars (b) Improving organic matter content (c) Chemical amendments
2. Chemicals (growth regulators)	2. Mechanical loosening (i) Paraplow (ii) Chiselling in the row zone (iii) Reduced/controlled traffic	2. Maintaining a continuous ground cover (i) Cropping system (ii) Mulch farming, no-tillage, alley farming (iii) Soil fertility maintenance and fertilizer use	
3. Biological methods using cover crops with known allelopathic and competitive effects	3. Agroforestry	(b) Gully erosion control 1. Runoff diversion 2. Vegetation establishment 3. Land forming	
4. Physical suppression effects	4. Improving biotic activity of soil fauna, e.g. earthworms that increase macroporosity by creating biochannels		
5. Appropriate combinations of above techniques	5. No-till farming with crop residue mulch		

1. Improving soil organic-matter content and soil structure:

In addition to contributing to the nutrient capital, improvements in soil organic matter stimulate faunal and microbiological activity in the soil. Some by-products of microbial decomposition bind colloidal particles into aggregates. Biochannels created by earthworms serve as transmission pores that facilitate air and water movement. Organic-matter content influences total porosity and pore-size distribution. All these factors are important in soil productivity restoration. In addition, monitoring alterations in soil and environmental characteristics during the restoration phase is important. Some important variables to be monitored are soil structure, organic-matter content, annual cycling and turnover of major nutrients and water, and the amount and quality of the biomass produced. These experiments should provide the information needed to establish the critical levels of soil organic-matter content, nutritional levels, porosity and pore-size distribution, available water-holding capacity, and the effective rooting depth to sustain different land-use systems. For example, it is important to know the critical level of macroporosity below which the growth of upland crops is drastically curtailed, or the critical level of soil organic-matter content below which soil structure deteriorates very rapidly. These critical levels may be different for different soils and for different farming systems.

2. *Imperata* control

An important research priority in land restoration is the rehabilitation of *Imperata*-infested lands. Vast areas of once forested and productive lands are now colonized by *Imperata*. There are some 5 million ha of *Imperata*-infested land in Sumatra alone. Newly cleared land is rapidly being colonized by *Imperata*. Only some isolated experiments on *Imperata* control have been done; more comprehensive research is needed. The research envisaged should consider mechanical, chemical and biological techniques of eradication. Possible allelopathic effects among crops should be assessed with a view to its control and eradication.

Ultisols/Oxisols in Humid Asia

There are major differences in soils and vegetation characteristics in subhumid and humid ecological regions. Ultiosls and Oxisols that are the predominant upland soils in humid regions are acidic with low base-exchange capacity and with more severe nutritional constraints than the relatively fertile Alfisols of the subhumid regions. Soils of the humid regions may also contain toxic levels of Al and Mn in the subsoil. Over and above the compaction can also be yield-limiting in Oxisols and Ultisols depending on the terrain and land-use system.

The vegetation of the humid regions differs from that of the subhumid in terms of tree density, basal diameter of trees, and total biomass. Although the land-clearing options are similar to those listed in Table 1, in-situ burning is an important factor in Oxisols and Ultisols to neutralize soil acidity. Liming is also an important input for acid soil management.

There are also differences in the predominant cropping systems. Root crops (cassava, yam and sweet potato) are important for acid soils of the humid tropics. Also important are upland rice and rice-based cropping systems. In some regions plantain and bananas constitute a predominant cropping system.

Manual clearing with chain saw or mechanized clearing with shear blade, liberal applications of plant residue mulch, and frequent incorporation of planted fallows in crop rotation are important considerations. The application of appropriate doses of chemical amendments is also crucial for sustained productivity on these acid soils. In general, perennial crops may be more suited for acid soils in the humid regions than seasonal or annual crops.

NETWORK COORDINATION

Any overlap in the objectives of the three networks proposed should be considered in positive terms. The limited funding equipment and manpower should be effectively used. In addition, due consideration should be given to the alterations and trends in processes, properties and parameters influenced exclusively by the land-clearing process. Furthermore, predominant factors to be considered may be different for different networks. That is why coordination among different networks is essential.

An IBSRAM-sponsored workshop for Africa was held in Cameroon in February 1986. Research proposals were sought for different networks. The enthusiastic response indicated the need for such a coordinated approach. However, it is the right time to transform meetings and symposiums into practical field projects. Even a modest network of 3 sites, properly planned and implemented, would be a welcome start. I hope that the next meeting will be held to discuss the results obtained from such a network.

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MANAGEMENT OF VERTISOLS FOR IMPROVED AGRICULTURAL PRODUCTION IN THE TROPICS: ICIRISAT EXPERIENCE

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ABSTRACT

An overview of ICRISAT's experience in the management of Vertisols for improved agricultural production in the tropics is presented in this paper, and the following components are highlighted:

- land and water management,
- dry season tillage,
- dry sowing ahead of the onset of the rainy season,
- improved cropping systems,
- fertility management,
- efficient farm machinery, and
- appropriate crop management.

The Indian example raises issues and research needs for subhumid Asia at large.

INTRODUCTION

Vertisols are dark black soils which are a potentially productive group of soils within the tropical and subtropical climates. These soils are characterized by a relatively high amount (>35%) of shrinking and swelling clays, and are generally deep (>60 cm). Such soils therefore possess a high water storage capacity. The available water-holding capacity generally exceeds 200 mm in a 150-cm soil profile. Vertisols are highly suited for dryland agriculture and, depending upon the distribution of rainfall, provide 5-7 months of cropping season in the semi-arid tropics where the annual rainfall is 750-1100 mm, and some 7-10 months of cropping season in the subhumid and humid tropics.

Vertisols, however, because of their high clay content and related physical properties, and because of their predominant location in the valley bottom areas, present a challenge with regard to their management for increased crop production. Small farmers of limited means in the tropics are generally not able to cultivate them in time. Short-term waterlogging is another problem. Most farmers can only raise one crop a year on these soils, even in areas of relatively assured rainfall.

DEVELOPMENTS THROUGH ICRISAT RESEARCH

ICRISAT has now assembled a technology for improving the management of Vertisols suitable for the semi-arid tropics. It facilitates the growing of two crops, one in the rainy season and another in the post-rainy season. The application of the technology has resulted in a considerable improvement in crop production. Where a farmer formerly harvested about 1/2 a ton of sorghum or legume pulse using his traditional system, a total yield of some 3 tons of grain has been consistently harvested through a two-crop combination under the improved Vertisols management system at ICRISAT during the past 9 years of experimentation (Table 1). Furthermore, the introduction of the new system has resulted (i) in a considerable reduction in soil erosion; (ii) in much higher in-situ moisture conservation, and therefore in a higher rainfall use efficiency; and (iii) in much more dependable harvests year after year (Table 2).

The technology for improving the management of Vertisols is a framework. It consists of several interrelated components, each of which consists of several options. The components of the improved technology are:

Table 1. Grain yields of crops under improved and traditional Vertisol management systems in operational-scale watersheds at the ICRISAT Center.

Year	Rainfall (mm)	Improved systems				Traditional rainy-season fallow - post-rainy-season cropping	
		Maize-Chickpea		Maize-Pigeonpea			
		Maize	Chickpea	Maize	Pigeonpea	Chickpea	or Sorghum
		(kg/ha)					
1976-77	708	3116	650	3291	783	543	436
1977-78	616	3338	1128	2813	1318	865	377
1978-79	1089	2150	1340	2140	1171	532	555
1979-80	715	3029	586	1954	890	450	500
1980-81	751	4185	786	2918	968	596	563
1981-82	1073	3447	1321	2838	1074	1046	635
1982-83	667	3420	1378	2967	1027	1235	630
1983-84	1045	3019	2120	2776	1739	477	838
Long-term average.							
CV (%)							

1. Maize-chickpea sequential crop system.
2. Maize/pigeonpea intercrop system.

Table 2. Soil loss and water use in improved and traditional Vertisol management systems.

	Soil loss	Water use (ET)
Improved system with maize or sorghum/pigeonpea intercrop	1.5 tons/ha	67% of rainfall
Traditional system with rainy season cultivated fallow. Chickpea or sorghum grown in post-rainy season on stored soil moisture	6.4 tons/ha	30% of rainfall

- *Land and water management:* Improved land and water management practices are applied for alleviating the constraints, such as waterlogging, which arise due to the physical properties of Vertisols. Vertisols have very poor internal drainage when these soils are wet. Under the improved system of management, micro watersheds of 3-15 ha size were taken as units for land and water management and for agronomic practices. Surface drainage is improved through the provision of surface drains and land smoothing. In-situ water conservation improvements are brought about by laying out bed-furrow (ridge-furrow) cultivation systems along the contour. Since the surface runoff water is discharged in a controlled manner, the loss of soil is greatly reduced and water-use efficiency increases considerably (Table 2).

- *Dry season tillage:* Primary tillage to prepare a rough seedbed is best carried out soon after the harvest of the post-rainy-season or rainy season crops. Land should be harrowed whenever 20-25 mm of rain is received over a period of one/two days. When blade-harrowing is done, the clods easily shatter and a satisfactory seedbed is attained.

- *Dry sowing ahead of the onset of the rainy season:* Since preparation of the seedbed and the sowing of the crops present serious problems in Vertisols, we find that planting crops in dry soils before the commencement of the rains ensures their early establishment, and avoids the difficulty of planting in a wet, sticky soil. We have noted that dry seeding is successful where the early season rainfall is fairly dependable and seeds are placed at a depth of 7-10 cm. At the ICRISAT Center, good stands were established by dry seeding of crops such as mungbean, sunflower, maize, sorghum, and pigeonpea.

- *Improved cropping systems:* The introduction and adoption of improved cropping systems that provide a continuum of crop growth from the commencement of the rainy season until most of the available moisture is utilized by the crop. At ICRISAT we have found that this can be achieved by:

a) intercropping of long crops (e.g. pigeonpea) with short duration crops (e.g. maize or sorghum or soybean),
b) sequential cropping of crops, for example sorghum or maize followed by chickpea.

- *Fertility management:* In the tropics, the management of soil fertility is very important for realizing the full potential of improved cropping systems. The management of soil and fertilizer nitrogen is necessary in Vertisols. We have observed that the application of phosphates and zinc is often necessary as well. At ICRISAT the inclusion of legumes in the crop rotations or in intercrop systems has substantially reduced the fertilizer nitrogen needs of the subsequent cereal crops.

- *Efficient farm machinery:* For the successful implementation of an improved management system for Vertisols, we have observed that it is necessary to carry out all the operations in good time and effectively. Since draft animals are the main source of energy available with small-farm operators of semi-arid areas in Asia and Africa, much of ICRISAT's work is related to animal-drawn equipment. We have found that the use of a wheeled tool carrier (e.g. a Tropicultor) is most efficient in dealing with Vertisols in India.

- *Appropriate crop management:* In order to realize the full potential of improved land and water management and cropping systems, it is essential that an appropriate set of crop management practices should be adopted. Weed control, integrated pest management, the placement of fertilizers at appropriate depths and their application at critical stages of crop growth, are some of the crop management factors which could lead to the realization of high and sustained yields in Vertisols.

VERTISOLS IN THE HUMID AND SUBHUMID TROPICS OF ASIA

In Asia, Vertisols and vertic subgroups having an ustic/udic moisture regime are found mainly in India, Indonesia, Philippines, Sri Landa, Thailand, Burma, and

Vietnam (Figure 1). Although the area under such soils is small, these soils have a high agricultural potential which is largely untapped. For example, Vertisols in the subtropical regions of India, which have a ustic moisture regime (found in the eastern parts of Madhya Pradesh province) provide a water availability period for crop growth exceeding 200 days annually. However, these soils are used to raise only one crop of rice for a period of 110-120 days from July to October. Pre-rice and/or post-rice growing seasons are not effectively utilized. In Figure 2, the soil, climatic conditions, and the characteristics of the growing season for two Vertisol locations of subtropical India are given. Both receive about 1400 mm rainfall annually. More than 80% of the total annual rainfall is received during the four rainy months from June to September. The dominant soils of the region are Usterts, with an available water-holding capacity of the soil profile of about 150 mm. The data given in Figure 2 show that at Jabalpur the growing season extends from early June to mid-February. The total length of the growing season is 254 days. At Raipur, the length of the growing season is 201 days. At both locations, a crop of rice is transplanted in mid-July and harvested in October. At both locations, the soil profile is practically at field capacity at the end of the growing season for rice, and it could support a sequential crop of about 60 days duration (e.g. mungbean) at Raipur, and of about 110-120 days duration (e.g. sorghum or chickpea) at Jabalpur.

In the pre-rice growing season a green manure crop of 45 days duration could be raised at Jabalpur from June to mid-July. It could then be turned into the soil. The International Rice Research Institute (IRRI) has found that a 50-60-day-old green manure crop of *Sesbania* could supply about 40 kg N/ha to the subsequent rice crop. This practice can be adopted with advantage in areas where dependable rainfall is received in the pre-rice growing season.

Further, in our cooperative work with the International Rice Research Institute (IRRI) on the optimization of crop production in the rice-based cropping systems in India, we have found that the lack of suitable farm implements for preparation of the seedbed in Vertisol areas poses a problem both for the planting of pre-rice and post-rice season crops. We believe that the adoption of some of the components of improved Vertisol technology, notably dry-season

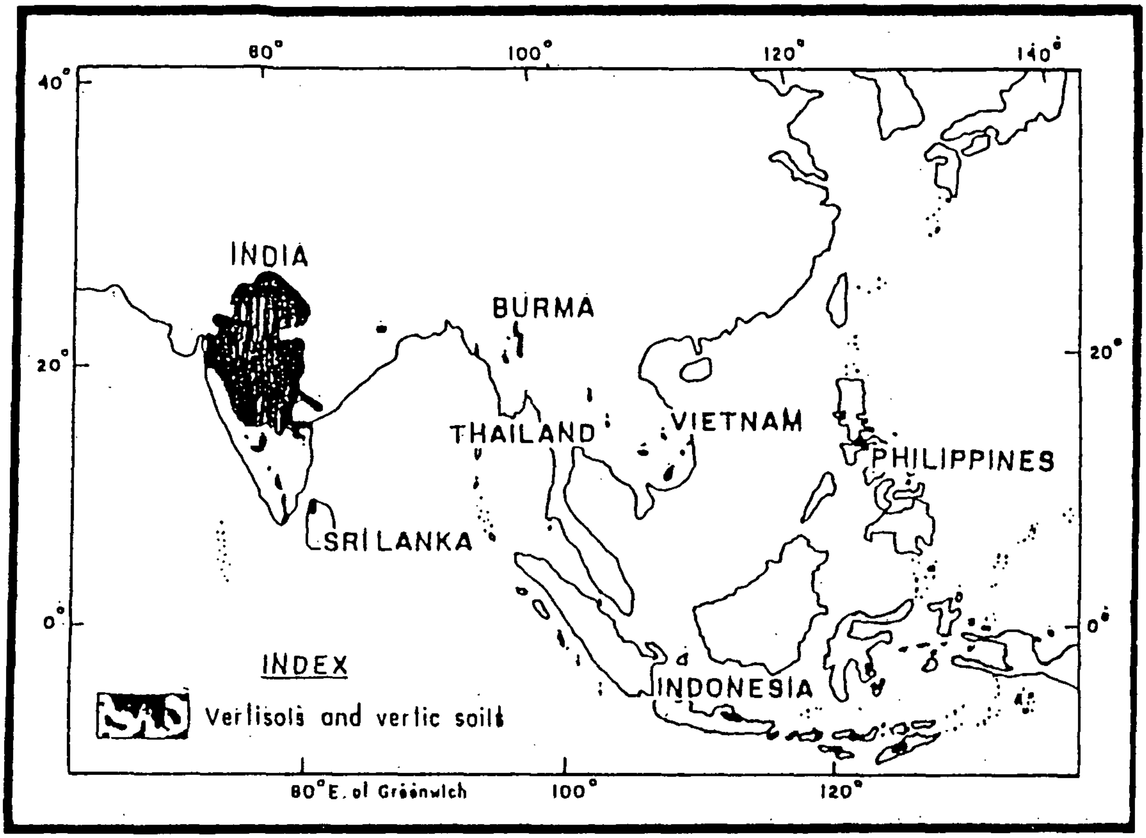

Figure 1. Areas of major distribution of Vertisols and vertic soils of the tropical and subtropical regions in south and southeast Asia.

Station - Elevation - State Lat. (N) Long. (E)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	DP*
RAIPUR - [298 m] - M.P.														
21° 14' 81° 39' Rainfall (mm)	12	20	23	15	17	194	392	394	249	62	8	2	1388	1151
Potential evapotranspiration (mm)	89	110	161	194	207	232	178	113	110	112	124	93	1723	
Water availability period (days) Ustalfs-Usterts [100-150 mm]**													201	
JABALPUR - [393 m] - M.P.														
23° 10' 79° 57' Rainfall (mm)	26	22	15	9	15	170	505	401	212	50	17	5	1447	1203
Potential evapotranspiration (mm)	70	89	135	165	203	173	106	99	107	113	78	63	1401	
Water availability period (days) Usterts-Ochrepts [150-200 mm]													254	

Rainy season — Stored soil moisture

* Dependable precipitation
** Soils suborder and available water-holding capacity

Figure 2. Soil, climate, and growing season characteristics of two locations in the subtropical Vertisol region of India.

tillage, dry sowing of crops ahead of the onset of the rainy season, the use of efficient animal-drawn farm machinery, and the application of the principles of improved cropping systems, could greatly improve the productivity of Vertisols in the humid/subhumid regions of south-southeast Asia.

Issues needing immediate attention:

- A complete inventory of soils (at the suborder level) and of climate (rainfall, evaporation, temperature, radiation) is necessary to characterize the agroecological potential of the Vertisols and vertic soils in the regions involved. These basic data would be required both for the design of improved technologies and for their transfer.

- An assembly of information on improved cropping systems suitable for Vertisols and vertic soils of the humid/subhumid tropics of Asia.

- An assessment of research needs, the identification of locations where research could be carried out, and the promotion of cooperation for an interchange of information.

- An exchange of germplasm of improved cultivars amongst institutions for the testing of new cropping systems.

- The identification of locations for training staff.

- The establishment of a Vertisol soils management unit.

- The location for the coordinator of a soil management unit network.

SOIL MANAGEMENT IN ASIA: RESEARCH SUPPORTED BY THE AUSTRALIAN CENTRE FOR INTERNATIONAL AGRICULTURAL RESEARCH

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ABSTRACT

This paper presents a review of ACIAR's involvement in soil management projects in Asia, and also gives an account of its association with IBSRAM in this endeavour. The management of acid tropical soil and tropical land clearing for sustainable agriculture are given as examples of ACIAR-IBSRAM collaboration, notably with regard to two ACIAR-supported projects in the region, namely the management of soil acidity for sustained crop production, a collaborative project between Malaysia and the University of Queensland; and the adaptation and establishment of shrub and tree legumes in acid soil. The latter investigations are being carried our by the Agency for Agricultural Research and Development (AARD) in Indonesia and the Commonwealth Scientific and Industrial Research Organization (CSIRO). There is also one project on the impact of various production technologies on soil erosion being undertaken by different Asian countries in collaboration with the Queensland Department of Primary Industries (DPI) and Griffith University, and this too is related to the shrub legume problem.

INTRODUCTION

More than a third of the world's population lives in Asia. In 1984, 2265 million people lived in Asian countries which have large areas in the humid monsoonal tropics (Table 1). Producing enough food for this vast population is one of the greatest problems which mankind has faced. Fortunately, new technology developed in Asia and adopted by farmers has led to large increases in rice production, which rose from 280 million t in 1972 to 422 million t in 1984 (ADB, 1985). Much of this increase has come from gains in yield per unit area in wetland rice areas which have good water control and relatively favourable environments, and where the modern, high-yielding varieties and chemical inputs of the new technology have been most effective.

Table 1. Population of humid tropical countries of south, southeast and east Asia.

Country	Population (millions) 1984	2000
Bangladesh	98	141
Burma	36	49
China	1,029	1,245
India	749	994
Indonesia	159	212
Malaysia	15	21
Philippines	53	76
Sri Lanka	16	21
Thailand	50	66
Vietnam	60	88
TOTAL	2,265	2,913

Source: World Bank - World Development Report 1986.

While the new technology for rice production has benefited large numbers of Asian farmers, people farming the less favoured or marginal lands have been bypassed by both the technology and policymakers, leading to the creation of substantial inequalities both within and between countries in the region (James, 1981). The bypassed areas are poorly endowed with natural resources and lack infrastructure. James has pointed out the urgent need for agricultural research on ways to raise the productivity of these upland areas. Population pressure in these and favourable agricultural areas is likely to continue to increase since, as shown in Table 1, a further 650 million will be added to the population between 1984 and the year 2000. The extent to which the increased population will be absorbed in already crowded urban areas, existing marginal or favourable agricultural areas, or in new lands developed for agriculture will depend on the resources available in each country (Table 2). Some countries such as Bangladesh, China and India already have high population pressure in existing agricultural areas but have only limited capacity to expand agriculture into undeveloped forested areas. Indonesia has high population pressure but has relatively large forested areas which can be developed, albeit in areas geographically separated from the population centres. The forested areas which are being developed in Asia are, as might be expected, generally marginal for agriculture and, because of steep slopes or low soil fertility, have very fragile soils. The pressure on the soil resources in existing and newly developed marginal areas is likely to increase the risk of erosion which is already widespread, as can be seen in the scarred hillsides in many areas. Unfortunately, an important contributing factor is the extreme poverty of the farmers in these areas who must exploit the land to its limits in order to survive (Craswell, 1986).

Table 2. Arable land, forested land and agricultural population per ha of arable land in selected Asian countries.

Country	Arable land as % of total land, 1982	Forested land as % of total land, 1982	Agricultural population per ha of arable land, 1982
Bangladesh	68	16	8.5
Burma	15	49	1.8
China	11	14	5.9
India	57	23	2.6
Indonesia	11	67	4.6
Malaysia	13	67	1.5
Philippines	38	41	2.0
Sri Lanka	34	37	3.7
Thailand	37	31	1.9
Vietnam	19	31	6.3

Source: FAO - The State of Food and Agriculture 1984.

Soil erosion and less obvious problems such as soil acidity, salinity and low soil fertility are widespread constraints to food production in both upland and lowland areas of Asia (Dent, 1980).

From a series of meetings (IRRI, 1980; Craswell and Isbell, 1984; IBSRAM, 1985a, 1985b, and 1986), the most important soil constraints have been identified by IBSRAM as the target of three global soil management networks. These networks provide the focus of the IBSRAM program on Land Development and Soil Management in Monsoon Asia (LADASMMA) - Oxisols and Ultisols in upland conditions, Inceptisols on steeplands, and Vertisols in lowlands which are flooded during part of the year (Latham, 1986). The objective of this meeting is to launch the LADASMMA program which will be coordinated by IBSRAM. The purpose of my paper is to outline and describe a number of soils research projects which ACIAR has developed and show how these projects will be coordinated with the LADASMMA program.

Before proceeding to discuss specific soils projects, I would like to provide some background on ACIAR and its interactions with IBSRAM. ACIAR has been involved with IBSRAM programs since the 1983 meeting in Townsville where IBSRAM was formed (Craswell and Isbell, 1984). The charter of ACIAR is to: (a) identify important agricultural problems in developing countries; (b) commission bilateral research partnerships between developing country scientists and Australian scientists to solve problems in areas where Australia has special expertise; and (c) disseminate widely the results of that research. ACIAR's association with IBSRAM's workshops has greatly assisted our identification, in cooperation with soil scientists from national programs in Asia, of important soil management problems on which ACIAR research projects can be focused without duplicating research in other parts of the world. Furthermore, the continued association of ACIAR projects with the LADASMMA program will ensure that the research results "spill over" to other countries in Asia - and eventually through IBSRAM's global networks to other countries - thus enhancing the payoff from ACIAR's research investment.

Management of Acid Tropical Soils in Asia

Ultisols and Oxisols cover large areas of humid tropical Asia (Table 3). Similar soils occur in the humid areas of tropical Australia. In many of the Asian countries, a substantial proportion of the acid soil areas are under primary or secondary forest or have been temporarily abandoned to anthropic savanna (von Uexkull, 1984). The occurrence of *Imperata* grassland is testament to the failure of agricultural development in large areas of some countries. Some areas of acid soils are utilized for shifting agriculture and wetland rice, but by far the most extensive and successful use of these soils for permanent agriculture is for tree crops such as rubber, oil palm and cocoa and, in some countries, for sugar cane production. However technology suitable for the permanent production of upland annual crops is lacking and few farmers have the necessary skills or resources to implement the available technology (Dent, 1980). Pushparajah and Bachik (1985) concluded that there was a real need to consolidate the findings of arable cropping research with acid soils to provide a comprehensive picture linking the findings on soil chemistry, physics, nutrition, fertility and cultural practices, and crop adaptation.

Table 3. Estimated areas of acid tropical soils (Oxisols and Ultisols) in selected tropical Asian countries and Australia.

Country	Total land area of acid tropical soils	
	Million hectares	Percentage of total area
Burma	39	58
China	16	48
India	43	13
Indonesia	82	43
Malaysia	24	72
Papua New Guinea	8	17
Philippines	17	57
Sri Lanka	2	30
Thailand	42	82
Vietnam	24	73
TOTAL	297	
Australia	8	5

Sources: Nicholaides and Sanchez (1983) and Sanchez and Isbell (1979).

One of the key objectives of the acid soils component of the LADASMMA program is to validate existing knowledge and disseminate information on the soil management technologies of farming systems for these soils, with special emphasis on soil acidity, nutrient dynamics and mechanical practices for sustained production. As an institution with a global mandate, IBSRAM will utilize the international Acid Tropical Soils Network to ensure that technologies developed in Latin America (e.g. Sanchez, 1985) and Africa (e.g. Pieri, 1985) are evaluated in Asia. Conversely, technologies developed in Asia (von Uexkull, 1984; McIntosh *et al.*, 1981) will be assessed in tropical acid soil areas in the other continents. IBSRAM will encourage a multidisciplinary or farming systems approach to the validation of soil management technologies with emphasis on assessing their economic viability.

Acid tropical soils in Australia are relatively small in area (Table 3) but are important agriculturally because they are largely confined to the humid areas of the Queensland coast where sugarcane, improved pastures and horticulture are the main land use (Isbell, 1979). Since these are low-activity clay soils, scientists in Townsville and Brisbane have devoted considerable time to research on the dynamics of the pH surface charge characteristics and exchangeable cations when these soils are cultivated (Gillman, 1984; Bell, 1986). Interest in the surface charge properties of Malaysian soils at Universiti Pertanian Malaysia (Tessens and Shamsuddin, 1983) led to the initial proposal that an ACIAR project in this field be developed. After the IBSRAM Acid Soils Workshop in Brazil, a collaborative project on the Management of Soil Acidity for Sustained Crop Production was developed to include studies of not only aspects of the surface charge of the soils but also the aluminium, manganese, calcium and magnesium dynamics in acid soils.

The objectives of the ACIAR project are:

1. To evaluate the responses of groundnut, soybean, maize, and the cover crop legumes *Pueraria phaseoloides* and *Calopogonium caeruleum* grown in selected Malaysian Ultisols and Oxisols to the application of ground magnesium limestone:

(a) at sites where a long-term cropping system is to be established, and
(b) as an intercrop with young rubber plantings in the first 2-3 years prior to canopy closure.

2. To relate food crop and cover crop performance in both field and pot trials to an extended range of soil variables with a view to determining the best method of assessing the lime requirement of Malaysian and Australian Ultisols and Oxisols, and to monitor long-term changes in surface and subsoil acidity.

3. To determine the value of soil amendments in ameliorating soil acidity problems in Malaysian and in Australian Ultisols and Oxisols.

4. To examine the effects of the incorporation of liming materials and gypsum in both the surface soil and in the subsoil on the amelioration of subsoil calcium and magnesium deficiency and subsoil aluminium and manganese toxicity.

5. To determine the external solution calcium and magnesium requirements and the toxicity threshold concentrations (activities) of aluminium and manganese for growth and nodulaltion of the species and cultivars used in the Malaysian studies.

The research will be conducted in the field and greenhouse in Malaysia and in the laboratory and greenhouse at the University of Queensland.

ACIAR has also developed two projects concerned with the adaptation and establishment of shrub and tree legumes in acid soils. An AARD/ACIAR workshop (Craswell and Tangendjaja, 1985) established that one of the major problems in the utilization of multipurpose shrub legumes in Indonesia was the poor establishment and growth of these plants, particularly *Leucaena*, in acid infertile soils. A research project was therefore developed between the AARD forage research group at Balai Penelitian Ternak and the CSIRO Division of Tropical Crops and Pastures with the following objectives:

1. The evaluation of the performance of a range of shrub legumes in diverse soil/climatic

environments (multisite testing).

2. Characterization of the nutritional requirements of a range of shrub legumes and the definition of soil factors limiting their growth.

3. The provision and maintenance of genetic resources of shrub legumes.

The poor nodulation and early growth of shrub legumes in acid soils is a serious problem which is the subject of an ACAIR research project involving the Visayas State College of Agriculture and the University of the Philippines Los Banos in partnership with the Australian National University. The objectives are to determine the interrelationships between *Rhizobium* strains and promising legume tree species in different parts of the Philippines and select strain-host cultivar combinations tolerant of acid soils and/or find other economic management practices to alleviate this stress.

The emphasis on shrub legumes in these projects is based on the idea that biological nitrogen fixation is the most economically appropriate source of nitrogen for small farmers on marginal soils (Greenland, 1985). Furthermore, Wijewardene (1984) has emphasized the ecological sense of including trees or shrubs in any sustainable arable farming system which is replacing tropical rainforest. Hopefully the results coming out of the ACIAR shrub legume projects will soon be available and put to use in the LADASMMA program.

Land Development for Sustainable Agricultural Production

As much as 75 million ha of tropical forest in Asia is traditionally used for shifting cultivation (Suwardjo *et al.*, 1985). However, the shifting cultivators are shortening the bush fallow periods and tending to practice permanent agriculture because of mounting population pressure on land resources. Furthermore, large government supported schemes in Indonesia and Malaysia are responsible for the clearing of vast areas of tropical forest, while deforestation is continuing at an alarming rate in other countries of the region (Latham, 1986). Many aspects of the problems caused by land clearing were considered at the

IBSRAM meeting in Indonesia last year (IBSRAM, 1985a). The meeting concluded that work was needed on developing criteria to choose land to be cleared, validating ecologically compatible methods for land clearing, and validating and/or developing technologies for post-clearing land management and for the rehabilitation of degraded lands. At this meeting these activities will be refined for the LADASMMA program.

Sustainable technologies for tree crop production on cleared land in tropical Asia involve either manual clearing or careful mechanical clearing with the use of legume cover crops (Zakaria *et al.*, 1985; Pushparajah *et al.*, 1977). The greatest risk to sustainability is soil erosion, which is exacerbated by the high erosivity of intensive tropical rains (Lal *et al.*, 1978) and the fact that the shortage of available land is forcing developers and smallholders onto steeplands. Because the soil erosion risk is high, food production systems developed in temperate regions and based on the use of bare fallows are not sustainable (von Uexkull, 1984; Marston *et al.*, 1984). Similarly, the empirically based Universal Soil Loss Equation (YSLE) developed in a temperate area must be verified for a range of soils before it can be used in the tropics (Lal, 1980).

On steeply sloping land in the southern Philippines (Pacardo, 1985; O'Sullivan, 1985) and in the eastern islands of Indonesia (Piggin and Parera, 1985), farmers have adopted a technology based on contour plantings of rows of the shrub legume *Leucaena* which have stabilized the soil. A mulch of *Leucaena* leaves provides nitrogen and other nutrients to food crops such as corn grown in the interrow alleys. The prunings from the shrubs provide a bonus of fuelwood, thus reducing the removal of trees from the forests. Although some farmers have been using the alley cropping technology for many years, there has been insufficient research to evaluate it under a range of different slopes, soil types and climates (Craswell *et al.*, 1984).

In humid tropical and subtropical Queensland, as in Asia, the high intensity of summer rains has greatly contributed to the risk of soil erosion in the cereal- and sugar-producing uplands (Loch and Freebairn, 1985). Although the production technologies in Queensland are different from those in Asia, methods for measuring soil erosion in Queensland may find a direct application in Asian countries. Furthermore, the erosion and deposition process model developed by Rose (1985) may provide a basis for evaluating the impact of various soil management practices on soil loss in Asian countries as well as in Australia. Field validation of this process model in Asia would require much less experimental work than that required to develop and verify empirical relationships for the USLE in the tropics.

After the IBSRAM workshop on Land Clearing in 1985, a number of Southeast Asian countries sent project proposals to IBSRAM and ACIAR. A common theme in the research component of the proposals was the need to assess the impact of various production technologies on soil erosion. ACIAR has subsequently agreed to develop a project involving scientists from these Southeast Asian countries in a research partnership with the Soil Conservation Research Branch of the Queensland Department of Primary Industries and the School of Environmental Studies at Griffith University in Brisbane. Hopefully, the draft proposal for this project will be finalized after discussion at this meeting.

CONCLUSIONS

In this paper I have attempted to review briefly the problems of agricultural development in Asia, in the context of the pressure on the soil resources of the region, the important role for IBSRAM and the LADASMMA program, and the ACIAR projects providing focused support for research which hopefully will be integrated into the LADASMMA program. In this way, the efficiency and capacity of scientists in the national programs will be enhanced most effectively. The payoff will be improved agricultural productivity today without destroying the soil resource for the generations which follow us.

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SOIL MANAGEMENT RESEARCH: A SUGGESTED APPROACH

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ABSTRACT

The resources of Asia and the Pacific will continue to deteriorate due mainly to increasing population pressures, particularly in South Asian countries. Soil degradation is currently widespread and will continue to worsen with increased deforestation, soil erosion, salinity, and desertification. Most of the increase in food production during the last 20 years took place in irrigated areas, while yields in the rainfed areas, where soil problems are widespread, have remained stagnant or even declined. Since 72% of the arable land in Asia and the Pacific is dependent on rainfall, serious efforts are required to arrest soil degradation in the region. The role of IBSRAM in promoting soil management research in Asia is commendable, but the results of soil research should be relevant and useful to agricultural development. This can be achieved only if the approach and focus of soil management research are carefully planned and executed.

INTRODUCTION

Soil degradation is one of the major environmental problems which has received increasing attention and concern of resource scientists, environmental specialists, policymakers, international financing agencies and the general public. Recent published reports by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (1983) and the World Resource Institute (1986) indicate that soil degradation has become a severe problem in countries with high population density and widespread poverty such as Bangladesh, India, Indonesia, Nepal and Philippines. The establishment of the International Board for Soil Research and Management (IBSRAM) in 1984 to address soil problems is appropriate and timely since concerted efforts are urgently required to overcome these problems.

The objectives of this regional seminar are to develop national research proposals and to establish an operational mechanism for implementing soil management research in Asia. In discussing the various research proposals during the seminar, we should remember that soil degradation is a complex problem since it may be caused by deforestation, the introduction of rainfed agriculture, poorly managed irrigation systems, or overgrazing. However, the underlying cause in virtually all cases is greater human pressure on a fragile environment (see Appendix 1).

This paper begins with a brief review of the trends in population and the use of resources in Asia and the Pacific. It then describes the efforts of the Asian Development Bank (ADB) in addressing soil degradation problems. Finally, it offers a few suggestions on the approach and focus of soil management research in the Asian region.

TRENDS IN POPULATION AND RESOURCES IN ASIA AND THE PACIFIC

Population

Nearly all countries in Asia have supported family planning programs to reduce population growth. Overall, the annual growth of population in the region has declined from 2.35% in 1970-1975 to 1.73% in 1980-1985, and is projected to decline further to 1.22% by 2000-2005. However, the success of a family planning program varies from country to country. In general, the countries of South Asia (Pakistan, India, Nepal, Bangladesh, Sri Lanka and Burma) tend to have a higher annual growth rate than the countries of Southeast and East Asia (Japan, Republic of Korea, People's Republic of China, Philippines, Indonesia, Malaysia, Singapore, Thailand and Vietnam) (see Appendix 2). The countries of South Asia also have the lowest incomes and the highest mortality rates in Asia.

The population of Asia increased from 1.66 billion in 1960 to 2.82 billion in 1985 and is projected to increase to 3.54 billion in 2000. The pressure on land resources, measured in terms of the density of population, is highest in Bangladesh (702), followed by the Republic of Korea (413), Japan (323), Sri Lanka (250) and India (232), although there are also pockets of high population density in Indonesia (e.g. Java), Philippines and the People's Republic of China. The population density in Singapore (4434) is also extremely high, but this city-state has limited agricultural land.

Land Use and Cultivated Lands

The percentage of land under arable and permanent crops in 1980 was the highest in South Asia at 35% of the total land area, followed by Southeast Asia (16%), East Asia (10%) and the Pacific (5%) (see Appendix 3). However, land under forests was the highest in Southeast Asia at 56% of the total land area, while in the other three subregions forestland made up only 14 to 18% of the total land. Land under permanent pastures was the highest in the Pacific at 56% and the lowest in Southeast Asia at 5%. As a whole, arable land comprised only about 15% of the total area of 3051 million ha in the region.

The carrying capacity of cultivated lands is under increasing stress due to population growth, and the cumulative impact of deforestation, soil erosion, waterlogging, salinization and desertification. Most of the increase in food production in the future is expected to be achieved mainly through increased productivity or higher yields, since the cultivated area is projected to increase between only 4 and 15%

during 1980-2000. As a result of population growth, urban development and limited increase in cultivated lands, the arable land per capita and food reserves are likely to decrease further in the future. During the period from between 1971-1975 to 2000, arable land per capita is expected to decline from 0.26 ha to 0.13 ha in South Asia, from 0.35 to 0.20 ha in Southeast Asia, and from 0.13 ha to 0.08 ha in East Asia (see Appendix 4).

Forestland

Forests have a protective as well as a productive role. Their protective role includes the maintenance of an ecological balance between soil, water, flora and fauna, while their productive role is attributed to their ability to provide timber, industrial products, fuelwood and medicines (Ganguli, 1985). Ideally, forests should be managed by maintaining the balance between the two roles. However, since the beginning of civilization, man has been cutting down forests at a faster rate than reforestation has taken place. Taken as a whole, the rate of deforestation in the tropics exceeds the rate of reforestation by ten- to twentyfold. As a result, the Asian region, which was originally well endowed with forests, has at present a very serious deforestation problem.

Tropical forests are an extremely fragile ecosystem, highly susceptible to damage from human activities. Once damaged, the entire ecosystem can quickly unravel in the following sequence: interruption of nutrient cycling, soil erosion, downstream siltation, flooding, damage to irrigation systems and dams, and acute fuelwood shortages. The effects spread through agriculture, energy supply and water quality, and threaten the economic base of many regions.

In 1980 the Asian region was estimated to have some 657 million ha of land under natural forests, comprising 537 million ha of closed forests, 8.4 million ha of coniferous forests, 3.7 million of bamboo forests, 31 million of open forests and 35.5 million of secondary forests. In 1976-1980, over 1 809 000 ha of land was deforested annually. In 1981-1985, the total land deforested annually was estimated to have increased slightly to 1 827 000 ha (see Appendix 5). By the year 2000, if current trends continue, about 12%

of the moist tropical forests that remained in 1980 will be gone, as well as about 10% of the remaining dry tropical forests. Rates of loss vary greatly among countries since they depend on the following factors:

- logging activities for domestic construction industries and/or for export;
- removal of wood for fuel and charcoal to meet the energy demand in the rural areas;
- widespread practices of shifting cultivation or slash-and-burn agriculture;
- forest encroachment by the landless;
- large-scale conversion of forests to agriculture and plantations, opening of land for settlement of the landless, and establishment of urban and industrial centers; and
- other factors, such as fire and overgrazing by livestock.

The Asian countries can be divided into three groups, depending on the annual rate of deforestation and the extent of the area deforested annually. These are:

* Group I: Malaysia, Thailand, Lao PDR, Philippines, Nepal, Vietnam and Sri Lanka, which have high rates of deforestation (0.7 to 3.9% per annum) and large areas deforested annually (58 000 to 255 000 ha/year);
* Group II: Indonesia, India, Burma, Cambodia and Papua New Guinea, which have low rates of deforestation (0.1 to 0.5% per year) but large areas deforested annually (22 000 to 600 000 ha/year); and
* Group III: Bangladesh, Pakistan and Bhutan, which have low rates of deforestation (0.1 to 0.9%) and small areas affected (2000 to 8000 ha per year).

Soil Resources

The countries of Asia and the Pacific depend largely on the quality of their soils for their development. With a continuing increase in population, there is a constant search for new cropland. Unused land generally has problems of soil type, climate, accessibility or topography that severely limit its agricultural potential.

Ironically, while the search goes on for new agricultural land, the existing crop- and rangeland base in Asia is being steadily diminished because of changes that reduce or completely destroy its agricultural productivity. The soils of Asia are for the most part inherently infertile and are prone to rapid deterioration when subjected to intensive cultivation and poor management. About 82 to 86% of the soil resources are affected by factors such as drought, acidity, low fertility, shallow depth and waterlogging (FAO, 1977).

Soil degradation is the second major scourge of the environment after forest degradation, and is the result of several processes. The first and the most widespread is soil erosion. The second is changes in the water and salt content of the soil. The third is the reduction of land productivity in the arid and semi-arid region, which is misleadingly called "desertification" since the appearance and spread of sand sheets and dunes may be, but often is not, involved.

Soil Erosion

Soil erosion is widespread and occurs in arid, semi-arid and humid regions. It causes major losses in agricultural and forest productivity; although over time it has also been responsible for the productivity of such fertile areas as the Nile, Indus, Ganges, and Mississippi river valleys. Many factors cause erosion, but the two most important are the degree of slope and the amount of bare soil exposed to the elements as a result of human activities such as deforestation and cultivation. As croplands become overworked and mismanaged, erosion often rises dramatically.

Erosion has two major kinds of effects: on-site and off-site. With regard to on-site effects, erosion reduces the water-holding capacity of soil by selectively removing organic matter and the finer particles. It also removes soil nutrients as well as soil organic matter. Finally, erosion limits plant growth by restricting the depth of soil available for root exploitation. Over time, erosion reduces crop yields and returns drastically, forcing the farmers to abandon the land and move to a new location.

Off-site effects are also severe, not so much for food production as for the infrastructural aspects. The soil particles removed from the eroding fields are blown away by wind or washed away into streams, creeks and major waterways. Studies have indicated that the major rivers in Asia, such as the Huang (Yellow), the Ganges, the Irrawady and the Mekong, have much higher annual suspended loads than the rivers in Africa and Latin America (see Appendix 6). These data suggest that the erosion rate in Asia is very high, which could be attributed to high population density of the plains and mountains, intensive cultivation and the high rate of deforestation. The high sediment load of rivers has also been responsible for damage to irrigation systems and for shortening the life of hydroelectric projects.

The damage caused by soil erosion has not been quantified in Asia. In the United States, which has carried out the most extensive investigations of erosion rates and effects, about 3 billion metric tons of sediment are washed into waterways each year with off-site damage estimated at US$6.1 billion (World Research Institute, 1986). The damage includes a decline in fish populations, the loss of recreation potential, the destruction of coral reefs, a decrease in the amount of water stored in reservoirs, the loss of hydropower potential, and the cost of dredging rivers and harbors for navigation.

Depending on site characteristics, erosion can be controlled by appropriate management, including reforestation, agroforestry, well-designed terraces, prevention of overgrazing, or zero tillage. Despite the availability of erosion control techniques, it is difficult to convince wealthy landowners, much less impoverished subsistence farmers, to budget time and money for erosion control techniques whose payback period may be measured in years or even generations. Even policymakers do not fully appreciate the long-term damage caused by erosion. This is why soil erosion has been called a "quiet crisis" and a "creeping catastrophe."

Among Asian countries, the South Asian countries (Afghanistan, Pakistan, India, Bangladesh and Nepal) and the People's Republic of China suffer heavily from both wind and rainfall erosion of the soil as a result of overgrazing, intensive cultivation and large-scale deforestation. In Southeast Asia, very serious rainfall erosion has been reported in various parts of Thailand, Philippines and Indonesia (particulary Java and Sumatra). The worst soil erosion problems probably take place in Nepal and the Philippines due to a combination of highly erodable soils, steep slopes, high population density, high rainfall, and widespread deforestation.

The available data suggest that soil erosion will become more severe as the population density continues to increase, and human activities intensify to grow more food and to search for more cropland.

Waterlogging and salinity

In semi-arid or arid areas of extensive systems of irrigation, waterlogging and salinity problems are widespread. Waterlogging is simply saturation of the root zone of the soil with water as a result of over-irrigation or seepage of water from irrigation canals without an adequate compensating system of drainage. As water builds up in the soil and rises upwards toward the surface, the second problem of salinity starts, i.e. deposition of salts on the soil. Although this problem is not as widespread as soil erosion, in the countries where it occurs the social and economic consequences can be even more serious than soil erosion or deforestation. A good example is the collapse of the ancient Sumerian civilization in Mesopotamia in the plains of modern Iraq in 1700 BC, largely as a result of loss of arable land to salinity.

At present, problems concerned with waterlogging and salinity occur mainly in Pakistan, India, and the People's Republic of China. Pakistan has the most extensive and oldest irrigation network in the world, serving an area of about 15 million ha. Due to a poor drainage system, in 1976 some 1.2 million ha were severly affected by waterlogging and a further 6 million ha were moderately affected. Furthermore, 3 million ha were laid to waste through salinity, especially in Sind province. To repair this damage, Pakistan has embarked on a costly program of subsurface drainage with the assistance of multilateral and bilateral agencies.

India also suffers significantly from waterlogging and salinity, particularly in Punjab, Uttar Pradesh, Gujarat, Maharashtra and Orissa. Of a total irrigated area of about 40 million ha, about 6 million ha are reported to be waterlogged or saline. The People's Republic of China has a similar problem, but the extent of the irrigated area affected by waterlogging or salinity is not known.

Desertification

Desertification is broadly defined as a process which reduces the productivity of land in semi-arid or arid areas as a result of deforestation, overgrazing, waterlogging, salinity, soil erosion and other factors (ESCAP, 1983). In Asia, there are deserts in Afghanistan, People's Republic of China, Pakistan and India. In all these areas the major factors causing desertification are low rainfall, reduction of vegetation cover due to deforestation, overgrazing and salinity. Desertification reduces land productivity and living standards of the people concerned. The United Nations Conference on Desertification (UNCOD) held in 1977 estimated that the problem was increasing although detailed information was not available. Measures to combat the problem had been introduced in Bangladesh, People's Republic of China, India, and Pakistan, in the 1977-1984 period, but with limited effect.

UNCOD estimated that of the 630 million people in the drylands of the world, the Asian share is 60% or 378 million people, and of the 78 million people in the world currently living on lands which are already desertified, 28 million or 36% are in Asia. The annual rate of desertification worldwide is estimated at 6 million ha of which about a million ha are being desertified annually in Asia (ESCAP, 1983).

Food Production

Despite a 70% increase in the Asian population during 1960-1985 (from 1.6 billion to 2.8 billion) and the rapid deterioration of soil, forest and land resources, the total cereal production in Asia increased by 96%, from 394 million tons to 773 million tons (FAO, 1983). Over the same period, net annual imports of cereals by the Asian countries declined sharply. The impressive increase in food production was attributed to massive irrigation development, rapid adoption of high-yielding varieties, increased application of chemical fertilizer and appropriate pricing policies (Asian Development Bank, 1986a). With the increase in cereal production, there was improvement in per capita daily calorie intake and per capita daily protein intake. However, it should be noted that most of the increase in cereal production took place in irrigated areas where yields and cropping intensity could be increased substantially through water control and the use of improved seeds and modern inputs.

Of the more than 212 million ha of irrigated land in the world, 120 million ha or 57% are in Asia (World Research Institute, 1986). At present, about half of the total food production in Asia comes from irrigated land. The International Food Policy Research Institute estimated that by the year 2000 about 73% of future increases in food production will come from irrigated areas. In rainfed areas, on the other hand, cereal yields have remained stagnant or even declined due to unreliable rainfall, soil erosion, low soil fertility and other constraints. Most of the soil degradation activities discussed above generally take place on rainfed areas where the majority of farmers live. About 72% of the arable land in Asia is dependent on rainfall for agriculture. The incomes and living conditions of most farmers in rainfed areas have not improved compared with those of farmers in irrigated areas. The challenge that must be met is to find ways to increase crop productivity in rainfed areas using proven cropping systems and technology packages.

ADB's EXPERIENCE IN AGRICULTURAL DEVELOPMENT AND ENVIRONMENTAL RESOURCES PROTECTION

The ADB began operations in 1966. During 1968-1985, it approved 774 loans in the aggregate amount of US$17.5 billion for 704 projects in 27 developing member countries (DMCs) in Asia and the Pacific (ADB, 1986b). The largest recipient of Bank loans has been Indonesia (19%), followed by Pakistan and the Philippines (both 14%), the Republic of Korea (12%) and

Bangladesh (10%). The agriculture sector, including irrigation, forestry, fisheries and livestock, accounts for the largest share of Bank lending - 31% or US$4.8 billion - followed by the energy sector (20%) and the transport and communications sector (13%). During the first five years of lending operations (1968-1972), ADB lending to the agriculture sector as a percentage of total lending averaged 17%, but this increased gradually to an average of 39% during the last three years with greater availability of concessional funds and increasing importance accorded by the Bank to agricultural development (ADB, 1985).

The major focus of ADB lending in the agriculture sector has been on food self-sufficiency, particularly in rice, in addition to other objectives such as improvement of farm incomes and generation of employment in the rural areas. During the late 1960s and early 1970s it became apparent that economic development often had damaging effects on the natural environment, reducing its capacity to sustain long-term development and threatening human health and welfare, ADB's concern for environmental issues was evinced in 1978 when it published a paper entitled "Environment Protection and Development Financing by the Asian Development Bank." Between 1981 and 1983, it engaged two environment specialists to review projects financed by ADB, incorporate environmental protection in Bank-assisted projects, improve environmental awareness among ADB staff, develop environmentally oriented projects, and encourage the integration of environmental and natural resources planning in policies and programs. The environment specialists also issue guidelines to encourage more effective planning and environmental management of its development projects, for example on land clearing (ADB, 1986c).

It is well recognized that there is a close relationship between sustainable development and optimal use of environmental and natural resources. Thus, the challenge that must ultimately be met is to find ways to meet the demands of growing populations and accompanying economic activity without destroying the resource base. The essentials for successful environmental management are knowledge, political will and money. All these are in short supply in the developing countries. ADB therefore has an educational as well as a financial role to play in the rational use of natural resources.

ADB's activities in the agriculture sector are not limited to financing development projects. Since 1978 ADB has formulated a number of projects with the main purpose of restoring, rehabilitating, protecting and improving the management of natural resources and living conditions in human settlements. Such projects include reforestation, watershed management, development of water resources and fisheries, irrigation and drainage, urban development, and public health. Some of the typical examples of these projects are given below.

Forestry Projects

Since 1977 the Bank has financed 14 forestry projects in the aggregate amount of US$211 million. Two forestry projects which should have a big impact on the reforestation of denuded areas are the Hill Forest Development Project in Nepal and the Forestry Development Project in the Philippines. These projects are still in the early stages of implementation, and therefore it is too early to determine their impact on the environment. But one of the major issues in appraising this type of project concerns difficulties in quantifying the economic benefits of reforestation, since there is no direct relationship between deforestation and crop loss and other damage downstream.

ADB has also financed community forestry projects in Bangladesh and Sri Lanka in which wasteland is being utilized for growing tree crops to meet the fuel energy demand in rural areas. However, these projects experience implementation problems due to poor coordination, shortage of trained manpower, and inadequate monitoring and evaluation.

Drainage Projects

In cooperation with the World Bank and other bilateral agencies, ADB has financed a large drainage project (Left Bank Outfall Drain Project) in Pakistan to reclaim irrigated areas which have been badly affected by waterlogging and salinity. When completed, the project will benefit about 516 000 ha of irrigated land. A drainage project of this nature is very costly but it is the only way to overcome salinity in semi-arid and arid areas.

Land Resource Evaluation and Planning Projects

ADB has recognized the need for effective land-use planning as the basis for effective environmental (particularly soil) management. Since 1983, it has provided technical assistance to Indonesia, Bangladesh, Thailand and Sri Lanka, and it is expected that such assistance will be provided to Nepal, Pakistan and Bhutan. ADB is considering financing major land resource evaluation and planning projects in these countries, with some US$40 million already committed.

ADB fully recognizes that comprehensive land resources evaluation and planning projects are urgently needed in its DMCs for the development of sound environmental management. In most of these countries economic development will continue to be carried out to meet the needs of growing populations; but what is crucial is that this development be done with careful planning, taking into account the potential constraints and prospects for development so that it will result in minimum environmental degradation.

To sum up, the DMCs in Asia and the Pacific are becoming increasingly aware of the need to improve the management of renewable natural resources for sustained development. However, it would take decades for these countries to effectively arrest the deterioration of renewable resources because: (i) decisionmakers and the public have yet to become sufficiently aware of environmental degradation and protection; (ii) the lack of adequate information on natural resources and the shortage of trained manpower; (iii) limited financial resources and the lack of clear lines of responsibility; and (iv) weak enforcement agencies (ADB, 1986c).

ROLE OF IBSRAM IN SOIL MANAGEMENT RESEARCH

Ideally, agricultural projects should be implemented only after a comprehensive and detailed assessment of the resource base, and of the constraints and prospects for development have been made, and also after appropriate technologies have been developed. In many cases, however, agricultural projects have been implemented without research. There are many reasons why this is widespread in developing countries. First, development often cannot await the results of research.

Second, most policymakers do not appreciate the importance of research in project formulation and implementation. Third, agricultural research has been accorded low priority in most countries. Fourth, where research is being undertaken, its results have failed to meet the development needs because the research is irrelevant or the results are ambiguous. As a result, agricultural projects are formulated on the basis of "guesswork" or borrowed inappropriate technology.

This situation, of course, should not be tolerated considering that many agricultural projects have failed, partly due to poor formulation and implementation or lack of understanding of the local sociocultural conditions. It is heartening to note that thirteen CGIAR[1] -funded international agricultural research institutes and twelve non-CGIAR international agricultural research institutes have been established .o assist developing countries to increase food production (see Appendix 7). The green revolution experienced in Asia during the last two decades has been partly attributed to the research activities of the international agricultural research centers, particularly the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT).

The International Board for Soil Research and Management (IBSRAM) was established in 1984 primarily to assist and speed up the application of soil science in increasing food production in developing countries on a sustained basis. It has neither the resources nor facilities to carry out research on its own, but it is envisaged that it will operate through a number of regional soil management networks, each with a research base and collaborating with national programs within its respective regions. To finance its activities and expansion program, IBSRAM relies on financial contributions from multilateral and bilateral agencies. Under the present economic conditions, it is extremely difficult to obtain financing because: (i) the amount of grant funds which can be provided by donor agencies

1. CGIAR (Consultative Group for International Agricultural Research) provides financial assistance to the international agricultural research centers. At present, CGIAR has 42 members including 26 governments, 11 international organizations and development banks, and five foundations.

cannot keep pace with the growth of the international research centers; and (ii) there is no longer any urgency to increase food production in Asia due to a rice surplus and the depressed prices of food grains in the region. Therefore, IBSRAM has to formulate its research strategy carefully so that it can develop into an effective organization and attract financing from donor agencies.

Short-Term and Long-Term Strategy

Based on the inaugural workshops which have already been held, IBSRAM has selected three areas of soil management research: (i) management of acid tropical soils; (ii) management of newly cleared tropical soils; and (iii) management of Vertisols. Since newly cleared tropical soils tend to be acid soils, the first and second topics are likely to be dealing with similar problems, and hence there are basically two distinct research areas to be considered in this seminar. Of these two areas, research on tropical acid soils is extremely important in Southeast Asian countries, particularly with regard to methods of land clearing, land development, and the rehabilitation of degraded soils, such as alang-alang-infested soils in Indonesia. Research on Vertisols would be highly relevant in India and other South Asian countries where such soils are commonly found. In the future, however, IBSRAM should also consider research on soil salinity and desertification since these are also important soil problems in Asia. To be effective, soil management research coordinated by IBSRAM should be linked with the activities of other international research centers to avoid duplication of efforts.

Field experiments on soil management could yield useful results in terms of reliable soil information, crop/soil relationships, a choice of alternative cropping systems, fertilizer regimes, and improved soil conservation practices, which would strengthen the activities of the national governments and external funding agencies in project identification, preparation and implementation. However, such research is usually conducted over several years and in different locations to obtain meaningful data. In the meantime, IBSRAM should also consider a short-term strategy which would keep the donors and the national programs continuously interested in IBSRAM's activities and results. It is suggested that the short-term strategy should include the strengthening of the information unit under IBSRAM which would have the following tasks:

- Compilation of up-to-date and reliable information on soil, land and forest resources and the extent of soil degradation in developing countries. Such information is urgently required in view of the fact that the data currently available are inaccurate, and sometimes conflicting.

- Preparation of summaries of the results of successful soil research undertaken in the various institutions all over the world which may be relevant to the needs of developing countries.

The above information should be disseminated widely not only to soil scientists but also to policymakers involved in agricultural development, and to the bilateral and multilateral financing agencies.

Criteria for Evaluation of Research Proposals

The soil scientists who will present their papers during the first two days of the seminar are expected to discuss the most appropriate approach and focus of soil management research from the viewpoint of soil science. I do not intend to duplicate their papers since I am not a soil expert. Instead, I would like to go beyond the subject of soil science since agricultural development must take into account the complex interactions of plants, soils, water, animals and people, and above all, the cost and benefits of such an undertaking. The results of soil research will only be useful and relevant to agricultural development if it takes into account the socioeconomic aspects of the farmers, the potential and constraints of agricultural development, and the likely cost and benefits of the technology to be developed by the research scientists. These aspects should be incorporated in the formulation of soil management research.

Soil management research is not only time-consuming but also expensive. Carefully formulated and planned research is a prerequisite to ensure that our efforts in promoting soil management research in the developing countries will not be wasted. Before we discuss and evaluate the various research proposals to be presented by the national programs on the third and fourth day of the seminar, I would like to suggest that the meeting should first establish criteria and guidelines for prioritizing and evaluating research proposals. Some of the criteria and guidelines may include the following:

- the research must clearly address the major problems of soil degradation commonly found in Asian countries;
- the research must be in line with the priorities of governments;
- the research should be expected to make a major impact on soil productivity, and produce policies and procedures for possible adoption by governments;
- the research should consider the development of a cost-effective technology appropriate to the conditions of small farmers in Asia; and
- the research should be multidisciplinary, involving the cooperation of a soil scientist, an agronomist, an agricultural economist, a sociologist and an agricultural engineer.

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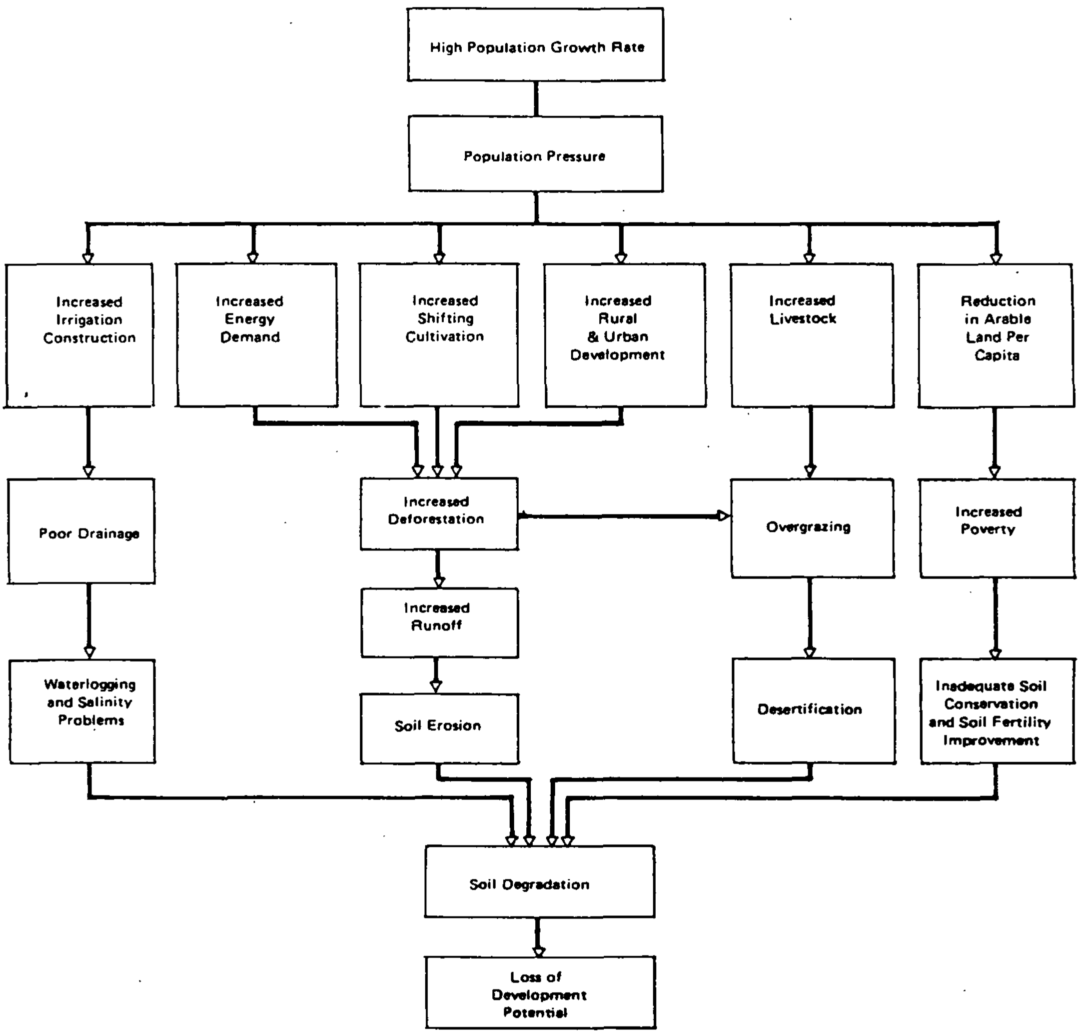
APPENDIX I

FACTORS CONTRIBUTING TO SOIL DEGRADATION PROBLEM



APPENDIX II

TREND IN POPULATION GROWTH IN ASIA

COUNTRY	ANNUAL GROWTH OF POPULATION (%) 1960-65	1980-85	2000-05	POPULATION (MILLIONS) 1985	2000	POPULATION DENSITY/KM^2 IN 1985
SOUTH ASIA						
1. AFGHANISTAN	2.08	2.04	1.95	14.6	24.2	23
2. BANGLADESH	2.47	2.74	2.04	101.1	145.8	702
3. BURMA	2.28	2.52	1.94	39.5	55.1	58
4. INDIA	2.50	1.99	1.15	761.2	961.5	232
5. NEPAL	2.90	2.33	1.94	16.5	23.0	112
6. PAKISTAN	2.66	3.08	2.02	101.7	142.5	127
7. SRI LANKA	2.43	2.03	1.20	16.4	20.8	250
SOUTHEAST ASIA						
1. INDONESIA	2.14	1.76	1.15	164.9	204.5	86
2. KAMPUCHEA	2.45	2.89	0.89	7.4	9.9	41
3. LAO PDR	2.37	2.51	1.93	4.4	6.2	19
4. MALAYSIA	3.00	2.29	1.35	15.5	20.6	47
5. PHILIPPINES	3.04	2.49	1.53	54.7	74.8	182
6. SINGAPORE	2.81	1.27	0.54	2.6	3.0	4,207
7. THAILAND	3.02	2.09	1.44	51.6	66.1	95
8. VIETNAM	2.19	2.02	1.51	59.5	78.1	181
EAST ASIA						
1. JAPAN	0.99	0.57	0.29	120.0	127.7	323
2. REPUBLIC OF KOREA	2.64	1.39	0.88	40.9	49.5	413
3. PEOPLE'S REPUBLIC OF CHINA	1.76	1.17	0.95	1,063.1	1,255.6	111

SOURCE: WORLD RESOURCES 1986

APPENDIX III

LAND USE PATTERN BY SUB-REGIONS
1980
('000 Hectares)

	South Asia	%	Southeast Asia	%	East Asia	%	Pacific	%	Total	%
Land Area	641,816	100	436,610	100	1,134,018	100	838,697	100	3,051,141	100
Arable Land and Permanent Crops	227,168	35	71,721	16	107,466	10	45,629	5	851,984	15
Permanent Pastures	114,043	18	19,952	5	344,034	30	466,262	96	944,291	31
Forest and Wood Land	102,470	16	243,567	56	163,167	14	150,171	18	699,375	22
Other Land	198,135	31	100,370	23	519,351	46	176,635	21	995,491	32

Source: FAO, Production Yearbook 1982
ESCAP, Handbook on Agricultural Statistics for Asia and the Pacific, 1982.

APPENDIX IV

TOTAL AND PER CAPITA CROPLAND AND RESOURCES
1971-75 AND 2000

Region	Cropland & Potential Cropland (million hectares)	Cropland a/ (million hectares) 1971-75	Cropland a/ (million hectares) 2000 (Projected)	Cropland Per Capita (hectares) 1971-75	Cropland Per Capita (hectares) 2000 (Projected)
Industrial Market Economies (Total)	1,023.3	400.3	399.1	0.55	0.46
United States	540.5	200.5	208.0	0.95	0.84
Western Europe	225.1	90.1	87.0	0.26	0.22
Japan	13.7	5.7	5.1	0.05	0.04
Other Major Exporters b/	244.0	104.0	99.0	1.58	0.94
Centrally Planned Economies (Total)	884.4	414.5	420.0 c/	0.35	0.26
Eastern Europe	114.4	54.4	X	0.43	0.36
USSR	552.5	232.5	X	0.93	0.73
China, People's Republic of	217.5	127.5	X	0.16	0.11
Less Developed Countries (Total)	2,232.0	662.0	723.5	0.35	0.19
Latin America	611.5	136.5	165.0	0.47	0.28
North Africa/Middle East	221.5	91.5	91.0	0.47	0.22
Other African LDCs	760.5	160.5	182.5	0.62	0.32
South Asia	437.5	207.5	207.0	0.26	0.13
Southeast Asia	99.9	34.9	41.0	0.35	0.20
East Asia	101.1	31.1	37.0	0.13	0.08
WORLD (TOTAL)	4,139.7	1,476.8	1,538.6	0.39	0.25

X = Not available

Notes:

a. Cropland includes land under permanent and temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens (including cultivation under grass), and land temporarily fallow or lying idle. This category is called "arable and permanent cropland" by FAO.
b. Canada, South Africa, Australia and Argentina.
c. Cropland in centrally planned countries is thought to be near maximum. Growth in land used outside the agricultural sector approximately balances cropland area increase.

Sources:

1. U.S. Council on Environmental Quality, the Global 2000 Report to the President, p. 97 and p. 99.
2. U.S. Geological Survey (USGS), Supporting Data for Environmental Trends (USGS, Washington, D.C., 1983), p. 232.

APPENDIX V

AREAS OF NATURAL WOODY VEGETATION (All Information Including Fallows) 1980 and ESTIMATED 1985 AND AVERAGE ANNUAL DEFORESTATION 1976-80 AND ESTIMATED 1981-85

	Area Woody Vegetation						Annual Deforestation ('000 ha)	
	Total (1000 ha)		Percent Country		Percent Region			
	1980	1985	1980	1985	1980	1985	1976-80	1981-85
Bangladesh	1,242	1,227	8.70	8.59	0.78	0.28	8	8
Bhutan	2,370	2,360	50.54	50.62	0.53	0.54	2	2
India	72,082	72,531	21.93	22.06	16.19	16.48	147	147
Nepal	2,461	2,046	17.40	14.47	0.55	0.46	84	84
Pakistan	3,585	3,860	4.46	4.80	0.81	0.88	7	7
Sri Lanka	2,727	2,371	41.56	36.14	0.61	0.54	25	58
Burma	52,641	52,590	77.64	77.56	11.82	11.95	95	105
Thailand	16,975	15,280	25.53	22.98	3.82	3.47	333	253
Brunei	560	560	97.14	97.14	0.12	0.13	7	5
Indonesia	158,155	157,160	82.40	81.89	35.53	35.71	550	600
Malaysia	25,820	25,191	78.08	76.18	5.80	5.72	230	255
Philippines	13,030	11,570	43.47	38.60	2.93	2.63	101	91
Kampuchea	13,273	13,203	73.32	72.93	2.98	3.00	15	25
Lao PDR	19,360	19,085	81.76	80.60	4.35	4.34	125	100
Vietnam	21,190	21,415	63.38	64.05	4.76	4.86	65	65
Papua New Guinea	39,705	39,595	86.00	85.91	8.92	9.01	21	22
TOTAL							1,809	1,821

Source: FAO - Forest Resources of Tropical Asia, 1981.

APPENDIX VI

ESTIMATED ANNUAL SOIL EROSION WITHIN DRAINAGE BASINS OF SELECTED RIVERS OF THE TROPICS

River	Drainage Basin Area (10^3 km^2) and countries		Average Annual Suspended Load	Estimated Annual Soil Erosion From Field
			Metric tons x 10^6	Metric tons/ha
A. Africa				
Congo	4,014	(Several)	65	3
Niger	1,114	(Several)	5	0.8
Nile	2,978	(Several)	111	8
B. Asia				
Chao Phraya	106	(Thailand)	11	21
Irrawaddy	430	(Burma)	299	139
Damodar	20	(India)	28	284
Ganges	1,076	(India)	1,455	270
Kosi	62	(India)	172	555
Mahanadi	132	(India)	62	93
Mekong	795	(Several)	170	43
Red	120	(China)	130	217
Yellow	668	(China)	1,600	479
C. Latin America				
Caroni	91	(Venezuela)	48	105
Amazon	5,776	(Several)	363	13
Orinoco	950	(Several)	87	18

Source: S. A. El Swaify et al, 1982.

APPENDIX VII

CGIAR-FUNDED INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

	Name	Year Estab-lished	1984 Budget ($ Mn)	Research Areas	Geograpahic Coverage
1.	CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia	1968	23.1	Cassava, field beans, rice, tropical pastries	Latin America, Global
2.	CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), Mexico	1966	21.0	Maize, bread wheat, durum wheat, barley, triticale	Global
3.	CIP (Central Internacional de la Papa) Lima, Peru	1971	10.9	Potato	Global
4.	IBPGR (International Board for Plant Genetic Resources), Rome, Italy	1974	3.7	Plant genetic resources.	Global
5.	ICARDA (International Center for Agricultural Research in the Dry Areas), Aleppo, Syria	1976	20.4	Farming systems, wheat, barley, triticale, broad bean, lentil, chickpea, forage crops	Dry areas of West Asia and North Africa
6.	ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Andhra Pradesh, India	1972	22.1	Chickpea, pigeon pea, pearl millet, sorghum, groundnut, farming systems	Semi-arid tropics
7.	IFPRI (International Food Policy Research Institute), Washington, D.C., USA	1975	4.2	Food Policy	Global
8.	IITA (International Institute of Tropical Agriculture), Ibadan, Nigeria	1967	21.2	Maize, rice, cassava, sweet potato, yams, cowpea, lima bean, soybean, farming systems	Tropical Africa, Global
9.	ILCA (International Livestock Center for Africa), Addis Ababa, Ethiopia	1974	12.7	Livestock production systems	Tropical Africa
10.	ILRAD (International Laboratory for Research on Animal Diseases), Nairobi, Kenya	1973	9.7	Trypanosomiasis, theileriosis	Global
11.	IRRI (International Rice Research Institute), Manila, Philippines	1960	22.5	Rice, rice-based cropping systems	Global, Asia
12.	ISNAR (International Service for National Agricultural Research), The Hague, Netherlands	1980	3.5	National Agricultural Research	Global
13.	WARDA (West Africa Rice Development Association), Monrovia, Liberia	1971	2.9	Rice	West Africa

APPENDIX VII
(cont.)

NON-CGIAR INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

	Name	Year Established	Budget ($ Mn)	Research Areas	Geographic Coverage
1.	ICIPE (International Center of Insect Physiology and Ecology), Nairobi, Kenya	1970	4.8 a/	Integrated control of crop and livestock insect pests and insect vectors of tropical diseases.	Worldwide tropical zones.
2.	AVRDC (Asian Vegetable Research and Development Center), Shanhua, Taiwan	1971	3.b b/	Tropical vegetable crop production (tomato, Chinese cabbage, sweet potato, soybean and mungbeans).	Worldwide in tropics.
3.	INTSOY (International Soybean Program), USA	1973	0.9 c/	Soybean germplasm preservation, production, processing and utilization; economic and policy analyses of soybean marketing.	Worldwide.
4.	IFDC (International Fertilizer Development Center), Urbana, Illinois, USA	1974	9.8 d/	Development of new or improved fertilizers and technical know-how for developing countries.	Worldwide, special emphasis on tropical countries.
5.	NIFTAL (Nitrogen Fixation by Tropical Agricultural Legumes Project), Honolulu, Hawaii	1975	1.7 c/	Development of biotechnology on nitrogen fixation by legumes and training of researchers and extension leaders.	Tropical and sub-tropical regions.
6.	ICLARM (International Center for Living Aquatic Resource Management), Manila, Philippines	1975	1.7 b/	Development of small-scale fisheries through tropical stock assessment and improvement, integrated farming, and information dissemination.	Tropical regions.
7.	ICRAF (International Council Research on Agro-Forestry), Nairobi	1977	4.2 c/	Development of appropriate agro-forestry systems and technologies.	-
8.	ICDUP (International Council for Development of Underutilized Plants), USA	1978	0.2 c/	Introduce or expand production of winged bean (Psophocarpus tetragonolobus), medical plants, forage plants to developing countries.	Worldwide.

a/ 1982 budget.
b/ 1983 expenditures.
c/ 1983 budget.
d/ 1982 expenditures.

APPENDIX VII
(cont.)

	Name	Year Estab- lished	Budget ($ Mn)	Research Areas	Geograpahic Coverage
9.	IDI (Interntional Dambala (Winged Beans) Institute), Sri Lanka	1982	0.3 e/	Basic and applied research for domestication and commercial use of winged bean.	Worldwide.
10.	IIMI (International Irrigation Management Institute), Sri Lanka	1984	5.0 f/	Irrigation management, training, dissemination and exchange of information.	Worldwide.
11.	IBSRAM (International Board for Soils Research and Management), Bangkok, Thailand	1984	1.0 g/	Land development, soil management dissemination of information and training of soil researchers.	Worldwide.
12.	INIBAP (International Network for the Improvement of Bananas and Plantains), Canada	Initial process stage	1.8 f/	Strengthen regional and national breeding programs, distribution of disease-free germplasm, and organize workshops and training.	Worldwide.
	Total		35.0		

e/ 1983 and 1984 budgets.
f/ Proposed annual budget.
g/ Proposed 1985 annual budget.

Second Session: Site selection

Chairmen: S. Buol
F. Hj Ahmad

PHYSICAL AND SOCIOECONOMIC CONSIDERATIONS IN SITE SELECTION

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ABSTRACT

This paper discusses the physical and socioeconomic factors that must be considered in site selection, and highlights some of the important constraints that may be encountered. The first criteria to be established concern national priorities in terms of the required cropping systems and the areas to be developed. Agroecological zones and more specific physical and socioeconomic characteristics then need to be considered. The notable socioeconomic factors to be considered are farm size, land tenure, labour availability, power availability, the educational and technical background of the farmers, income levels of the farmers, extension efforts, credit availability, access to input facilities and product markets, and the cooperation of the farmers. In addition the following logistic issues arise: the size of the site, the accessibility of the site, and its proximity to the research station. The main constraints to site selection are the location - specificity problem, the common lack of an adequate secondary data base, and the time-consuming and expensive baseline survey which is often conducted.

INTRODUCTION

The importance of on-farm and/or site-related research has increased over the last 15 years, responding to the demand for more farmer-relevant technology. Site-based research is expensive and demands more skilled manpower. Therefore it is necessary to select sites that are representative, appropriate, important from a national or regional point of view, and accessible.

This paper discusses the factors that should be considered in site selection and highlights some of the important constraints that may arise.

WHY SITE RESEARCH?

Agricultural research has traditionally concentrated on research stations. It was controllable, reliable and logistically convenient. Modern technology in its early stages, did not pose many problems of acceptance since it was adopted in more favourable environments which tended to represent research station conditions. Moreover the immediate problem at that time was increasing food production. However, with the technology moving to less favourable areas, the case of acceptance of this technology was lost. The variability in the environment where the technology was introduced both from a physical and socioeconomic point of view, made it apparent that on-farm research or site-specific research needed to be given attention.

The complexity that exists within a farming environment further justifies the need for on-site research. In general small farmers make decisions in an environment that requires complex farming systems to ensure a sustainable and varied food supply for domestic needs as well as adequate surpluses for the market. Byerlee *et al*. (1982) identify some of the factors involved in decision making as follows:

a. long growing seasons, especially in the tropics;
b. unreliable input and output markets, uncertain climates, low farm incomes (which increases the importance of risk);
c. consumption of part of the produce by farm households;
d. the importance of family labour.

This complexity in most cases results from (i) direct physical and biological interactions between production activities, (ii) competition and complementarity between resource use, and (iii) the multiple objective function of the farm household (Byerlee *et al.*).

Site research must be able to capture as much as possible the variability that exists and overcome some of it, making the technology more adaptive. Site research should be farmer-responsive and react to a better understanding of the farmer's environment. Furthermore, site research, if targeted to the required environment, should add assurance that resulting technologies will meet farmer needs. It also provides an opportunity for interaction between research and extension, and in the long run involves other supporting institutions, particularly credit and marketing. It can also fine-tune on station research and provide a continuous feedback to researchers, to extension personnel, and to formulators of agricultural policy.

STRATEGY FOR SITE RESEARCH

Site research generally tends to be expensive and is certainly more costly than station research. This is because of the higher operational costs that will be borne in terms of personnel, vehicles and land rents. (However it is low in overhead costs as compared to station research.) Due to the general scarcity of resources it is necessary to determine the optimal number of experiments that should be conducted which would provide an opportunity to increase the productivity of the resources in an acceptable environment.

The selection of the environment in which research will be conducted then becomes important. The essential criterion for identifying sites is the extent to which the final recommendations are affected. The International Maize and Wheat Improvement Center (CIMMYT) proposes a recommendation domain (RD) concept, involving a group of farmers with roughly similar practices and circumstances for whom a given recommendation will be broadly appropriate. In this instance, socioeconomic criteria may be just as important as the agroclimatic variables in delineating domains. Hence it is necessary to give careful consideration to both the physical and socioeconomic factors in site selection.

PROCEDURES IN SITE SELECTION

Although no formal procedure exists for site selection, there are guidelines that have proved useful.

Firstly, policymakers will have to indicate broadly the target area that needs special attention in relation to a researchable project. The decision could have political or economic importance from either a national or a regional perspective. In the experience of the cropping systems program in the Asian region, the primary emphasis has been on crop intensification to realize increased food production. for example the cropping systems site in Sri Lanka concentrated on a small reservoir (tank) program that covered an area of 104 200 ha where there were 3000 such small reservoirs (Sikurajapathy and Senaratne, 1977). In Thailand, the Ubon site typified a 500 000 ha rainfed area located in the northeast region (Chandrapanya, 1977). In Indonesia, the Indramayu site in West Java typified 1.1 million ha of rainfed land in Java (Effendi *et al*., 1976).

Secondly, the research team has to stratify the broad area into subareas or subgroups. These usually take the form of agroecological regions or agroclimatic zones. The physical characteristics of the area therefore become the cornerstone of the site in relation to the target area. This process can take a reasonable time period and hence a rapid appraisal may be resorted to.

Thirdly, the research team selects a site that will be used for the research program within the target area. Criteria used for site selection are (i) physical, (ii) socioeconomic, and (iii) managerial and logistic.

Physical Criteria

The researcher should determine the extent to which some of the specific characteristics in the environment are met by the selected site. Its relationship to rainfall, land type, soils, climate and any other characteristics must be considered. Examples of sites selected by the International Rice Research Institute (IRRI) cropping systems program with reference to the environments in which they were located is presented in Table 1. These sites were selected because they represented conditions found in important agroecological complexes in Asia (IRRI, 1986).

Physical characteristics of selected sites by national programs for cropping systems studies are presented in Table 2. These sites are within specific agroecological zones in the individual countries. A detailed classification of each site enables researchers to categorize the representativeness of the site, and tentatively estimates the land surface over which results should apply.

The physical characteristics tend to be relatively easier to handle than the socioeconomic factors, largely because they are goal-oriented and their variability is relatively low. The important criterion to be kept in mind is that the site should be representative of the broad environment.

Socioeconomic Factors

The technology to be developed at a site should be appropriate to the specific area. A useful approach in relating environmental factors to the potential of cropping systems was proposed by Zandstra (1977). In this approach environmental factors included physical resources (related to climate and land), economic resources (land, labour and capital availability) and socioeconomic conditions.

Table 1. Environments in which on-farm CSR has been conducted by IRRI departments.*

	Tanauan, Batangas	Oton-Tigbauan, Iloilo	Manaoag, Pangasiwan	Solana, Cagayan	Guimba, Neuva Ecija	Claveria, Misamis Oriental
Years of full operation[1]	1973-76	1975-79	1975-79	1980-83	1984-87	1985-88
Rainfall[2]	5 wet 4 dry	6 wet 4 dry	5 wet 6 dry	5 wet 5 dry	5 wet 4 dry	6 wet 2 dry
Topography	Gentle volcanic slopes	Broad flat marine plains and alluvial-colluvial interhill plains	Broad flat alluvial plains	Alluvial terraces	Broad flat alluvial plains	Gentle to steep volcanic slopes
Traditional rice cultural type	Upland[3]	Favorable rainfed lowland[4]	Favorable rainfed lowland[5]	Drought and submergence prone lowland[6]	Partially irrigated lowland	Upland
Dominant soil great group	Hapludolls	Pelluderts, Eutropepts	Eutropepts	Tropaquepts	Tropaquepts, Eutropepts	Dystropepts
Surface soil texture range	Sandy loam to clay loam	Clay and silty clay	Clay loam to silty clay loam	Silty clay loam to clay	Loam to silty clay	Silty clay to clay
Soil reaction range (pH)	5.0 to 6.2	6.5 to 7.2	6.7 to 7.3	6.0 to 6.7	6.5 to 7.3	4.0 to 4.7
Farm size (ha)	1.3	1.5	1.1	3.0	1.6	3.0
Family size	5.9	5.7	5.8	6.4	6.0	5.3

*Source: The Cropping Systems Research Program of the International Rice Research Institute, 1986.

1. Frequently staff from one or more disciplines are retained to continue investigations on topics such as control of a specific disease, comparisons of social organization between farmers operating in different hydroecological strata, or profiles of human nutrition.
2. A month with long-term mean rainfall total exceeding 200 mm is wet; if the total is less than 100 mm, it is dry.
3. Rice is cultivated on unpuddled and unbunded fields. Rainfall is the only water source.
4. In most years rainfall is sufficient to cultivate rice without yield being significantly reduced by drought stress.
5. Rainfall patterns and terrain characteristics combine to create an environment in which drought stress is frequent, but on occasion, rainfall is sufficiently intense to submerge the rice crop canopy for more than 4 or 5 days.
6. Rainfall plus irrigation water is insufficient for all farmers in an irrigation command area to cultivate a second rice crop without some farmers encountering yield-reducing drought stress.

Table 2. Physical characteristics of eight rainfed cropping systems research sites under the Asian Cropping Systems Network.

Site	Latitude	Longitude	Elevation above sea level (m)	Landtype	Soil textural range	Soil pH	No. of rainy weeks/ year	Total annual rainfall (mm)
1. Para, Nepal	27'04'N	84'58'E	115	Rainfed lowland	Silty-silty loam	7.0	34	1699
2. Pumdi Bhumdi Nepal	28'14'N	84'00E	900	Rainfed lowland	Silty loam-loam	4.7	36	3787
3. Bhogra Bangladesh	23.5'N	90.4'E	30	Rainfed lowland	Silty loam-silty clay	6.9	34	1668
4. Katupotha, Sri Lanka	6.2'N	80'E	30	Rainfed lowland	NG*	NG*	30	1836
5. Paranthan Sri Lanka	8.8'N	80.5'E	NG	Rainfed lowland	Sandy-sandy clay	NG	NG	NG
6. Bangphae Thailand	13.8'N	99.8'E	NG	Rainfed lowland	Silty clay loam-silty clay	6.5-8.0	26	710
7. Blega, Madura Indonesia	7'7'30"S	113'8'6"E	8	Rainfed lowland	Sandy loam	6.2	29	1131
8. Jrengkek, Madura, Indonesia	7'7'30"S	113'8'6"E	8	Rainfed lowland	Loam-sandy loam	6.8	30	1467

*NG = not given.

One of the major issues in site research concerns the degree of potential for adoption of the new technology. In this context the development and dissemination of modern rice and wheat varieties have been studied extensively. Increases in rice production in Bangladesh, Indonesia, South Korea, Pakistan, Thailand and Philippines amounted to over 3% annually between 1972 and 1979 (Herdt and Capule, 1983), and modern semi-dwarf varieties of wheat were adopted in over 44% of the wheat-growing areas in the world in a 15-year period (Dalrymple, 1979). This rapid adoption of modern technology in rice and wheat is described by Dalrymple (1979) as "perhaps the most significant technical change in agriculture in less developed countries (LDCs) in this century." Feder *et al.* (1982) observe that despite these efforts, immediate and uniform adoption of new technology has been rare. They argue that after a process of learning and experimentation, a new equilibrium level is attained with respect to resource utilization. The socioeconomic factors that influence adoption are therefore many and complex. Denning (1985) identifies a number of them:

* farm size
* land tenure
* labour availability
* power availability
* educational and technical background of the farmer
* income level of the farmers
* extension effort
* credit facilities
* access to input supplies and product markets
* cooperation with farmers

Some of the above are more important while others are less important. The institutional environment within which changes take place is also an important factor.

Farm size

Feder *et al.* (1982) offers the theoretical basis for suggesting an effect of farm size as related to the divisibility of the innovation. Where there are large fixed costs, smaller farms have a reduced tendency for adoption. Binswanger (1978) indicated a strong positive relationship between farm size and the adoption of tractor use in South Asia. Farm size may be correlated with a large number of explanatory variables which include access to input markets, capacity to bear risks, access to extension services and, in some instances, wealth. While the correlation between farm size and technology adoption does not appear consistent, it is still an important consideration in terms of development of appropriate technology.

Land tenure

Theoretically it could be assumed that farmers who are share-tenants, and have to share the increased product of their investment would seem less likely to adopt a new technology. Parasarathy and Prasad (1978) found that tenants were less likely to adopt modern varieties than owner-cultivators in certain regions of India. Flinn *et al.* (1980) and Shakya and Flinn (1984) indicated that owners are more likely than tenants to adopt modern varieties in Nepal.

Land tenure plays an important role in site selection, particularly in the context of soil conservation issues. In a situation involving a community of tenant farmers where the right to cultivate is allotted on a season by season basis, there is little incentive for the tenant to engage in soil conservation measures, particularly if it is at his own expense. An issue that surfaces in this context is the relationship between group farming enterprises as against individually owned holdings. Group decisions in the case of soil conservation measures are easier to implement than decisions of individual farmers.

Labour availability

New technology is generally accompanied with a change in the labour requirements from the existing situation. While certain technologies are labour-saving (mechanization in place of human or animal power, direct seeding of rice), others are labour-demanding (irrigation, use of modern varieties). This necessitates an understanding of the existing labour situation at a particular site and in the study area in general. In the absence of a well-developed labour market, farmers will find it difficult to use the new technology efficiently if it competes with scarce labour resources during periods of labour bottlenecks.

Power availability

New technology developed in the past made it more profitable to use either animal or tractor power as against human labour. The availability of these resources can influence the adoption of the improved technology, particularly if there is a heavy demand for them. In a study of Mindanao in the Philippines, Denning (1980) found that 40% of the surveyed farmers indicated that they would cultivate more land if they could own or hire an extra draught animal.

Educational and technical background of the farmers

A commonly discussed socioeconomic variable is the educational level of the farmer. Associated with this is the age of the farmer and his family, particularly those of his children. A large number of studies have indicated that more literate, better educated farmers have a higher adoption rate (Chinnappa, 1977; Flinn *et al.*, 1980; Feder and Slade, 1984). Education is correlated with factors such as wealth or capital availability, and consequently extension efforts in the first instance could target the educated group, where adoption would be better. The educational levels of children who are living and working on the farm will also influence the adoption rate. (This assumes that children have a greater opportunity for schooling than was available for their parents.)

Income levels of the farmers

The income level of farmers plays a significant role in the adoption of new technology. The inability of the farmer to absorb any increased costs of new technology will result in at least a partial rejection of the technology. An understanding of the farmer's present levels of income, both farm and non-farm income, will reflect the relative profitability of his current enterprises, either agricultural or non-agricultural, and provide an idea of the debt-bearing capacity of the proposed technology.

Extension effort

Many studies have documented the importance and role of extension in the adoption of modern technology. (Benor and Harrison, 1977; Benor and Baxter, 1984; Shakya and Flinn, 1984; Feder and Slade, 1984.) The involvement of extension agents at the initial site selection process will provide a source of information about the "general awareness level" among farmers. Further their involvement in the research program will enhance the adoption process. The spread of new technologies developed in the cropping systems programs in Sri Lanka, Philippines and Bangladesh has been mostly due to the involvement of the extension officers.

Credit availability

Most new technology, if it is to be suitable for adoption, relies on the farmer's accessibility to forms of formal and informal credit. (This assumes that the new technology is more expensive than what is already being used.) Differential access to credit has been evidenced as influencing the adoption of new technology (Schutjer and van der Veen, 1977; Chinnappa, 1977; Shakya and Flinn, 1984). Soil conservation meeasures generally need additional cash investments, and unless readily available to the farmer, need to be supplemented.

Access to input facilities and product markets

Though not directly related to technology dealing with soil improvement and management, the access to input and output markets is important in site selection. A site isolated from the mainstream of market facilities could be the cause of difficulties in obtaining supplies. Moreover if the new technology leads to greater crop production efficiencies, the ability of the farmer to dispose of his produce at competitive prices becomes important.

Cooperation of farmers

Lastly, but certainly not the least important factor that will effect site selection, is the cooperation that the site researchers will obtain from the farmers. This is critical to site research. In the selection of farmers the concept of the "average" farmer is presented. This concept is used to represent those farmers that share most of the socioeconomic characteristics that are peculiar to the site. However in practice, while this general concept should be borne in mind, the cooperation of the individual farmers in the research activities is important. Farmers should appreciate the nature of the research activities, be familiar with the objectives of the research, and have realistic expectations of how they will benefit from them.

Managerial/Logistics

In addition to the physical and socioeconomic factors, managerial and logistic issues are involved. Among them are the following:

- size of the site
- accessibility
- proximity to research station

Size of site

An important consideration in the management of a site is its size. Size refers to the physical area on which experiments are actually involved. It also refers to the number of farmers there are on fields where it is planned to conduct experiments. Often this aspect is ignored until the project is under way, and it is then realized that the site is either too large or too small.

It is desirable that the research team conduct a rapid reconnaisance of the area in order to ascertain the area involved. The actual logistics of movement and transport could be affected by the size, as well as the running costs of the research program.

Accessibility

To ensure the close involvement of all associated with the research program, accessibility to the site should be reasonably good. While the on-site research team could live at the site, other researchers too should be able to visit it as often as possible.

Proximity to research station

Different views have been expressed regarding whether a site should be located in proximity to a research station. Both situations merit consideration. The underlying assumption is that it is necessary to have a constant feedback between findings and problems that surface at the site and which require further investigation in the research station environment. It is therefore desirable to have research sites within operational limits of research stations.

CONSTRAINTS TO SITE SELECTION

The considerations listed above appear quite comprehensive. Many problems however arise in actual implementation. The issues involved are:

- the location-specificity problem
- an inadequate secondary data base
- the difficulties in conducting a baseline survey

Location Specificity Problem

On-farm research is usually location-specific. Research projects cannot be satisfactorily implemented over large geographical areas without making modifications in accordance with local needs and conditions. Menz and Knipscheer (1982) propose two strategies to overcome this difficulty. Firstly, emphasis should be on a limited number of parameters which are relevant to potentially produceable technologies. Secondly, it is appropriate to design less than fully developed systems, leaving farmers and extension agents to adapt them to specific needs. Adaptive research is location-specific, and a multistage process is required to ensure the real benefits of the research program.

Inadequate Secondary Data Base

In order to select a site it is necessary to examine a large volume of secondary data which will help adequately describe the site environment. A common difficulty faced by researchers is the lack of such a data base.

Under the circumstances, it is necessary to conduct a research for the data, in some instances through a number of agencies. This is time-consuming, labourious and expensive, but certainly cheaper than going into a site and ignoring past information. Usually a baseline survey needs to be conducted in order to obtain the information required.

Baseline survey

Baseline surveys have been associated with long drawn-out data-collection exercises, which are time-consuming and expensive. However, at present a number of new approaches, such as key informant surveys (van der Veen and Mathema, 1980) and rapid site description (RSD) techniques are adopted, which can quickly provide an understanding of the research area.

CONCLUSION

With the emphasis on site-oriented research, selection of representative sites where the technology developed will be appropriate to the farming community has become important. A number of physical and socioeconomic factors determine the criteria for the selection of sites. These criteria, if considered judiciously, will enable the researchers to select a site that will be both representative and appropriate.

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SITE SELECTION FOR AGRICULTURAL RESEARCH OR EXPERIMENTATION IN THAILAND

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ABSTRACT

Agricultural research has been conducted in Thailand for 89 years, and has had an impressive impact on the progress of agriculture. However this research would probably have been more efficient if more attention had been paid to proper site selection. The following criteria for site selection are generally accepted: (i) the site must be research-objective oriented; (ii) intensive long-term experiments should normally be situated in existing experiment stations; (iii) convenient access to experiment sites is necessary as is a well-equipped meteorological station; (iv) fields must normally be flat. If available experiment stations are not suitable, farmers' fields can be considered. On-farm experiments, even if desirable, are often difficult to conduct due to the inconvenience involved in taking care of the plots, the possible damage by animals, and the long-term security of the agreement with the farmer.

DLD and DOA have altogether 150 centers and stations in Thailand. Many of them have been characterized in a general sense, but

few detailed soil surveys have been conducted, so there is the possibility of large soil variation in the experiments.

INTRODUCTION

Agricultural research and experimentation in Thailand have a long history (89 years), almost as long as the history of the Ministry of Agriculture and Cooperatives. Obviously the results of past research and experiments have had some impact on the progress of agriculture in the country. However, it could have been much more effective if more attention had been given to the sites chosen for the experiments. As Sono (1984) remarked, "The current agronomic experimental design mostly emphasizes crops and treatments with little or no site characterization. Hence, the outcome of the experiments have limited application."

Many government agencies, including academic institutes, conduct agricultural research and experiments. Within the Ministry of Agriculture and Cooperatives, two major departments - the Department of Agriculture (DOA) and the Department of Land Development (DLD) - carry out research and experiments under the provisions of its mandate. The DOA concentrates on the development of new crop cultivars and the performance of crops under different management practices, while the DLD emphasizes pedology, soil erosion and degradation problems, and the reclamation of problem soils.

Although the mandate has been set, a certain overlap is still unnavoidable due to the nature of agricultural research and experiments, which always involve four closely related factors: soil, crops, management and environment. Academic institutes, such as un versities and agriculture schools, also conduct research and experiments with more freedom in selecting the field of work. However, due to limited funds, their research and experiments are often carried out in collaboration with government or international agencies. Their sites for experiments are normally located in the institute's lands, allocated as an experiment field, or in government experiment stations.

Site Selection Criteria

Regarding the site selection for the experiments, there is no standard set of criteria which all the agencies and institutes use in common. Each one seems to have its own ways; but by and large the following criteria are typical:

- The site must be research-objective oriented.

- The sites for intensive long-term experiments must be located in the existing experiment stations situated in areas where interesting crops are grown extensively, as for example:

  * Rice: experiments on rice are always conducted at the rice research centres of each region and their network stations:

    - Prae Rice Research Centre for the upper northern region;

    - Phitsanulok Rice Research Centre for the lower northern region;

    - Rangsit Rice Research Centre for the central region;

    - Ubon Rajathani Rice Research Centre for the northeastern region;

    - Prachinburi Rice Research Centre for the southeastern region;

    - Pattalung Rice Research Centre for the southern region.

  * Maize: Experiments on maize are carried out at the Nakorn Sawan and the Prabhudhabath Field Crops Research Centres, and at the National Maize and Sorghum Research Centre, Pak Chong, Nakorn Rachasima.

  * Sugar cane: Experiments on sugar cane are mainly carried out at the Uthong Field Crops Research Centre, Suphanburi, the largest sugar cane area of the country.

  * Cassava: Experiments on cassava are conducted at Rayong and Khon Kaen Field Crops Research

Centres. The Rayong centre represents the southeastern region while Khon Kaen represents the northeastern region. A large portion of the cassava production of the country comes from these two regions.

* Cotton: Cotton in mainly grown in Nakorn Sawan and Saraburi provinces and their neighbourhoods. Experiments on the crop have been carried out at Nakorn Sawan Field Crops Research Centre and the Prabhudhabath station.

* Kenaf: Kenaf used to be the major upland crop in the northeastern region until cassava diffused into the region, replacing a large part of the kenaf area. The experiments on kenaf are still continuing at Khon Kaen and Ubon Field Crops Research Centres and their network stations.

* Soybean: Experiments on soybean are carried out at the Chiengmai Field Crops Research Centre and at Prabhudhabath station. However, their research orientation is different. At Chiengmai, the experiments emphasize irrigated conditions while at Prabhudhabath the experiments concentrate on rainfed conditions.

* Peanut: Peanut is grown in many diverse areas. Experiments have been carried out at Khon Kaen, Rayong Field Crops Research Centre, and at Prae Rice Research Station. Each one represents a specific soil ecosystem.

* Mungbean: Experiments on mungbean have been conducted at Chinart Field Crops Research Centre and at Phitsanulok, Sri Samrong (Sukhothai province) upland crops stations. The reason for this arrangement is to allow the wider ranges of climatic conditions under which mungbean is cultivated to be covered.

- The site must have convenient access.

- Standard meteorological data-collecting equipment must be available.

- The field must be flat, reasonably large, and not have a truncated surface horizon.

- In the event that a suitable site for a specific-objective experiment cannot be found within the existing experiment centres or stations, farmers' fields or lands looked after by other government agencies, such as the Office of Land Reform for Agriculture, the Department of Cooperative Promotion, and the Public Welfare Department, can be used, with a preference for the latter.

PRIVATE PROPERTY vs. GOVERNMENT STATIONS

At this point, it would seem worthwhile to give brief information concerning the land tenure system in Thailand. In general, the land in the countryside is divided into two categories - private land and government land. Private land refers to land for which the government has issued land title deeds in different forms to individual land tenants. To use government land for any research program, formal contact with the government agencies concerned is necessary. For privately-owned land the agreement has to be made with the individual landowner. The agreement can be in various forms, notably paying cash for leasing, giving all the products to the landowner after collecting all necessary data, or both. In a few cases, normally involving large farms or estates, the government is allowed to use part of the farm or estate for experiments without any conditions.

Common problems arising from using a farmer's property for experimentation are: (1) the inconvenience in taking care of the experiment plots; (2) the high risk of there being damage to the experimental crops by farm animals, or even by the farmers themselves (farmers take no responsibility for any damage which may occur); (3) it is less secure, even with some kind of agreement: a farmer can take back his land at any time he wishes. With these constraints, most researchers prefer to use the land in the experiment centres or stations. However, there is also a handicap in selecting the existing centres or stations for experimentation. Since the locations of the centres or stations were decided on in accordance with the availability of land, the sites within these centres or stations may be appropriate for certain experimental objectives, but certainly will not meet every requirement for a good deal of the research or for many of the experiments.

DOA and DLD Offices and Stations

Figures 1 and 2 show, respectively, the distribution of the DLD regional offices and stations, and the DOA research centres and experiment stations. The DLD has 12 regional offices and 53 stations. The DOA has 6 rice research centres, 17 rice experiment stations; 7 field crops research centres, 12 field crops experiment stations, 6 horticultural research centres, 10 horticulture experiment stations, 3 rubber research centres, 17 rubber experiment stations, 1 sericulture research centre, and 14 sericulture research stations. From the distribution pattern, it can be postulated that the establishment of the research centres or stations of the DOA tends to favour projects with a technical objective, while the DLD favours more administrative-oriented projects.

There are 158 centres and stations altogether - 65 for DLD and 93 for DOA (see Appendix and Figures 1 and 2). Many of these stations have been surveyed in detail. Although the soils have been described, they have not been systematically characterized at most of the experiment sites. A great variability of soil properties is therefore to be expected within the experiment plots. Tables 1 and 2 in the appendix show soil types in some of the experiment centres or stations of the DOA and DLD respectively.

CONCLUSION

Up to the present, the established research centres and stations have mainly been selected as sites for experiments for the sake of convenience, and also to reduce the risk of damage, which is normally quite high in farmers' fields. The objective of the research is used as the basic criterion for deciding which centre or station is to be chosen for a particular experiment. If suitable sites cannot be located in any of the existing centres or stations, land under the control of other government agencies is considered as a second alternative. Farmers' fields are the last choice. Site characterization has been neglected, or has been carried out in the course of the research activities which ensued, and consequently the results of most research has had limited transference value. Dudal (1986) said, "Many research projects are not characterized as to the environment in which they are

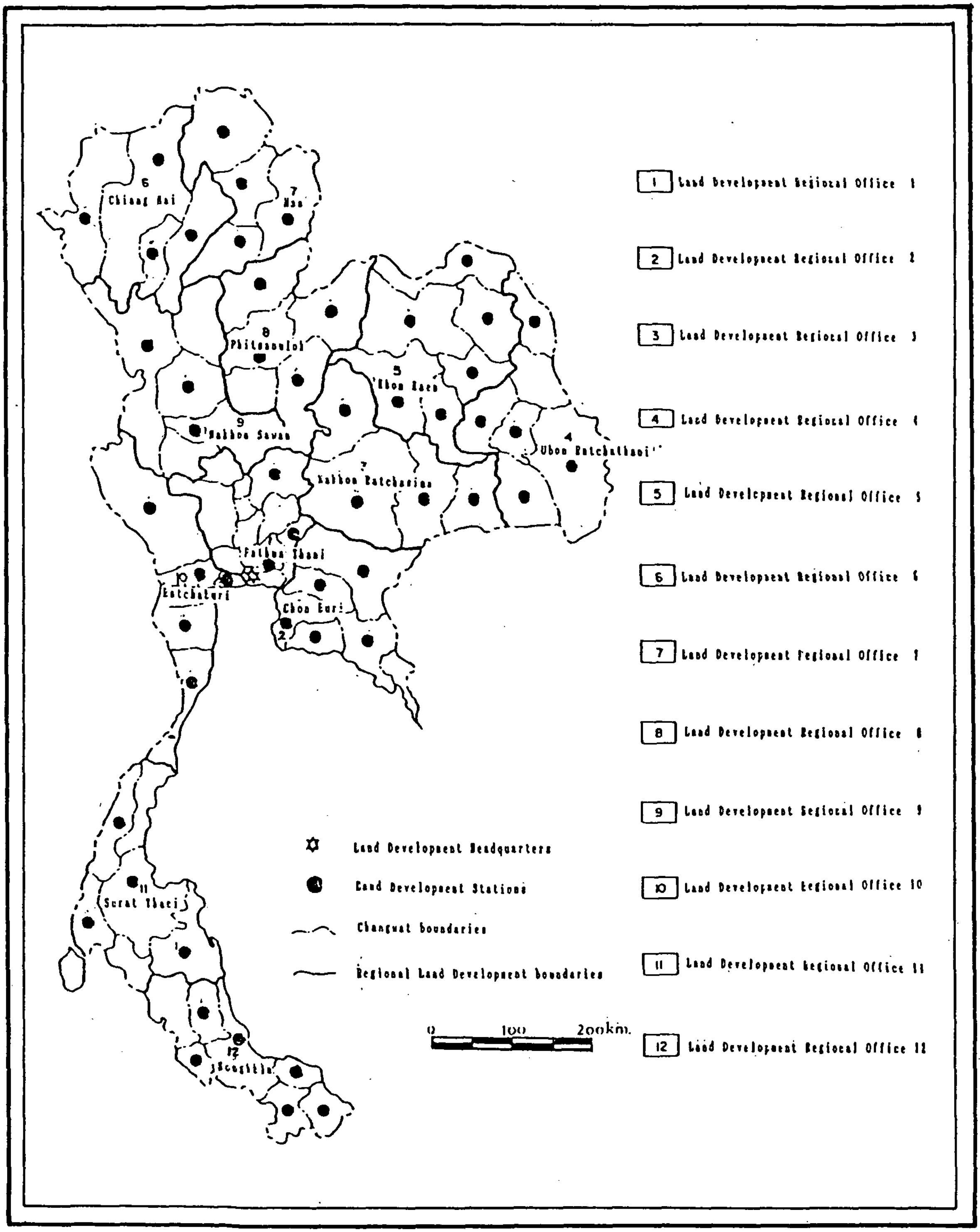

Figure 1. Map of location of DLD regional offices and land development stations.

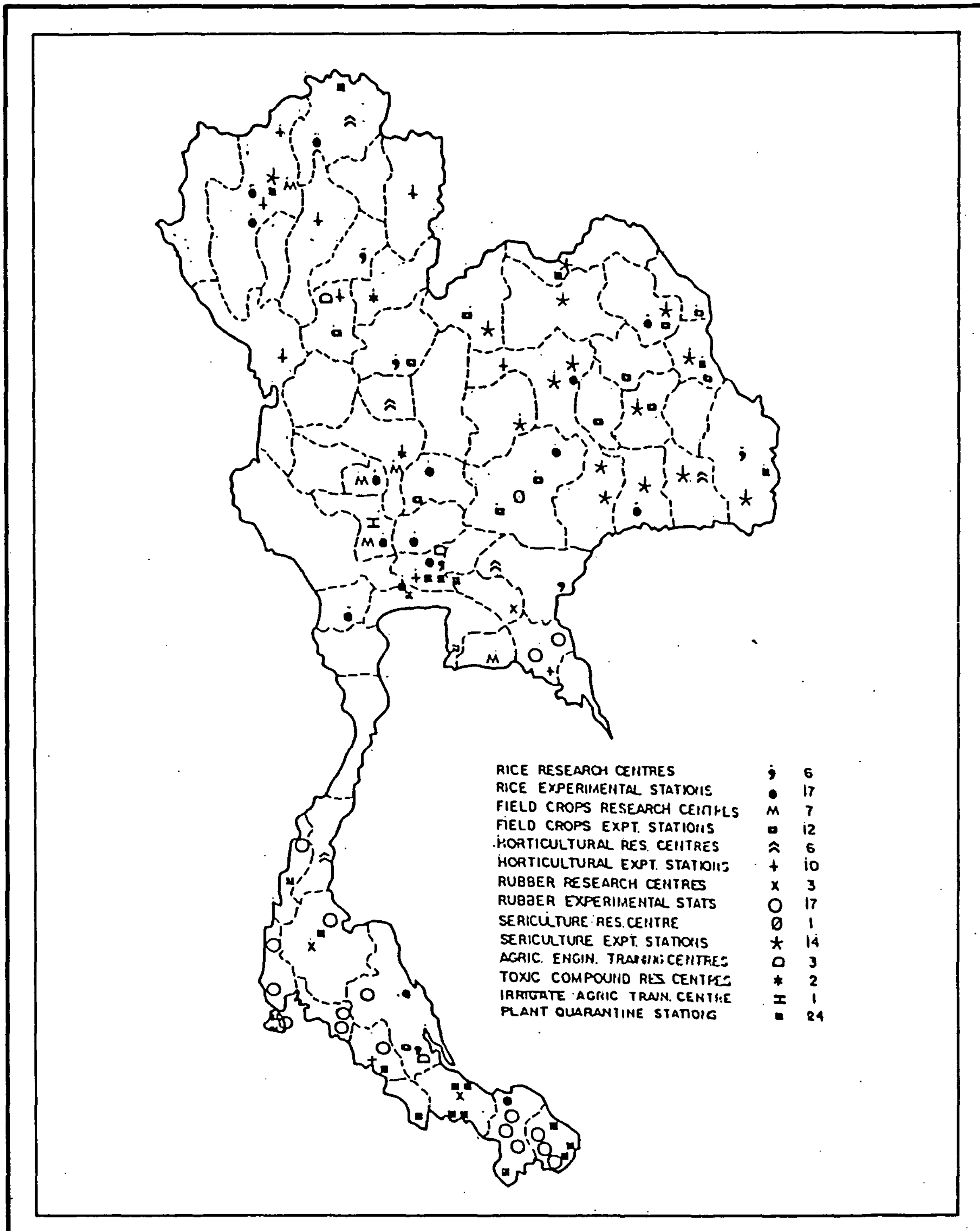

Figure 2. Map of location and identification of DOA research centres and experiment stations, 1984.

conducted, so that the extension of the results obtained to other sites becomes doubtful."

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APPENDIX

Table 1. Soils in some of the experiment centres/stations of the Department of Agriculture (DOA).

CENTRAL REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1 Rangsit Rice Experiment Station, Pathumthani province.	- very fine, kaolinitic, acid isohyperthermic Sulfic Tropaquepts 100%.
2 Chai Nat Field Crop Experiment Station, Chai Nat province.	- loamy, mixed, non-acid, isohyperthermic Aquic Ustifluvents. - clayey, mixed, non-acid, isohyperthermic Aeric Tropaquepts.
3 U-Thong Field Crop Experiment Station, Suphan Buri province.	- fine-silty, mixed, isohyperthermic Typic Haplustalfs. - fine, mixed, isohyperthermic Aeric Tropaquepts.
4 Phra Phutthabat Field Crop Experiment Station, Lop Buri province.	- clayey, kaolinitic, isohyperthermic, Oxic Paleustults.
5 Takhli (Tak Fah) Field Crop Experiment Stations, Nakhon Sawan province.	- very fine, montmorillonitic, isohyperthermic Typic Pellusterts. - clayey-skeletal, carbonatic, montmorillonitic, isohyperthermic, Udorthentic Haplustolls. - very fine, montmorillonitic, isohyperthermic, Typic Haplustolls.
6 Suphan Buri Rice Experiment Station, Suphan Buri province.	- no classification.
7 Pathum Thani Land Development Center, Pathum Thani province.	- very fine, mixed, acid isohyperthermic Sulfic Tropaquepts 100%.
8 Khok samrong Rice Experiment Station, Lop Buri province.	- fine-loamy, mixed, isohyperthermic Aeric Paleaquults.

NORTHERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1. Nan Horticulture Experiment Station, Nan province.	- clayey, mixed, isohyperthermic Oxic Paleustults. - clayey, kaolinitic, isohyperthermic Typic Paleaquults.
2. Chiang Rai Field Crop Experiment Station, Chiang Rai province.	- clayey, kaolinitic, isohyperthermic Oxic Paleustults.

Northern region (cont.)

3. Si Samrong Field Crops Experiment Station, Sukhothai province.	- fine-silty, mixed, isohyperthermic Udic Paleustalfs.
4 Mae Jo Field Crop Experiment Station, Chiang Mai province.	- coarse-loamy, siliceous, isohyperthermic Oxic Paleustults. - fine-loamy, mixed, isohyperthermic Aeric Plinthic Paleaquults. - fine, kaolinitic, isohyperthermic Typic Tropaquults.
5. Phitsanulok Rice Experiment Station, Phitsanulok province.	- no classification.
6. Lampang Land Development Center, Amphoe Hangchat Lampang province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults. - fine-loamy, mixed, isohyperthermic Typic Haplustults.

NORTHEASTERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1 Nakhon Phanom Horticulture Experiment Station, Nakhon Phanom province.	- Gray Podzolic
2 Mukdahan Field Crop Experiment Station, Mukdahan province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults 100%.
3 Ban Mai Samrong Field Crop Experiment Station, Nakhon Ratchasima province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults 100%.
4 Kalasin Field Crop Experiment Station, Kalasin province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults. - coarse-loamy, siliceous, isohyperthermic Ustoxid Dystropepts.
5 Noen Sung Field Crop Experiment Station, Nakhon Ratchasima province.	- fine-loamy, siliceous, isohyperthermic Vertic Tropaquepts. - very fine, mixed, non-acid, isohyperthermic Vertic Tropaquepts.
6 Maha Sara Kham Field Crop Experiment Station, Maha Sara Kham province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults.
7 Phimai Rice Experiment Station, Nakhon Ratchasima province.	- very fine, mixed, non-acid isohyperthermic Vertic Tropaquepts. - fine, mixed, non-acid, isohyperthermic Aeric Tropaquepts.
8 Mukdahan Field Crop Experiment Station, Mukdahan province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults 100%.
9 Loei Field Crop Experiment Station, Loei province.	- clayey-skeletal, mixed, isohyperthermic Typic Paleustults. - clayey, kaolinitic, isohyperthermic Oxic Paleustults.

Northeastern region (cont.)

10 Khon kaen Field Crop Experimeent Station, Khon Kaen province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults 100%.
11 Sakon Nakhon............ .... Sakon Nakhon province.	- fine-loamy, mixed, isohyperthermic Aeric Paleaquults. - fine-loamy, mixed, non acid isohyperthermic Aeric Tropaquepts.
12 Maha Sarakham Land Development Center, Maha Sarakham province.	- loamy, siliceous, isohyperthermic Arenic Paleustalfs. - coarse-loamy, siliceous, isohyperthermic Oxic Paleustults.
13 Khon Kaen Land Development Center, Khon Kaen province.	- coarse-loamy, siliceous, isohyperthermic Oxic Paleustults 64.8%. - fine-loamy, siliceous, isohyperthermic Oxic Paleustults 28.0%. - loamy, siliceous, isohyperthermic Arenic Paleustalfs 7.2%.
14 Ubon Land Development Center, Ubon province.	- fine-loamy , siliceous, isohyperthermic Oxic Paleustults 30%. - coarse-loamy siliceous, isohyperthermic Oxic Paleustults 70%.
15 Northeastern Regional Office of Agriculture, Khon Kaen province.	- fine-loamy, siliceous, isohyperthermic Oxic Paleustults 75%. - loamy, siliceous, isohyperthermic Arenic Paleustalfs 20%.
16 Surin Rice Experiment Station, Surin province.	- fine-loamy, mixed, isohyperthermic Aeric Paleaquults 100%.

SOUTHERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1 Nhaichong Rubber Experiment Station, Krabi province.	- clayey, kaolinitic, isohyperthermic Rhodic Paleudults 100%.
2 Saui Horticulture Experiment Station, Chumphon province.	- coarse-loamy, siliceous, isohyperthermic Oxic Plinthaquults. - fine-loamy, mixed isohyperthermic Oxic Plinthaquults.
3 Klongtom Rubber Experiment Station, Krabi province.	- fine-loamy, mixed, isohyperthermic Typic Paleudults 100%.
4 Nakhon Si Thammarat Rice Experiment Station, Nakhon Si Thammarat province.	- no classification.

SOUTHEASTERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1 Priew Horticulture Experiment Station, Chantha Buri province.	- clayey-skeletal, kaolinitic, isohyperthermic Typic Paleudults. - loamy-skeletal, mixed, isohyperthermic Dystropeptic Orthoxic-Tropudult. - clayey, kaolinitic, isohyperthermic Typic paleudults.
2 Huai Pong Field Crop Experiment Station, Rayong province.	- isohyperthermic Typic Quartzipsamments. - clayey, mixed, isohyperthermic Oxic Paleudults.
3 Rayong, Land Development Center, Rayong province.	- clayey, kaolinitic, isohyperthermic Typic Paleudults. - isohyperthermic Typic Quartzipsamments.
4 Nakhon Nayok Land Development Center, Nakhon Nayok province.	- very fine, mixed, acid isohyperthermic Sulfic Tropaquepts.

Table 2: *Soils in some of the experiment centres/stations of the Department of Land Development (DLD)*

CENTRAL REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1. Pathum Thani Land Development Center, Pathum Thani province.	- very fine, mixed, acid isohyperthermic Sulfic Tropaquepts 200%.

SOUTHERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1. Phikulthong Education and Development Center, Narathiwat province.	- Tropofibrists. - fine-clayey, mixed sulfic Tropaquepts. - fine-clayey, mixed Typic Fluvaguents. - fine-loamy, mixed Typic Paleaquults. - coarse-loamy, siliceous, Typic Paleaquults.
2. Yala Land Development Center, Yala province.	- Low Humic Gray. - Red Brown Lateritic. - Gray Podzolic.
3. Ranong Land Development Center, Ranong province.	- Red Yellow Podzolic. - Gray Podozolic. - fine-loamy, mixed Typic Paleudults.

SOUTHEASTERN REGION

Name of Centers/Stations	SOIL CLASSIFICATION
1. Chon Buri Land Development Center, Chon Buri province.	- coarse-loamy, siliceous Typic Paleudults. - Red Yellow Podzolics. - Typic Quartzipsamments.

Southeastern region (cont.)

2. Rayong Land Development Center, Rayong province.	- isohypertheric Typic Quartzipsamments. - loamy-skeletal, mixed, Oxic Paleustults. - fine-loamy, mixed, Oxic Paleustalfs. - clayey-skeletal, mixed, Oxic Paleustults. - clayey, kaolinitic, isohyperthermic Typic Paleudults.
3. Khao Hin Son Education and Development Center, Chachoengsao province.	- loamy, siliceous Grossarenic Paleustults. - siliceous, Typic Ustipsamments. - fine-loamy, mixed, Oxic Paleustults. - coarse-loamy, mixed, Oxic Paleustults. - fine-loamy, mixed, non-acid Aeric Tropaquepts.
4. Nakorn Phathom Land Development Center, Nakorn Phathom province.	- fine silty, mixed, Udic Haplustalfs. - fine-clayey, mixed, Aeric Tropaqualfs. - very fine-clayey, mixed, non-acid Vertic Tropaquepts.
5. Nakorn Nayok Land Development Center. Nakorn Nayok province.	- very fine, mixed, acid, isohyperthermic Sulfic Tropaquepts.

NORTHEASTERN REGION

Name of Centers/Stations	SOIL CLASSIFICATION
1 Kalasin Land Development Center, Kalasin province.	- fine-loamy, siliceous, Oxic Paleustults. - fine-loamy, mixed, Aeric Paleaquults. - Ustoxic Quartzipsamments. - fine-loamy, siliceous, Oxic Paleudults. - fine-loamy, mixed, non-acid, Aeric Tropaquepts.
2 Khon Kaen Land Development Department, Khon Kaen province.	- loamy, siliceous, Oxic Paleustults. - loamy, siliceous Oxic Paleustults. - Ustoxic Quartzipsamments.
3 Thung Kula Ronghai Land Development Center, Roi Et province.	- very fine-clayey, mixed, non-acid Vertic Tropaquepts. - fine-loamy, mixed, Aeric Paleaquults. - fine-laomy, mixed, Typic Natraqualfs. - Aquic Quartzipsamments. - fine-loamy, siliceous, Oxic Paleustults.
4 Udorn Thani Land Development Center, Udorn Thani province.	- fine-loamy, siliceous Oxic Paleustults. - Ustoxic Quartzipsamments. - clayey-skeletal, mixed, Typic Plinthustults. - loamy-skeletal, mixed, Petroferric Haplustults.
5 Khon Kaen Land Development Center, Khon Kaen province.	- coarse-loamy, siliceous, isohyperthermic Oxic Paleustults 64.8%. - fine-laomy, siliceous, isohyperthermic Oxic Paleustults 28.0%. - loamy, siliceous, isohyperthermic Arenic Paleustalfs 7.2%.

Northeastern region (cont.)

6 Ubon Land Development Center, Ubon province.	- fine-laomy, siliceous isohyperthermic Oxic Paleustults 30%. - coarse-loamy, siliceous, isohyperthermic Oxic Paleustults 70%.
7 Maha Sarakham Land Development Maha Sarakham province.	- loamy, siliceous, isohyperthermic Arenic Paleustalfs. - coarse-loamy, siliceous, isohyperthermic Oxic Paleustults.

NORTHERN REGION

Name of Centres/Stations	SOIL CLASSIFICATION
1. Chiang Mai Land Development Center, Chiang Mai province.	- fine-loamy, mixed Aeric Plinthic Paleaquults. - fine-loamy, siliceous Oxic Paleustults. - clayey, mixed, Oxic Paleustults. - loamy-skeletal, mixed, Oxic Paleustults.
2. Nan Land Development Center, Nan province.	- loamy-skeletal, mixed, Oxic Paleustults. - fine-loamy, siliceous Oxic Paleustults. - coarse-loamy, mixed, Oxic Paleustults.
3. Chiangrai Land Development Center, Chiangrai province.	- clayey, kaolinitic Plinthic Paleustults. - (Mc) - (Nm)
4. Phetchaboon Land Development Center, Phetchaboon province.	- very fine-clayey, montmorillonitic Typic Chromusterts. - (Pe) - loamy-skeletal, mixed Oxic Paleustults.
5. Tak Land Development Center, Tak province.	- U.S. classification.
6. Lampang Land Development Center, Hang Chat, Lampang province.	- fine-loamy, siliceous isohyperthermic - fine-loamy, mixed isohyperthermic Typic Haplustults. - loamy, mixed, non-acid Typic Ustifluvents. - fine-silty, mixed, Typic Tropaqualfs. - fine-loamy, mixed, Aeric Plinthic Paleaquults.

SITE SELECTION FOR AGRONOMIC EXPERIMENTATION: MALAYSIAN EXPERIENCE

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ABSTRACT

The paper considers the factors that affect the variability of soil in a given field. Lithological and pedological factors are identified as the major causes of inherent variation. Such variations can often be large and induce a significant differential effect, even on the growth of tree crops. Biogenetic variability due to vegetation and faunal activity is also encountered. However, the presence of the latter is often confined to only a few soils. The largest variability of chemical properties is induced by management practices, such as burning residues and fertilizer use, especially in tree-crop areas. Such large variability entails more intensive sampling.

The adverse influence of such variations on the differential effects of treatments can be minimized by proper planning and layout. This initially entails the detailed study and mapping of the experiment site. Subsequent blocking of treatments and layout in the field should consider the soil variations observed.

INTRODUCTION

Location and Climate

Peninsular Malaysia stretches about 725 km from north to south and 325 km from east to west (at its widest), and lies within 1° to 7°N latitude and 100° to 104° longitude. Physiographically, the peninsula consists of a central mountain range (1000 to 2500 m altitude) flanked on both sides by rolling and undulating hills (100 to 800 m elevation), adjoining terraces (of 20 to 100 m elevation), and coastal plains.

Peninsular Malaysia has an "Afi" type of climate according to Koppen's classification. This is a tropical wet climate with minimum temperature variations of below 5°C between the warmest and coldest months. The mean annual temperature is 24° ± 1.7°C; the mean annual rainfall is 2000 mm, and the mean relative humidity is over 80%.

Three major agroecological zones, differentiated on the basis of rainfall distribution, are recognized in peninsular Malaysia. These are:

- the northern region, characterized by a clear and regular dry season and where the soil moisture control exhibits ustic tendencies;

- the central region, characterized by a short but fairly regular dry season and a udic moisture regime; and

- the southern region, characterized by the absence of a regular dry season, and in some parts by a soil moisture regime which is close to perudic.

Most of the soils in the country (except those on the terraces and coastal plains) are Ultisols and Oxisols. Most of these areas have already been mapped at a reconnaissance level, while a substantial portion of the soils under cultivation have been mapped at a semi-detailed level.

Crops

Currently, most of these soils are planted with perennial plantation crops, such as rubber, oil palm, and cocoa. Crops such as maize, groundnuts, vegetables and fruits are also cultivated, but only to a fairly limited extent.

The major crops in Malaysia are rubber and oil palm. While oil palm is cultivated mainly by large plantations and organized schemes, rubber is mainly cultivated by small farmers. These small farms, of less than 4 ha each, account for about 60% of the total area of 2 million ha under rubber.

The rubber is generally planted in avenues which are about 7 to 9 m apart. The spacing between avenues varies with the terrain and the distance between trees in each row, which varies from 2 to 3.5 m. At the time of replanting or new planting, some of the small farmers use the interrow area (the space between two avenues or rows of trees) to cultivate cash crops, such as groundnuts, maize, chillies, banana, etc. When annual crops are used, two crops per year can generally be obtained. Such cropping can continue only for a period of two to two-and-a-half years before the shade from the closure of the canopy of growing trees makes such intercropping impossible. Where intercropping is not carried out, creeping legume covers are often established.

The cultivation of annual crops, such as groundnuts, maize, etc., is generally not done on a continuous basis on a given piece of land. In addition to their cultivation as intercrops, these crops are cultivated as off-season crops in rice cultivation, etc. Arable annual crops do not play a major role in the agriculture of Malaysia. However, with the decline in price of the major agricultural commodities, such as oil palm and rubber, and with the possible existence of an oversupply syndrome, there is a growing interest in diversification to such food crops, at least for import substitution. Hence there is a growing need to look into ways of improving the cultivation and management of annual crops on the acid soils in Malaysia, and to make the necessary agronomic trials. This paper considers the problems of selection of sites for such agronomic trials.

SOIL MICROVARIABILITY

Soil microvariability can be a source of difficulty when setting up field experiment trials. Chan *et al.* (1974) demonstrated that variations in soil texture, soil depth, soil drainage and soil slope can influence the girthing of a perennial tree crop like rubber by 2 to 15%, and its yield performance by 3 to 24%. The effect of soil microvariability on the growth and performance of upland food crops is also pronounced, leading to uneven stands of crops over short distances, and this is particularly marked under prevailing conditions which are characterized by a low level of management in several parts of the tropics (Moorman and Kang, 1978).

Soil Physico-Chemical Properties

Most tropical soils are dominated by low-activity clays, mainly kaolinite and sesquioxides having a low cation exchange capacity. In these soils, plant nutrients are easily leached. Nutrients may not be readily available to plants, as in the case of phosphorus in most Oxisols and in those Alfisols and Ultisols with a high content of reactive iron and aluminium oxides. Organic matter content in the surface soil plays a major role in regulating plant nutrient levels in these soils, and variation in organic matter content within short distances could have a pronounced effect on the crop. Additionally, the water-holding capacity of many soils in Malaysia also varies markedly (Soong, 1977). Considering the dominant physical and chemical properties of soils of the humid tropics with low-activity clays, it can be understood why slight changes in these properties are strongly reflected in the growth of most annual crops. Furthermore, small changes in the thickness of the surface soil may lead, under certain rainfall distribution patterns, to a very uneven growth of annual crops or creeping legume covers (Figures 1 and 2).

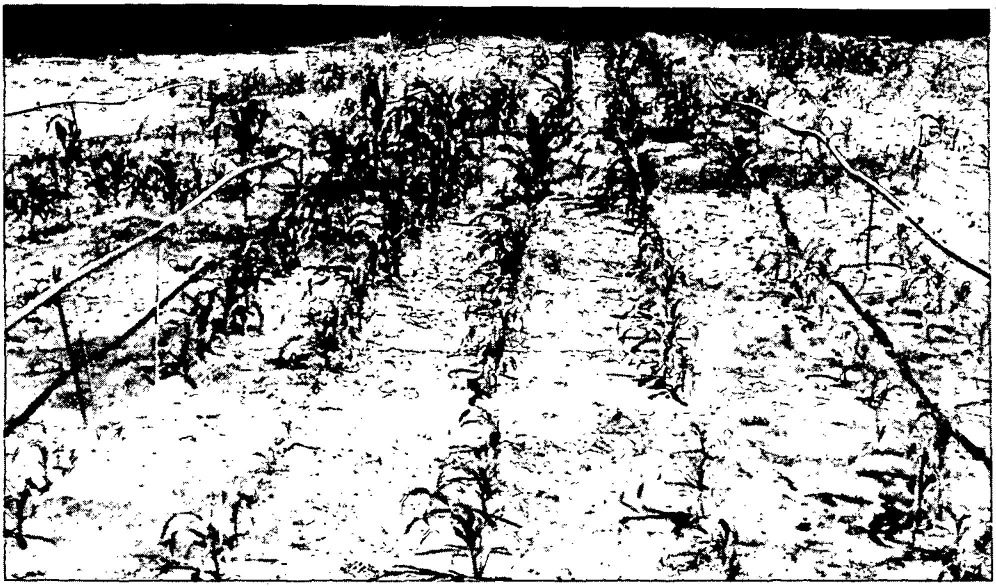


Figure 1. The differences in the heights of the maize plants show difference in growth due to soil variation. This slide was taken in the experiment plot in Sungei Buloh.

Figure 2. Variation in growth of groundnut plants in Holyrood series soil in an experiment plot in Kuang, Sungei Buloh.

Lithological and Pedological Variability

Parent materials of soil may vary over short distances. The influence of variable contents of coarse fragments in the subsurface horizons on crop performance may therefore be considerable. Localized outcrops of bedrock also contribute to microvariability. Major lithological variations and geochemical gradients at short distances also appear important in older transported materials and sedimentary rock formations (Beckett and Webster, 1971). Lithological variability of the surface soil can be induced or reinforced by soil losses due to surface wash, soil creep or gullying, and local deposition of erosion products, resulting in short-range alterations of soil material and hence an increased soil variability.

The combined effects of both lithological and pedological influence on soil microvariability over short distances in a spatial distribution of a landscape in Malaysia have been documented (Noordin, 1980; Song, 1981; Zainol, 1984; and Chan, 1985). Many cases of detailed soil mapping carried out at scales of Rf. 1:6336 or 1:3168 (1 inch to 4 chains) have revealed the geographical occurrence of small parcels of variable soil units over small areas. Figure 3 illustrates this point adequately. It shows two fields found in the Rubber Research Institute of Malaysia's experiment station in Sungei Buloh. From north to south, stretching for about 800 m over an area of 21.1 ha, 11 distinct different soil units were mapped. The soil units encountered represented contrasting sources of parental origin: from granites (Rengam series) through sedimentary rocks (Munchong and Bungor series), subrecent alluviums (Sogomana series), recent alluviums (soil complexes) to organic deposits (Subang series). Some of these soil units occurred in scattered small parcels of 0.1 to 0.4 ha, interspersed between the larger Rengam series soil units, within which microvariations in soil textures in surface and subsurface horizons were clearly detectable. In a more recent site-specificity study carried out by Chan (1985), six contrasting soil units were encountered, with five other distinguishable soil units differentiated by microvariations of soil depth and soil slope over a small area of 31 ha (Figure 4). The small sizes of these units (averaging 1 to 2 ha) were clearly identifiable during mapping. At the same time, it is possible to obtain areas with one soil series but with different phases occurring within a small area (Figure 5). The inclusions of colluvial deposits is to be expected.

The effects of such a mosaic distribution of soil units scattered over a small area on crop growth can be marked. This has been demonstrated for microvariations of soil texture, and soil depth (Chan *et al.*, 1974) for a given soil area (Table 1).

From such studies as described above, it is clear that microvariations over short distances are likely to occur in most landscapes. These microvariations can influence performance of even a perennial tree crop like rubber.

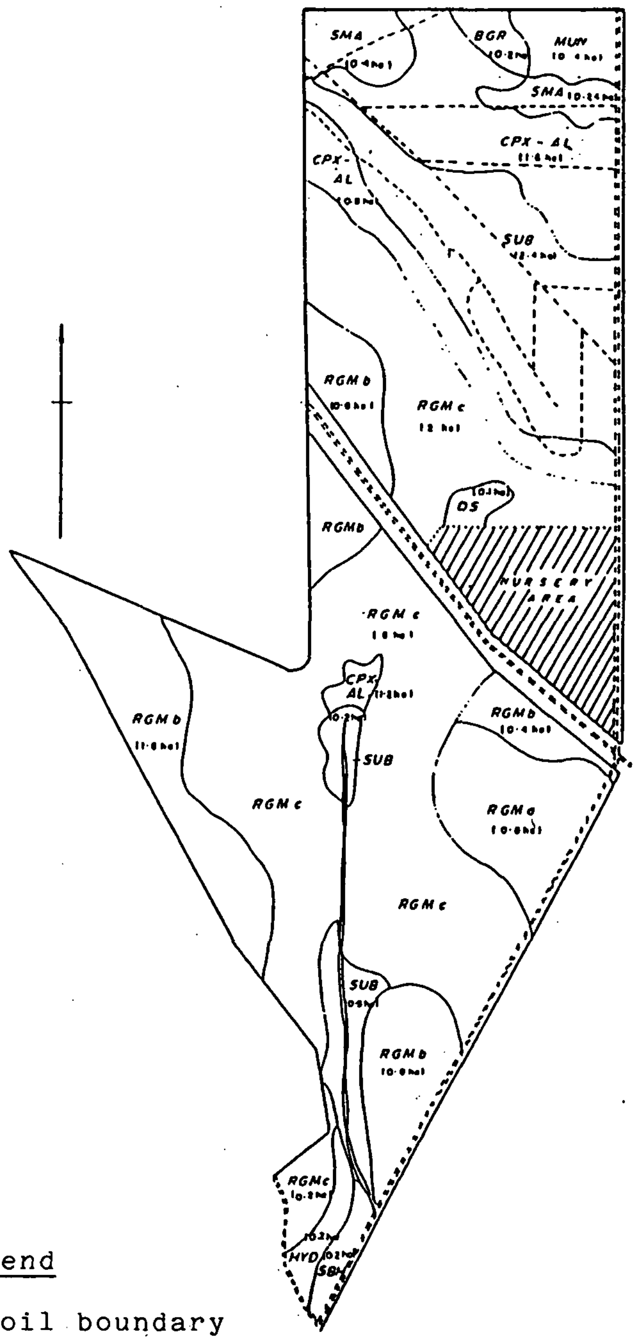
These findings add weight to the concept that lithological and pedological factors are probably the major sources of soil microvariation over short distances in a landscape, and that because of such phenomena it is difficult to obtain small homogeneous soil areas for ideal field experimentation.

Biogenetic Variability Due to Faunal Activity

The build-up of mounds by termites has a significant effect on soil microvariability (Lee and Wood, 1971). These differences are reflected in the variable growth performance of the crops. The physical soil properties, such as structure, bulk density and water-holding capacity, are different in soils from mounds as compared to surrounding surface soils. Chemical differences, such as organic matter, pH, extractable cations, P, K, Ca, and Mg, are also different (Norhayati *et al.*, 1986).

Biogenetic Variability Due to Vegetation

The effect of the type of trees prior to clearing or covers in freshly cleared land constitutes another important source of microvariability. Under legume covers, the organic matter and N content are significantly higher than in the soils of the surrounding areas. Pushparajah (1984) has shown that the type of covers present could have long-term effects on the soil.



Graphic legend

________	Soil boundary
========	Road
--------	Field drains with intermediate drains

Scale = 1:3168

Figure 3. Detailed soil map of R.R.I.E.S., Sungei Buloh Fields: SHND (ii) and 48 E.

Soil legend

BGR	Bungor - coarse sandy clay loam, 3-8% slope; subsoil coarse sandy clay loam to coarse sandy clay, >40" deep; well drained; slightly eroded.
HYD	Holyrood - coarse sandy loam, 3-8% slope; sub soil coarse sandy loam; >40" deep, somewhat excessively drained; slightly eroded.
MUN	Munchong - clay, 3-8% slope; subsoil clay, >40" deep, well drained; slightly eroded.
RGMa	Rengam - coarse sandy clay, 3-8% slope, sub soil coarse sandy clay, 20-40" deep, well drained, slightly eroded.
RGMb	Rengam - coarse sandy clay loam to coarse sandy clay 3-8% slope; subsoil coarse sandy clay, >40" deep; well drained; slight eroded.
RGMc	Rengam - coarse sandy clay loam, 3-8% slope; subsoil coarse sandy clay loam; >40" deep; well drained; slightly eroded.
SBH	Sungei Buloh - loamy coarse sand, 3-8% slope; subsoil loamy coarse sand, 20-40" deekp, excessively drained; slightly eroded.
SMA	Sogomona - clay loam, 0-3% slope, subsoil clay loam to silty clay; 0-20" deep; somewhat poorly drained.
SUB	Subang - organic clay, 0-3% slope, subsoil organic clay; 0-20" deep; somewhat poorly drained; slightly eroded.
CPX-AL	Complex alluvium - surface soil organic coarse sandy loam, coarse sandy clay loam, underlain by interbedded coarse sandy loam, gravelly sand and silty clay.
DS	Disturbed soil area.

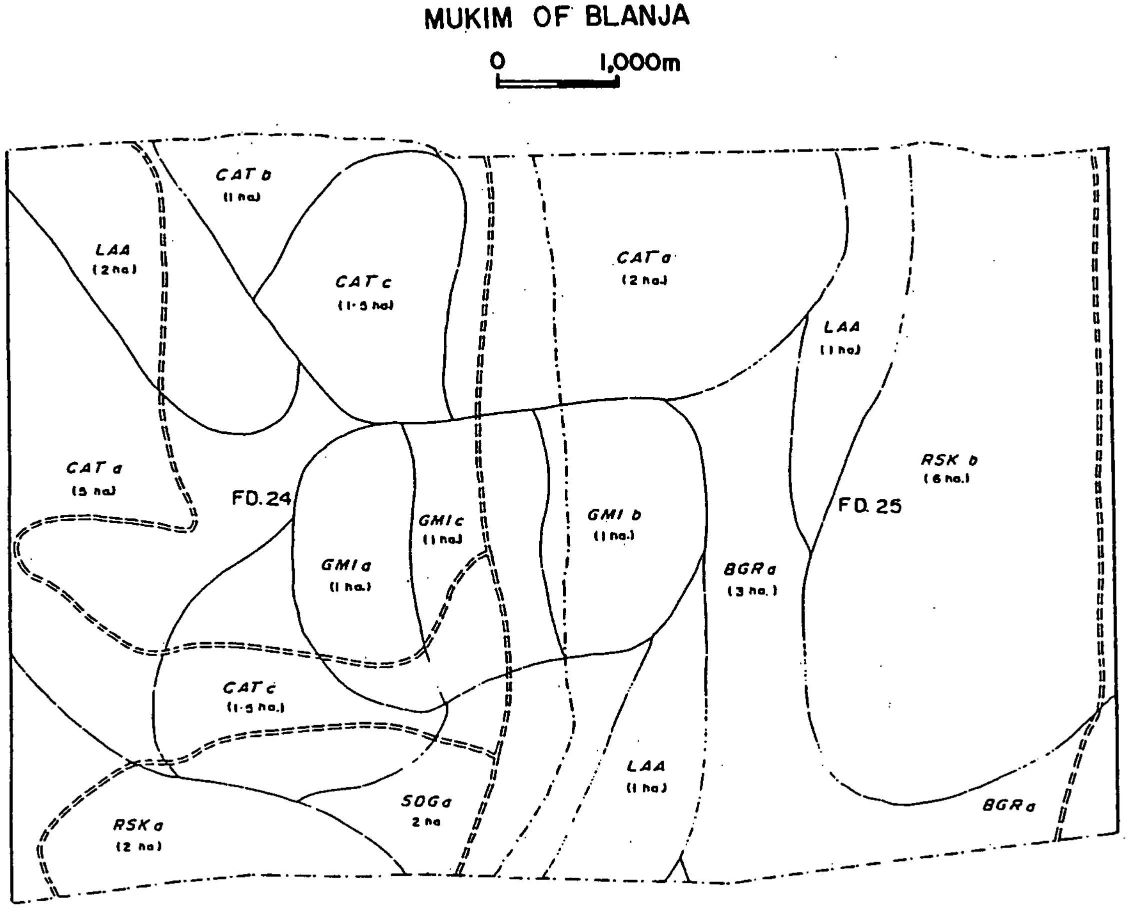


Figure 4. Detailed soil map of Serapoh Estate Fields: 24 and 25.

Soil legend

BGRa	Bungor series; sandy loam topsoil, sandy clay loam to sandy clay subsoil, >100 cm deep, 30-65% slope, well drained, moderately eroded.
CATa	Chat series, clay topsoil, clay subsoil, >100 cm deep, 16-30% slope, moderately well drained, slightly eroded.
CATb	Chat series, clay topsoil, clay subsoil, >100 cm deep, 30-65% slope, moderately well drained, slightly eroded.
CATc	Chat series, clay topsoil, clay subsoil, 0-50 cm deep, laterized shale met within 50 cm, 3-8% slope, moderately well drained, slightly eroded.
GMla	Gajah Mati series, clay topsoil, clay subsoil, >100 cm deep, laterites met within 50 cm, 3-8% slope, moderately well drained, slightly eroded.
GMlb	Gajah Mati series, clay topsoil, clay subsoil, >100 cm deep, laterites met within 50 cm, 7-16% slope, moderately well drained, slightly eroded.
GMlc	Gajah Mati series, clay topsoil, clay subsoil, >100 cm deep, laterites met within 50 cm, 16-30% slope, moderately well drained, moderately eroded.
RSKa	Rasak series, sandy clay loam topsoil, sandy clay to clay subsoil, >100 cm deep, 16-30% slope, well drained, moderately eroded.
RSKb	Rasak series, sandy clay loam topsoil, sandy clay to clay subsoil, >100 cm deep, 30-65% slope well drained, moderately eroded.
SDG(a)	Serdang series, sandy loam topsoil, sandy clay to clay subsoil, >100 cm deep, 30-65% slope. Somewhat excessively drained, moderately eroded.

cal alluvium.

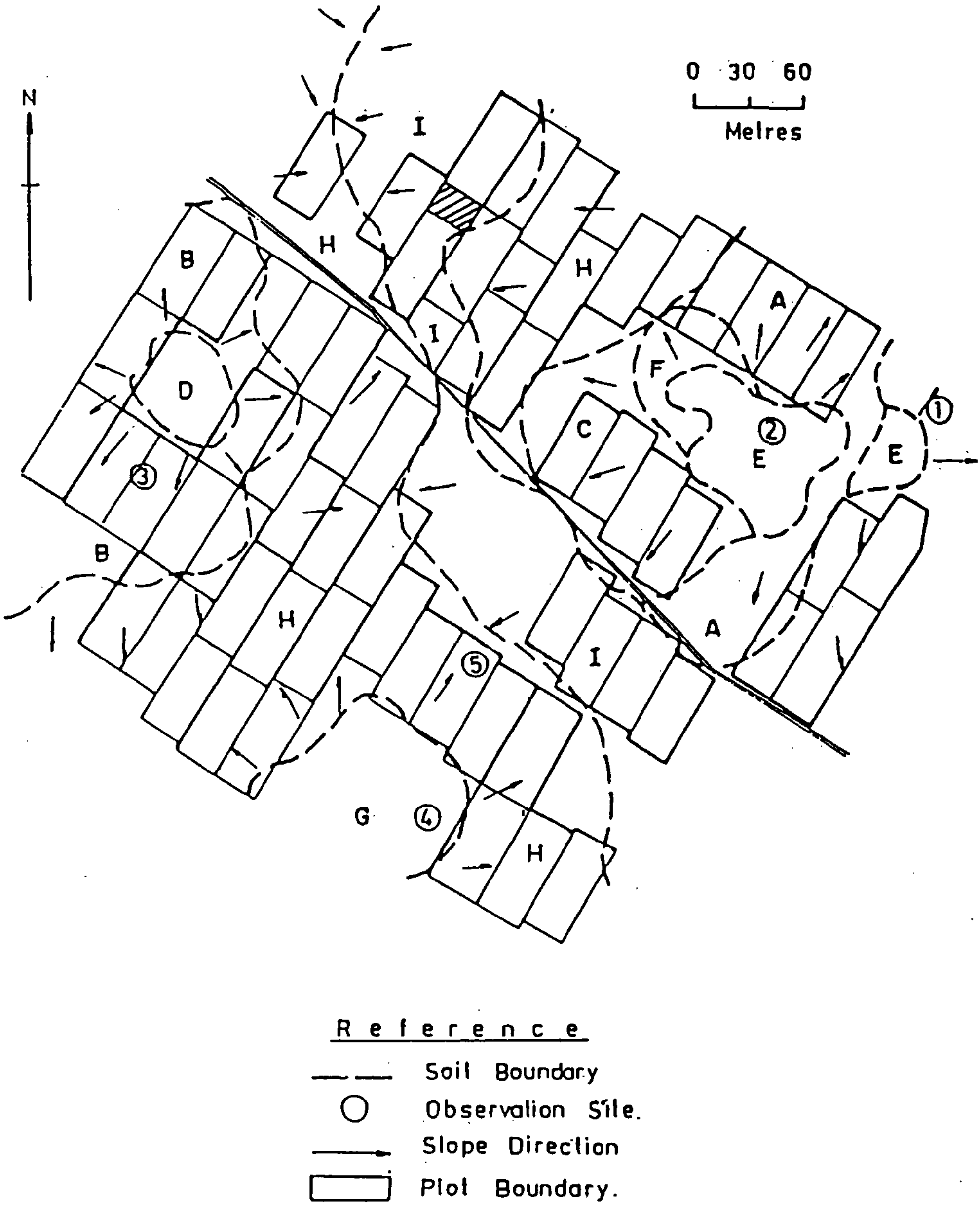


Figure 5. Soil variability in an experimental site on a field of 10 ha (Durian series - Typic Plinthudult Ultisol.

Soil legend

A Durian clay loam
1-3° slope; subsoil clay; 100-125 cm deep; moderately well drained.

B Durian clay loam
3-5° slope; subsoil clay; 100-125 cm deep; moderately well drained.

C Durian clay loam
3-5° slope; subsoil clay; moderately well drained; medium laterite phase 50-125 cm.

D Durian clay loam
5-8° slope; subsoil clay; moderately well drained; medium laterite phase 50-125 cm.

E Durian clay loam
8-12° slope; subsoil clay; moderately well drained; high laterite phase 0-50 cm.

F Durian fine sandy clay loam
1-3° slope; subsoil clay; moderately well drained; high laterite phase 0-50 cm.

G Durian fine sandy clay loam
5-8° slope; subsoil fine sandy clay; 25-50 cm deep; moderately well drained.

H Colluvium of Durian fine sandy loam
1-3° slope; subsoil fine sandy clay loam; 100-125 cm deep; well drained.

I Colluvium of Durian fine sandy loam
1-3° slope; subsoil fine sandy clay loam; 100-125 cm deep; moderately well drained.

Table 1. Effect of morphology and physiography of soil on growth and yield of *Hevea* (Chan *et al.*,1974). 1974).

Hevea Clone	& age	Soil series	Slope %	Drainage	Depth (cm)	Texture Topsoil	Subsoil	Performance of rubber (as %) Girth	Yield
				Soil texture					
PB 5/51	8 yrs	Rasau	0-1	Well drained	125	sandy clay loam	sandy clay	100	100
			0-1	Well drained	125	sandy clay	clay	103	118
				Depth of soil					
PB 5/51	13 yrs	Malacca	8-12	Well drained	0-25	clay	clay	100	100
			8-12	Well drained	25-50	clay	clay	104	124
				Slope					
BP 5/51	1 yr	Malacca	3-5	Well drained	0-25	clay	clay	100	100
			5-8	Well drained	0-25	clay	clay	101	106
			12-26	Well drained	0-25	clay	clay	103	113

Variability Due to Man's Activities

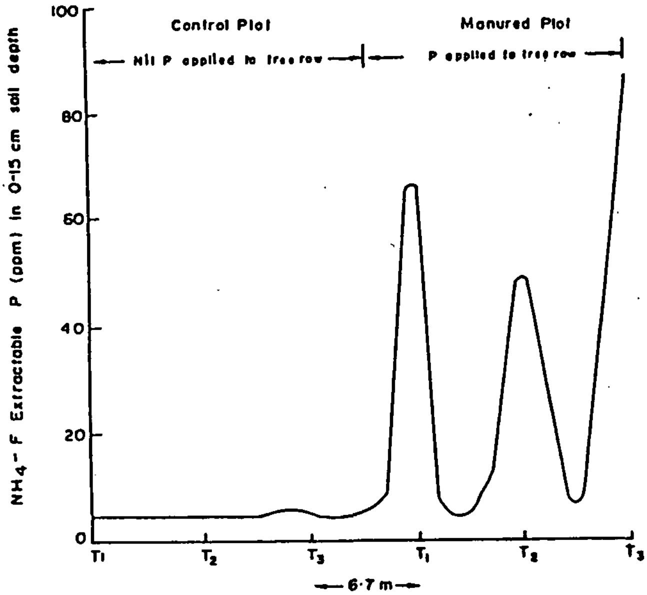
Under shifting cultivation or mechanical clearing for planting or replanting, trees and branches are assembled in one or several spots in the field and burned. Such spots show a better crop growth due to local concentrations of plant nutrients, P, Ca, Mg, K and even N under conditions of "slow burning" (Sanchez, 1976).

With time, the variable growth of crops will diminish under continuous cultivation as regards most chemical soil parameters. Heterogeneity in physical soil parameters is, however, more persistent.

Variability of Chemical Properties of Soil

Chang *et al.* (1977) showed that the Rengam series, a Typic Paleudult derived from granite, was less variable than the Munchong series, a Tropeptic Haplorthox. However, when the land was cultivated with perennial tree crops, e.g. rubber, the fertilizer practice led to even greater variability within a given field. This was because, though the trees are planted in avenues of about 6 to 7 m apart, the fertilizers are often applied broadcast on a strip of about 1 m along the tree rows. Thus, with time, chemical changes were evident (Figure 6). Though the figure shows changes in phosphorus levels horizontally across the field (with peaks along the tree rows), such changes on chemical parameters (e.g. pH, Ca [ppm], etc.) and on some physical parameters have also been reported (Pushparajah *et al.*, 1976).

A study of the pH of soils in a given phase of soil on a Durian series soil (a Typic Plinthudult, an Ultisol) showed that even when plot sizes of 0.16 ha in the interrows were considered, the pH varied from 4.3 to 5.2 (Figure 7): there was no consistent pattern. When pH variations in smaller plots of 4 x 40 m were considered on an Oxisol (Figure 8), the variation in pH ranged from 4.45 to 6.5. Such large variations can affect the interpretation of the final results obtained.



Key: T1, T2, T3 = tree rows and distance T1 to T2 etc. is on scale 1 cm = 3.35 m.

Figure 6. Influence of fertilizer on soil nutrient status.

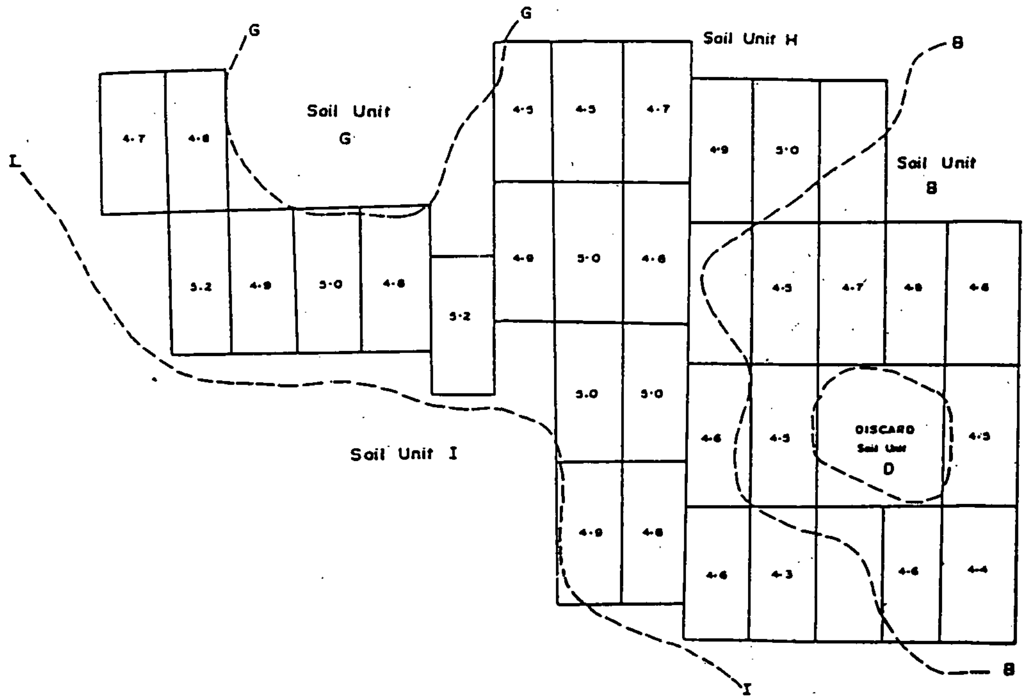


Figure 7. Variation in pH in experiment plots of 0.16 ha each.

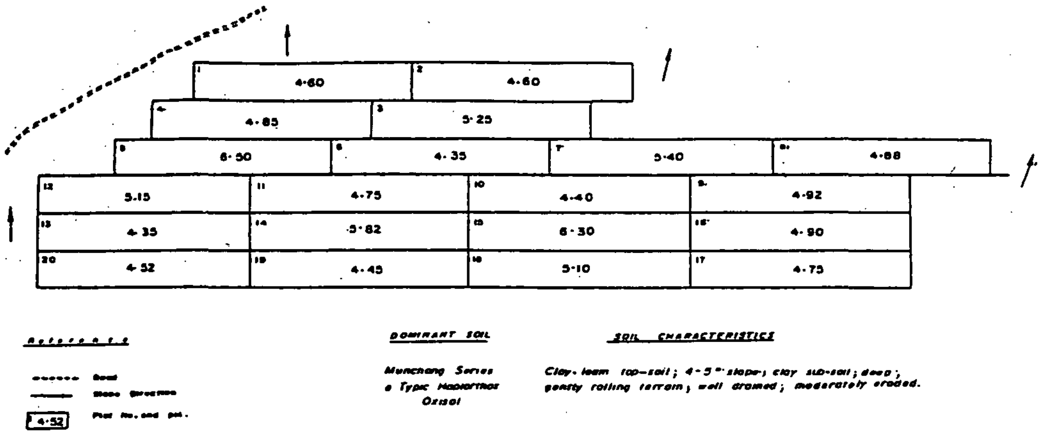


Figure 8. Variation of pH in an experiment field on an Oxisol (on plot sizes of 6-40 m).

Sampling for Analysis

Watson *et al.* (1964) showed that for experiments on plot sizes of 0.004 ha on a Rengam series (an Ultisol) with nutrient levels indicated in Table 2, ten sampling points were sufficient to determine treatment mean values of %C, and %N and NH_4-N (ppm), with an accuracy of 20% of the treatment means. For NO_3-N and available P, about 20-30 points were needed to determine the mean contents to an accuracy of 30% of the treatment means. There were no significant differences between bulked and unbulked samples; this being the case, only one bulked sample per plot is required for analysis. This emphasizes the need for considering proper sampling intensity both for pre-treatment and post-treatment samples.

Table 2. Mean standard deviation and coefficient of variations.*

Property	Mean	Range for 4 treatments	s.d.	C.V.(%)
%C	1.655	1.563-1.869	0.343	20.6
C%	0.124	0.118-0.132	0.023	18.6
NH_4-N (ppm)	8.35	5.00-11.63	1.62	19.4
NO_3-N (ppm)	3.48	0.72-9.01	2.35	67.5
Avail P O (ppm)	34.4	22.1-50.3	18.9	55.0

* Based on 4 treatments in triplicate, with 20 cores per sample.

PROPER SITE SELECTION

It is evident that soil microvariability exists over short distances in most landscapes. This microvariability has a significant effect on crop growth and performance. Consequently, it poses difficulties in the selection of ideal homogeneous areas for setting up field experimentation. However, this depends to a large extent on the size of the field area used. If the total experiment area is very small, viz. 1 ha or less, soil microvariability to pedogenetic properties may not be such a major problem as they could be if the experiment areas exceed 1 ha and reach sizes of 5-10 ha. However, chemical variations would be a main source of variation in smaller plots.

Experience has shown that it is essential to obtain a detailed map of the site. The layout of the trial should be such that the replicates, and/or even blocks within a replicate, are assigned to fit into minor soil variations. This would enable variations in soil to be accounted for as "block errors", thus minimizing interference with treatment effects. As indicated, the cultivation of arable grain crops, e.g. groundnuts and maize, is often carried out in the interrow and mainly in small farms. This being the case, trials will generally have to be laid down in the fields of such farmers. At the same time as the intercrop is being cultivated, rubber plants are established and maintained. The maintenance includes the use of fertilizers and weedicides. Care should be taken to prevent spray drift. The possibility of fertilizers (applied to the rubber) being washed to the intercrop and hence to treatment plots in the interrow should not be overlooked. Adequate measures to prevent such contamination need to be implemented.

As three major agroecological zones are present (based on rainfall distribution), these three regions have to be considered in site selection. The importance of appropriate sampling (including intensity and sample size) cannot be overemphasized.

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Third Session: Site characterization

Chairmen: A.J. Smyth
Vo Tong Xuan

SOIL VERTICAL AND LATERAL DIFFERENTIATION

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ABSTRACT

Three scales of organization - the basic assemblage, the horizons, and the soil mantle - are taken as a starting point for the study of vertical and lateral differentiation. The morphological characters, or basic combinations, are mainly colour, aggregates, porosity, and concentration features. They have a significance not only in terms of pedogenesis, but also in terms of soil management. They may vary according to seasons or as a continuous trend on a longer-term evolution, and are specially organized in horizons and in catenas. The limits between soil features and horizons are important both vertically and laterally. Catenas can be lithosequences, toposequences or chronosequences. An understanding of these organizations and of their dynamics is very important in choosing the site for an experiment station.

INTRODUCTION:

MORPHOLOGICAL ORGANIZATION OF THE SOIL

Soil, as is the case with all natural bodies, is an organized, structured entity - that is, the organic and mineral constituents of the soil are arranged with specific relationships between them.

The morphological organization of the soil exists at all scales of observation:

- from the basic assemblage of the particles, that we can observe with the microscope,
- up to the arrangement of the pedological systems at a regional scale.

In fact, when we want to know how to use soils, it is important to study and interpret three scales of organization:

1. The scale of the basic combinations of the constituents. These basic combinations are expressed in terms of:
   - colour
   - aggregates
   - porosities
   - nodular and linear concentrations.
2. The scale of the horizons:
   - each horizon is characterized by one or several types of basic assemblages.
3. The scale of the pedological mantle:
   - this is made up of the vertical superposition and the lateral succession of several horizons.

The morphological organization of the soil is equivalent to the anatomy of a plant or of an animal. This morphological organization is, at one and the same time, the result and the driving force of the dynamics of the soil. Hence we know that the morphological organization of the soil is:

- the evidence of the past history of the soil, and also
- the expression of the actual dynamics (mainly the hydric and the biological dynamics) of the soil.

This means that when we want to evaluate, to understand, and to use the fertility of a soil, we have to study in detail the morphological organization of the soil - at the different scales of its organization.

THE MAIN MORPHOLOGICAL CHARACTERS

The description and the interpretation of the vertical and lateral variations of soils can be made by studying four groups of morphological characters:

- the colours;
- the aggregates;
- the porosities;
- the concentration features.

A detailed study of these morphological characters enables us to make certain deductions with regard to the morphological composition, dynamics and fertility of a soil, and these are briefly reviewed below.

1. The colours can be interpreted in terms of:

* the presence of determined constituents:
  - organic matter
  - iron
  - carbonates

* the state of some constituents:
  - reduced iron
  - goethite
  - hematite

* the dynamic processes:
  - biological activities
  - hydric evolution
  - migration of clay
  - carbonation
  - salinization

By studying these different aspects of the soil, we can deduce some information about several chemical and physical features: the absorption complex, the pH, the texture, and so on.

2. The presence and the morphology of the aggregates (rounded, angular, laminar), and the dimension and stability of these aggregates, can be interpreted in terms of:

   * texture
   * clay mineralogy and dynamic (swelling)
   * presence of organic matter
   * absorption complex and pH
   * biological activity
   * hydric dynamic

   So the aggregation gives good indications about:

   * chemical fertility
   * accessibility of this fertility to the roots

3. To be well understood and well interpreted, the porosity has to be:

   * first: described in terms of the morphology and origins of the soil:

     - alteration
     - particle assemblages
     - biological activities
     - fissuration
     - assemblage of rounded aggregates

   * second: • measured in terms of:

     - total porosity
     - porosity of the aggregates
     - porosity of the micro-aggregates: textural porosity
     - structural porosity, i.e. the porosity between the aggregates

In terms of fertility, it is most important not only to have data about the macro- and microporosity that influence the dynamic of the water, but also to have detailed observations about the space and time variations of the porosity: abrupt variations of the porosity are never good for the fertility.

4. The concentration features are organizations which result from mechanisms involved in the transfer of the constituents in the soils:

   - cutans
   - nodules
   - sand capping
   - band
   - pedotubules

   In terms of fertility, these concentration figures give good indications regarding:

   - the mechanisms of leaching and of accumulation in the different horizons of the soil, and
   - the biological activity.

TIME AND SPACE VARIATIONS OF THE MORPHOLOGICAL CHARACTERS

Colours, aggregates, porosity and concentration figures are characters which express the basic assemblages of the soil, and which vary in relation to the time factor and in relation to the space factor.

A. In relation to the time factor, there are two types of variations:

   1. Seasonal variations: the morlphology of the soil varies at each moment in relation to the variations of humidity, temperature, and biological activities (vegetal and animal). These variations have a big influence on the physical and chemical fertility.

   2. Progressive modifications, year after year: this concerns the more or less rapid evolution of the pedological mantle. This

evolution can be greatly accelerated by the way in which the soil is used, notably with regard to:

- compaction
- disaggregation
- leaching of clay
- erosion

It is absolutely necessary, if we want to protect the fertility of the soils, to observe and to measure with precision the morphological evolution of the soils.

B. In relation to the space factor, it can be seen that the morphological characters of soils are organized in horizons, in which vertical superposition and lateral succession define the morphology of the pedological mantle.

At these smaller scales, the scale of the profile and the scale of the catena, it is very important to observe in detail where and how the morphological changes take place - that is, where and how the appearance, the disappearance, the aggregates, the porosities and the concentration figures occur (see Figure 1).

Each one of these vertical and lateral changes is meaningful in terms of physico-chemical properties and in terms of the dynamics (the water dynamic for example), as well as in terms of the potentiality and vulnerability of the soils. It is these morphological changes that we have to represent on detailed soil maps (see Figure 2).

CONCLUSION:

STUDY OF THE MORPHOLOGICAL LIMITS

It is important to emphasize the importance of studies which examine the limits that mark the vertical and the lateral variations of one or several morphological characters of the pedological mantle: it is as important to know about the limits as what exists between the limits.

We know that in terms of the lateral distribution of the soil characteristics we have three main types of catena or sequences:

1. <u>The lithosequences</u>: The lateral variations are concerned with the variations of the rocks. In these sequences:

   - the vertical differentiation limits are dynamic limits, i.e. they vary as a consequence of the evolution of the soil; but

   - the lateral differentiation limits are fixed: they correspond to the rock limits.

2. <u>The toposequences</u>: The lateral variations are determined by the topography. We know that in general in these types of sequence all the limits are dynamic, and it is very important to know how, and at what speed, the vertical and lateral differentiation limits evolve.

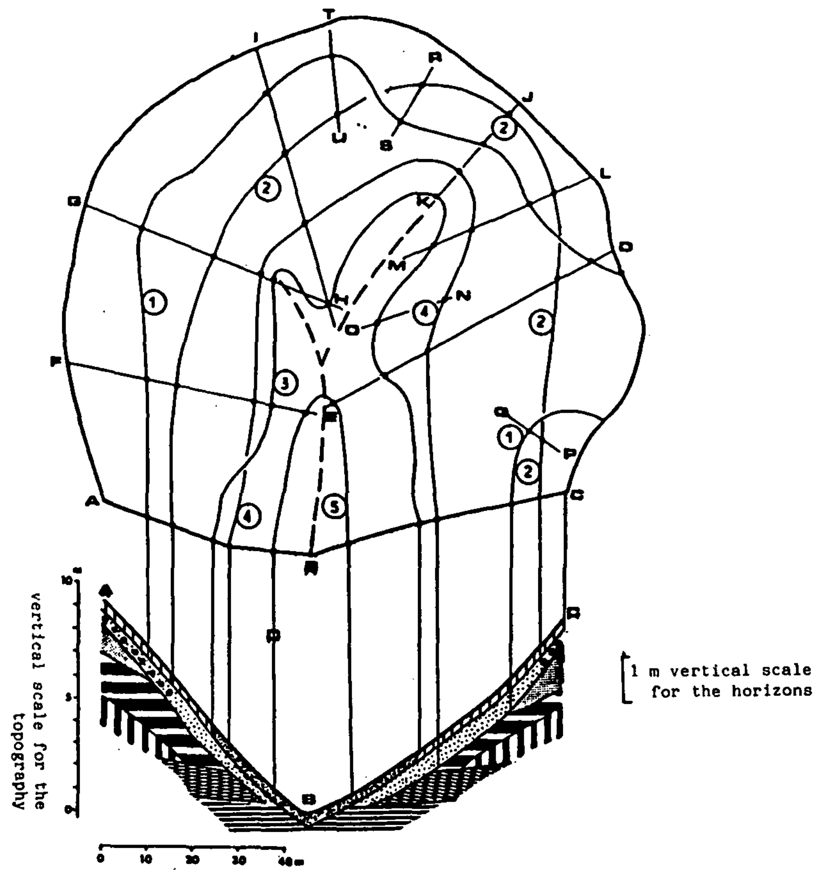
3. <u>The chronosequences</u>: The lateral variations are determined by the age of the soils, i.e. the age of the material on which the soil rests.

   - chronosequence along a slope, i.e. the evolution of carbonate accumulation as a factor of the age of the surfaces (see Figure 3), or

   - chronosequence of landscapes, i.e. the chronosequence of the transformation of an Oxisol to a Spodosol (see Figure 4).

It is, then, by studying and mapping the chronosequence that we can partially answer the question concerning how and at what speed the vertical and lateral differentiation limits evolve (see Figure 5).

Finally, it is in relation to all these morphological data - vertical, lateral, and dynamic morphological data - that we can situate, with considerable precision, an experiment station which aims to test the use of the pedological mantle in relation to the anatomy and physiology of the pedological mantle concerned (see Figure 6).

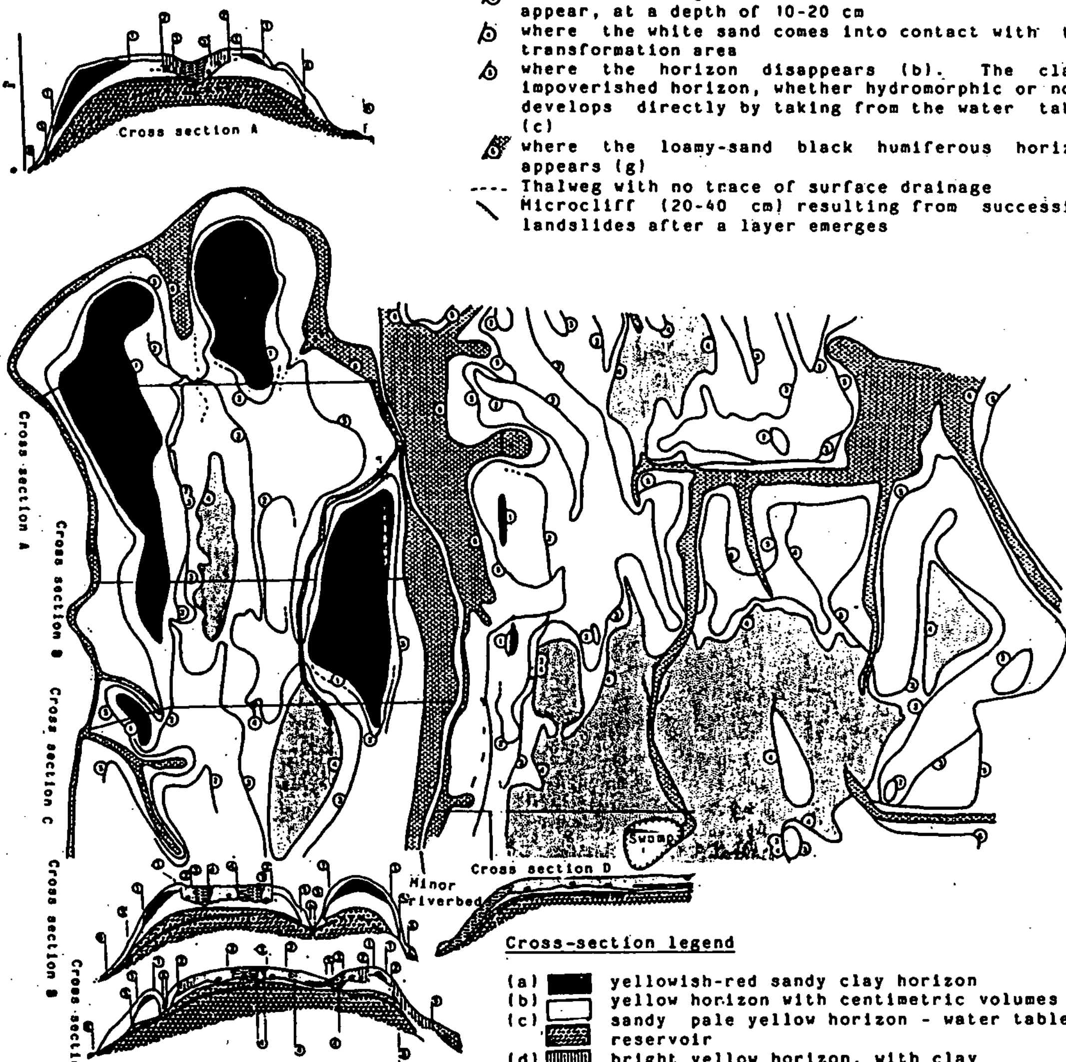


Isodifferentiation curves

Note: The characterization of each curve is drawn for an observer crossing the curve from the side where the number is placed:

(1) where the compact red horizon disappears (d)
(2) where the nodules disappear (c)
(3) where the hydromorphic characteristics of the humus horizon appear (g)
(4) where the purplish-red sericitous horizon disappears (e)
(5) where the white horizon reaches the base of the humus horizon
/ where the isodifferentiation curve has been located

Figure 1. Analytical phase: cross section and plan (after Boulet, Humbel and Lucas, 1982).



Plan legend. Characterization of isodifferentiation curves from the viewpoint of an observer crossing them from the side where the number is placed.

- where the yellowish-red horizon disappears (a)
- where a transformation area appears between (d) and (b)
- where the beige and white millimetric islands appear, at a depth of 10-20 cm
- where the white sand comes into contact with the transformation area
- where the horizon disappears (b). The clay-impoverished horizon, whether hydromorphic or not, develops directly by taking from the water table (c)
- where the loamy-sand black humiferous horizon appears (g)
- ---- Thalweg with no trace of surface drainage
- Microcliff (20-40 cm) resulting from successive landslides after a layer emerges

Cross-section legend

(a) yellowish-red sandy clay horizon
(b) yellow horizon with centimetric volumes of red
(c) sandy pale yellow horizon - water table reservoir
(d) bright yellow horizon, with clay impoverishment increasing as curve 3 is approached
(e) pale yellow horizon changing to beige in a lateral direction, impoverished clay, with hydromorphic features increasing as curve 4 is approached
(f) white sandy horizon
(g) black sandy loam horizon
pedorelic
roof of the layer { observed / interpolated }

Figure 2. Diagram of the cross sections and prelittoral bars.

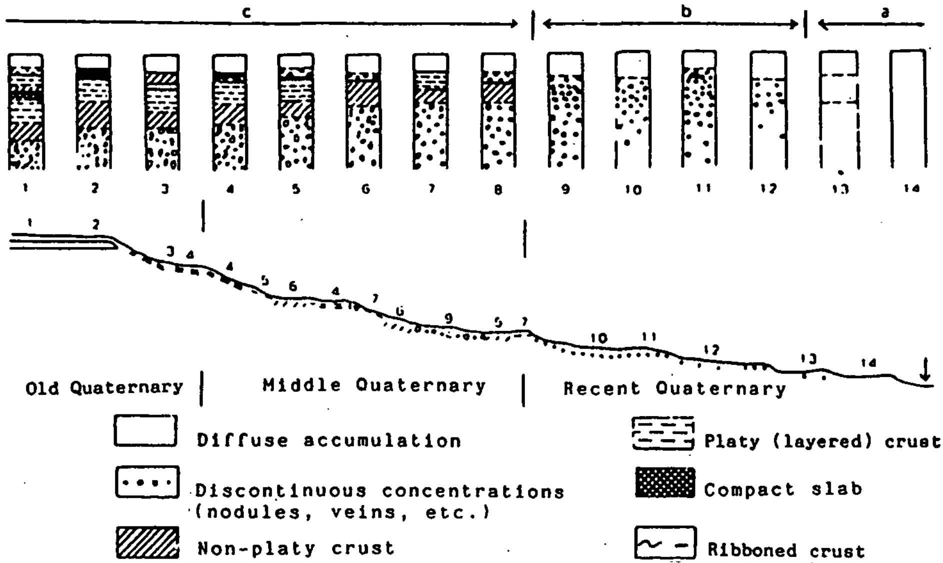


Figure 3. Distribution of the main types of calcium carbonate accumulation as determined by the ages of the surfaces and of the soils (the length of the sequence varies between tens of metres to a hundred metres and more; the difference in altitude between and Old and Recent Quaternary is in the order to tens of metres (Zebra, Morocco).

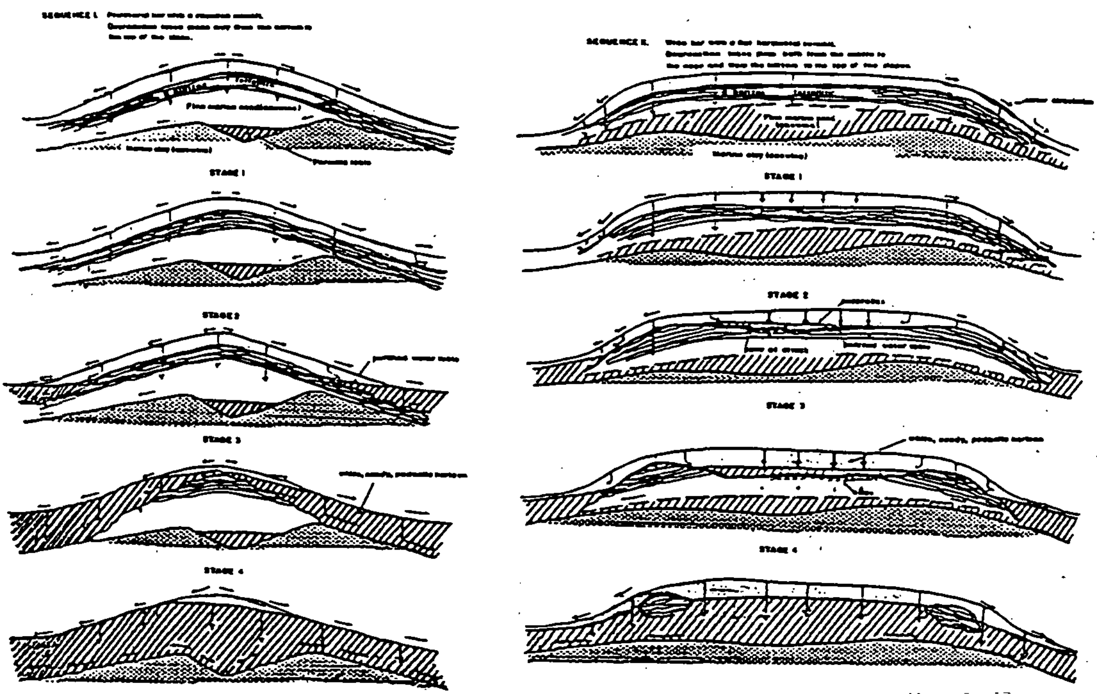


Figure 4. Stages in the evolution of prelittoral bars (after Boulet, Humbel and Lucas, 1982).

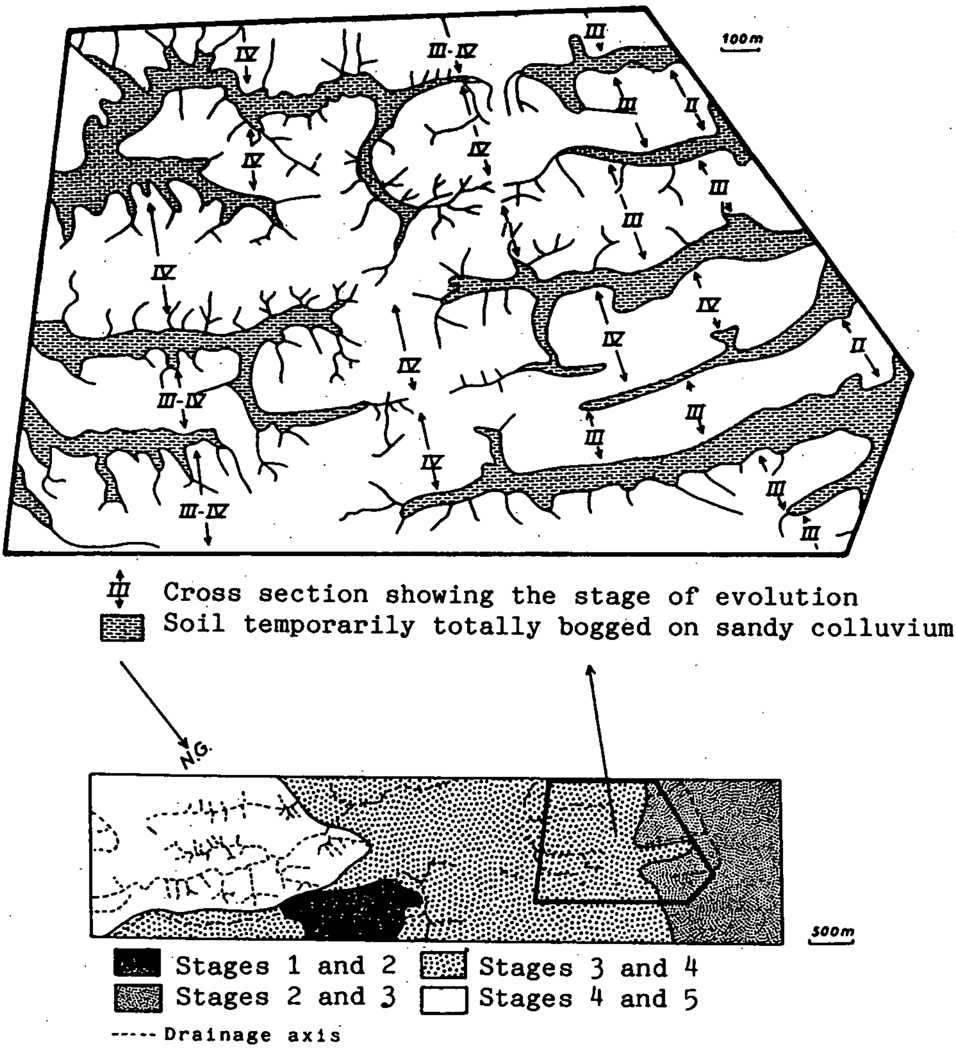


Figure 5. Synthetic map of prelittoral bars.

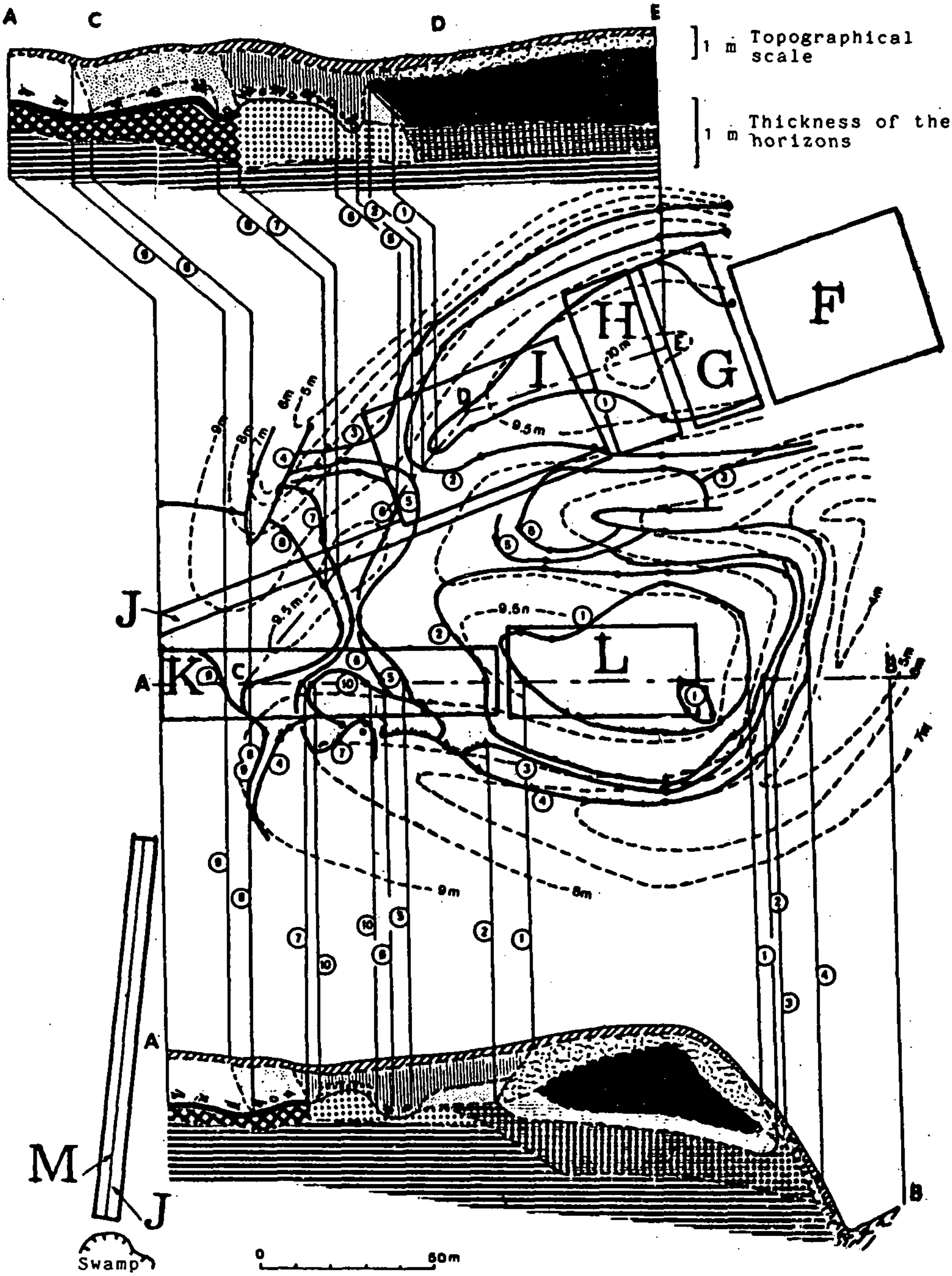


Figure 6. An example of agropedological experimentation on prelittoral bar.

PEDOLOGICAL LEGEND (SUMMARY)

Cross Section Legend

Horizon limits: progressive — rapid
planic floor of perched table

(a) humiferous horizon, sandy;
(b) strong brown sand to sandy clay;
(c) yellowish red sandy clay;
(d) strong brown sandy to sandy clay;
(e) strong brown with cm volumes of red, clay decreasing downwards;
(f) light yellow with cm volumes of red, sandy, water-table reservoir;
(g) dark brownish yellow sandy to sandy clay;
(h) brownish yellow deeply impregnated with organic matter: the impregnation depth of organic matter and the clay impoverishment increases from curve 1 towards curve 7
(i) strong brownish yellow sand to sandy clay;
(j) yellow with volumes of red main less indurated sand to sandy clay;
(k) transition between (h) and (j) by interpenetration and relicts (from j into h)
(l) dark brownish yellow, getting gradually lighter with depth, sandy;
(m) light grey to white, sandy;
(n) ochre, organic brownish black streaks, sandy clay;
(o) red pedorelics more or less indurated;
(p) pedorelics;
(q) grey humiferous volumes;
(r) ochre spots along the pores.

Legend for the Isodifferentiation Curves

Centifugal differentiation

(1) change from 7.5YR to 10YR in 18-20 cm (b) → (h);
(2) where (b) disappears;
(3) where pedorelictual volumes appear (o);
(4) where ochre spots appear in 18-25 cm.

Centripetal differentiation

(1) (2) as given above;
(5) where pedorelictual volumes appear (p) at the bottom of (h);
(6) where humiferous volumes appear (q);
(7) where a planic limit appears;
(8) where white sand appears (m);
(9) where the brownish-yellow material disappears (m);
(10) where the clay-impoverished material gets thinner (<40 cm) (h), and where the characteristics which appeared with curves 5 and 6 disappear;
where the isodifferentiation curve can be seen.

AGRONOMIC EXPERIMENTATION (Philippe Godon, IRAT)

Manioc
- F: collection (42 varieties)
- G: fertilization trial
- H: herbicide trial
- I: behaviour trial (5 varieties)
- J: behaviour trial (6th variety)

Soybean
- K: behaviour trial, with and without ridges, and with and without liming
- L: diversification trial (5 varieties, 6 repetitions)
- M: behaviour trial, only one treatment

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SOIL AND SITE CHARACTERIZATION FOR SOIL-BASED RESEARCH NETWORKS

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ABSTRACT

Soil and site characterization are crucial elements in any kind of soil-based research. The characterization process takes on a new dimension when research networks are considered, as compared to experimentation at a single site. Reproductibility of site characteristics at other locations is the single important constraint in a network, and since this is not always feasible, the alternative is good characterization and documentation of site characteristics.

The paper provides some guidelines on aspects to be considered in soil and site characterization. The IBSNAT approach is used as an example, and some of the minimum data sets are used as illustrations. The need for a data base management system is empahsized and some aspects are elaborated to show the complexity of establishing a network.

INTRODUCTION

Collaborative research through networking is becoming increasingly popular for various reasons, and notably:

* they are cost effective,
* they have the capability of testing a hypothesis under different agroecological environments,
* each participant of the network contributes his efforts and derives benefits from the cumulative data of the network,
* as networks have in-built quality control mechanisms, the credibility of research results is assured,
* scientists and institutions are strengthened.

These benefits of networking are only realized if:

* there is a strong central leadership for both the administrative and technical aspects,
* each participant has comparable facilities to conduct the research,
* each participant has a commitment to the objectives of the network.

The technical success of networks is a function of the objectives and nature of the research. Some of the factors influencing soil management research networks include:

* soil and site characterization,
* design of experiments,
* agronomic management of the experiments,
* accuracy and objectivity of observations and measurements,
* availability of backstopping services.

Research networks may be national, regional or international; in each case, the general principles are the same though the objectives vary. Multinational networks are organized by regional and international institutions, such as the International Agricultural Research Centers (IARCs) of the Consultative Group on International Agricultural Research (CGIAR). In addition to these, there are collaborative efforts which are not formally organized as a network. In a network, participants are linked together by a common objective and a commitment to work towards that objective; the objective may change with time due to information gathered as the work progresses, but there is a consensus of opinion among the researchers with respect to any change.

SOIL BASED RESEARCH IN LESS DEVELOPED COUNTRIES (LDCs)

Practically every country has some kind of agricultural research station. The research output, however, varies from insignificant to highly sophisticated. LDCs in general have some common constraints which include lack of facilities, trained personnel, and funds to conduct the research. There are other factors which interplay, making research in these countries either nonproductive or less reliable. Some of these are:

Research management

Research projects tend to be *ad hoc* and not related to national priorities. In general, research projects are not vetted; previous work is not consulted and there is no obligation to periodically report progress - and peer review is nonexistent. In addition, research results are not published.

Support services

National institutions tend to be compartmentalized, and even though facilities exist for supporting services, these are not readily available to scientists in another department or division. Research results are consequently incomplete. Collaborative research and multidisciplinary approaches are fancy words in reports or project proposals and do not play a real role in the project support activities of many LDC organizations.

Technical backstopping

In many LDCs, the local scientist may be the only one in his field and has few opportunities to discuss or obtain an outside opinion of his work. He soon becomes disillusioned and his productivity drops.

Career benefits

In general, it is not rewarding to be a dedicated research scientist in LDCs. Promotion prospects for such persons are few or, due to a lack of personnel, they are rapidly promoted beyond their level of competence. With an incompetent or disinterested person as the head of an institution, further research suffers.

For some or all of these reasons, international networks attain a special significance and importance. In some parts of the world they are the only means of conducting reliable research; in others, they have a catalytic role.

CONCEPT OF BENCHMARK SOILS AND SITES

The term 'benchmark soils' was popularized by the Benchmark Soils Project of the Universities of Hawaii and Puerto Rico funded by the U.S. Agency for International Development. The term has been used with different meanings, and for this reason Eswaran (1984) provided some definitions for 'benchmark soil', 'benchmark site', and 'network of benchmark sites'.

Benchmark soil

> A benchmark soil is a reference soil that is adequately characterized in terms of its properties and environmental conditions. It is also sufficiently significant in terms of its distribution in the country or region so that performance data derived from experiments on it may be related to other soils with similar characteristics. The information about benchmark soils can be extended to many of those closely related in classification.

The accuracy of predicition desired determines the categoric level of classification of the benchmark soil. In a national program, phases of soil series may be the level of comparison; while at a regional or international level, the soil family level or phases of the family may be the most practical form of classification. Homogeneity within a class is a function of the class, e.g. in the Haplorthoxes or

Paleudults variation of properties is small, while in a Ustifluvent, it is generally large. Class boundaries are based on morphogenetic criteria, and as a result closely related classes may have similar response patterns, e.g. a Tropeptic Haplorthox and a Typic Paleudult are mineralo-chemically similar, and if they have similar particle size class, their management and response to management are similar. Consequently, a benchmark soil could be selected such that the sphere of transferability of the, information derived from research on it becomes very large. Depending on the objectives of the research, a cluster of soil families could be defined with the benchmark soil serving as the focal point for investigations.

Benchmark site

A benchmark site is an area of land where the dominant soil is a benchmark soil and where there are few or no dissimilar soils. The homogeneity of the land, with respect to variations in critical properties from the typifying benchmark soil, is its most important attribute.

A site is a tract of land and is characterized by not only its geomorphic position in the landscape but also the environmental conditions. To be representative in the network, the site must occupy similar geomorphic positions. The soil on a piedmont and a plateau may be taxonomically the same, but the variations in geomorphic position may affect crop performance. Attention must also be given to the microenvironment. A site in the middle of the jungle may serve some purposes but may become the breadbasket for all the pests in the area; this site, in terms of the microenvironment, will be different from one in the middle of a cultivated area.

Network of benchmark sites

Benchmark soils within a country or region linked together by a commonality of research objectives forms the network of benchmark sites. Sharing research data and collaborative work on soil management for crop performance and soil use, leading to a rational basis for agrotechnology transfer, is the common goal of the network collaborators.

Selection of the benchmark sites is perhaps the single most important task of the network leadership. All subsequent work and results depend on this selection and the characterization of these sites.

Attributes of a benchmark site

To serve as a benchmark site, the area must have all or most of the following attributes:

- The soil at the site must be well characterized and also conform to the definition of a benchmark soil. Characterization includes not only pedological but also fertility parameters and variations of some diagnostic characteristics. A soil with an argillic horizon beginning at 60 cm, and another, which has been slightly eroded and has an argillic horizon at 35 cm, are taxonomically the same, but from a performance point of view, and particularly where moisture stress is critical, may be quite different.

- The site must have few or no dissimilar soils, particularly limiting inclusions. This requires a detailed soil survey of the potential experiment fields and careful selection of the site. The survey should not only evaluate pedological variations but also fertility variations.

- If cultivated, the agronomic history of the area must be well documented, and in such areas a fertility variability survey is mandatory. In addition, one or two crops must be grown prior to commencement of the research to establish homogeneity.

- Weather monitoring facilities must exist or be established. Soil moisture and temperature must be part of these facilities. Preferably monitoring of these variables should commence a year before the start of the research.

- The site must be located so that experiments are inspected daily, particularly with respect to insect and pest damage and the collection of phenological information.

CONSIDERATIONS IN THE SELECTION OF NETWORK SITES

The International Board for Soil Research and Management (IBSRAM) has three Soil Management Networks (SMNs):

* Acid Soils SMN
* Vertisols SMN
* Land Clearing SMN

In this paper only the 'acid soils' will be considered. Prior to site selection, it is necessary to define the group of soils being considered and list the desired attributes of the soils and sites. Each participant then locates a site with these attributes, and in addition provides a detailed report on the variability within the identified site with respect to the central concept.

Properties of Acid Soils

The term acid soils is not a generic name and connotes different things to different persons. For SMN purposes it needs a definition, such as:

Definition

"An acid soil is a mineral soil which does not have a sulfuric horizon or sulfidic material within 1.5 m of the soil surface, and which has:

- more than 40% Al saturation and less than 0.3 meq of exchangeable calcium in some subhorizon within 25 cm of the mineral soil surface, or

- has more than 4 meq extractable Al in some subhorizon within 25 cm of the mineral soil surface, and

- has more than 4 meq extractable Al in some subhorizon within 1.25 cm of the mineral soil surface."

This definition will confine the acid soils to the Ultisols, a few Alfisols and some of the Oxisols. Even though soil acidity may be critical, other soil properties may subdue or exaggerate the effects of soil acidity. These include the following, and the SMN must decide on the kinds of soils to be included in the network.

- Soil moisture regimes (SMRs)

  Udic and ustic SMRs are the most extensive; acid soils are rare in xeric and aridic. Wet acid soils (aquic SMRs) may present other problems and so may be excluded.

- Soil temperature regimes (STRs)

  Isohyperthermic and isothermic STRs are probably the most important for consideration.

- Particle size class in the control section

  Moisture stress accentuates soil acidity problems, and so loamy classes are more susceptible than clayey classes. The classes that could be included are:

fine clayey	- 60% clay
clayey	- 35 to 59% clay
fine loamy	- 18 to 34% clay

- Activity of the clay

  Soil acidity becomes critical in the high activity clay (HAC) soils, and by definition these soils have a cation exchange capacity of more than 16 meq per 100 g clay. Such soils are largely in the typic and a few in the oxic subgroups of the Alfisols and Ultisols; and if this definition is accepted, it will exclude the Oxisols.

- Amount of organic matter

  Organic matter complexes the aluminum and ameliorates its effects. For definition purposes, soils with less than 12 kg of organic carbon / m^2 to a depth of 1 m are included in the concept of acid soils. This will confine the soils mostly to the lowland tropics.

- Soil depth

For pragmatic purposes, it may be necessary to confine research on acid soils to those deeper than 1.25 m. Also soils with more than 35% by volume of stones - skeletal and fragmental classes - may be excluded.

- Slope

Slopes of less than 8% are perhaps most amenable for research purposes. The length of the slope must be such that a tract of land sufficiently large for experimentation should be available. If possible, terraced land must be avoided.

Properties of the Site

Attributes of the site have been given previously. Once a site has been identified, it is necessary to establish its homogeneity.

1. Detailed soil survey

The soil survey must be made not only of the tract of land where the experiment is being conducted but also of the adjoining pieces of land. Attention must be given to other limiting conditions such as rock outcrops and microvariability. In Alfisols and Ultisols, depth to the argillic horizon may be an important factor, especially in ustic SMRs bordering aridic. Variations of surface texture, organic matter/color or stoniness are important variables.

2. Fertility variations

Once the experiment areas have been identified, the fertility status of the plots must be established. This survey serves two purposes: (a) it documents homogeneity and (b) it provides information on the initial state of the soil. Fertility of both the surface and subsurface horizons is monitored.

3. Soil evaluation

A soil pit is dug close to the experiment site and characterized. Satellite samples are also taken between experiment plots to establish variability.

4. Monitoring climate

A climatic station is established close to the experiment site. If irrigation is one of the treatments, soil moisture monitoring equipment is established close to the experiment plots.

5. Pests and diseases

The services of an entomologist and a pathologist need to be obtained to monitor these vectors.

MONITORING OF EXPERIMENTS AND EXPERIMENTAL CONDITIONS

The success of the research is dependent on monitoring the experiments, and particularly the experimental conditions. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project, based on the experience of its predecessor, the Benchmark Soils Project, has developed documentation for this (IBSNAT, 1986). It is essential that similar documentation be developed for the SMN. Such information becomes extremely useful when analyses of the data are made.

IBSNAT has identified 'Minimum Data Sets (MDSs)' of each of the properties which it needs to validate its computer models. As the SMNs will need most or all of these, some of the forms are excerpted and included here, largely to illustrate the magnitude of the work involved. The success of the SMN depends on all participants compiling the documentation as accurately and impartially as possible.

Appendix 1 gives an example of 'Schedule of activities for experiments' as envisaged by IBSNAT and Appendix 2 gives a list of the Minimum Data Set forms. Examples of these forms are included in Appendix 3. The completed forms and other information are periodically mailed to the network coordinating institution.

Processing of Experimental Data

Prior to commencing the SMN, due thought must be given not only to the kinds of experiments to be conducted but also the manner of processing the data. The SMN must develop a Data Base Management System with the assistance of statisticians. For its objectives, IBSNAT has developed the Decision Support System for Agrotechnology Transfer (DSSAT) (IBSNAT, 1986b), and Appendix 4 shows examples of DSSAT components as entered in the computer.

CONCLUSION

Soil and site characterization, though an initial step in the experimental procedure, is an important activity which must also be based on a number of other considerations, including the collection and processing of data. Managing a network is distinctly different from conducting experiments at one location, such as those done by national research organizations. Coordinating the activities, reporting the data, trouble-shooting, providing support services and technical assistance are all part and parcel of the network activities. If any one is not well executed, the network is doomed to failure.

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APPENDIX I

SCHEDULE OF ACTIVITIES FOR EXPERIMENTS

Collection of the IBSNAT minimum data set in an experiment requires foresight and planning. The activities of land preparation, initial soil sampling, planting, biomass measurements, phenological observations, and final soil sampling must be coordinated.

A hypothetical schedule of activities is shown for a single-factor nitrogen rate experiment with a 120-day maize cultivar grown/under dryland conditions. The days are expressed relative to planting on Day 0 (zero).

Day	Activity
-180 to -90	Decide on experimental site location, experimental factors, and experimental design; calculate size of field area needed; and ensure that land, machinery, laboratory, and human resources are adequate. Ensure that the soil characteristics of the plot are similar to those of available soil pedon characterization data, and if they are not, arrange for IBSNAT to characterize the soil at the site.
-90 to -14	Obtain all necessary inputs and equipment for experiment, and ensure that weather instruments are calibrated.
-14 to 0	Since both N and drought stress are possible limiting factors in the experiment, at least within 2 weeks before planting day, take preplant soil samples for initial soil water, pH, NO_3, NH_4, P, and K. Conduct final land preparation, preplant fertilizer application, herbicide application, etc.
0	Plant the selected crop, and apply any other fertilizer, herbicide, and pesticide treatments.
0 to 120	After planting, apply and record dates and amounts of products used for weed, insect, and disease control (as necessary).
3 to 10	Record date of VE stage (emergence) by plot.
12 to 20	Record date of V6 stage (6 leaves collared), and take first biomass harvest.
20 to 30	Apply supplemental N fertilizer (if necessary).
50 to 70	Record date of R1 stage, and take second biomass harvest.
110 to 130	Record date of R6 stage, and take final harvest yield components.
110 to 144	Take postharvest soil water, pH, NO_3, NH_4, P, and K samples.
110 to 160	Begin data entry on floppy diskettes.

APPENDIX II

LIST OF MINIMUM DATA SET FORMS[†]

FORM A - Institutional Information

FORM B - Nearby Long-term Climatic Stations

FORM D - Experimental Site

FORM E - Experiment

FORM F-1 - Experimental Factors and Levels

FORM F-2 - Experimental Factors and Levels

FORM F-3 - Experimental Factors and Levels

FORM F-4 - Experimental Factors and Levels

FORM G - Experimental Layout

FORM H - Experimental Plots

FORM I-1 - Soil Fertility Measurements (Preplant)

FORM I-2 - Soil Fertility Measurements (Other)

FORM J-1 - Soil Water Contents (Preplant)

FORM J-2 - Soil Water Contents (Other)

FORM K - Tillage

FORM L - Cultivar

FORM M - Planting

FORM N - Fertilizers, Inoculants, and Amendments

FORM O - Biocides and Hormones

FORM P - Irrigation

FORM Q - Crop Damage

FORM R-1 - Phenological Growth Stage Components

FORM R-2 - Growth Analysis Harvest and Final Yield Components

FORM S - Plant Nutrient Concentrations

[†]Note: FORMS C-1 and C-2 are contained in a separate booklet titled <u>Minimum Data Set FORMS C-1 and C-2</u>.

APPENDIX III a

FORM A
INSTITUTIONAL INFORMATION

Institute ID: --

Institute Name: --

Mailing address: -------------------------------------

Country: ---------------------

Telex: ------------------

Telephone: ---------------------

APPENDIX III b

FORM D
EXPERIMENTAL SITE

Institute ID: __ Site ID: __

Site name: __________________________

*Pedon no.: _____________

Soil series name: __________________________________

*Soil classification (Family level of soil taxonomy):

____

____

Description of site (Geomorphology or position in landscape):

____

____

Natural vegetation:

____

Years in cultivation and past management practice:

____

____

*Latitude (deg.,min.): ___.__ Direction (N, S): _

*Longitude (deg.,min.): ___.__ Direction (E, W): _

Elevation (m): ____

Weather station ID: __

Distance from weather station (km): __._

APPENDIX III c

FORM I-1
PREPLANT SOIL FERTILITY MEASUREMENTS

Institute ID: __ Site ID: __ Experiment No.: __

Method of ___ extraction: ________________________

DATE dd/mm/yy	*PLOT(S)	*UPPER	*LOWER (----cm----)	---pH---- *H_2O	KCl	*NO_3-N	*NH_4-N (------g/Mg	P	K -------)	Al %
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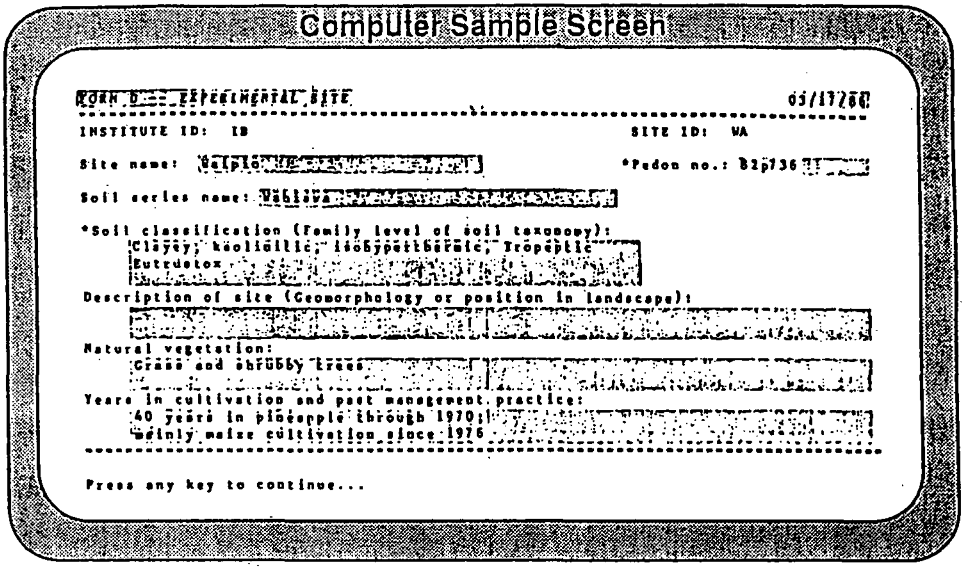
APPENDIX IV b



Computer Sample Screen

FORM D -- EXPERIMENTAL SITE 03/17/86

INSTITUTE ID: IB SITE ID: WA

Site name: Waipio *Pedon no.: B2p736

Soil series name: Wahiawa

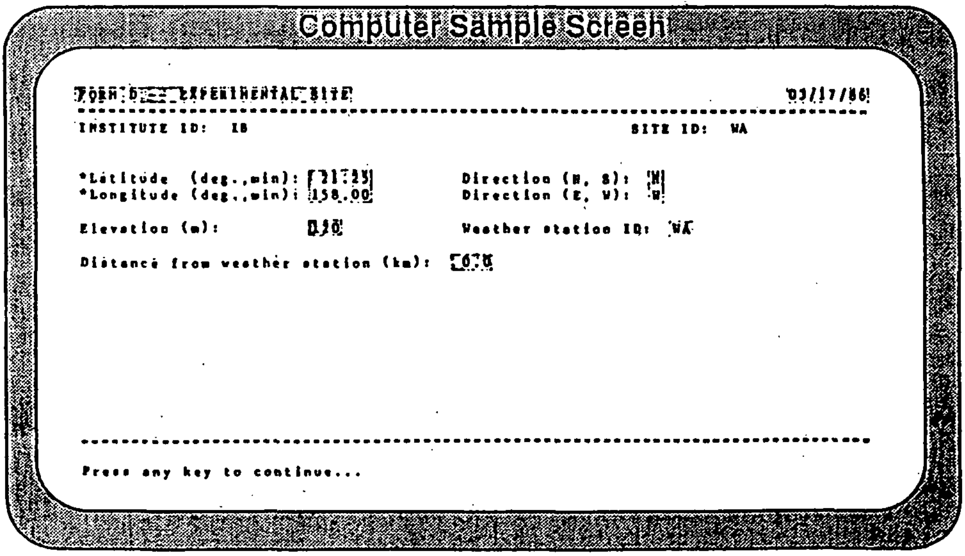
*Soil classification (Family level of soil taxonomy):
Clayey, kaolinitic, isohyperthermic, Tropeptic
Eutrustox

Description of site (Geomorphology or position in landscape):

Natural vegetation:
Grass and shrubby trees

Years in cultivation and past management practice:
40 years in pineapple through 1970;
mainly maize cultivation since 1976

Press any key to continue...



Computer Sample Screen

FORM D -- EXPERIMENTAL SITE 03/17/86

INSTITUTE ID: IB SITE ID: WA

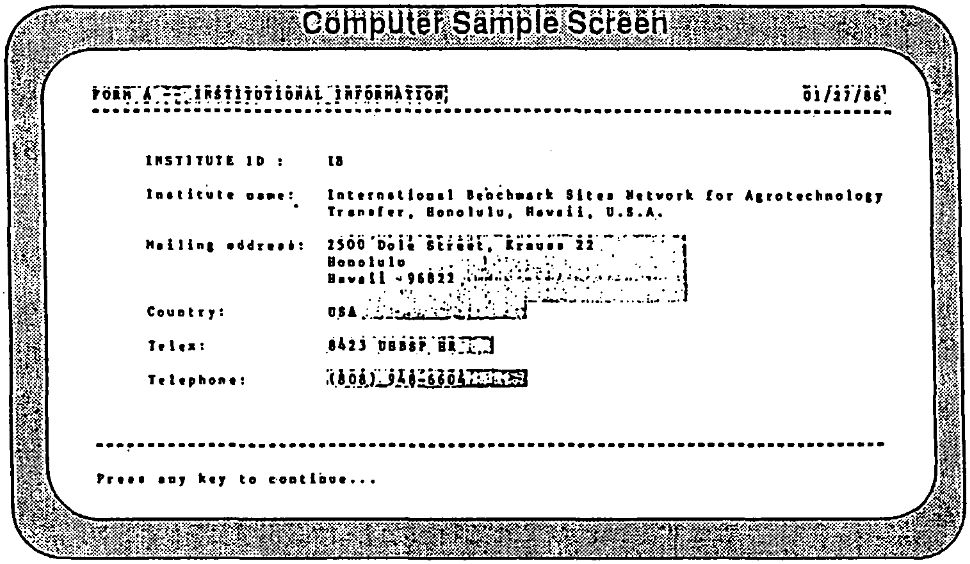
*Latitude (deg.,min): 21.25 Direction (N, S): N
*Longitude (deg.,min): 158.00 Direction (E, W): W

Elevation (m): 130 Weather station ID: WA

Distance from weather station (km): 6.0

Press any key to continue...

APPENDIX IV a



Computer Sample Screen

FORM A -- INSTITUTIONAL INFORMATION 01/27/86

INSTITUTE ID : IB

Institute name: International Benchmark Sites Network for Agrotechnology Transfer, Honolulu, Hawaii, U.S.A.

Mailing address: 2500 Dole Street, Krauss 22
Honolulu
Hawaii 96822

Country: USA

Telex: 8423 UHBSP HR

Telephone: (808) 948-6604

Press any key to continue...

AGROCLIMATIC PARAMETERS FOR SITE CHARACTERIZATION

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ABSTRACT

The paper considers how weather data and models driven by weather data are essential in our attempts to compare and predict performance of crops and cropping systems in various climates and soils being addressed by the IBSRAM networks represented in this forum. Suggestions are also presented on how IBSRAM could develop a standard set of weather data recording recommendations and support the adoption and development of expert systems to facilitate the transfer of research experience and research methodology among collaborating members.

INTRODUCTION

The climate of Southeast Asia includes both humid tropics and wet-dry tropics. The humid tropics generally do not have a dry season, or have only a few months which are relatively drier. These areas are located in the lowlands on or near the equator where daylength and solar radiation show little seasonal variation and the relative humidity is high. Diurnal temperature variation is greater than the total annual variation. Rainfall is often of high intensity and strongly localized in the form of thunder showers (Nieuwolt, 1968).

Further from the equator, the seasonality of the rainfall becomes more striking. The wet-dry tropics include many different rainfall regimes. Jackson (1977) has classified these according to the relative length of the rainy and dry seasons. The seasonal distribution of rainfall reflects the migration of the Intertropical Convergence Zone and the advance, retreat and intensity of the monsoon.

An intrinsic part of the tropical climate is the great yearly variability. Regional climate anomalies may be related to large-scale changes in atmospheric circulation. For example, rainfall anomalies in Indonesia are closely tied to the El Nino Southern Oscillation phenomenon. During 1982-83, El Nino experienced drought while unusually heavy rains occurred in normally dry islands of the Eastern Pacific. In monsoon areas, there is a great variation in rainfall totals as well as the timing of the onset and retreat of the monsoon (Hastenrath, 1985).

In using agroclimatic information to characterize a site, it is important to consider the climate of the region as well. Many different factors are involved in rainfall variability which make forecasting and prediction difficult. Moreover, local differences may be quite marked. Data from distant stations may not be representative for the study site (Doorenbos and Pruitt, 1977). Even at the site, attention must be given to the proper location of weather instruments. Methods of analysis and models should be chosen which make the best use of available data.

This paper describes selected applications of climate data in crop and soil management. The importance of standardized data collection for use in simulation models is discussed, and possible climatological activities for the IBSRAM Asian Network are presented.

SELECTED APPLICATIONS IN SOIL AND CROP MANAGEMENT

Agroclimatic Classification

The FAO agroecosystems classification is based on the length of the growing season, as determined by the period of water availability. The growing season is defined as the period in days during a year when precipitation exceeds half the potential evaporation, together with the time required to evapotranspire stored water at the potential rate. The growing season must also include a period during which the precipitation exceeds potential evaporation. Fourteen categories are formed, at monthly intervals (12), somewhat less than 365 days, and continuously moist. This classification has been developed for countries from Pakistan to Vietnam, including 898 million ha, and is based on data from 590 weather stations. These groupings were superimposed on the FAO World Soil Map and estimated suitabilities of maize, soybean, groundnut, cassava, and sweet potatoes were tabulated and consolidated into a land suitability classification (Oldeman, 1983).

The IRRI agroclimatic classification for rice-based cropping patterns is intended to identify macro soil-climate zones that represent the spectrum of rice-growing areas in Southeast Asia. The main criteria were the amount of monthly rainfall and the length of consecutive wet months (>200 mm). The zones were then subdivided according to the length of the dry period (months with <100 mm), and the resulting grouping produced 8 agroclimatic zones. This classification was applied to Indonesia, and indicated that 59% of the country has a least 7 consecutive wet months and 25% of the country has at least 2 consecutive dry months (Oldeman, 1982).

Nieuwolt has described the agroclimatic zones of Peninsular Malaysia using the Agricultural Rainfall Index. Rather than use monthly rainfall means, rainfall probabilities are used which better reflect the great yearly variability. These are compared with crop water needs as estimated by potential evapotranspiration (E_o) in calculating the agricultural index. Rainfall is given as a percentage of E_o. For example, in the main growing stage plants need water at a rate of 80-120% of E_o. An agricultural index of 80 or greater would indicate that water is sufficient for most plant needs. A dry season is defined as a period in which the Agricultural Rainfall Index is less than 40 or, in other words, less than one-half of the crop water needs are being supplied by rainfall (Nieuwolt, 1982).

Although agroclimatic classifications are quite general they can be useful in certain decision-making contexts. If there is little other information, that provided by the FAO or IRRI system is a great help. For long-range planning, regional planners may need to consider broad limitations on cropping patterns and alternative crops. General classifications facilitate the identification of major concerns and large areas requiring further detailed investigation. Such broad patterns are also useful in quickly identifying potential similarities in cropping systems, and consequently in identifying potential sources of new ideas or practices that have been developed elsewhere. This transfer methodology, called transfer by analogy, requires, as a minimum, some sort of classification system. Such methods of transfer are useful, but additional transfer methods should be developed that are based on more quantitative data and accumulated farmer and researcher experience. Methods that permit such transfer will be discussed in later sections on the use of agroclimatic data for soil and crop management.

Soil Genesis and Classification

Climatological information is important in understanding soil development processes. Water and temperature are basic factors in chemical weathering. The transport or lack of transport of weathering products dramatically affects clay mineral formation as well as soil profile development. For example, the proposed ferrolysis of clay minerals assumes long-term fluctuation in the water level, which must be driven by seasonal rainfall variation (Brinkman, 1978). Many of the other considerations of climate in soil genesis and classification are considered in Buol (1973).

Consideration of climate is of critical importance to the correct classification of soils. Perhaps one of the weakest aspects of soil taxonomy is its classification of climate. However, this view depends on one's expectations of taxonomy. Currently water status and temperature are the most influential weather characteristics considered in soil taxonomy (Ikawa, 1978). Of these two, water status in the soil moisture control section (Table 1) is more important, and is not usually measured by standard weather stations. Measurements of water content in the control section throughout the year are desirable. Frequently such data are not available, so efforts have been directed towards estimating a simple water balance to help augment the few actual measurements of water status in the control section.

Table 1. Climate/weather measurements needed for soil classification, e.g. for use with soil taxonomy (after Ikawa, 1978).

Soil Moisture

Soil moisture control section: Defined as the portion of soil in which the upper boundary is the depth to which a dry soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours.

Few details are provided as to how to measure soil moisture status in the control section, but measures of reduction and soil-water potential are needed periodically, depending on the moisture regime.

Soil Temperature

Temperature regimes consist of "the mean annual temperature, the seasonal fluctuations from the mean, and the mean warm and cold soil temperatures gradient within the main root zone, which is the zone from a depth of 5 to 100 cm." Temperature regimes usually require a temperature measurement at 50 cm, or at a lithic or paralithic contact at regular times during the year. It is possible to estimate soil temperatures from air temperatures, which are frequently measured in standard weather stations. Also an estimate of mean annual soil temperature can be made by a single measurement at 10 m depth (Soil Survey Staff, 1975).

The other parameter, soil temperature, is customarily estimated from air temperature data commonly available from standard weather stations. Measurements at 50 cm and possibly at a location in the crop root zone have been suggested. It seems advisable for participants in the IBSRAM network to develop a common procedure which would permit these parameters to be consistently measured or estimated for classification and genesis purposes.

Water Balance

Water-balance studies have many applications in agriculture and are often an underlying factor in crop and soil management decisions. A simple water budget considers precipitation, potential and actual evapotranspiration, soil moisture storage, and surplus (Jackson, 1977). Potential evapotranspiration incorporates various climatic factors including temperature, wind, humidity, and solar radiation. Complex water-balance models integrate many different climate, soil, and plant parameters including phenological and physiological information. The type of water balance chosen depends on the purpose and the data available.

Evapotranspiration is a basic component used in determining crop water requirements and in water-balance calculations. The methods chosen for deriving this variable depends on the data available. For example, if only temperature data are available, the Blaney-Criddle formula relating temperature and daylight hours to crop water use is an option. If sunshine hours and temperature are obtained, the radiation method can be used. The Penman method, which gives much better results, requires temperature, humidity, wind, and sunshine duration or radiation (Doorenbos and Pruitt, 1977).

The Priestley-Taylor modificaiton of the Penman formula requires only temperature and solar radiation data. The equation uses net radiation values, which can be derived from these variables or measured directly by a net radiometer. This evapotranspiration estimate has been found to be a satisfactory alternative to Penman in the humid tropics (Gunston and Batchelor, 1983). Pan evaporation data reflects the integrated effects of wind, radiation, temperature, and humidity from open water (Doorenbos and Pruitt, 1977). A pan coefficient is used to relate these values to crop water loss.

Simple water balances are used in climate classification and in determining the beginning and end of the growing season. Doorenbos and Pruitt (1977) have detailed the use of water balance studies in planning irrigation. Rainfall, runoff, and drainage are important in soil erosion studies and in determining water movement through the soil profile. In considering water-yield relationships, more information on the type of crop and its development stage is needed. Most of the applications of agroclimatic parameters mentioned in this paper involve waterbalance considerations.

Cropping Pattern Design

Climate and weather expectations play a major role in designing cropping systems. This is reflected in many of the agroclimatic classifications mentioned above. For example, Oldeman's climate grouping for upland rice in Indonesia is timed to coincide with the onset of the rainy season. Our personal experience with cropping patterns in West Sumatra is that the first crop of rice is synchronized with the onset of the rainy season and that rice planted later in the year is more likely to suffer from blast damage. Harvesting is frequently another consideration. Ripening and drying of grain for harvest is obviously influenced by weather. Frequently this influence is so strong that grain legumes are planted so that they can be harvested at the driest possible time.

The timing of the rice crop and the subsequent deep-rooted crops on the Vertisols of India are another typical example of synchronizing crop and weather. Proper estimation of timing, however, requires dependable, long-term weather data. The most important data for this purpose include daily rainfall, radiation, temperature, relative humidity, and their monthly and seasonal means.

Soil and Water Conservation

Soil and water conservation planning is usually determined by expectations of the weather, usually rainfall. Yet this planning needs to be as quantitative as possible. This again requires data for precise estimates of weather variability. Frequently, however, planning for erosion prevention requires longer-term weather records because of the need to be prepared for the extreme: e.g. a system may need to be designed for a fifty-year maximum rainfall or storm event. The best current design of water retention and conservation programs also needs a thorough hydrologic analysis. This requires considerable data, including daily rainfall and evaporation data as well as other soil data. In addition, a characterization of storm frequency, intensity, and duration is needed.

Crop Performance

When agronomists and soil scientists conduct field experiments they frequently refer to weather conditions as major influences affecting the overall yield or response to their carefully designed and replicated treatments. All too often the conclusions of field research are blunted by unfavorable or unusual weather conditions. A standard practice is to repeat a field experiment at least two years, or for at least two crops, to somehow ensure that an adequate sample of the weather effects has been taken. Yet most would say that two years is scarcely an adequate sample of weather conditions.

Crop simulation models offer an alternative to such expensive, sometimes hit and miss, experimentation. Once mathematical relationships between crop growth and the various weather and soil characteristics are determined, these can in many cases be tested through simulation approaches to explore the range of possibilities suggested by the ranges in weather and soil data.

SIMULATION MODELS AND MINIMUM DATA SETS

The group of models being developed by the IBSNAT project is used to estimate crop production under a variety of soil and weather conditions. To date, models are available for maize, soybean, and wheat, and models for rice and peanut are also being developed.

This central group of crop simulation models is designed to access a common, standardized set of soil and weather data files. The soils and weather data should then be able to support the running of the simulation models in an effort to compare the probable performance of the various crops either singly or in a rotation in which one crop is planted at one time followed by another. This common set of data is called the 'minimum data set' and consists of the minimum data required to drive the various models. In this way the data requirements are determined by the use for which the data are collected. It seems that a similar approach would be useful for IBSRAM, i.e. determine the type of simulation model or method of interpreting results, and then determine the data requirements to fully support that activity.

One of the advantages of conducting research in this manner is that each collaborator can contribute his data to the central data bank and, depending on the agreement, may receive several data sets in return with which to test their crop, weather, or soil information. Similarly, certain global objectives can be addressed by the network as a whole, and effects and responses in one region can be extrapolated to others because of standardized experimental methods.

The selection of the recommended minimum weather data set needs to reflect the scope and objectives of the networks. For example, if the network consists of a common set of treatments replicated throughout the network, then one may wish accompanying weather data to aid in explaining the inevitable seasonal variations in growth conditions at the various locations. For this application, identical weather data would be needed for each site to be included as covariables in prediction equations, or as different inputs to the respective crop simulation model. If the purpose is to use crop simulation models to compare the growth potential of soils of various regions then one must ensure that there are adequate data to run the models. Additional data would be needed to check and validate critical aspects of the simulation models for the various regions. The networks may also be interested in encouraging the establishment of weather stations for the traditional purposes of weather characterization, in addition to the specific requirements of soil and crop management considerations of the network.

Nonetheless, there seems to be a relatively standard set of data that is required for most purposes. The weather data considered 'minimum' by the IBSNAT project include daily rainfall, minimum and maximum temperature, and solar radiation. These data are largely those required for Priestley-Taylor estimates of potential evapotranspiration. There probably is more variation in the quality and supervision of how the data are collected that may be of concern to this group. For example, data on solar radiation requires considerably more attention and supervision than does rainfall recording or maximum and minimum temperature recording because of need to recalibrate the sensors. The sensors, data recording procedures, and data must be checked and verified frequently or else one may lose much of the data and reduce reliability.

Various types of data are required in order to explain variation in crop yield or in the reliability of crop yield. Of the usual variables considered in relating crop production and performance to weather data, that of rainfall tends to be most variable and in most need of careful consideration. The problem is the nature of rainfall: it is essentially an event phenomenon, yet the results of each event are highly dependent on the intensity and duration of that event. This means that the characteristics of the event are far more important than the average of such events over the usual time step considered - whether it be daily, weekly, or monthly. For example, it is precisely the excess rainfall that must be considered in runoff, erosion, drainage and leaching phenomena. Estimates of such excesses must be made dynamically as they occur, not on time averages. Unfortunately, current data recording equipment do not yet have the built-in intelligence to sense such an 'event' and switch into an intensive data collection mode in which the various components of actual intensity, runoff, infiltration, and drainage sensors would record all the essential characteristics of the event. The current methodology of recording all variables at approximately the same time step ignores the unique attributes and influences of each weather variable. Work is needed immediately to build in the appropriate intelligent sensors in order to record the critical events and times for each of the weather variables. The results of past recording strategies have been largely dictated by the availability of sensors to characterize the important variation.

EXPERT SYSTEMS

As indicated above, a variety of weather data is needed to adequately satisfy the requirements of the many different agricultural uses. These data are usually collected by a wide variety of sensors each with their particular sensitivity and calibration requirements. The sensors are often in need of calibration. Moreover, the data need to be checked by an expert soon after collection so that errors in measurement, calculation, or in reading the instruments can be corrected. Those with considerable experience and knowledge can frequently look at a set of weather data and determine which of the measurements seems to be in error or which is inconsistent with the other data. We propose that IBSRAM consider developing an expert system which would permit the inexperienced to make the comparisons and exercise some of the expert judgement needed to diagnose and correct early problems in weather-data recording. A similar effort would seem useful to consider as an aid in determining the kinds of data needed for specific applications or specific models.

CONCLUSION

Efforts to collect the data suggested by the above applications should be coordinated with national weather bureaus, the World Meteorological Organization or other international programs for assistance in locating weather stations and obtaining long-term weather records. Some general recommendations can be summarized as follows:

- Identify the minimum weather data sets for experiments that will be shared with collaborators. The minimum weather data set collected by IBSNAT could serve as a preliminary model.

- Identify weather data sources and collaborators. This includes identifying climatological stations and weather-recording networks within the region that already exist. This should include a list of sources of weather data for each participating country.

- Establish an international reference data base for agroclimatic parameters.

- Develop expert systems to determine data requirements for selected uses of climate and weather data. Also develop systems to check the consistency of existing weather data and warn the collectors of problems of data quality.

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Fourth Session: Chemical aspects

Chairmen: H.R. Von Uexkull
Tian Ren Yu

THE ROLE OF ALUMINIUM IN ACID SOIL INFERTILITY

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ABSTRACT

Aluminium toxicity is one of the major factors limiting plant growth on acid soils, and in this paper the response of plants to aluminium in solution culture, the factors influencing the level and forms of soluble aluminium in soils, and the diagnosis of aluminium toxicity in soils are discussed.

Recent research in solution culture has shown that only monomeric solution aluminium is phytotoxic and that the sum of the activities of the monomeric species provides the best index of toxicity. For legumes, nodulation has been shown to be more sensitive to solution aluminium than plant growth, and root infection and/or nodule initiation appear to be more sensitive to aluminium than subsequent nodule development. At aluminium solution concentrations which have strong inhibitory effects on nodulation, there appears to be no effect on the functioning of nodules in nitrogen fixation.

In soils, the level of soluble aluminium is determined primarily by the diagnosis of aluminium toxicity, and most attention has been focused on soil measurements. Soil pH

allows prediction of the likelihood of aluminium toxicity but provides no information on potential severity of toxicity. Exchangeable aluminium and exchangeable aluminium saturation also suffer as indices of toxicity in that critical values for plants vary widely across soils. Soluble aluminium has perhaps the greatest potential for use as a diagnostic tool for toxicity. Further advances in this area will depend on the development of analytical techniques to accurately distinguish between the toxic monomeric and the nontoxic organically complexed forms.

INTRODUCTION

Naturally occurring acid soils resulting from acid parent materials and/or intense weathering are widespread throughout the world. In the tropics, highly leached, low base status, acid soils belonging to the Oxisol and Ultisol orders comprise about 1675 million ha or 38% of the total land area; in the Asian tropics, 333 million ha (38% of the land surface) fall into these categories (IBSRAM, 1985).

The extent of acid soils in the world is also being increased by human activity through acid deposition from air polluted by industry (Hutchinson and Havas, 1980) and by agricultural practices such as the application of ammoniacal fertilizers, intensive irrigation, removal of basic cations in harvested crops (Jackson and Reisenauer, 1984), and the growth of leguminous crops and pastures (Haynes, 1983).

Acid soils are commonly infertile with plant growth being limited by one or more commonly interacting factors, including low pH *per se* toxicity of aluminium or manganese, deficiencies or low availability of calcium, magnesium, phosphorus or molybdenum, and changes in microbiological activity (Foy, 1984). A further constraint to plant growth in these soils may arise from water stress resulting from the restriction of root development in acid subsurface horizons (Adams, 1984). Of all the factors limiting plant growth on acid soils, aluminium toxicity is the most important. The objectives of this paper are to review (1) the response of plants to aluminium in solution culture, (2) the factors influencing the levels and forms of soluble aluminium in soils, and (3) the diagnosis of aluminium toxicity in soils.

EFFECTS OF ALUMINIUM ON PLANT GROWTH - SOLUTION CULTURE EVIDENCE

An understanding of the effects of soluble aluminium on plant growth is made easier by using solution culture techniques which allow careful control of solution parameters such as pH, total aluminium concentration and ionic strength - which, in soil systems, are more difficult to manipulate. Prior to a discussion of solution culture studies which document the effects of aluminium on plant growth, however, the chemistry of aluminium in solution will be briefly discussed.

Chemistry of Aluminium in Solution

When an aluminium compound dissolves in water, the released Al^{3+} coordinates with six OH_2 groups. Each OH_2 group dissociates a H^+ in sequence as the pH increases to produce the additional monomeric ions $AlOH^{2+}$, $Al(OH)_2^+$, $Al(OH)_3^0$, $Al(OH)_4^-$ and $Al(OH)_5^{2-}$ (coordinated OH_2 groups deleted). Thus, the total concentration of aluminium in solution is the sum of the concentrations of the various monomers. Knowledge of the ionic strength of the solution allows calculation of the activity of each of the species at any given pH through the use of the Debye-Huckel equation. From a plot of the relative log of the activities of the ionic species against pH (Figure 1), it can be seen that the anionic species $Al(OH)_4^-$ and $Al(OH)_5^{2-}$ only become significant in the alkaline range.

In aluminium solutions with low OH:Al ratios, most of the aluminium occurs as monomeric species; at high OH:Al ratios, however, aluminium polymers may form. Wada and Wada (1980) found that the proportion of polymeric aluminium in solution increased linearly from approximately 2% at an OH:Al ratio of 0 to approximately 95% at an OH:Al ratio of 2.7. The equilibrium between the monomeric and polymeric forms of aluminium does not appear to be rapid (Hsu, 1968).

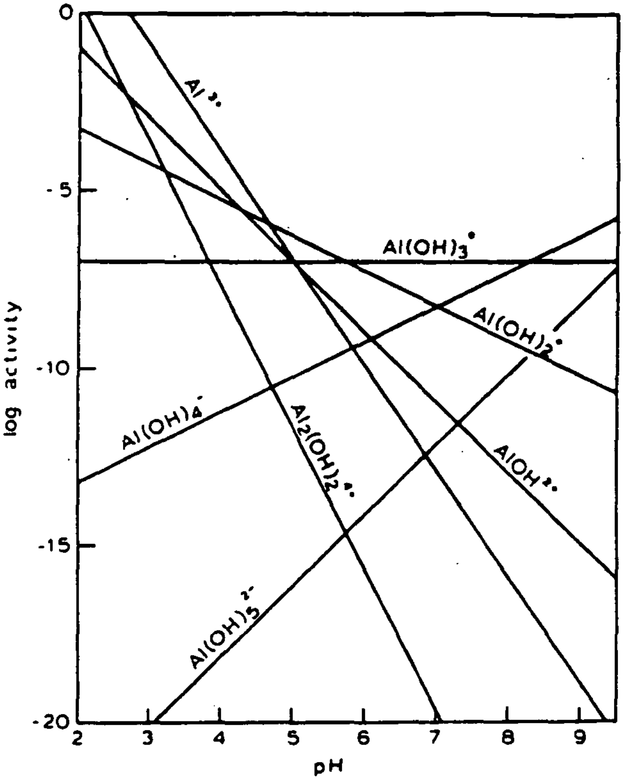

Figure 1. The activity of Al^{3+} and its hydrolysis species in equilibrium with gibbsite (Lindsay 1979).

In solutions containing sulphate, the chemistry of aluminium is additionally complicated by the fact that monomeric aluminium species can form soluble complexes such as $AlSO_4^+$ and $Al(SO_4)_2^-$ (Lindsay, 1979). The addition of phosphate can also result in the formation of soluble complexes with aluminium monomers. Polymeric aluminium species are apparently readily precipitated by phosphate (Hsu, 1968), although White *et al.* (1976) identified metastable soluble polymeric species of aluminium and phosphate in dilute solutions.

When monomeric and polymeric forms of aluminium occur in solution, accurate characterization of solution species depends on how accurately the formula of the various species and the thermodynamic constants for the reactions describing their formation are known. While there have been some attempts to calculate the activities of monomeric and polymeric species in this way (e.g. Nair and Prenzel, 1978), the uncertainty associated with the composition of the polymers and their associated formation constants has led to other techniques of species characterization. By using the different rates of reaction of monomeric and polymeric aluminium with complexing agents in colour development reactions, it is possible to measure only monomeric aluminium (e.g. Blamey *et al.*, 1983). The concentrations and activities of the various monomeric species can then be calculated in the manner outlined earlier.

Effects of Soluble Aluminium on Plant Growth

Solution culture techniques provide an outstanding opportunity for scientists to study the effects of aluminium on plant growth under conditions which reproduce, in large part, the properties of acid soil solutions. Notwithstanding, many solution culture experiments have employed aluminium concentrations in excess of those commonly found in acid soil solutions, together with high phosphate concentrations and solution pH values that would result in considerable loss of aluminium from solution (Blamey *et al.*, 1983). Plant response to aluminium toxicity has usually been evaluated by reference to the nominal applied concentration, and less often by reference to the total measured concentration (Alva *et al.*, 1986a). The latter approach still suffers from the limitation that it includes both monomeric and polymeric aluminium. Only monomeric aluminium is phytotoxic, and its activity is considerably influenced by ionic strength (Blamey *et al.*, 1983; Alva *et al.*, 1986a; Kim *et al.*, 1987).

The effects of solution aluminium on plant growth have been approached in two ways. The principles established in short-term studies (ca. 4 days) with whole plants in which root elongation has been used as the growth index (Blamey *et al.*, 1983; Alva *et al.*, 1986a) have provided the basis for studying longer-term effects of aluminium concentrations, characteristics of those found in acid soil solutions on whole point growth (Kim *et al.*, 1987). Blamey *et al.* (1983) described the effects of aluminium toxicity on soybean root elongation in terms of the sum of the activities of monomeric aluminium species (Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al(OH)_3^\circ$ and $Al(SO_4)^+$). Subsequently, Kim *et al.* (1987) used low ionic strength nutrient solutions, in which 98% of the total aluminium was present as monomeric species, to show that subterranean clover cv. Mt. Barker was much more sensitive to aluminium toxicity than had been indicated in less closely controlled earlier studies (Munns, 1965; Bouma *et al.*, 1981). Expression of the results of these studies on the basis of calculated values of Σ activities of monomeric aluminium species, did not eliminate differences among the studies (Figure 2). On the basis of further study of the effects of phosphorus/aluminium molar ratio and of calcium concentration on root elongation of four species, Alva *et al.* (1986a) provided an explanation of the apparently lower toxicity of aluminium to subterranean cover in the studies of Munns (1965) and Buma *et al.* (1981) than in those of Kim *et al.* (1987). This explanation rests in the lower concentration, and thus activity, of monomeric aluminium as a result of the much higher solution phosphate concentrations used in studies other than those of Kim *et al.* (1987).

Alva *et al.* (1986b) evaluated a number of aluminium indices as predictors of aluminium toxicity to plants grown in nutrient solutions. They concluded that the sum of the activities of monomeric species was the best index of toxicity, accounting for 72 to 92% of the variation in root elongation over 4 days. The concentration of monomeric aluminium species was satisfactory when the range of ionic strengths was narrow, but proved unsatisfactory when the range of ionic strengths was wide and ionic strength effects on the activities on monomeric species were substantial.

The solution culture studies of aluminium reviewed above have focused on the toxicity of monomeric species. In acid soil solutions, a considerable proportion of the total aluminium may be present as soluble complexes with organic acids. However, solution culture techniques have rarely been used to determine the effects of organic acids on aluminium phytotoxicity. Hue *et al.* (1986) have determined the length of cotton taproots after 48 hours growth in nutrient solutions containing aluminium (1.85-18.5 μM) and short-chain carboxylic acids (5-50 μM). The aluminium detoxifying capacities of the acids were positively correlated with the relative position of OH/COOH groups on the main carbon chain, particularly those that favoured the formation of stable 5- to 6-bond ring structures containing aluminium.

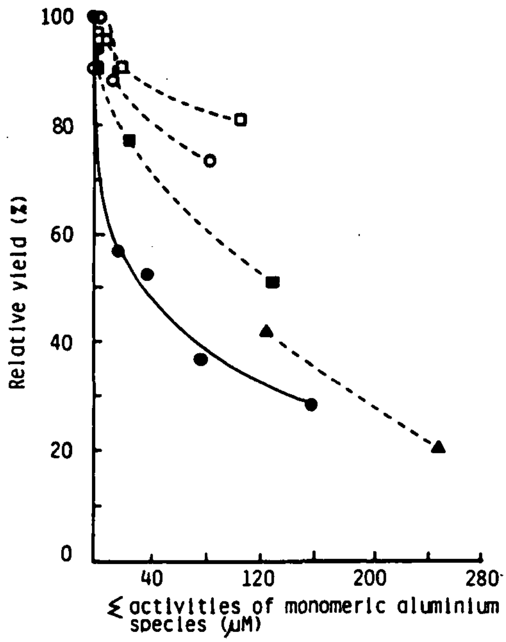

Figure 2. Relationship between relative yield of shoots of *Trifolium subterranean* cv. Mt. Barker and Σ activities of the monomeric aluminium species in nutrient solutions in separate studies. (●) Kim *et al*. (1987), (■) Munns (1965) 100 μM calcium, (□) Munns (1965) 5000 μM calcium, (▲) Osborne *et al*. (1981), (o) Bouma *et al*. (1981).

Effects of Soluble Aluminium on Rhizobia, Nodulation, and Nodule Function

Aluminium toxicity effects on the growth of legumes have often been studied in nutrient solutions supplying adequate inorganic nitrogen (e.g. Munns, 1965; Andrew *et al*., 1973); Bouma *et al*., 1981; Kim *et al*., 1987). However, the growth of legumes on acid soils in the field normally depends upon the establishment and functioning of an effective legume-*Rhizobium* symbiosis. The more severe depression of growth by aluminium of six *Stylosanthes* species when dependent on symbiotic nitrogen fixation than when supplied with adequate inorganic nitrogen (Carvalho *et al.*, 1981a) suggests there are special effects of aluminium on the legume-*Rhizobium* symbiosis. These effects may be on the survival or growth of rhizobia, on nodulation, on nodule function, or directly on host-plant growth.

Aluminium is a potent stress to the growth of free-living rhizobia. Some strains of slow-growing rhizobia can grow at reduced rates or survive in defined liquid media or nutrient solutions containing aluminium at concentrations as high as 50 to 100 µM (Keyser and Munns, 1979; Carvalho *et al.*, 1981b; Hartel and Alexander, 1983); however, the reductions in growth rate could have consequences for colonization of the rhizophere and for nodulation. Fast-growing rhizobia appear to be less tolerant to aluminium than slow-growing rhizobia. Kim *et al.* (1985) have shown that survival of *Rhizobium trifolii* both in nutrient solution and in the rhizosphere of subterranean clover was markedly reduced by 6.4 µM aluminium.

Nodulation is particularly sensitive to aluminium. The concentration of aluminium or activities of monomeric aluminium necessary for a 10% reduction in nodulation is generally lower than that required for a 10% reduction in plant growth (Table 1). Exceptions include bean (see Table 1), *Stylosanthes guianensis* cv. Oxley in which host plant growth and nodulation were about equally sensitive to aluminium toxicity (Murphy *et al.* 1984), and soybean for which there is some evidence that the effective limitation on growth and nitrogen fixation is the susceptibility of the host plant to aluminium toxicity rather than nodulation failure (Munns *et al.*, 1981). In the latter study, the critical aluminium concentration for a 10% reduction in the growth of shoots of soybean cv. Clark was 10 µM; unfortunately, no attempt was made to use solution culture to assess the critical aluminium concentration for nodulation. Aluminium not only prevents some plants from nodulating, but also delays and depresses nodulation (Table 2). Carvalho *et al.* (1982a) used transfer experiments to show that the early stages of nodulaton, viz. root infection and/or nodule initiation, were more sensitive to aluminium than subsequent nodule development. Reduced nodulation due to aluminium has been reported in species in which rhizobia enter through spaces between epidermal cells at lateral root junctions.

Table 1. Critical solution aluminium concentration or Σ activities of monomeric aluminium species ($\Sigma a_{Al\ mono}$) associated with 10% reduction in nodulation and plant growth.

Plant species	Aluminium parameter	Nodulation (M)	Critical value Plant growth (M)	Reference
Stylosanthes hamata	Al concn.	35	90	Carvalho *et al.* (1982a)
Stylosanthes scabra	Al concn.	8	40	Carvalho *et al.* (1982a)
Subterranean clover cv. Bacchus Marsh	Al concn.	0.6	12	Kim *et al.* (1985)
Soybean cv. Fitzroy	$a_{Al\ mono}$	0.4	5-9	Alva *et al.* (1987)
Soybean cv. Fitzroy	$a_{Al\ mono}$	2.0	9.8	Suthipradit (pers. comm.)
Peanut cv. Red Spanish	$a_{Al\ mono}$	7.3	31.0	Sithipradit (pers. comm.)
Green gram cv. Berken	$a_{Al\ mono}$	0.8	7.1	Suthipradit (pers. comm.)
Cowpea cv. Vita 4	$a_{Al\ mono}$	3.8	25.5	Suthipradit (pers. comm.)
Cowpea cv. Ife Brown	$a_{Al\ mono}$	1.2	26.7	Suthipradit (pers. comm.)
Bean cv. Carioca	Al concn.	27	14	Franco & Munns (1982)
Bean cv. Venezuela 350	Al concn.	20	28	Franco & Munns (1982)

1. Sand culture with Hushing nutrient solution.

Table 2. Effects of aluminium on number of days to appearance of the first nodule and dry weight of nodules per plant of *Stylosanthes hamata* and *Stylosanthes scabra* maintained at constant aluminium concentrations throughout the experiment (Carvalho *et al.*, 1982a).

Species	Solution aluminium concentration (M)		
	0	25	100
	Time to appearance of first nodule (days)		
S. hamata	7.0	7.5	13.5
S. scabra	7.0	11.2	22.0
	Nodule dry weight (mg/plant)		
S. hamata	0.70	0.73	0.19
S. scabra	0.20	0.14	0.01

Aluminium, at solution concentrations which have strong inhibitory effects on nodulation, appears to have no effect on the functioning of nodules in nitrogen fixation. Thus, Carvalho *et al.* (1982b) showed that nitrogen fixation by well-nodulated plants of three *Stylosanthes* species was independent of solution aluminium concentrations as high as 100 µM, both when measured by an increase in total nitrogen content of the plants (Table 3) and by acetylene reduction assay on the roots of plants harvested at 10 and 20 days after imposition of the aluminium treatments. Franco and Munns (1982) also failed to find any effect of aluminium concentrations up to 83 µM on the growth of nodules already initiated in the absence of aluminium or on acetylene reduction (nigrogenase) activity.

Table 3. Effects of solution aluminium concentration on the amount of nitrogen fixed (mg/plant) by three *Stylosanthes* species during two successive 10-day intervals after imposing aluminium concentrations of 0, 25 and 100 µM (Carvalho *et al.*, 1982b).

Time interval between harvests	Solution Al concn. (µM)	*S. humilis*	*S. hamata*	*S. scabra*
Day 0 to day 10	0	4.8	0.90	1.2
	25	4.6	0.83	1.5
	100	5.3	0.82	1.3
Day 10 to day 20	0	15.5	1.8	1.7
	25	15.5	2.0	2.3
	100	16.8	1.9	1.5

CHEMISTRY OF ALUMINIUM IN SOILS

Sources of Soluble Aluminium

Aluminium is ubiquitous in the earth's crust, being the third most abundant element after oxygen and silicon. During the weathering of primary minerals such as feldspars and micas, aluminium is released and precipitated as secondary minerals, particularly aluminosilicates. With the continued weathering of soils, these silicates become unstable and, since the loss of silicon is greater than aluminium, the latter precipitates as oxides and hydroxides (Lindsay, 1979).

Aluminium dissolved from primary or secondary minerals enters the soil solution and undergoes the series of hydrolytic reactions referred to previously. The resultant species may then adsorb on cation exchange sites as monomers or polymers. Additionally, the element may enter into complexation reactions with both solid and soluble forms of organic matter.

Thus the level of aluminium in the soil solution will be governed by the solubility of aluminium-containing minerals, exchange equilibria involving inorganic surfaces, and complexation reactions with organic matter. In the following section, the relative importance of each of these reactions in influencing the level of aluminium in the soil solution is discussed.

Factors Affecting Soil Solution Aluminium

Mineralogy

Under equilibria conditions, it can be argued that the level of soluble aluminium should be governed by the solubility of aluminium-containing minerals such as the aluminosilicates and amorphous and crystalline forms of $Al(OH)_3$. Marion *et al.* (1976) concluded that gibbsite was of importance in controlling soluble aluminium only in highly weathered soils, whereas aluminosilicates such as kaolinite and montmorillonite were more important in controlling the solubility of the element in moderately weathered soils. Amedee and Peech (1976), however, suggested that the solubility of aluminium in KCl and $CaCl_2$ extracts of highly weathered soils was determined by the solubility of an amorphous form of $Al(OH)_3$ (K_{sp} $10^{-9.66}$) rather than the more insoluble gibbsite (K_{sp} $10^{-8.04}$).

The solution activity of Al^{3+} and related monomeric species in equilibrium with amorphous and crystalline forms of $Al(OH)_3$ is determined by pH (increases with decreasing pH), whereas the activity of these species in equilibrium with aluminosilicates is governed by both pH and the activity of $H_4SiO_4^o$. For example, in moderately weathered soils where the $H_4SiO_4^o$ activity may be of the order of 10^{-3} M, solubility calculaltions show that the Al^{3+} activity supported by kaolinite at any given pH is lower than that arising from gibbsite. However, in highly weathered soils where the $H_4SiO_4^o$ solution activity is much lower, the Al^{3+} activity should increase towards that predicted from the solubility product of crystalline or amorphous forms of $Al(OH)_3$ (Lindsay, 1979).

The interpretation of experimental solubility data is influenced by the validity of the methods used to determine the activity of Al^{3+} (and related monomers) in solution. In calculalting activity products such as $(Al^{3+})(OH^{-})^{3}$, one must be able to analytically discern between monomers and polymers and between inorganic and organically combined solution aluminium. Only relatively recently has attention been focused on these analytical difficulties (Adams and Moore, 1983; Hue *et al.*, 1986).

The mineralogy of a soil also influences the supply of aluminium to the soil solution through its effect on the magnitude of the cation exchange capacity and thus on the potential level of exchangeable aluminium. For any given exchange capacity, the actual amount of exchangeable aluminium is strongly influenced by pH and decreases rapidly to very low values at about pH 5.5 (Juo, 1977). The distinction between truly exchangeable and nonexchangeable aluminium (hydroxy-aluminium interlayers and surface coatings) is often not clear (Bache and Sharpe, 1976), however, and the validity of techniques for measuring this fraction are considered later in the paper.

With an increasing degree of weathering, the cation exchange capacity of soils decreases as kaolinite and then iron and aluminium oxides and hydroxides replace higher capacity minerals such as montmorillonite, vermiculite and illite; the relative proportion of the permanent to variable (pH and ionic strength dependent) cation exchange capacity also decreases with weathering as a result of this change in mineralogy (Uehara and Gillman, 1981). Thus, the amount of exchangeable aluminium has been found to decrease with intensity of weathering (Tessens and Shamshuddin 1983), but the percentage of the cation exchange capacity neutralized by aluminium (aluminium saturation) is often high in weathered soils such as Oxisols and Ultisols (Sanchez, 1976). This distinction between the absolute amount of exchangeable aluminium and aluminium saturation is important in terms of the aluminium toxicity diagnosis and in the assessment of the lime requirement. While there is considerable evidence that soluble aluminium in soils increases with increasing saturation of the exchange capacity (Kamprath, 1984), there is no unique relationship between these two parameters across soils.

Organic matter

Although the role of organic matter in influencing aluminium solubility in soils has not received as much attention as that of soil minerals (Hargrove and Thomas, 1981), there is evidence that it has a marked effect on the toxicity of the element. Aluminium released from minerals can be complexed by soluble and solid forms of organic matter causing the acid dissociation constants of the soil organic fraction to be decreased to approximately 10^{-6} compared with the value of 10^{-4} to 10^{-5} for carboxylic acids; thus organically complexed aluminium is not readily exchangeable with KCl but can be partially removed with strong acids or other metal cations such as Cu^{2+} (Thomas and Hargrove, 1984). Studies have shown that soil solution levels of aluminium are lower in organic soil than mineral soils at the same pH (Evans and Kamprath, 1970) or in soils receiving additions of organic matter (Hargrove and Thomas, 1981). Furthermore, solution culture studies by Bartlett and Riego (1972) and Hue *et al.* (1981) have confirmed that soluble aluminium-organic complexes are not toxic to plants.

pH and ionic strength

Aluminium toxicity in soils rarely occurs above pH 5.5. As the pH decreases below this value, the solubility of the element increases exponentially so that the probability of aluminium toxicity to plants becomes higher the lower the pH (McLean, 1976). This increase in soluble aluminium is related primarily to the solubility of $Al(OH)_3$ and aluminosilicates. Associated with a decrease in pH for a given soil is an increase in exchangeable aluminium, which probably equilibrates with the soil solution aluminium fairly rapidly.

In solution culture, the effect of ionic strength on the activity of monomeric aluminium species is reasonably predictable. In the absence of soluble polymeric and solid phase aluminium, the activity of the monomers will decrease with increasing ionic strength caused by the addition of a nonaluminium salt because of the decrease in activity coefficients. Where soluble polymeric species are present, this effect may be outweighed by the conversion of polymeric to monomeric forms. For example Blamey *et al.* (1983) found that increasing the ionic strength of a nutrient solution reduced the concentration of polymeric aluminium at high OH:Al ratios.

In soils where soluble aluminium is in equilibrium with exchangeable aluminium, structural aluminium in minerals, and aluminium in various organic combinations, the effect of ionic strength on solution aluminium will be determined by its effect on the solubility of these forms, in addition to the direct effect on activity coefficients of monomeric ions. Thus increasing the ionic strength of a soil through the addition of a soluble fertilizer has been found to markedly increase soluble aluminium (Fried and Peech, 1946; Brenes and Pearson, 1973). This effect is probably related to the effect of the electrolyte in displacing aluminium from the exchange complex and to the resultant depression in pH which then increases the dissolution of aluminium-containing minerals.

DIAGNOSIS OF ALUMINIUM TOXICITY IN SOILS

Plant Measurements

Symptoms

Toxic levels of aluminium depress the growth of many plants, but the symptoms of aluminium toxicity are not well defined. Foy (1984) indicates that foliar symptoms of aluminium toxicity often resemble those of phosphorus deficiency, induced calcium deficiency or iron deficiency. The roots of aluminium-affected plants are characteristically stubby in appearance, and the root tips and lateral roots may become thickened and turn brown; the whole root system has a coralloid appearance, having many thickened lateral roots but lacking in fine branching. Mild aluminium toxicity, however, may restrict plant growth in acid soils without plant roots or shoots showing any well-defined symptoms, and these subclinical effects have led to an underestimation of the importance of aluminium toxicity as a limitation to plant growth in these soils.

Tissue concentrations

Although some effort has been made to establish critical aluminium concentrations for toxicity in plant tops, this approach has not been successful in reflecting the limitations of aluminium toxicity on plant growth. The suggestion that the accumulation of aluminium in plant tops may reflect prior root damage caused by aluminium toxicity (Foy, 1984) may account for this lack of success.

Soil Measurements

Before discussing the various soil measurements that have been proposed to diagnose aluminium toxicity, it is relevant to reiterate that solution culture studies have shown that plant response to the element is determined by the solution activity of monomeric species. Thus monomeric aluminium activity in the soil solution should be a good predictor of aluminium toxicity for a given species if (i) the ratio of uptake of aluminium by the plant to the content of the element in the soil solution is sufficiently low that the solution activity does not change substantially with plant growth, or (ii) any decrease in activity of aluminium resulting from plant uptake is readily buffered by the release of aluminium from solid phase or soluble non-toxic (polymeric and organic) forms. If neither of these assumptions is true for a given soil, then one would predict that a combination of solution activity and an estimate of the buffer capacity should provide the best correlation with plant performance. Viewed against these general comments, the suitability of those parameters which have been generally proposed as useful diagnostic parameters (pH, exchangeable aluminium, exchangeable aluminium saturation, and soluble aluminium) can now be discussed.

pH

Although pH permits some prediction of the likelihood of aluminium toxicity, this parameter does not provide information on the potential severity of the toxicity. At pH values greater than 5.5, the level of soluble aluminium is rarely high enough to cause toxicity. Below this pH, the soluble aluminium concentration increases rapidly, but there appears to be no unique relationship between it and pH (Adams and Lund, 1966; Evans and Kamprath, 1970; Richburg and Adams, 1970; Carvalho *et al.* 1980).

Exchangeable aluminium

Exchangeable aluminium is normally defined as the amount of the element extracted by an unbuffered neutral salt such as 1M KCl. Whether or not all of the aluminium extracted in this manner is neutralizing negative charges has been the subject of some debate. It appears that in many soils 1M KCl extracts true exchangeable aluminium in addition to variable amounts of nonexchangeable forms, which could include amorphous $Al(OH)_3$, hydroxy-aluminium interlayers in aluminosilicates, or organic aluminium complexes. Evidence for this arises from the fact that the amount of aluminium extracted with salt solutions increases with (i) concentration of the extracting solution (Bache and Sharpe, 1976), (ii) soil:solution ratio (Ayres *et al.*, 1965), (iii) decreasing pH of the extractant (Skene and Sumner, 1967), and (iv) the number of successive extractions (Amedee and Peech, 1976).

Notwithstanding the possible deficiencies of neutral salt solutions in measuring exchangeable aluminium, this parameter has been used extensively in soil acidity investigations, especially for predicting the lime requirement (Kamprath, 1984). In the latter case, the improvement in plant growth on a given soil following lime application is generally well correlated with exchangeable aluminium. Poor correlations are generally obtained, however, when comparisons are made across soils (Adams and Lund, 1966; Adams and Hathcock, 1984).

Exchangeable aluminium saturation

This parameter can be defined as the proportion of the effective cation exchange capacity (ECEC) which is occupied by exchangeable aluminium, where ECEC is the sum of exchangeable bases, hydrogen and aluminium. This index of aluminium has been found to be more useful in predicting aluminium toxicity than the absolute amount of exchangeable element (Kamprath, 1978; Kamprath, 1984), but for a given plant species the critical saturation percentage often varies widely over a group of soils because the relationship between aluminium saturation and soluble aluminium is not a fixed one. Thus Adams and Moore (1983) showed that the aluminium saturation of toxic subsoils for the growth of cotton (*Gossypium hirsutum* L.) roots varied from 2.2 to 77%, whereas that of nontoxic subsoils ranged from 0 to 66%.

Soluble aluminium

Interest in relating soil solution aluminium to plant growth in acid soils started over 50 years ago (Pierre, 1931). Subsequently, a number of studies showed a relationship between plant growth and soluble aluminium but the critical aluminium concentration for toxicity varied among soils (e.g. Adams and Lund, 1966; Evans and Kamprath, 1970). In the study by Adams and Lund (1966), the correlation between the solution aluminium and plant response was greatly improved by expressing the solution level of aluminium as the molar activity of Al^{3+}. Similarly, in a study of the root growth of coffee (*Coffea arabica* L.) on six acid soils to which several levels of lime were added, Pavan *et al.* (1982) found that growth was more highly correlated with aluminium activity in the saturation extract ($r = 0.97$) than with any of the other four acidity parameters investigated.

Recent work by Adams and Moore (1983) and Adams and Hathcock (1984) has failed to show a consistent relationship between soil solution aluminium concentration or activity and the incidence of aluminium toxicity to cotton roots. These studies identified aluminium-toxic horizons which ranged in soil solution aluminium concentration from <0.4 to 14 µM, whereas in nontoxic horizons the range was <0.4 to 134 µM. This finding may be related to the analytical difficulty of distinguishing between monomeric inorganic aluminium and organically complexed forms of the element (Adams and Moore, 1983). As indicated previously, current evidence suggests organically complexed aluminium is not phytotoxic, and thus it is anticipated that the suitability of soluble aluminium as a predictor of phytotoxicity will be enhanced if a valid technique for discriminating between the inorganic and organic forms of the element in solution can be developed. Current research at the University of Queensland involving colorimetric methods with short-term reaction times holds promise for the development of such a method.

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SOIL ACIDITY MANAGEMENT WITH EXPERT SYSTEMS

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ABSTRACT

Soil acidity management should use a multifaceted approach, taking into account crops, soils, weather, and farmers' preferences. The recommendation process should be structured to ensure that major considerations are not overlooked. A rule-based expert system based on IF (condition) THEN (consequent) constructions has been developed to solve this problem. An expert system shell which provides a text editor and an interference mechanism is used, with Prolog as the declarative language.

The data currently required are Al plus H extracted by KCl, after determining critical aluminum saturation values for crops. Soil and weather data are used and combined to develop water-balance criteria. If laboratory data are not available, inferences from Soil Taxonomy are made. Before being entered in the data base, soil survey data are preprocessed, synthesizing the soil depths to which crop may grow or which may result from farmer cultivation and mixing operations. This pooling of information provides estimates of soil variability, which makes it possible to give precise estimates along with recommendations.

THE ROLE OF EXPERT SYSTEMS IN SOIL ACIDITY MANAGEMENT

Soil acidity is both a crop management problem and a soil management problem. In the past, we have tended to work with only one aspect at a time. A multifaceted approach, including crops, soils, weather and farmer preferences is needed in order to develop the best recommendations. The recommendation process should be structured to ensure that major considerations outside of one's area of expertise are not overlooked. One way of doing that is to systematically and patiently ask all pertinent questions. Experience shows that the novice frequently overlooks the broad questions and tends to find an explanation too quickly (Clancey, 1986). A good diagnosis should build on answers to the preliminary, broad questions, eventually narrowing in on a precise assessment of the problem.

Expert systems or knowledge-based systems were designed to record the questions, and the questioning sequence, of a highly experienced knowledgeable expert. As a result of experience, experts typically develop a repertoire of the most likely causes to be attributed to certain observations. This "knowledge base" is what the expert would use to determine the nature and cause of a problem and to make recommendations based on the answers to a list of questions. Depending on the subject, various types of information are needed for a diagnosis. In expert systems for soil management, soil taxonomic category and soil analytical data are needed. We have been assembling soil data from soil survey investigations to supply data as a general background to specific recommendations. A well-organized method of representing and retrieving such information becomes important as the volume of information grows. Rather than use standard data base management software for this purpose, however, we wish to capture and retrieve information in a way that is more natural to the information and to the user.

The quality of recommendations developed by an expert system is determined first by the quality of the expert's knowledge and second by the accuracy with which that knowledge is represented in the system. Methods to ensure the quality of the information and the accuracy of representation are only beginning to be developed. Later in this paper we will discuss knowledge representation in soil management and our own observations and experience.

The most innovative part of expert systems is the ease with which a variety of information can be represented and used in decision-making. This variety of information ranges from quantitative information, including statistical relationships such as regression equations and physical or chemical "laws" (sometimes referred to as "algorithmic" information), to less precise general rules of thumb or hunches that have been developed from hard-gained experience in the field (sometimes referred to as "heuristic" information). The latter type of information can now be preserved and utilized in a more systematic way.

KNOWLEDGE REPRESENTATION

Organizing and structuring information for representation in an expert system has given us new insight into the characteristics of agricultural information. When we seek to represent our information in a quantitative manner, it is apparent that there is a large amount of useful information that cannot be represented. A large amount of the useful information is heuristic information. Heuristic information is based on experience. This might include, for example, the fact that an approach has 'worked' in the past, is a good place to start questions, or as a conjecture it costs little or risks little if it is not correct. Clearly much of this type of knowledge can be gained best, and perhaps only, by experience. As a result of the importance of experience much of our working knowledge of agricultural systems seems to be quite regional. While the components of agricultural systems may be similar, the critical components for any one system may be completely different. This regionality of agricultural information needs to be recognized and represented to obtain a high quality knowledge base for soil and crop management.

In early versions of the soil acidity expert system we attempted to include taxonomic information, realizing that both diagnostic and accessory information is of considerable use in warning the user of possible problems in managing their particular soil. Qualifiers such as aquic- and fragi- are clear indicators of potential problem conditions for agriculture. This type of information should be considered in further expert systems concerning soil and crop management.

In using Soil Taxonomy as an organizational framework to store and retrieve information electronically, however, we have encountered several problems, which have led us to try more natural ways of storing and retrieving the information. The method most commonly used in developing expert systems, is 'rule-based' information storage. A rule-based knowledge base has most of its information stored as rules. A rule is a combination of antecedent conditions and consequents - a sequence of IF condition THEN consequent constructions. The antecedent conditions are the conditions required for the consequent to be inferred logically.

Another method of storage and retrieval of such information is based on 'frames' - hierarchical structures that can provide a framework for storage of diagnostic taxonomic criteria as well as properties correlated to, or frequently associated with, taxonomic category. For example, in the taxonomy of plants, each plant has a genus name, a species name, a family name, a class name, etc. Each name includes a progressively larger number of members until the plant and animal kingdom level is reached. Progressively more organisms are included at each level in the hierarchy and the statements become more general. Each level has its own criteria for differentiating among groups at that level. Within one taxon, the most specific category has "inherited" all of the features of the criteria from categories above. The frame concept in knowledge representation provides a computer-based structure for storing taxonomic criteria. The criteria can then be used to infer properties from higher levels in the taxonomy by tracing the inheritance of the properties and characteristics. Some preliminary results and observations associated with the use of frame representation have been given in Jones *et al.*, (1986). We have made preliminary use of a frame-based system in capturing and representing soil information for use in soil management (Table 1).

Table 1. Use of frames to represent soil taxonomic information.

```
------------------------------------------------------------------------
frame (ultisol):
************************************************************************
subsumers:  soil

subsumees:  xerult ustult udult humult aquult

properties
name_of_ultic_criteria + ((1,4), ultic_criteria)

frame (humult):
************************************************************************
subsumers:  ultisol

subsumees:  haplohumult tropohumult palehumult sombrihumult

properties:
suborder_diagnostic_properties + [Other ultisols that have
         either or both of the following characteristics:
          1. Have 0.9% or more organic carbon in the upper 15 cm
             of the argillic:  or
          2. Have 12 kg or more organic carbon in the soil per
             square meter to depth of 1 m below the base of the mineral
             surface, exclusive of any 0 horizon that may be present.]
name_of_ultic_criteria = ((1,4), ultic_criteria)

frame (haplohumult):
*********************************haplohumult****************************
subsumers:  humult

subsumees:

properties:
great_group_diagnostic_properties = [Other humults]
suborder_diagnostic_properties = [Other ultisols that have
         either or both of the following characteristics:
          1. Have 0.9% or more organic carbon in the upper 15 cm
             of the argillic:  or
          2. Have 12 kg or more organic carbon in the soil per
             square meter to depth of 1 m below the base of the mineral
             surface, exclusive of any 10 horizon that may be present.]
name_of_ultic_criteria = ((1,4), ultic_criteria)
------------------------------------------------------------------------
```

DEVELOPMENT OF ACID3, AN EXPERT SYSTEM FOR ACID SOILS

We have developed a soil acidity recommendation system that can be expanded to include many of the facets of soil and crop management as necessary rational information. Expert system techniques are used to obtain pertinent information from the user which is then combined with information in the system knowledge base to develop recommendations concerning the amounts of lime and other materials as suggested by the user's responses. This is achieved by using the information supplied by the user to determine the next questions. For example, if the user indicates that he is not familiar with the Sitiung transmigration area, the original region of application of the system, then the system will indicate that some Soil Taxonomy information will be needed in order to determine whether a valid recommendation is possible. If the user's soil is not of the orders Oxisol, Ultisol, then the diagnostic approach may not be valid and the system will so indicate. In this manner the system responds to the user's answers in determining the next step in the consultation and, as typical of expert systems, will respond to queries of why by indicating the rule or the rationale behind the questions asked of the user.

The data currently required for our expert system are extractable Al plus H as determined by KCl extractable bases for use in calculation of Al saturation, estimates of bulk density and approximate depth of incorporation. The system has been developed for the equation proposed by Cochrane *et al.* (1980) which determines how much lime must be added to reduce the aluminum saturation of the soil to that tolerated by the crop. Extractable Al plus H is thus emphasized as the primary basis for liming. Equally important is the critical aluminum saturation level required by a crop to sustain near maximum growth. Critical aluminum saturation values for the major agronomic crops have been estimated from field experiments and tabulated in the system. If the grower wishes recommendations for crops other than these, values of critical aluminum saturation must be entered.

The system currently being developed (ACID4) uses soil survey and weather data, if available, for the area in question. Soil and weather data will be combined to develop a water balance from which drought and fertility interactions can be deduced. For example, the system will access soil survey data and determine whether particular constraints are likely. If the laboratory data are not available, inferences from Soil Taxonomy are made. However, if a grower does not have specific data or if there are no soil survey data for the area, no recommendation will be developed.

SOIL DATA BASE

Soil survey data are preprocessed before inclusion in the data base. Preprocessing includes synthesizing soil depths to which the crop may grow or which might result from farmer cultivation or mixing operations. At the present time we synthesize by depth increments of 15 cm. This enables us to consider what soil characteristics the crop might encounter at various depths of rooting. In addition, this standardization of depths permits pooling soil survey information in a manner necessary to derive estimates of variability. With pooled data, the mean values of extractable Al and H can be computed together with corresponding estimates of variances for the soil area. For the Sitiung soil survey area in Indonesia we have computed the means and variances of extractable Al plus H, effective CEC, and soil pH for most mapping units. Having these calculations stored in the soil data base permits the generation of an estimate of precision of the recommendation as it is being generated (Table 2). In this way, the recommendation is based on more complete knowledge not only of a mean value but also of the expected variation in the recommendation. To our knowledge this is not systematically done at present.

By directly accessing a soil data base for a region, a person without extensive knowledge of soil chemical measurement or of crop nutrient requirements can develop recommendations nearly as accurately and comprehensively as an experienced person with chemical data in hand. This system further permits far more precise recommendations than is possible with Soil Taxonomy alone. All the warnings, inferences and experience suggested by Soil Taxonomy can be included as cautions when advisable. Key concepts or data are documented in the system for reference and for teaching inexperienced users.

Although we are currently using soil survey data only in developing recommendations for acid soil management, such data will be useful for making other soil and crop management decisions. These data, together with accurate weather records, could provide a sound basis for rapid assessment of potential use and for identification of possible management constraints for land-use planning in new areas, and also could provide a repository for current experience and management of existing systems. Future versions of the system will provide a more extensive soil data base and will utilize water-balance information to assess the effect of increasing the depth of rooting on drought resistance, nutrient leaching, and Ca movement into the subsoil. As described above, the soil data base will include estimates of variance associated with each of the data for use in forming estimates of precision for computed values for the variety of interpretations.

Table 2. Propagation of error through simple equations as predicted by first-order uncertainty analysis (assuming uncorrelated inputs). An example using Cochrane's equation to predict lime requirement (following Benjamin and Cornell, 1970).

Step 1. Write the equation,

LR = LF*(Extral - CAS (ECEC))

where LR = lime requirement, LF = lime factor (assumed to be 1.5),

Extral = extractable Aluminum (cmol (+)/kg), CAS = critical Aluminum saturation expressed as a decimal between 0 and 1, ECEC = effective cation exchange capacity (sum of Al, Ca, Mg, K, and Na), cmol (+)/kg).

Step 2. Write the partial derivatives for the input variables:

dLR/dECEC = -1.5 CAS
dLR/dAl = 1.5
dLR/dCAS = -1.5 ECEC

Step 3. Evaluate the derivatives at the mean values of the input variables. Means and variances of Al, ECEC, and CAS for the Sitiung, Indonesia case:

Variable	Mean	Variance
ECEC	5.75	1.30
Al	5.09	1.06
C.Alsat	0.30	0.05

so:

dLR/dECEC = -0.45
dLR/dAl = 1.5
dLR/dCAS = -8.63

Step 4. Multiply the evaluated derivatives by the variances associated with the means of the input variables using the formula Var (LR) = bT*C*b, where bT is the transpose of the vector of partial derivatives, C is the covariance matrix, and b is the vector of partial derivatives. Note: we have assumed uncorrelated inputs which results in zero off diagonal elements of the covariance matrix. To include covariance one needs only to supply the covariances and multiply as before.

	Derivatives	Covariance matrix		
LR/ECEC	-0.45	1.30	0.0	0.0
LR/Al	1.50	0.0	1.06	0.0
LR/C.Alsat	-8.63	0.0	0.0	0.05

Var(LR) = 6.37 or the standard deviation is 2.52 Mg lime/ha

USING SOIL TAXONOMY TO RETRIEVE SOIL INFORMATION

Several difficulties have been encountered from the current method of representing and classifying soil information. These difficulties include the following:

The actual classification of a soil must be done according to the sequence described in Soil Taxonomy. Following a different sequence can result in a completely different classification of the soil. This aspect of the sequence, which is critical to consistent classification, is the procedural aspect. Not only must the criteria for classification be specified but also the sequence in which they are applied. As we will see later, the procedural aspect imposes constraints on information retrieval and the interpretation of taxonomic information. For example, a soil with aquic properties within the surface 30 cm will be classified as an Oxisol if the sequence specified in Soil Taxonomy is followed. If, for various reasons, one first looked at Ultisol criteria, the soil would be classified as a Plinthaquult. Thus the classification depends on the sequence in which the diagnostic criteria are applied.

The retrieval of taxonomic information associated with a soil name, however, is not a procedural action. We may retrieve information or make interpretations on any soil series, family, or great group in any sequence that suits our needs. This type of query is declarative in that the question is stated without regard to sequence. Thus the action of classifying a soil is procedural, but the retrieval of information concerning a particular soil is declarative. This mixing of procedural and declarative approaches is likely to lead to inefficient information retrieval as well as cases of misunderstanding. One result of the procedural aspect is that one could have a soil classified for example as a Plinthaquult and as an Oxisol. The properties of the soil fit both sets of criteria; but because Oxisols precede in the classifying procedure, the soil should be an Oxisol. Thus, Soil Taxonomy does not fit the criteria of a key for use in automated information retrieval.

One suggestion might be to ensure that the specific diagnostic properties are both 'necessary' and 'sufficient' to classify a particular soil in any sequence. Even though the necessary diagnostic properties of a soil category are clearly stated in Soil Taxonomy, the 'sufficient' deficiency presents problems. To be sufficient to classify the soil it must not only have the diagnostic properties but these properties must also be considered or evaluated in the sequence prescribed by the Taxonomy. Hence the phrase, found abundantly in the Taxonomy, "Other Oxisols that are not Aquox, Humox, Torrox, or Ustox." From an information retrieval viewpoint this also presents problems. One must know the diagnostic criteria for not only Orthox but for Orthox, Humox, Torrox, and Ustox in order to infer the properties of Orthox.

One other observation relates to the use of 'or' in the Taxonomy. At various levels of the taxonomic key one is presented with options of one set of criteria or another. Having optional criteria in this manner increases the probability of having sufficient data to classify the soil. From an information retrieval viewpoint, however, there are difficulties. Offering divergent criteria for the options of the 'or' leads to significant loss of information upon retrieval. Upon retrieval one does not know which of the divergent options describes the soil, and one cannot definitively state that the soil has either of the sets of criteria. An analogy is the loss of information when one expresses minimum temperature as a percentage of maximum temperature. One might obtain a percentage of 80% for both 20/25 and 12/15, but the consequences to a crop are dramatically different. We have lost the information on maximum and minimum temperature in forming the percentages. In a similar manner we have lost the criteria on either side of the 'or' that we used in classifying our soil. An example of the use of 'or'in Taxonomy is given in Table 3. Thus we find that the 'or' makes classifying soils easier but results in a loss of information in the resulting classification.

Table 3. Example of the use of 'or' in Soil Taxonomy.

C. Other soils that

1. **Have an aquic moisture regime and have plinthite that forms a continuous phase within 30 cm of the surface of the mineral soil; or**

2. **Have an oxic horizon within 2 m of the soil surface but do not have a plaggen epipedon and do not have either an argillic or a natric horizon that overlies the oxic horizon.**

go to: Oxisols, p. 323

These considerations point to the need to re-evaluate the fundamental concepts of purpose and logical structure in this method of information condensation, storage, and retrieval.

USING TAXONOMY TO INFER QUANTITATIVE SOIL PROPERTIES

More and more scientists, policymakers, and land-use planners are requiring numerical data in making decisions. Taxonomy has been used to group and classify objects and properties into units that can be managed and manipulated conceptually for making decisions. With the advent of microprocessor-based tools for data and information management, we have substantially expanded our ability to retrieve specific data and use it in decision-making. For example, few people can remember the morphological composition of soils as explicity described in profile descriptions, nor of the exact numbers of cation contents, clay contents, etc. in each of the horizons of a large number of the soils with which they work. However, most of them are able to retain the key features of the information and readily use these features in decision-making and in discussing general concepts. Discussions and decisions can be markedly improved by access to specific data, particularly if there is a need to reconsult data when faced with an unexpected question. This points out the advantage of having access to the specific data whenever and wherever one is in a decision-making position. Intelligent data bases, those which store both facts and logical relationships, improve the quality of decisions and problem-solving in soil management situations.

Certain applications of Soil Taxonomy in the past have taken advantage of the ability of Taxonomy to retain the essential information without losing all the detail. With new information management techniques this purpose and use of Taxonomy is changing and we are asking Taxonomy to be more descriptive and retain more information. At the same time, availability of shared data bases is growing which will offer rapid access to specific detailed information, an option that in the long term will fundamentally alter the purpose and use of Soil Taxonomy.

If well designed, an expert system with supporting weather and soil data bases could serve as an information transfer mechanism among researchers, and also serve as an effective decision support system for a variety of users from laboratory personnel with data needing interpretation to land-use planners with little data. With the inclusion of a soil data base and weather data, such systems could be used by government planners to explore potential costs or various land development schemes. These systems are a powerful new method of using soil survey information for land-use planning.

Expert systems which have been carefully crafted to contain practical, experience-based knowledge offer potential assistance in developing problem-solving methods and procedures to diagnose and suggest remedies for soil acidity-related constraints to crop growth. Such systems can be improved by increased amounts of soil, crop and weather data. The data base format offers a method to store, in a highly accessible way, the soil, crop, and weather data needed to develop accurate diagnoses and recommendations by the expert system.

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SOIL ORGANIC MATTER, CROP RESIDUE AND GREEN MANURE MANAGEMENT

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ABSTRACT

It is generally agreed that the management of tropical soils for plant production requires a careful look at the soil organic matter content. Results of some studies in Thailand reveal that organic matter content of highly leached upland soils is commonly low, and it decreases sharply within 40 cm from the soil surface. Long-term experiments on the effects of crop residue and green manuring crops on the yield of field crops have given favorable results, suggesting the need for organic matter maintenance in the soils to sustain economically feasible crop production. Techniques for soil organic matter maintenance should be explored on broad soil groups to suit each crop practice so as to assist in the practical transfer of soil management technology.

INTRODUCTION

It is recognized that soil organic matter plays an important role in determining the physicochemical and microbiological properties of soils (Brady, 1974). The properties that can be enhanced by soil organic matter include bulk density, moisture content and moisture retention, soil aggregation and aeration, soil permeability and infiltration capacity, cation exchange capacity, and other chemical properties (Brady, 1974; Eiumnoh, 1977; Kononova, 1966; Parr *et al.*, 1978; Zawadzki, 1970). Some activities of heterotrophic microorganisms, especially non-symbiotic N_2 fixers, can be stimulated by organic matter in soils (Vangnai, 1978). In humid tropical conditions where soils have been continually leached and the rate of mineralization is rather rapid, the influence of organic matter on the other properties of soils is commonly intensified (Sanchez, 1976). There is therefore a need to maintain organic matter in order to sustain or promote the fertility and productivity of soils in agricultural practices, and the upland soils in Thailand share this requirement. To develop management strategies for the maintenance of soil organic matter, it is important to consider the general organic matter status of the soils, the crop residue and the management of green manure. The purpose of this paper is to present some data on the organic matter status of upland soils in Thailand, and to disucss some results of the experiments on crop residues and green manure management conducted on these soils. The data and results may be used as background information for formulating a soil-based research program.

STATUS OF ORGANIC MATTER CONTENT IN UPLAND SOILS

It is not uncommon for upland soils under forest conditions in Thailand to have high to very high organic matter in the surface soil. Some data concerning these soils are given in Table 1. Nevertheless, the zone enriched with organic matter in these soils is not thick, and there is always an abrupt cessation of organic matter content between the upper and the lower parts of the profiles. The profile shows variations in some other chemical properties as well, similar to those exhibited by the organic matter content. The marked difference of cation exchange capacity values between the upper and the lower part of the soil profile strongly indicates the influence of organic matter. This is probably a typical condition for the humid tropics.

In order to compare the soils under forest with those under other kinds of land use, the same set of

Table 1. Organic matter status and other related properties of some soils under forest in Thailand.

Depth (cm)	Horizon	O.M. (%)	Avail. P (ppm)	Avail. K (ppm)	CEC meq/100 g	B.S. (%)	pH 1:1H_2O	Remarks
			Orthoxic Palehumults; fine-silty, mixed, isohyperthermic					North
0-35	A1	11.86	3.7	65	26.32	2.85	5.2	(Chiang Mai)
35-58	A2	5.40	6.1	24	20.15	3.77	5.2	Hill evergreen
58-82	Bt1	2.29	2.0	23	21.13	5.31	4.8	
82-105	Bt2	1.30	0.8	14	6.48	3.90	4.8	
105-195+	BC1	0.32	0.6	18	11.93	5.07	4.7	
			Oxic Paleustalfs; fine, kaolinitic, isohyperthermic					North
0-5	A1	5.51	42	269	13.94	57.3	6.4	(Chiang Mai)
5-25	Bt1	2.11	1.5	312	10.66	58.3	5.2	Deciduous
25-50	Bt2	0.92	1.2	230	10.30	42.2	4.8	
50-95	Bt3	0.75	0.39	136	10.32	50.1	4.8	
95-115	Bt4	0.84	0.9	81	9.27	56.6	4.9	
115-135	Bt5	0.75	0.8	85	9.17	57.3	5.1	
135-170	2Bt6	0.58	1.0	78	8.90	57.4	5.1	
170-182+	2BC	0.51	1.4	39	8.20	56.9	5.2	

properties for the latter soils is shown in Table 2. These are properties of well established soil series in different physiographical regions of Thailand (Moormann and Rojanasoonthon, 1972). Their organic matter content in the epipedon is collectively low, but the trend of its distribution within the profiles is similar to those presented in Table 1. It will be noted that the lower amount of organic matter content in the surface soil does not result in any marked difference of chemical properties between the surface soil and the lower horizons.

Though all of these soils are deep to very deep, the zone which contains a reasonable amount of organic matter is not particularly thick. Normally the sharp break can be observed within a depth of 40 cm, and coincides with the upper limit of the argillic horizon of the soils. In many soils, however, clay coats due to erosion can also be observed in the surface soils, and in such cases the zone of organic matter can rarely exceed 20 cm.

Data on the organic matter in the soils can be compiled for each region in Thailand, based on the results of the soil surveys carried out by the staff of the Soil Survey Division in the Department of Land Development. Scattered data can be obtained from the individual research of soil scientists in the Department of Agriculture and the universities. So far, however, there have only been a few research projects conducted to evaluate the extent and persistence of organic matter in the soils. For the northeast region, it has been reported that under native vegetation the organic matter content of some upland soils may be as high as 10% (Pairintra, 1981). Nevertheless, in areas subjected to long periods of cultivation, the range of the average values of organic matter content of upland soils in the northeast region is 1.0 to 1.5% (Department of Land Development, 1981, 1983; Ragland and Craig, 1983). Due to the highly leached acidic condition of the soils, chemical fertilizer management does not seem to be very effective, and methods for soil fertility status improvement have been sought. Various recommendations have been made for improving the soil organic matter content, viz. the introduction of crop residues or plant remains, composts, organic wastes, animal manure and green manure into the soils, and recently some experiments have been carried out to assess these procedures.

Table 2. Organic matter status and related properties of soils under different land uses.

Depth (cm)	Horizon	O.M. (%)	Avail. P (ppm)	Avail. K (ppm)	CEC meq/100 g	B.S. (%)	pH 1:1 H_2O	Remarks
		Mae Taeng series: Oxic Paleustults; clayey, kaolinitic, isohyperthermic						North
0-13	A1	1.21	41.10	72	3.5	43.10	5.6	Cassava
13-24	AB	0.53	68.5	81	3.9	46.13	5.7	
24-60	Bt1	0.31	4.4	94	5.3	29.81	4.9	
60-115	Bt2	0.19	1.7	43	6.3	14.85	5.3	
115-146	Bt3	0.18	0.9	36	6.2	23.33	4.9	
146-180+	Bt4	0.10	1.6	50	6.1	36.99	5.1	
		Yasothon series: Oxic Paleustults; fine-loamy, siliceous, isohyperthermic						Northeast
0-14	A	1.11	7.0	59	1.8	44.3	5.8	Kenaf
14-43	Bw1	0.72	3.0	12	1.3	14.7	4.1	
34-62	Bw2	0.49	2.0	8	1.2	17.8	4.3	
62-85	Bt1	0.49	2.0	8	2.1	16.2	4.1	
85-115	Bt2	0.34	2.0	8	2.0	15.1	4.1	
115-150	Bt3	0.31	1.0	8	1.6	22.6	4.1	
150-175	Bt4	0.31	2.0	4	1.3	26.4	4.1	
175-200+	Bt5	0.26	1.0	4	1.6	16.6	4.1	

CROP RESIDUE AND ITS MANAGEMENT

Though returning crop residues into the soils reduces the loss of plant nutrients, the actual management of this procedure involves several problems. The first problem is the short growing season. Normally, to allow the crop residue to decompose completely a period of at least two or three weeks is required before the following crop can be cultivated successfully under rainfed conditions. The second problem is plant pests. Sometimes the crop residues have to be burnt away just to stop the pests. Thirdly, some crop residues are essential for other uses, i.e. animal feeding, mushroom production, or even mulching.

Most of research work conducted on crop residues in the past decade has concentrated on rice straw in the lowland areas to improve the yield of rice (Naklang *et al*., 1980a, 1980b). All of the results suggest that the incorporation of rice straw markedly increases the growth and yields of rice, especially when rice straw is used continuously and/or in combination with chemical fertilizer.

For the upland soils under field crops, some results from experiments have been encouraging. An experiment on the effects of crop residues on sorghum yield has been reported (Thawornmas and Dechsongchan, 1979), and details of the treatments are shown in Table 3. It was found that the incorporation of crop residues, Vigna (harvested), mungbean and groundnut tended to increase the yield of sorghum (see Table 4). Also, long-term experiments designed to evaluate the effects of crop residues on cassava yields were carried out from 1975 through 1981 and reported by Sithibusya *et al*. (1981). The experiments were conducted on Ultisols at three different locations. The design of the experiments was randomized complete block with four replicates and eight treatments or rotation pattern (see Table 5). The results clearly indicate that the incorporation of crop residues (legumes) in the crop rotation systems increases the yield of cassava markedly (see Table 6). The average organic matter contents of the soils at Huay Pong and Banmai Samrong when crop residues were returned increased from 1.1 and 1.2% to 1.5 and 1.4% respectively. However the level of organic matter content of the soil at Khon Kaen remained virtually constant.

Table 3. Treatment description of the experiment conducted by Thawornmas and Dechsongchan (1979).

1	Check (Sorghum)
2	Check + 20-20-0 (kg/rai)
3	*Clitoria*[1] - sorghum
4	*Clitoria*[1] - sorghum + 20-20-0 (kg/rai)
5	*Crotararia*[1] - sorghum
6	*Crotararia*[1] - sorghum + 20-20-0 (kg/rai)[3]
7	*Vigna*[1] - sorghum
8	*Vigna*[1] - sorghum + 20-20-0 (kg/rai)
9	*Vigna*[2] - sorghum
10	*Vigna*[2] - sorghum + 20-20-0 (kg/rai)
11	Mungbean[2] - sorghum
12	Mungbean[2] - sorghum + 20-20-0 (kg/rai)
13	Groundnut - sorghum
14	Groundnut - sorghum + 20-20-0 (kg/rai)

1. as green manure crops.
2. as harvested crops.
3. 6.25 rai = 1 hectare.

Table 4. Effects of incorporation of crop residues and chemical fertilizers on sorghum yield (Thawornmas and Dechsomgchan, 1979).

Treatment[1] No.	Straw dry weight of first crops (kg/rai)[2]	Seed or pot weight of (kg/rai)	Sorghum yield (kg/rai)
1	--	-	84
2	--	-	341
3	527	-	266
4	148	-	203
5	2,139	-	287
6	2,152	-	550
7	702	-	181
8	774	-	428
9	559	1,111 (fresh pot)	276
10	847	1,171 (fresh pot)	376
11	148	78	197
12	85	56	142
13	464	178	260
14	421	162	410

1. Detailed treatments are described in Table 3.
2. 6.25 rai = 1 hectare.

Table 5. Treatment description of the long-term experiment conducted by Sithibusya *et al.*, 1981.

Treatment[1] No.	Treatment[2]
1	Cassava (every year)
2	Cassava 1 year - groundnut 1 year
3	Cassava 2 years - groundnut 1 year
4	Cassava 3 years - groundnut 1 year
5	Cassava 1 year - mungbean 1 year
6	Cassava 2 years - mungbean 1 year
7	Cassava 3 years - mungbean 1 year
8	Cassava (every year)

1. All treatments, except treatment No. 8, recieved chemical fertilizers 8-8-8 kg/rai.
2. Year indicates growing season.

Table 6. Effects of crop residue incorporation on cassava (root) yield (ton/rai) (Sithibusya *et al.*, 1981).

Treatment No.[1]	Cassava (root) yield (ton/rai)[2]		
	Huay Pong[3] (6th year)	Banmai Samrong[3] (6th year)	Khon Kaen[3] (5th year)
1	4.81 (5.97)	3.89 (5.49)	4.08 (2.95)
2	-	-	5.28 (3.84)
3	5.88 (6.63)	4.26 (5.22)	4.42 (3.07)
4	5.19 (6.50)	4.48 (5.07)	5.07 (3.50)
5	-	-	5.01 (3.52)
6	5.42 (6.90)	4.51 (5.41)	4.24 (2.97)
7	6.02 (6.99)	3.89 (5.52)	5.40 (3.82)
8	4.42 (4.50)	3.01 (3.65)	2.26 (1.75)

1. Treatment descriptions are presented in Table 5.
2. Numbers in parenthesis indicate weight of upper parts of cassava.
3. Huay Pong, Rayong (southeast coast)
   Banmai Samrong, Nakhon Ratchasima (northeast)
   Khon Kaen (northeast).

There are many more results from experiments on the incorporation of crop residues of different forms into soils to increase the yield of the main crops, and all the results so far suggest the beneficial effect of maintaining organic matter content by using crop residues in the soil management practices.

GREEN MANURE AND ITS MANAGEMENT

It is recognized that legumes generally possess suitable characteristics for use as soil-improving crops. These plants contain a relatively high nitrogen content, and due to their special characteristics they can grow well on soils with low organic matter and nitrogen contents, and can subsequently help to improve the organic matter status of the soils. Recently several experiments have been conducted on green manuring crops (Donsae *et al.*, 1981; Na Nagara and Pliesri, 1975; Sukthumrong *et al.*, 1986; Thawornmas *et al.*, 1977). *Crotararia, Vigna sinensis, Lablab pupereous, Mimosa invisa, Sesbania speciosa* and *Arachis hypogaea* are the legumes popularly used as green manure in Thailand.

Long-term rotations of green manure-corn were practiced for six years at the National Corn and Sorghum Research Center in Pak Chong, Nakhon Ratchasima. The experiment plots were on Pak Chong soils (Oxic Paleustults; clayey, kaolinitic, isohyperthermic). It was observed that the yields of corn improved rapidly under repeated rotation of *Lablab* and *Mimosa*, and reached a plateau of 6-7 tons/ha in the fourth rotation. Phosphorus and NP fertilizers accelerated the rate of yield improvement to a certain extent but did not show any distinct advantage after the fourth rotation. Soil analyses clearly showed an accumulation of total nitrogen and organic matter under both *Lablab* and *Mimosa* rotations, indicating an abundant supply of organic nitrogen from both legumes (Sukthumrong *et al.*, 1986). Another report of a study conducted on the long-term effects of mulching with fertilization under corn-legume cropping on corn yield and soil chemico-physical properties also indicated that green manure plays an important role in soil improvement and the maintenance of organic matter (Phetchawee *et al.*, 1986). The last study was also carried out on an Oxic Paleustult; clayey, kaolinitic, isohyperthermic.

CONCLUSION

From the data and results presented, it will be apparent that upland acid soils in Thailand under different cropping practices generally have organic matter levels which are too low. The response of crops in terms of growth and yield is always favorable when crop residue and green manure management is practiced and therefore the maintenance of organic matter content on these soils is genuinely needed for successful cropping. Since there are several methods to choose from to suit a particular environment, further specific research related to different soils would seem to be advisable. Nevertheless, the chemical and physical properties of these acid upland soils are not dramatically different, and consequently it would be more practical to consider only broad groups of representative soils in the research rather than very specific soils so as to ensure that the more generalized results can be directly applied at the farm level. In addition, most of the experiments conducted encompassed the use of chemical fertilizers. Therefore to overstress the organic aspects of fertilizer and organic matter maintenance can be quite misleading.

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DYNAMIC BEHAVIOR OF PLANT NUTRIENTS IN UPLAND SOILS IN NORTHEAST THAILAND

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ABSTRACT

In 1985, the Agricultural Development Regional Centre (ADRC) in northeast Thailand initiated a project to improve the management of sandy infertile soil under rainfed conditions. About 30 series of upland soils in the northeast were collected in 1985 and their chemical and physical properties were analyzed. In low and middle or high terraces, most soil series showed a sand or sandy texture, while there were more clayey soils in the flood plain or in areas subject to erosion.

Corn cultivation was carried out in pot experiments to study the soil productivity of three upland soils. They showed very low nitrogen, relatively high potassium, and all except one had poor phosphorus resources. The nitrogen utilization rate in sandy soils was lower than that in clayey soils.

Concrete-frame plots measuring 3 x 3 m were used in investigations to determine water runoff and soil loss in sandy soils and clayey soils, and it was found that the amounts were rather smaller in sandy soils than in clayey soils. But the leaching of nitrogen, potassium and magnesium in sandy

soils filled into eslon tubes was quicker than in clayey soils.

The nutrient movement in Warin soils was studied by using a lysimeter. The results indicated that considerable amounts of exchangeable bases were leached out, as well as nitrate and chloride ions. Nitrate leached out in mulching plots and compost plots was slightly higher than in non-mulched plots. Double amounts of fertilizer caused more nutrient loss by leaching, but the growth and yield of plants were worse than in the plots where normal fertilizer was applied with the incorporation of mulching or compost. Depending on the amount of leaching, the nitrate content in the soil accumulated much more in the subsoil than in the surface soil.

INTRODUCTION

The northeast constitutes one third of both the population and land area of the whole kingdom, but generates only 15% of the gross domestic product. The region was developed through deforestation starting in the 1940s onward, and rapidly lost its crop productivity since various crops were planted by individual farmers for basic subsistence. The alternating droughts and floods or heat and humidity of the tropics accelerated the decomposition of organic resources in the arable lands; nutrients were lost through crop removal and leaching, and erosion from the soils also occurred, especially in soils with a low clay content.

The soils of the northeast are mostly sandy soils of sandstone origin. These sandy soils are fine sand or sandy loam on the surface with some increase of clay content at a certain depth, and they are quite infertile in comparison to the soils of other regions of the country.

To increase agricultural production in the northeast, an improvement of the production pattern, from an extensive to an intensive system will be required, especially in the sandy infertile upland soils. Appropriate utilization of land and water resources has to be studied using scientific methodology; cropping systems suited to localities also need to be developed.

The present study is intended to clarify the behavior of water, nitrogen and potassium in sandy soils in relation to mulching effects. It is being carried out at the ADRC experimental farm as a part of the research program of the Agricultural Development Research Project in northeast Thailand. This is an ongoing project, with some of the findings being presented in this paper.

Fertility Status of Various Soil Series in the Northeast

Approximately 30 soil series in the northeast were sampled in late 1985 and these samples were analyzed for their chemical and physical properties. The data are shown in Table 1.

The table indicates that the soil series from the areas of the flood plain and the erosion surface are mostly of clayey soils, while the soils from the low terrace and the middle and high terraces are mostly sandy, except those of the Phon Phisai series.

In addition, more than half of the samples show a low pH, and 9 out of 51 soil samples have high acidity. Most soils in the northeast have low available phosphorus contents, except in the case of some particular soil series.

Growth of Corn on Three Different Upland Soils

Most of the soil series in the northeast are sandy and of low fertility, which means that only cassava and kenaf can adapt naturally to them; but corn and sorghum can also be grown if given special care. Decreasing soil productivity is often observed in ongoing land utilization systems.

This trial is intended to clarify the effects of each nutrient element on the growth and yield of corn grown on three major soil series of Oxic Paleustults.

Table 1. Some analytical results in the major soils of the northeast.

	Lab No.	Soil series	Depth cm	pH H_2O	pH KCl	yl	Texture	Available (ppm)	Location/land use
Flood plain	31	Tha muang	0-15	8.03	7.30	0.4	CL	69.4	Nong Khai/jute
	32	"	15-	8.04	7.41	2.1	SiCL	58.8	
	33	Sanpaya	0-10	6.90	5.73	0.4	CL	31.0	Nong Khai/rice
	34	"	10-40	6.51	5.13	0.4	CL	8.8	
	35	"	40-60	6.45	4.93	0.5	CL	25.8	
	36	Ratchaburi	0-15	6.40	5.20	0.4	SiCL	43.0	Nong Khai/jute
	37	"	15-35	6.60	5.41	1.5	SiCL	42.0	
	38	"	35-	6.80	5.50	3.2		3.0	
	56	Sri Songkhram	0-11	4.52	3.73	18.2	LiC	14.0	Mahasarakham/rice
	57	"	11-22	4.38	3.61	70.3	LiC	2.0	
	58	"	22-35	4.40	3.73	31.7	LiC	2.0	
Low terrace	61	Tha tum	0-8	6.20	4.50	1.5	S	2.0	Roi-et/bare land
	62	"	17-28	7.70	6.22	1.4	SCL	1.0	
	74	On	0-24	6.30	5.23	1.7	L	12.0	Sakonnakorn/rice
	71	Phen	0-10	5.18	3.90	14.0	SL	4.5	Sakonnakorn/bare land
	72	"	10-34	5.60	4.70	5.9	SCL	0.8	
	73	"	34-58	5.52	4.26	26.9		1.5	
	66	Ubol	0-12	5.65	4.41	2.4	S	1.0	Srisaket/bare land
	67	"	12-25	5.80	4.49	2.1	S	1.0	
	68	"	25-42	5.52	4.33	3.4	S	0.5	
	59	Udorn	0-12	5.71	4.23	2.1	S	5.5	Roi-et/rice
	60	"	12-25	6.20	4.51	1.8	S	1.0	
	63	Kula Ronghai	0-15	5.04	3.95	4.4	LS	28.5	Kula Ronghai/mango trees
	64	"	24-36	5.01	4.00	6.4	SL	26.0	
	65	"	36-60	5.21	4.17	5.9	LS	14.5	
Middle high terrace	1	Korat	0-21	6.53	6.06	1.2	S	80	Tha phra/cassava
	2	"	21-40	6.41	5.81	1.6	S	21	
	3	"	40-60	6.20	5.49	1.7		41	
	21	Satuk	0-20	6.60	5.70		S	6	Khon Kaen
	22	"	20-	6.42	4.81		LS	2	Kham bon/jute-cassava
	84	Warin	0-23	5.21	4.21		SL	16.3	Khon Kaen
	85	"	23-53	4.63	4.14		SL	6.6	ADRC/jute
	86	"	53-91	5.01	4.51		SL		
	87	"	91-	4.60	4.11		SL		
	15	Yasothorn	0-18	5.30	4.20	3.1	LS	9	Ban Kham bon
	16	"	18-28	4.94	3.92	5.9	SL	2	/jute, cassava
	23	Namphong	0-14	6.00	5.05	1.6	S	2	Ban Kham bon
	24	"	14-34	6.32	5.41	1.6	S	1	/jute, cassava
	39	Phon Phisai	0-15	5.20	4.00	7.5	SCL	4.8	
	40	"	15-25	5.10	4.00	32.4	LiC	3.3	
	41	"	25-	5.00	4.10	28.2	LiC	3.0	
	75	Sakon	0-12	6.10	4.98	1.9	SL	8	Sakonnakhon/forest
	76	"	12-23	6.40	5.32	2.1		4	
Erosion surface	50	Loei	0-20	5.65	5.10	1.8	LiC	3.0	Chiang Khan/taro
	51	"	20-30	5.70	5.20	2.0	LiC	2.5	
	52	"	30-	5.31	4.80	1.3	LiC	1.5	
	48	Wanghai	0-16	6.20	5.31	2.0	CL	4.0	Loei FCES/corn
	49	"	16-	6.07	5.02	2.0	CL	1.8	
	45	Wang Saphung	0-12	5.25	4.01	4.9	SCL	4.3	Loei FCES/bare land
	46	"	12-35	4.94	3.90	17.2	SCL	1.8	
	47	"	35-	4.90	3.72	30.9	CL	2.0	
	42	Thali	0-17	6.17	5.49	2.7	LiC	4.0	
	43	"	17-30	6.31	5.31	0.7	LiC	4.0	Loei FCES/cotton
	44	"	30-	6.02	5.28	1.8	CL	1.5	
	53	Chiang Khan	0-10	5.98	5.00	2.0	SCL	3.0	Chiang Khan/corn
	54	"	10-20	6.76	5.40	1.3	L	1.5	
	55	"	20-40	5.66	4.42	3.5	L	1.0	
	172	Pak Chong	0-15	7.30	6.30		LiC	31.5	Pak Chong LDS/grass
	173	"	15-28	7.15	6.15		LiC	3.8	
	174	"	28-45	7.00	6.01		LiC		

Work plan

Series of soils:

- Tha Phra soil in the Korat soil series: Gray podzolic soil representing sandy soils from Ban Nan Kung, Tha Phra, and Muang Khon Kaen.

- Phra Phutthabat soil in the Pakchong soil series: Reddish-brown lateritic soil representing standard soil for corn cultivation and of CL.

- Loei soil in the Chiangkhan soil series: Reddish-brown lateritic soil representing northeast fertile soil from Loei Field Crop Experiment Station and of LiC.

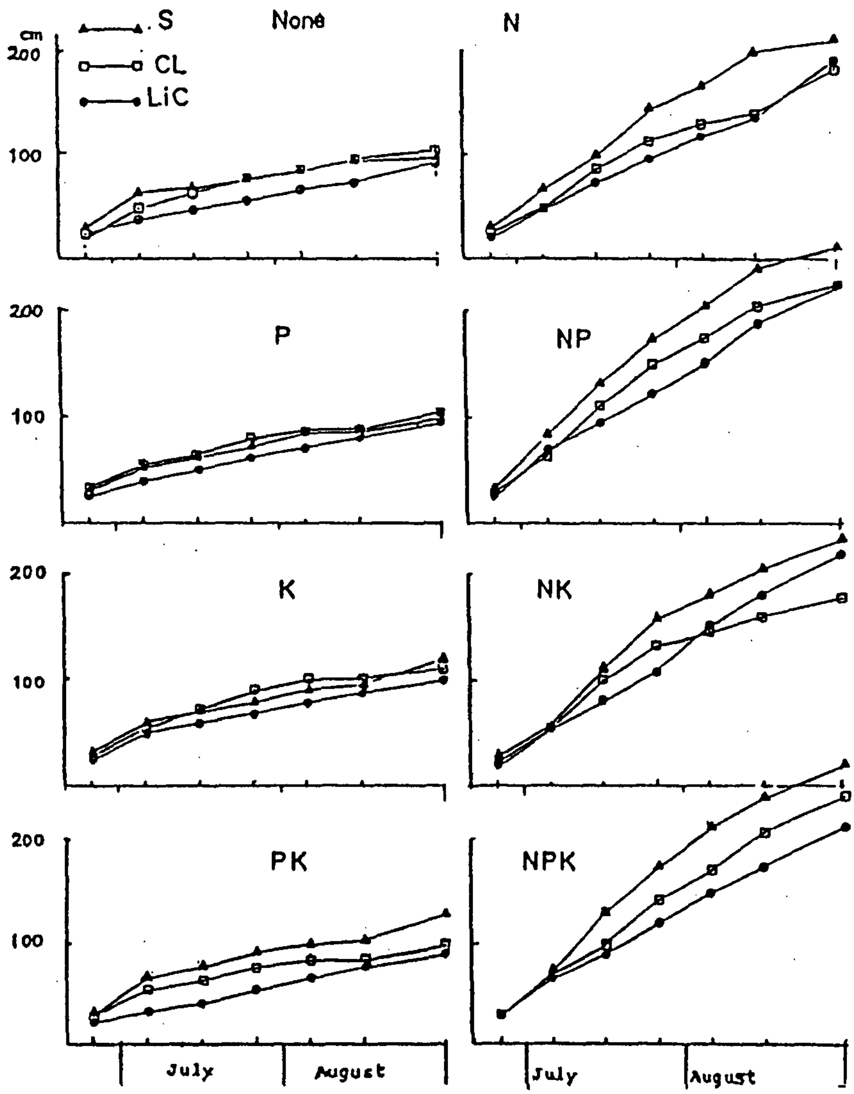
In this trial, corn (Suwan-1) was seeded on 13 June 1985; the treatment and fertilizer application is shown in Table 2.

Table 2. Design of pot experiment.

Plot	N	P_2O_5	K_2O	Remarks	
1. Control	-	-	-	Pot size 0 20 cm x 15 cm	
2. P only	-	0.6	-		
3. K only	-	-	0.6	Corn	
4. PK	-	0.6	0.6	Suwan-1	
5. N only	1.4	-	-	Weight of dry soil (kg/pot)	
6. NP	1.4	0.6	-	Korat	4.8
7. NK	1.4	-	0.6	Phraputtabat	5.3
8. NPK	1.4	0.6	0.6	Loei	5.3

Results

The results show that the effect of nitrogenous fertilizer was most pronounced; the corn plants could not yield any ears without nitrogen. As for phosphorus (P), a clear effect was found in the Phra Phutthabaht soil series. Generally, the effect of potassium was not clear. Figures 1 and 2 indicate clearly the effect of fertilizers in each soil series.



Legend
S = Korat soil
CL = Phra Phutthabat soil
LiC = Loei soil

Figure 1. The progress of plant height in each of the three soils.

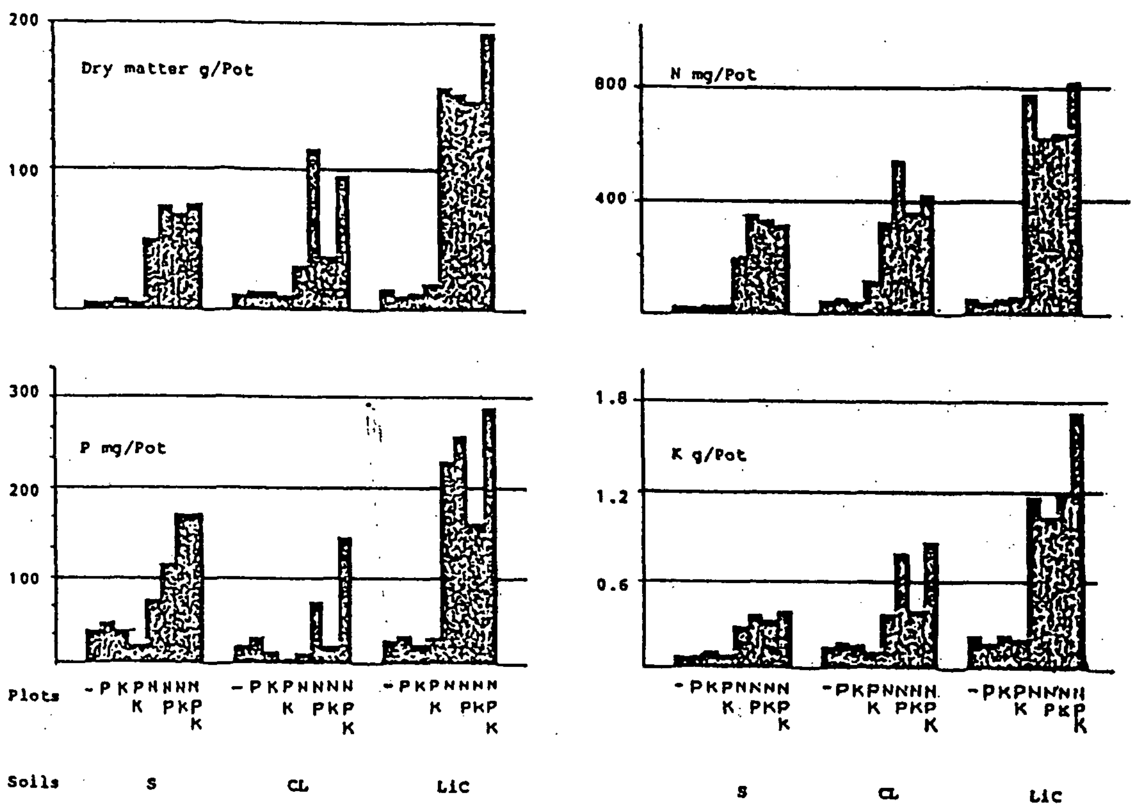


Figure 2. Dry weight and nutrient uptake in each plot at harvesting time.

Figure 2 also shows the nutrient uptake (N, P and K) in these three soils. Loei soil has a better reaction to fertilizer, especially nitrogen, while sandy Korat soil has a poor response to nitrogen.

The texture of Korat soil was real sand and was low in C, N, cation exchange capacity (CEC) and available P, while others had high clay contents and were rather rich in C, N, CEC and P, as shown in Table 3.

Table 4 indicates the reaction of each soil to nitrogen application and the rate of nitrogen utilization. In sandy soil, applied nitrogen may be lost quickly through watering. Therefore studies are required on the dynamic behavior of nutrients in each textured soil of low fertility.

Table 3. Soil properties of the tested soils.

Name of soil	P.S.D. (%) Sand	F. Sand	Silt	Clay	pH H_2O	KCl	T-C (%)	T-N (%)	CEC (me)	AV. P (ppm)
Korat	25.3	65.5	6.5	2.7	6.7	5.7	0.26	0.027	3.9	4.7
Phraputtabat	18.0	21.0	37.3	23.6	5.8	4.2	0.70	0.067	6.7	7.5
Loei	20.0	31.4	14.3	34.3	6.2	5.1	0.69	0.068	9.2	15.5

Table 4. Nitrogen balance in each soil.

Name of soil	Average uptake amount (g/pot) Plots with N	Plots without N	Differences	N applied (g/pot)	Utilization rate (%)
Korat	0.29	0.029	0.27	1.4	25
Phraphuttabat	0.41	0.059	0.35	1.4	25
Loei	0.72	0.049	0.67	1.4	48

Table 5. Kinds of tested soils.

Name of plot	Location of sampling	Texture	Water-holding capacity at pF 1.5	pF 4.0
Satuk (Suk) soil	Ban Kham Bon	LS	30.1	2.8
Warin (Wn) soil	ADRC field	SL	25.4	3.7
Korat (Kt) soil	Ban Tha Phra	SL	28.4	4.7
Roiet (Re) soil	Ban Na Ngarm	LiC	27.7	10.2
Pakchong (Pc) soil	Pakchong LDC field	LiC	39.6	24.9
Loei (Lo) soil	Chiangkhan	LiC	33.4	20.6

Study on Water Runoff and Soil Loss in Sandy to Clayey Soils Filled in Concrete Frames

Soil conservation is the most essential technique required to improve the crop productivity in rainfed areas. Thailand has carried out extensive research work on the effects of several factors affecting soil erosion. The authors set out to obtain fundamental data on water runoff and soil losses in the typical soil types varying from sandy to clayey.

Method

Test plot: 122 sets of concrete frames, 3 x 3 m^2 and 0.8 m in depth were set up at the ADRC experimental farm, as shown in Figure 3. With the cooperation of Khon Kaen Field Crop Research Center and the Fifth Regional Office of Land Development, six representative soils of the northeast were taken from different places and filled into the frames, as shown in Table 5.

Crop management:

- 17 December 1985-21 March 1986: soybean with irrigation and without fertilizer;
- 17 June-4 September: corn with chemical fertilizers under rainfed conditions;
- 10 September: rice bean and sorghum (Utong 1) seeded separately in a half of each plot, without fertilizer but with corn-stalk mulch under rainfed conditions.

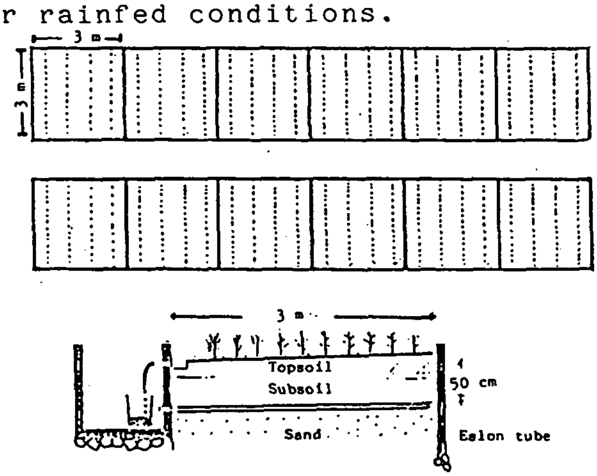


Figure 3. Outline of the concrete frame.

Runoff water and soil losses were determined at each rainfall, starting from 7 May.

Results

The analyses of the soil properties are shown in Figure 4. Not only the texture but also the physical characteristics of the soils are quite different between sandy soils and clayey soils. The CEC is low in sandy soils. The pH and available phosphorus contents are different in each soil management.

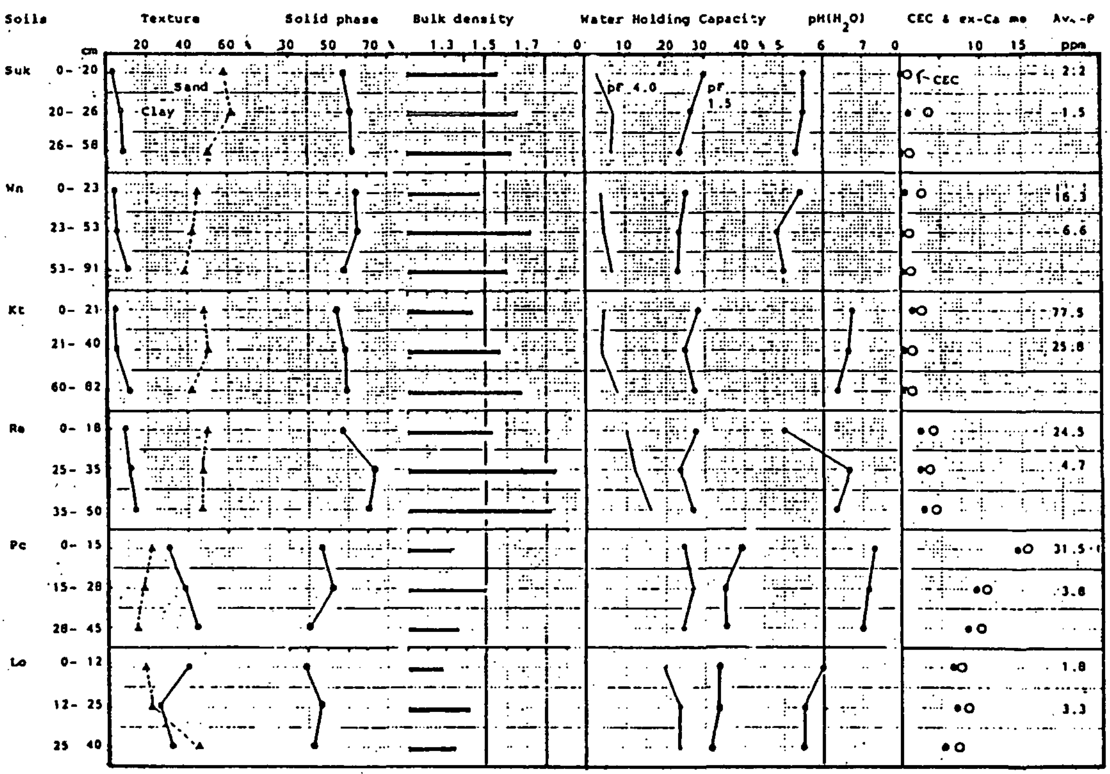


Figure 4. Soil properties filled into each concrete frame.

The data collected on water and soil runoff are shown in Figure 5. At the initial period, bare land showed a higher amount of runoff; it gradually decreased as the plant canopy covered the surface. When the soils were compared, the three sandy soils showed lower values. This particular season did not have much rainfall per day, as shown in Figure 6. Thus the runoff in this season was not high.

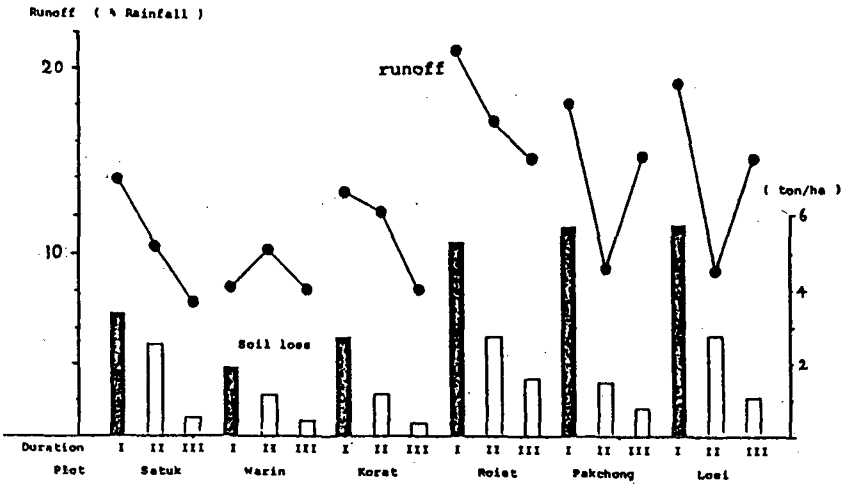


Figure 5. Soil runoff and loss in six soils filled in the concrete frame during corn cultivation.
Duration: I May 24-June 20
II July 26-August 27
III September 1-30

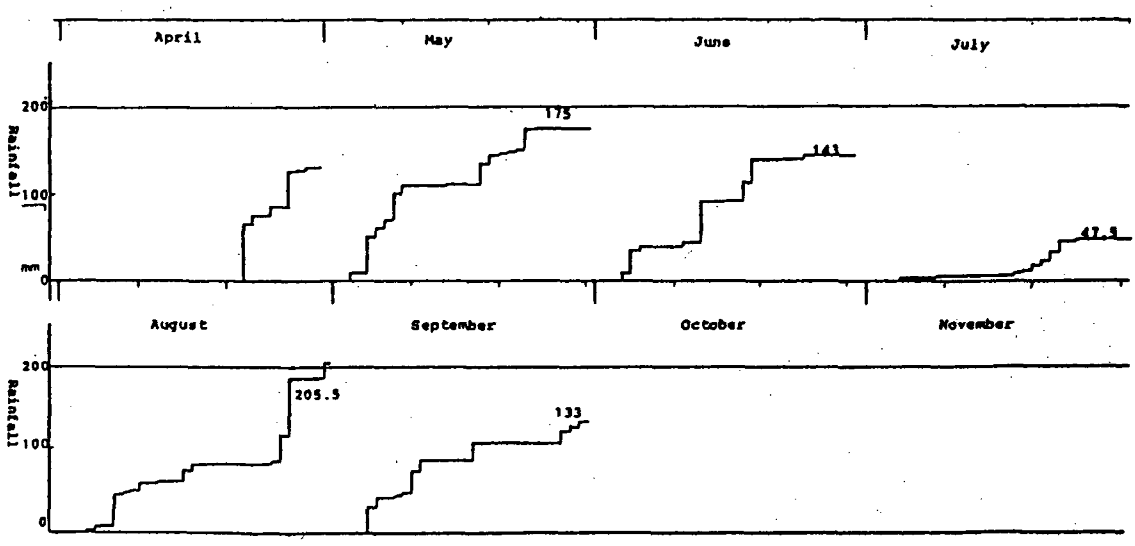


Figure 6. Rainfall distribution in the ADRC in 1986.

Figure 7 shows some data relating to plant growth. Corn (Suwan 1) was planted on 7 June. The germination was generally good because there was sufficient soil moisture at that time; but the growth was slow and rather poor in sandy soils.

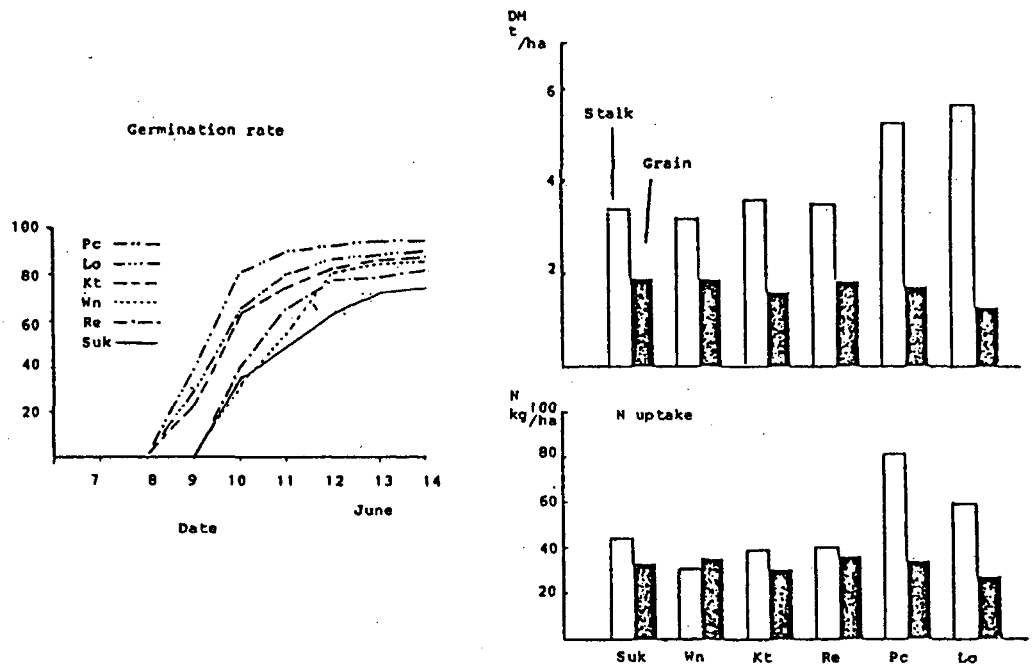


Figure 7. Germination rate, yield and N uptake in each plot.

In the early growth stages, the plots with Korat, Pakchong, and Loei soils showed better growth. But due to less rainfall during one month, starting from 20 July, the corn plants showed serious wilting in every soil. This was particularly true for the plots with Loei and Pakchong soils, which showed quick and serious symptoms of wilting; the corn stopped growing and yielded higher numbers of unmatured ears in these plots as compared to the plots with Warin and Satuk soils. After a certain amount of rainfall on 7 August, the corn began to regrow, but grain yields were generally poor. If there had been enough rainfall throughout the growth period, the grain yields would have been greater in the plots with Loei and Pakchong soils.

The authors also determined the amount of nutrient uptake by the corn plants by examining them at the harvest. A higher nitrogen uptake in the corn stalk was observed in the plots mentioned above, corresponding to the higher fertility of the soils.

Regarding the leaching of nitrogen, Igarashi *et al.* reported that Khon Kaen and Mahasarakam soils had quick leaching out of nitrogen in his test field as compared with other soils. The authors carried out a test to check nitrogen leaching in various soils by using eslon tubes (23 cm^2 in section and 15 cm long) without a bottom. The different soils were filled in the tubes and placed outdoors with nitrogenous fertilizer (27.5 mg of N per tube) applied on the surface of each tube. Very little nitrogen remained after 100 mm of rainfall in most soils, except in the Loei and Pakchong soils, as shown in Figure 8.

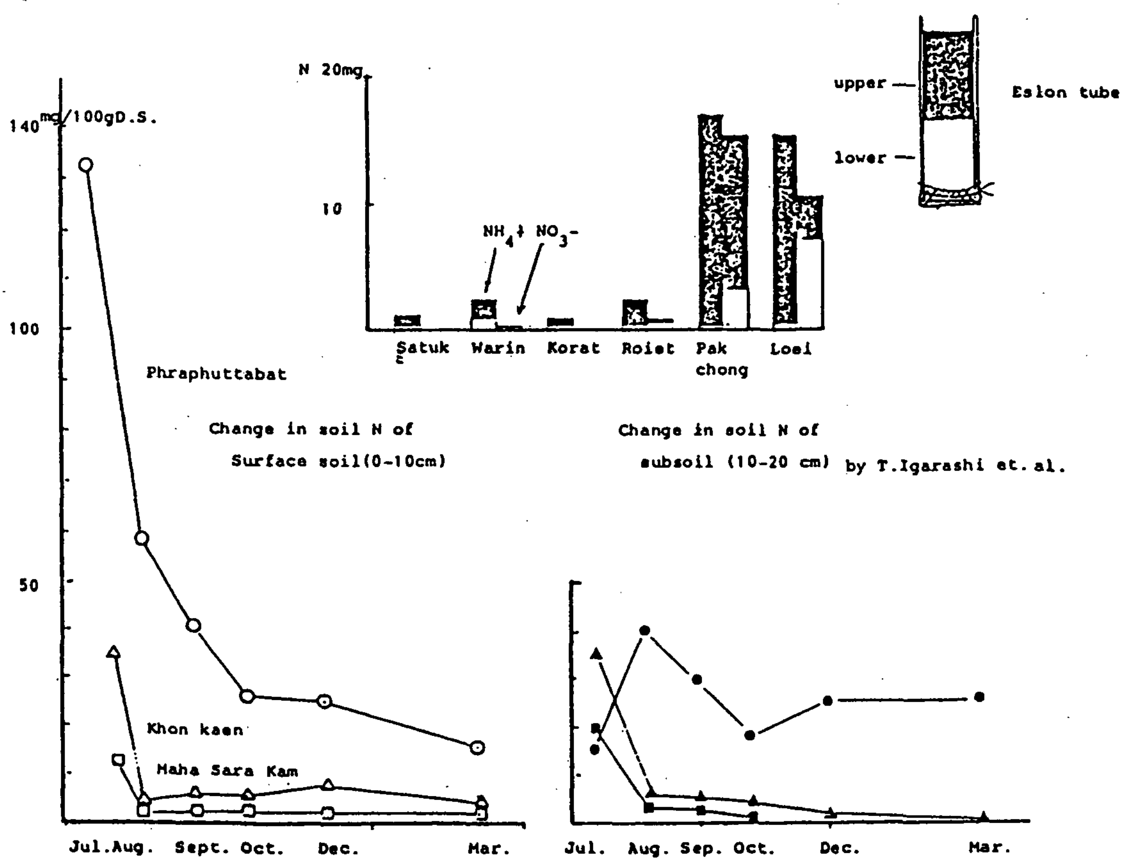


Figure 8. Nitrogen leaching out in sandy soils.

Table 6. Treatment of the lysimeter trial in 1986.

(g/m²)

No.	Treatment	N	P_2O_5	K_2O	Lime	DOM
1.	Fertilizer	12	12	6	-	-
2.	Fertilizer, 2 times	24	24	12	-	-
3.	No.1+lime	12	12	6	134	-
4.	No.1+lime+corn stalk mulch	12	12	6	134	625
5.	No.1+lime+green manure mulch	12	12	6	134	625
6.	No.1+lime+rice straw compost	12	12	6	134	1250

Note; Fertilizer used = AMS, TSP and MK.
Half amount of N is top-dressed after one month of germination.
Maize Suwan 1 seeded on June 7.
Lysimeter area = 1.13 m².
Organic matter.

	N	P	K	Ca	Mg
Corn	1.06	0.13	0.53	0.37	0.41
Crotolaria	2.12	0.11	0.70	0.91	0.30
Rice-straw compost	0.73	0.02	0.50	0.15	0.17

Table 7. The balance sheet of nitrogen and potassium.

(g/m²)

N				K_2O			
Fertilizer +OM	Plant uptake	Peroolantion water	Soil remained	Fertilizer	Plant uptake	Peroolantion water	Soil remained
12	4.5	1.3	6.5	6	5.5	6.6	17.6
12	5.8	1.4	6.5	6	5.2	6.6	20.7
+6.6				+4.0			
12	6.4	1.9	4.5	6	4.7	6.4	19.8
+13.3				+5.3			

Note: The plus (+) figure is from organic matter.

Nutrient Movement in Soils Concerned with Plant Growth

Some nutrients in soils may be easily leached by neavy rainfall. A lysimeter test was set up to investigate the dynamic behavior of nutrients in upland soil with reference to the effect of mulching.

Method

The trial was started on 6 May 1986. Warin soil from ADRC was filled into each lysimeter to a depth of one meter so as to represent the actual profile of the soil the horizon. Six treatments were set up on 7 June, as shown in Table 6. The data on plant growth, percolated water, and the soil nutrient status were collected.

Results

The percolated water was collected from each plot after every rainfall to estimate the percolation ratio at every rainfall. The ratio was 54% in May and gradually decreased in proportion to the growing canopy of corn, as shown in Figure 9.

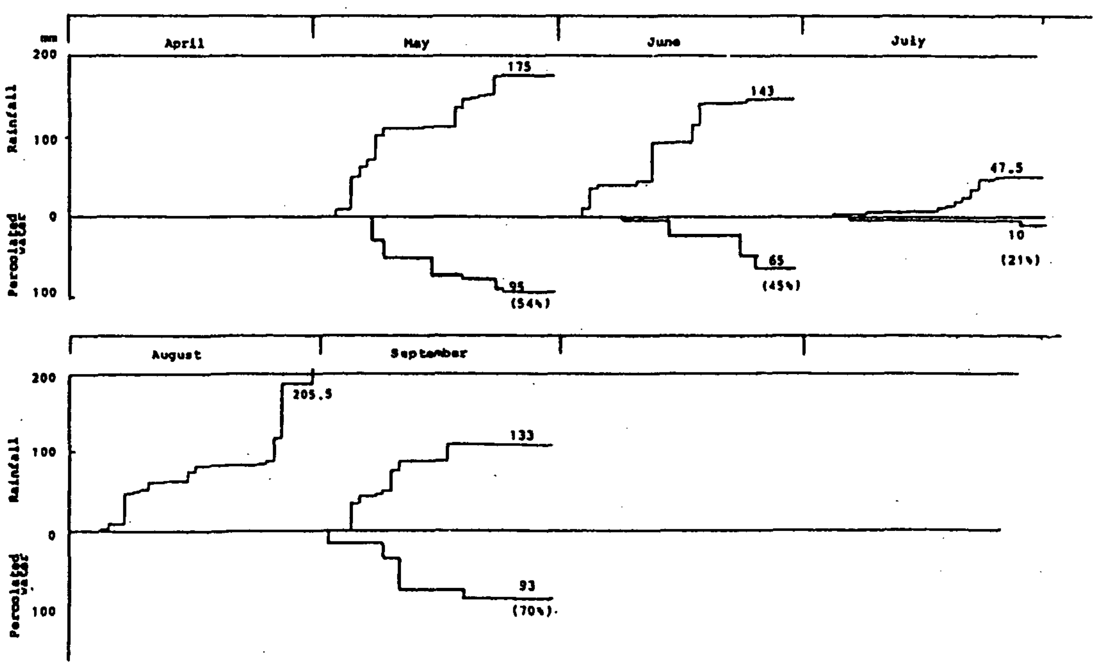


Figure 9. Rainfall and percolation water in each month.

After the application of fertilizers and organic matter, the percolated water samples were analyzed for certain elements. The data shows the difference in each plot, starting from September (see Figure 10).

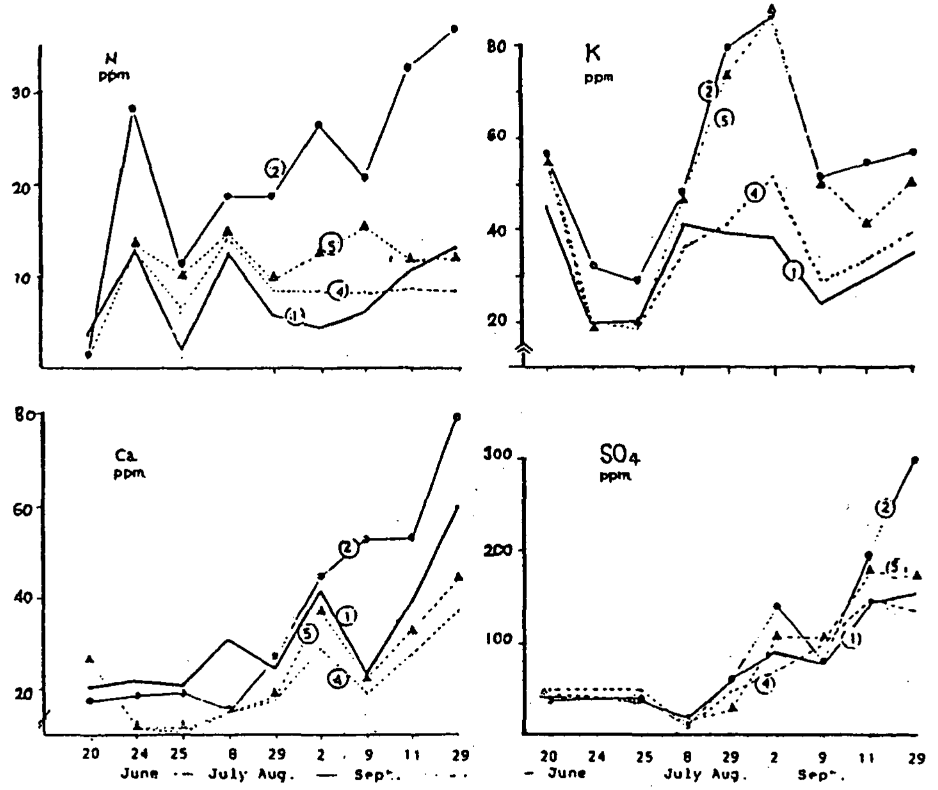


Figure 10. N, K, Ca and SO content in percolation water in each pot.

The germination and initial plant growth observed after two weeks of germination showed some differences between the mulched plots and the non-mulched plots. The fresh weight of mulching on plots 4 and 5 was about twice the weight used on plots 1-3, as shown in Figure 11.

Figure 12 shows the corn yield at harvest as well as the N, P, and K uptake in grain and stalk for each plot. The plots treated with fertilizer and organic matter showed a higher grain yield than those treated with heavy chemical fertilizer (twice that of the others), while the stalk weight was highest in the plots treated with heavy fertilizer. As a whole, the plots treated with compost gave the highest grain yield.

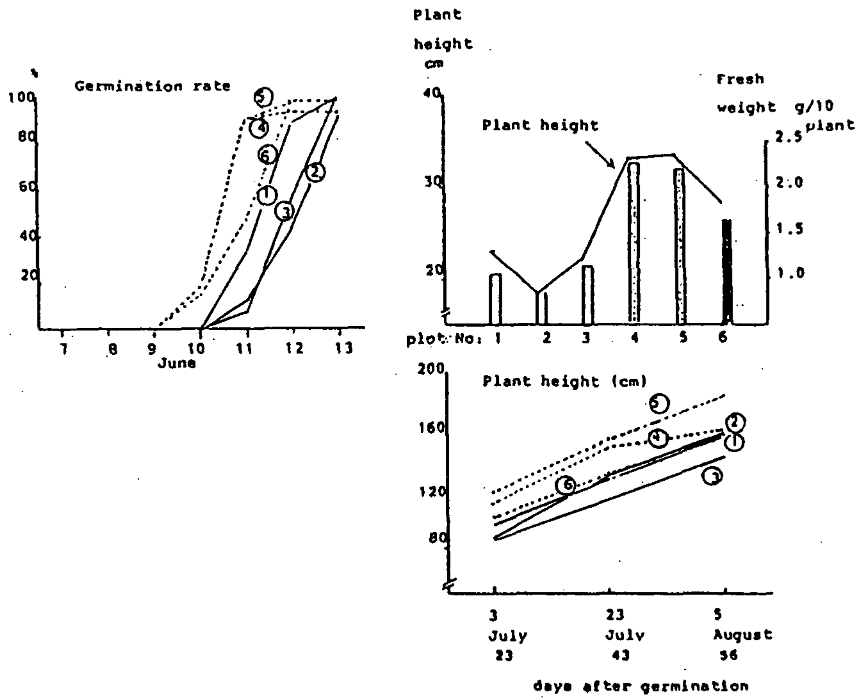


Figure 11. Plant growth in each plot.

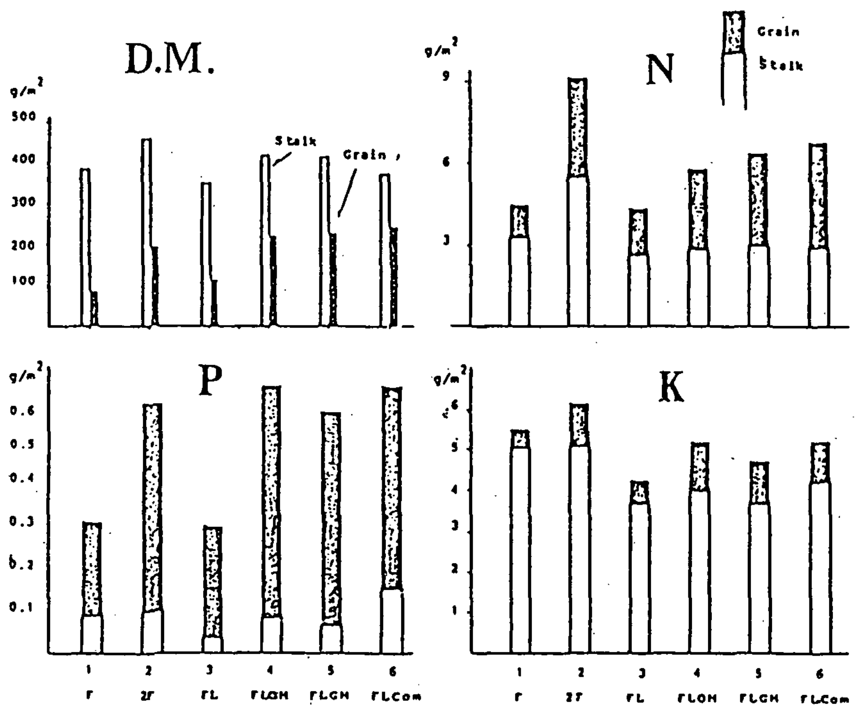


Figure 12. Dry matter yield and N, P and K uptake in each plot.

Mulching favourably affected phosphorus uptake as opposed to potassium uptake, and slightly increased the efficiency of nitrogen.

Table 7 shows the amounts of nitrogen and potassium in three portions, namely: plant uptake, percolated water, and water remaining in the soil. The amount of nitrogen originating from organic matter is not clear from this table, and the amount in percolated water is relatively low because there was less rainfall. As for potassium, the exchangeable potassium in the soil itself has to be taken into account. This study will continue to investigate these aspects.

CONCLUSION

The authors have obtained a certain amount of information on soil and water management in sandy soils, and the study is still in progress. The findings obtained so far can be summarized as follows:

- The low nitrogen recovery rate in sandy soils under rainfed conditions has to be improved. For this purpose, a study of the behavior of nitrogen in soils is essential.
- Poor germination, both in rate and speed, should be tackled with reference to different kinds of crops.
- More attention should be focused on water percolation as the collection of surface runoff water is rather difficult.
- The behavior of the elements originating from mulching materials is important; a methodology for investigating this behavior should be developed in the near future.

Acknowledgements

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Fifth Session: Physical aspects - FCC

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MANAGEMENT OF SOIL COMPACTION AND SOIL-WATER AFTER FOREST CLEARING IN UPLAND SOILS OF HUMID TROPICAL ASIA

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ABSTRACT

Drought and soil compaction are caused by the destruction of soil structure under intensive cultivation. Soil structure is particularly unstable in upland soils that contain predominantly low-activity clays and are low in organic matter. Water control involves managing surface runoff and minimizing losses due to seepage and evaporation. Mulch farming and reduced-tillage techniques are effective measures in runoff control and in improving soil-water availability. The incidence of grass/legume cover crops in rotation with methods of deforestation and subsequent farm operations cause more severe soil compaction than manual clearing and manual farming techniques. Soil compaction can be alleviated by mechanical and/or biological means. Biological techniques, such as growing appropriate crop species, have long-lasting effects. Deep-rooted woody perennials improve macroporosity, increase the water infiltration rate and encourage deep-root penetration. Methods of mulch procurement and cultural practices relevant to small landholders are discussed.

INTRODUCTION

Drought or floods, important constraints responsible for low crop productivity on the upland soils of humid regions in tropical Asia, are partly caused by the inability of the soil to absorb and retain rainfall. The intensity and frequency of these soil moisture imbalances are aggravated by soil compaction caused by the interaction between the management of the soil surface and the prevailing climate. Both drought and flood may occur on the same soil. The intensity and frequency of the drought or flood are strongly determined by soil properties, climatic characteristics, land use, and soil and crop management systems. Although conditions of soil compaction and water imbalance occur frequently in soils with predominantly low-activity clays, the adverse effects of these soil-related constraints can become disastrous under extremes of management.

Low, erratic and unreliable rainfall plays an important role in drought incidence, but soil and soil management may have an overwhelming effect on the intensity and frequency of drought occurrence. The ability of soil to absorb rainfall and retain it within the effective root zone plays an important role in drought avoidance and in maintaining a favorable soil-water-air balance. Soil-water acceptance depends on soil structure and its stability to wetting and on the predominance, continuity and stability of macrochannels. The available water-holding capacity of the root zone is governed by soil texture, pore-size distribution, and effective root depth. Loss of plant-available soil water is caused by seepage, evaporation and uptake by weeds.

SOIL CHARACTERISTICS

Upland soils in humid tropical Asia are predominantly Alfisols, Ultisols and Oxisols. In the Philippines, Ultisols occupy 11.3 million ha, and Alfisols 2.8 million ha (Briones, 1982). In all these soils, the subsurface clay accumulation gives rise to an argillic layer that hinders infiltration. The slow water movement is further aggravated by surface seal and crust formation, a common feature of these soils especially when the organic matter content is low

(Kubota *et al.*, 1982). Major soil-related constraints to intensive land use in Asia were outlined by Dent (1980) (Table 1). Although Table 1 provides a general outline of major constraints, the incidence of drought stress is underestimated, presumably because of the high and frequent rainfall. In spite of the frequent rains, however, crops suffer from frequent drought stress because these soils have low available water-holding capacity (Kubota *et al.*, 1982). Drought stress is also a serious constraint on red soils in tropical China (Qi-Guo, 1982).

Table 1. Major soil-related constraints to intensive land use in Asia (Dent, 1980)

Constraint	Percentage of total land area affected	
	South Asia	Southeast Asia
Physical		
Drought	43	2
Shallow rooting depth	23	6
Poor drainage	11	19
Nutritional	8	59
None	18	14

Table 2 lists the physical properties of some upland soils in Thailand. These soils are characterized by a high bulk density, low drainable porosity, low hydraulic conductivity, and low available water-holding capacity. The physical properties of an Ultisol from Sitiung, West Sumatra, reported by Sudjadi (1984) also indicate low drainable porosity and low permeability. Soil water permeability is further decreased by forest clearing by heavy machinery (Table 3).

A rapid decline in soil physical and nutritional properties of soils with continuous cultivation is one of the major reasons for yield decline. In Thailand, Kotoba et al., (1982) reported a decline in yield of cassava on unfertilized plots at Sattahip, Huai Pong and Korat (Figure 1). Also in Thailand, experiments conducted at the Sa Nan Research Station indicated a rapid decline in the yield of mungbeans, rice and maize (Table 4). Yield declines are due to a number of factors, of which soil compaction and drought stress are very important.

Table 2. Physical properties of some important soils of Thailand (Kubota et al.,1979; Chaiwanakupt and Tongyai, 1982).

Great Soil Group FAO Soil Taxonomy	No. of samples	Bulk density (g/cm^3)		Drainable porosity %		Hydraulic conductivity of surface soil (cm/sec)	Available water capacity[1] mm/m profile
		Surface	Subsoil	Surface	Subsoil		
Gray Podzolics (SE) Ultisols	6	1.70	1.64	9.3	10.9	10^{-3}-10^{-6}	71.8±16.7
Gray Podzolics (NR) Ultisols	10	1.62	1.51	16.8	21.2	10^{-3}-10^{-4}	87.3±12.9
Red Yellow Podzolics Plinthustults	12	1.51	1.47	13.5	14.7	10^{-3}-10^{-6}	85.4±19.2
Reddish Brown lateritics Plinthustults	9	1.27	1.52	13.8	15.8	10^{-3}-10^{-5}	77.8±17.3

1. AWC measured between P^f 2.0 and 4.0

Table 3. Physical characteristics of an Aeric Tropaquult (Red Yellow Podsolic) soil from Sitiung, West Sumatra, after forest clearing by heavy machinery (Sudjadi, 1984).

Depth (cm^3)	Bulk density (g/cm^3)	Porosity (%)		Permeability (cm/hd)
		Total	Drainable	
0-5	1.11	58.1	10.7	0.03
25-30	0.98	63.0	11.3	1.06

The volume fraction of available water is 10 to 15%. Periodic drought stress is common

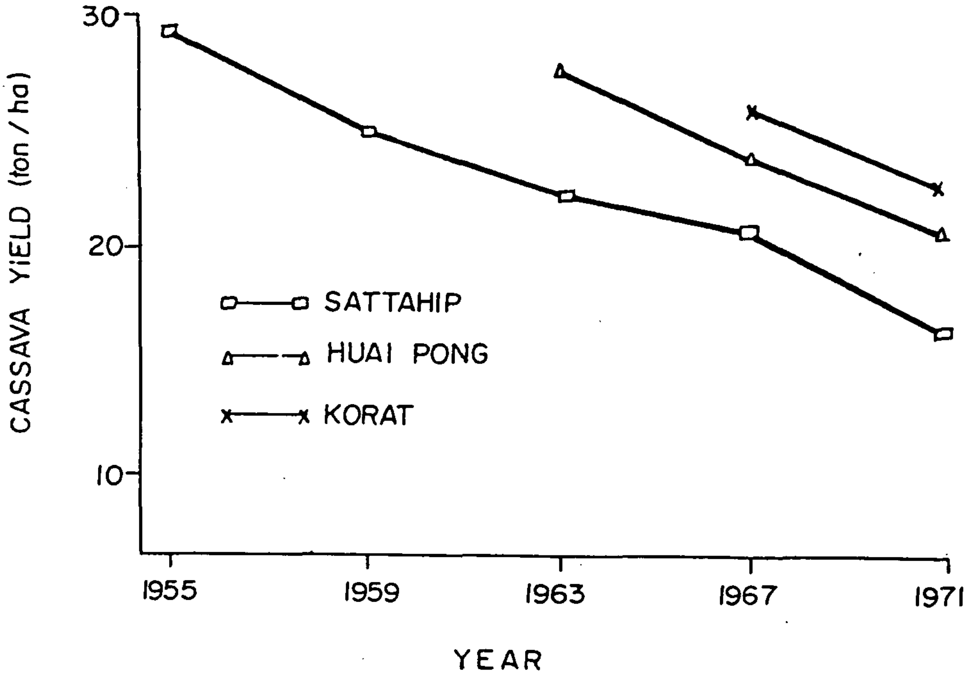

Figure 1. Effects of continuous cultivation on cassava yield from unfertilized plots at three locations in Thailand (Kubota *et al.*, 1982).

Table 4. Decline in crop yield due to continuous cultivation without added fertilizer, Sa Nan Research Station 1967-1979 (Chapman, 1978).

Year after clearing	Crop yield (kg/rai)				
	Cotton	Mungbeans	Rice	Maize	Peanuts
First (1967)	175	153	406	428	100
Second (1965)	127	178	302	101	185
Third (1969)	196	69	222	55	108

WATER MANAGEMENT

Each drop of rain received on a farmer's land is an asset to the farmer and should be so managed. There are three basic principles towards the effective utilization of this asset. One is that the losses due to surface runoff should be minimized. Another is that once the rain has soaked into the soil, the soil and crop should be managed so that water is conserved in the root zone and crop water use is increased. A third is that any surplus water should be stored for use as supplementary irrigation or for other purposes.

Runoff Management

Runoff can be managed by decreasing the amount and velocity of the runoff and by safely disposing of surface runoff for storage for future use. A range of soil surface management techniques and cropping systems are used to decrease runoff amount and runoff velocity. The soil surface should be continuously covered and protected from raindrop impact. This can be done by providing crop residue mulch, growing cover crops, and adopting a cropping system that provides a continuous ground cover. Some relevant crop management techniques include choosing quick-growing crops and crop combinations that establish a quick and early canopy cover, sowing early, establishing a good crop stand, controlling weeds adequately, and applying appropriate amounts of fertilizer at optimum times. Adequate weed control does not necessarily mean clean weeding. There is a critical level of weed cover below which crop yield is not drastically reduced but runoff and overland flow are severely increased. Some relevant soil and crop management systems to decrease runoff volume and peak runoff rate are listed in Table 5.

The safe disposal of surplus runoff is done through a series of engineering structures, e.g., cutoff drains, diversion ditches, graded channel terraces, grassed waterways, etc. The installation of these structures is capital-intensive, and the effectiveness of the structures depends on regular maintenance. Improperly installed and poorly managed structures are not effective and may cause severe losses. If the surplus water is to be stored in farm ponds, then steps should be taken to decrease siltation of the reservoir by decreasing sediment density in the overland flow. Soil detachment, soil splash, and sediment transport through rill and interrill erosion can be decreased by the soil and crop management techniques listed in Table.1.

Table 5. Soil and crop management systems to decrease surface runoff.

Principle	Techniques
1. Preventing formation of surface seal	Improve soil structure by addition of organic matter, mulching, no-till, cover crop, continuous canopy cover
2. Improving infiltration rate	Enhancing biotic activity of soil fauna, mulch farming, continuous ground cover, cover crops, reduced tillage
3. Increasing surface detention capacity	Rough soil surface (e.g. ridge-furrow system), vegetal cover, early planting, crop residue mulch, balanced nutrients, weed control
4. Decreasing runoff velocity	Vegetal barriers, close-canopy cover, strip cropping, early planting, mulch farming, balanced nutrients, weed control, ridge-furrow system, etc.

Soil-water Management

It is hard to substantially increase the plant-available soil water reserves of the root zone. Whereas crop residue mulch can decrease soil water loss during the first and second evaporation stages, the long-term effects of mulch on soil water conservation are negligible. In addition to decreasing soil-water evaporation, substantial and frequent applications of crop residue mulch also increase soil organic matter content and plant-available water reserves. However, the rate of mulch application to bring about any substantial effect may be as much as 10 to 20 tons/ha annually.

Different methods of obtaining crop residue mulch are shown in Table 6. Experiments conducted on a

Table 6. Cultural practices to procure mulch.

In-situ mulch			Brought-in mulch	
Crop residue	Planted fallows	Cropping systems	Organic	Inorganic/Synthetic
1. No-till	1. Live mulch	1. Mixed cropping	1. Farmyard manure	1. Solid e.g. polytheme
2. Minimum tillage	2. Sod seeding	2. Relay cropping	2. Crop residue	2. Liquid, e.g. soil conditioners
3. Zonal tillage	3. Green manuring	3. Sequential cropping	3. City waste	
4. Conservation tillage	4. integration of annuals with woody perennials . Alley cropping . Fodder banks . Wood lots . Contour management			

pineapple plantation in Taiwan indicated the beneficial effects of rice mulch on moisture conservation (Table 7). The use of polyethylene sheets as mulch material is becoming economically feasible for high-value cash crops. In Thailand, Kubota *et al.* (1982) observed that the use of rice straw mulch was a more effective water-conserving technique than subsoil tillage or intertillage operations (Table 8, Figure 2).

Table 7. Effects of mulching practices on moisture conservation under pineapple plantation in Taiwan (Taiwan Agric. Res. Inst., 1983).

Treatment	Soil moisture content (% by weight)
Complete rice-straw mulch	17.7
Interrow rice-straw mulch	15.5
Polyethylene sheet	15.0
Clean cultivation	14.5

Table 8. Increase in available soil moisture (mm per 1 m deep soil) due to soil management (Kubota *et al.*, 1982).

Soil management	Year of observation		
	1976	1977	1978
Intertillage	+6	-17+22	+33
Subsoiling	+7	-15	+10
Rice-straw mulch	+61	+30	+46
Rainfall (mm)	782	475	1000

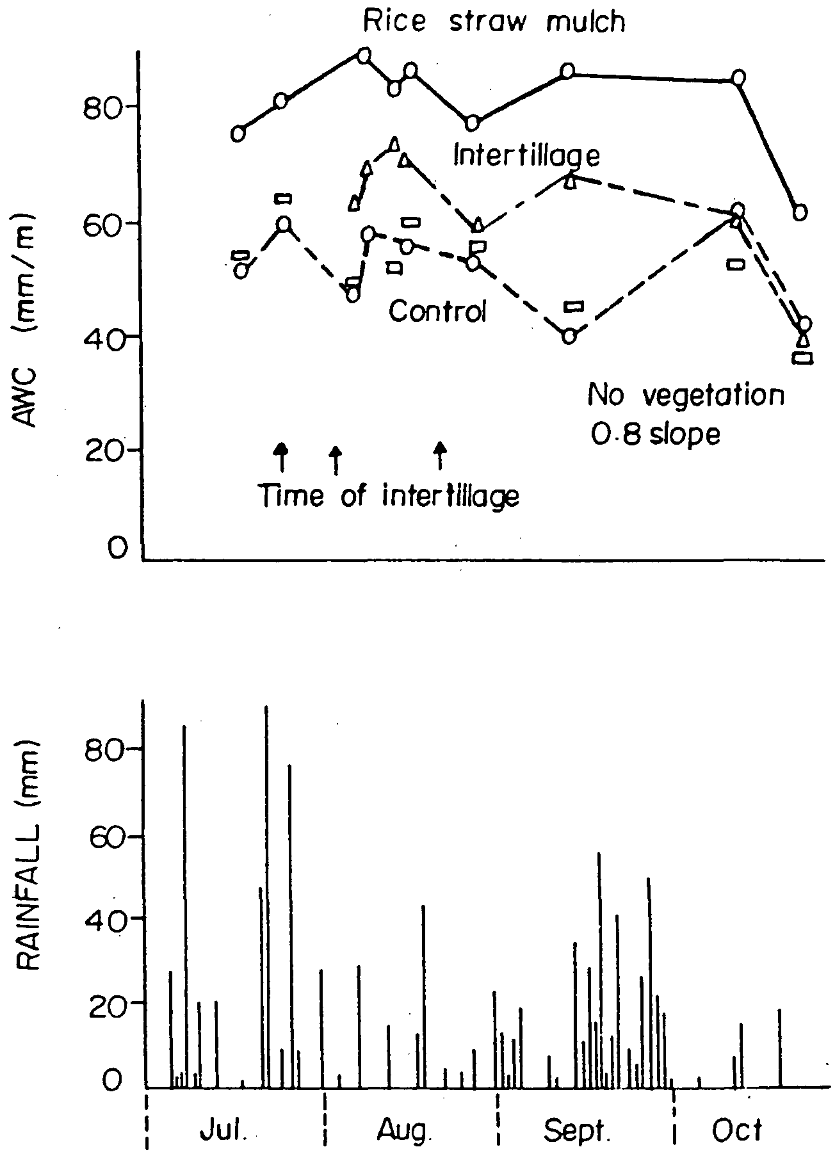

Figure 2. Effects of mulching and tillage methods on soil-water conservation (Kubota *et al.*, 1982).

A combination of crop residue mulch with no-till or reduced-tillage systems are generally applicable for soils with coarse-textured surface horizons and for grain crops. Experiments conducted in West Africa have shown that reduced-tillage systems are effective in the humid and subhumid tropics (Lal, 1984, 1986). In Thailand, Kubota *et al.* (1983) observed that soil water retention capacity decreased as the intensity of mechanical tillage increased (Figure 3).

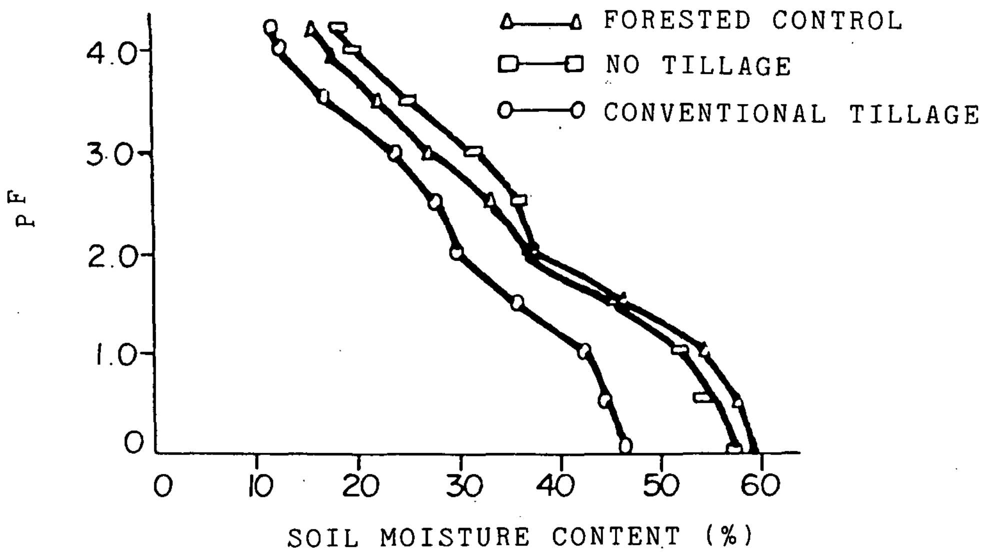

Figure 3. Effects of mechanical tillage methods on soil moisture characteristics of an upland soil in Thailand (Tulaphitak, *et al.*, 1983).

A frequent use of planted fallows in crop rotation is an important aspect of an effective no-till system. The choice of an appropriate cover crop is site-specific and depends on soil properties and rainfall regimes. There has been a tradition of using cover crops such as kudzu in plantation crops in Malaysia. In Taiwan, Want (1984) observed that *Centrosema* sp. and *Indigofera* sp. conserved more moisture than did grasses (Table 9). Similar observations were reported in Nigeria by Lal *et al.* (1978, 1981).

Cropping sequences, crop combinations and the use of planted fallows are important in mulch farming and soil-water management. Cover crop management involves either chemical or mechanical suppression. Mulch farming techniques are labor-intensive and become practically feasible only if they are an integral component of the predominant farming system of the region.

Table 9. Soil moisture conservation by mulching and growing cover crops in Taiwan (Wang, 1984).

Soil depth (cm)	Soil moisture content (% by weight)					
	Centrosema	Indigofera	Bahia grass	Guinea grass	Rice-straw mulch	Clean cultivation
15-20	9.3	9.8	8.6	8.4	10.2	8.3
25-30	10.2	11.2	9.9	10.0	11.3	9.9

Each value represents a mean of 5 separate measurements made during the dry season.

In addition to leaving mulch on the surface, slot mulching is also practiced to conserve soil and water. Trenches dug at regular intervals are filled with straw. These trenches encourage surplus runoff to seep into the soil. Straw mulch keeps the trenches open and enhances water infiltration.

Water Harvesting

Water-harvesting techniques are more appropriate for semi-arid than for humid regions. For small landholders, microwatersheds are designed to harvest water runoff from a part of the field. The soil in the donor region is compacted to encourage water runoff and is not cropped. The recipient zone is cropped and the soil is kept porous so that the water received will soak into the soil.

A variant of this technique for the humid region involves the construction of a farm pond in the valleys so that the surplus runoff can be stored. Farm ponds can be used for small-scale gravity irrigation, for aquaculture, and for other uses. Farm ponds are particularly successful in undulating terrain and may vary in size from 20 to 200 m^2 in surface area and from 50 cm to 100 cm in depth. The size may be larger for gently undulating terrain and for large farm holdings.

SOIL COMPACTION AND ITS ALLEVIATION

Forest removal and soil exposure by any method leads to soil compaction, although the magnitude and consequences are more drastic with mechanized than with manual land-clearing methods.

Shifting Cultivation

Partial land clearing by shifting cultivation is still widely practiced in the steeplands of tropical Asia. In Thailand, the total area cleared annually for shifting cultivation is estimated to be 30 000 to 40 000 ha or 0.5% of the total land area (Komkris, 1978). The percentage of total land area cultivated or fallow for shifting cultivation in Thailand is about 10.0%.

One of the factors responsible for deterioration in soil structure by shifting cultivation is the intense burning. Soil temperatures of 200 to 600°C at a depth of 1 cm are commonly observed during burning. The data by Zinke *et al.* (1978) in Table 10 show that soil temperatures are extremely high, especially in reburn piles. In addition to a deterioration in soil structure, burnt soil often also exhibits hydrophobicity and its water acceptance is decreased.

Table 10. Soil and surface temperatures (°C) during burning for shifting cultivation in the Lua Forest Fallow System in Thailand (Zinke *et al.*, 1978).

Elevation (+) or depth (-) from soil surface (cm)	Heavy fuel	Moderate fuel	Reburn pile
+2	650	450	600
+1	510-590	420	600
0 (surface)	427-590	205	430-570
-1	205-480	150	375-450
-2	150	70	325-375
-3	70	(soil moist)	150-300
-5	ND	ND	<150

ND = Not determined

Complete Clearing and Continuous Cultivation

Soil compaction is a major problem with continuous cultivation on structurally inert soils. Soil compaction is more severe in complete than in partial clearing. The magnitude and severity of soil compaction also depends on the method of land clearing. In general, mechanized methods of land clearing cause more severe soil compaction than do manual methods. The data in Table 11 from an experiment conducted on an Alfisol in southwestern Nigeria indicate that bulk density and penetrometer resistance were greater for mechanized clearing with shear blade and treepusher/rootrake than for traditional farming or manual clearing.

One way to alleviate compaction after mechanized land clearing is to sow a deep-rooted and quick-growing cover crop. Experiments conducted on an Alfisol in southwestern Nigeria indicated significant improvement in total porosity, in equilibrium infiltration rate, and in cumulative infiltration when *Mucana utilis* was sown immediately after clearing (Table 12). The data in Table 13 show significant improvements in the maximum water-holding capacity by growing *Mucana* cover. Improvements in soil physical properties by *Mucana* cover were more in manual than in mechanized clearing, implying that the length of fallowing required to bring about desired improvements is more in mechanized than in manual land clearing.

In addition to land clearing, soil compaction also becomes a major constraint with intensive land use, especially when motorized farm operations are used. Watershed management experiments by Lal (1985) showed that the rate of infiltration declined drastically with mechanized cultivation (Figure 4). The rate of decline for no-till differed from that of plowing. For example, the infiltration capacity for no-tillage and plowed watersheds decreased from 77 and 65 cm in 1976 to 38 and 28 cm in 1978, to 28 and 9 cm in 1979, and to 12 and 5 cm in 1980, respectively. This drastic decline indicates structural collapse and elimination of transmission pores caused by vehicular traffic. The decline was particularly severe near the turning points of farm equipment, where the soil appeared to be highly compacted for the first 10 m or so. The data in Figure 5 compare the infiltration rate near the turning point with the 50 m inside. The data show that the accumulative water infiltration for 2 h was 28% more inside the field than near the turning point.

Table 11. Effects of methods of deforestation on soil bulk density and penetrometer resistance of 4-5 cm layer (unpublished data of R. Lal).

Treatment	Bulk density (g/cm^3)				Penetrometer resistance (kg/cm^2)			
	1979 pre-clearing	1979	1980	1981	1978 pre-clearing	1979	1980	1981
Traditional farming	0.64	1.06	1.07	1.27	0.21	0.96	0.52	1.32
Manual clearing	0.68	1.17	1.17	1.39	0.20	1.4	0.75	1.19
Shear blade	0.70	1.19	1.37	1.38	0.26	1.0	1.84	2.19
Treepusher/rootrake	0.60	1.24	1.32	1.42	0.20	1.3	0.73	1.23

Each figure is a mean of 25 separate analyses.

Table 12. Effects of clearing methods and cropping treatments on physical properties of an Alfisol in southwestern Nigeria (Hulugalle *et al.*, 1986).

Treatments		Porosity	Equilibrium infiltration rate	Cumulative infiltration
Clearing	Cropping	$m^3 m^{-3}$	mm/r	mm/3 h
Manual	Cropped	0.55 b	0.22 cd	608 bc
Manual	Mucuna cover	0.59 a	0.08 a	1422 a
Shearblade	Cropped	0.54 c	0.02 cd	492 cd
Shearblade	Mucuna cover	0.57 b	0.04 b	764 b
Treepusher	Cropped	0.57 b	0.02 cd	287 de
Treepusher	Mucuna cover	0.59 a	0.004 d	329 de
Treepusher-rootrake	Cropped	0.53 c	0.002 d	193 e
Treepusher-rootrake	Mucuna cover	0.52 c	0.03 bd	557 bcd

Table 13. Effects of clearing methods and cropping treatment on the maximum water-holding capacity (0 suction) of an Alfisol at IITA, Ibadan (Hulugalle *et al.*, 1986).

Treatments		Volumetric water content at 0 suction $m^3 m^{-3}$ (%)
Clearing	Cropping	
Manual	Cropped	35.3 b
Manual	Mucuna cover	42.1 a
Shearblade	Cropped	29.5 c
Shearblade	Mucuna cover	34.9 b
Treepusher	Cropped	31.1 c
Treepusher	Mucuna cover	39.3 a
Treepusher/rootrake	Cropped	29.2 c
Treepusher/rootrake	Mucuna cover	33.0 b

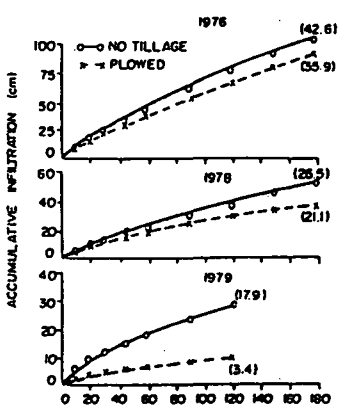

Figure 4. Effects of mechanized farm operations on water infiltration rate of an Alfisol for no-till and plowing methods of seedbed preparation (Lal, 1985).

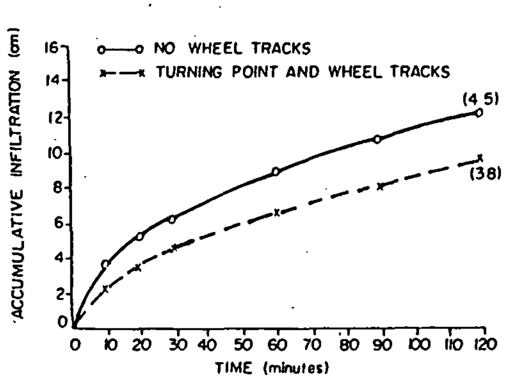

Figure 5. Comparison of infiltration rate near the turning point of the farm machinery with that of 50 m inside the plot (Lal, 1985).

Soil compaction can be alleviated by biological and/or mechanical means. Chiselling in the row zone increases macroporosity and improves infiltration rate. A para-plow (Figure 6) is also used to loosen the soil, although the power requirement can be prohibitive. Growing deep-rooted perennials is another effective and economic way of alleviating compaction and increasing both total and macro porosity. Hulugalle and Lal (1986) reported that sowing perennial pigeonpea in rotation with maize decreased soil bulk density and increased maize grain yield (Table 14). The effects of biological measures are more durable and longer-lasting than other measures, and biological measures do not involve the use of heavy machinery.

Table 14. Effects of growing a woody perennial on soil bulk density of a gravelly Alfisol growing maize at IITA, Ibadan (Hulugalle and Lal, 1986)

Cropping sequence	Bulk density (g/cm^3) at different days after seeding			Maize grain yield (t/ha)	
	2	29	90	Season 1	Season 2
Pigionpea-maize	1.38 a	1.36 b	1.33 b	2.8 a	2.7 a
Continuous maize	1.41 a	1.41 a	1.39 a	2.0 b	2.2 b

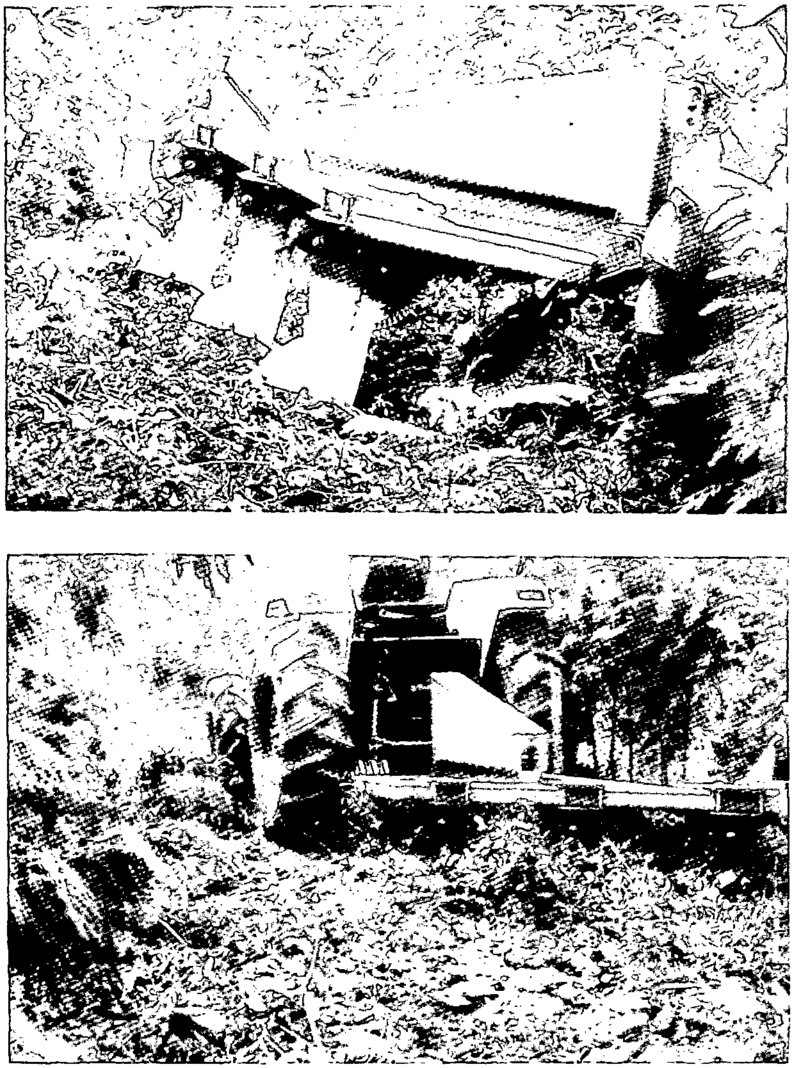

Figure 6. Paraplow (a) above the ground surface, and (b) while inside the soil.

PRODUCTION SUSTAINABILITY BY MULCH FARMING

The Green Revolution of the mid-1960s in Asia was brought about by the use of improved varieties grown on fertile soils with supplementary irrigation and application of agrochemicals. A majority of upland soil in humid tropical Asia are marginal lands on undulating to steep terrain. The farm size is usually small and the inputs and logistical support are not available. Improving yield on these soils of marginal fertility and of low and erratic water supply requires more than just introducing better varieties.

Mulch farming techniques improve soil fertility through the addition of plant nutrients and organic matter to the soil. They also maintain favorable soil temperature and moisture regimes, improve biotic activity of soil fauna, and alleviate soil compaction. However, the substantial quantities of mulch required for frequent and regular application are not available even for small landholders. There is a need to develop site-specific agronomic techniques to ensure production of adequate amounts of mulch materials.

Von Uexkull (1984) suggested a cropping system based on rotating food crops with cover crops (Figure 7). An appropriate cover crop is established immediately after land clearing. Once the soil properties are favorable, strips of cover crops 10 to 12 m wide are suppressed chemically or mechanically, and food crops (e.g., rice, maize, cassava, cowpea, etc.) are seeded through the mulch without seedbed preparation and without causing any soil disturbance. After growing two or three consecutive crops, food crops are rotated with cover crops. Von Uexkull (1984) suggested that a farm family could manage a total of 5 ha, of which 2.5 ha will be under food crops at any one time. If the cover crop is chosen carefully, this system would provide mulch and fodder and would minimize dependence on fertilizers and herbicides.

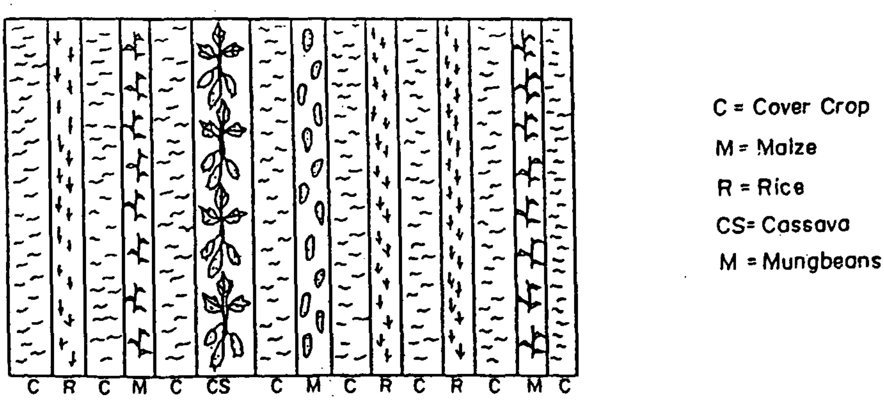

Figure 7. A schematic of the yield layout for growing food crops in rotation with cover crops (Von Uexkull, 1984).

Another useful approach would be to grow food crops in association with woody perennials. The alley cropping system is one such technique whereby food crops are grown in alleys formed by hedgerows of trees and shrubs (Kang *et al*., 1981). The hedgerows are cut back at planting and kept pruned during cropping to prevent shading and to reduce competition with food crops. With the development of proper management techniques of hedgerows and of food crops, the system can provide mulch and fodder.

Most of these systems, however, are not necessarily high-yielding. These systems minimize the use of agrochemicals, preserve soil and water resources, and sustain productivity. However, the technological packages are local-specific and need to be developed/adapted on site.

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CONTROLLING EROSION FOR CROPPING SYSTEM EXPERIMENTS

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ABSTRACT

Basic concepts concerning the processes involved in sheet and rill erosion are reviewed. The hope is that knowledge about erosion and deposition processes, which are the same the world over, will help free us from looking to soil-conserving solutions solely through the eyes of any particular technological and socioeconomic context.

Soil loss in any runoff event is the sum of the product of water flux and sediment concentration. Sediment concentration depends on the erosion process (or processes) operating. There is some distance downslope from the top of an experimental plot where rainfall detachment is the erosive mechanism. In this region protection of the soil surface from the damaging action of raindrops provides the major opportunity for reducing sediment concentration (and also enhancing infiltration, thereby reducing runoff). Both surface mulch and the standing crop are effective in raindrop interception.

Beyond some threshold distance downslope, sufficient streampower is achieved for the additional process of

runoff entrainment to commence. This leads to a fairly rapid rise in sediment concentration with downslope distance. Hence keeping slope length as short as is consistent with other objectives reduces total soil loss - a particular example of "small (-scale) is beautiful".

To reduce sediment concentration due to entrainment, cover must be in effective contact with the soil surface. Aboveground or aerial cover, which can reduce rainfall detachment, is completely ineffective in restricting entrainment of sediment. Only surface-contact cover is effective in reducing both erosion mechanisms. Thus, as full as possible use should be sought of maintained high levels of contact cover where this is compatible with other constraints. The humid tropics, with their generally high potential for vegetative production, allow a source of surface mulch; also if planting into or through surface mulch is feasible, then leaving soil vulnerable to erosion through stubble removal for planting can be avoided.

Opportunities for reducing erosion by reducing runoff are also briefly reviewed.

INTRODUCTION

Many factors have combined to increase the cultivation of potentially erodible land, whether that danger of erosion is due to slope steepness, inability to maintain adequate surface cover, or to soil or environmental characteristics. Hence there is a challenge to bring together varieties of soil-conserving technologies that are economically feasible and acceptable to the farmer, and feasible within the human and other resources available in particular social contexts.

It is only in the last decade that research has seriously addressed the problem of the connection between soil erosion and the productivity of man-managed ecosystems. The reasons for the late arrival of substantial research on such issues are not clear. It may have been thought the connection was obvious. Indeed the connection between soil erosion, food production, survival and human well-being often does appear to be direct and obvious, especially in marginal environments. Adamson (1983) provides a poignant case study, especially rich in the human dimensions of those relationships, based on research in Upper Volta.

However the relationship between soil erosion and productivity decline is also clearly part of a very complex suite of relationships involving plant and microclimatic factors above and below ground. Substantial research of good quality has been under way for much of this century, attempting to quantitatively interpret plant-environment relationships, even when the dynamic characteristics of the relevant microenvironment are not affected by soil erosion. Noting this, it is my view that we should be wary of deferring with confidence the insidious and often medium- to longer-term effects of soil erosion.

Because of the complexity of plant-environment relations, we should also not be surprised at the difficulty in quantifying the contribution made by erosion to productivity decline. There are those who use this difficulty to suggest that the consequences of soil erosion are perhaps not so important after all, and who point to the quite real possibility in some contexts of compensating for potential productivity decline by technological inputs such as extra fertilizer. This view can be dangerous as it ignores the complexity of the problem from a scientific point of view, and is likely to encourage unwarranted complacency in those ignorant of the reasons for this difficulty. Also the possibility of increased technological inputs substituting for lost soil productivity is often not economically feasible, especially in subsistence agriculture, but in any case is wasteful through environmental damage.

Thus, despite our admitted current limitations in quantifying the relationships between soil erosion and lost plant productivity, there are important reasons for seeing what varieties of opportunity there are to reduce soil-loss rates consistent with our agricultural objectives, and to evaluate such opportunities for likely effectiveness in terms of our current knowledge of soil-erosion processes. Hence let us turn first to the basic concepts of soil erosion, and then see how this knowledge may be of help in devising methods of controlling soil erosion in a variety of agricultural management and sociocultural contexts. The hope is that knowledge about processes, which are common the world over, will help free us from looking for solutions solely through the eyes of a particular technological and socioeconomic experience.

This discussion will be restricted to a consideration of erosion induced by water. The content will concentrate on cropping-system experiments, but should have some general application.

BASIC CONCEPTS OF EROSION

The total loss of sediment past any particular point in a landscape in an erosion event can be thought of as an accumulation through time of the rate (q_s) of sediment transport past that point.

Thus total soil loss = Σqs

where Σ represents the summation over time.

Sediment flow is moving water with sediment of some concentration (c) in this water.

Let q = volume of water crossing unit width normal to the flow per unit time (Figure 1), and

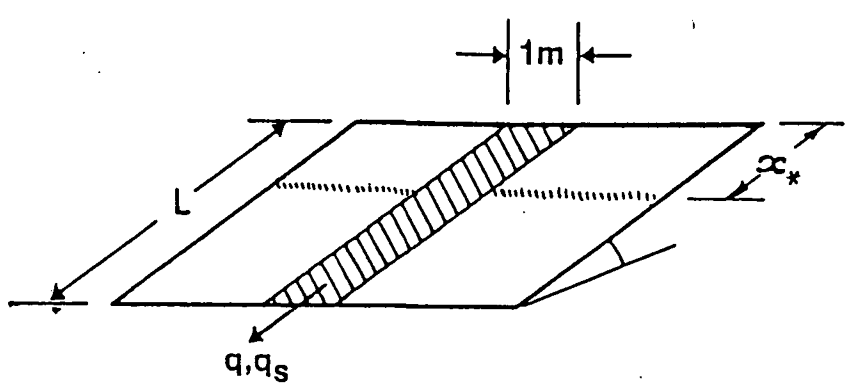

Figure 1. Illustrating flow of water and sediment from unit strip width on a sloping plane land element of length L.

c = mass of sediment per unit volume of fluid.

Then it follows from the definition of these terms that the sediment flow crossing unit width (normal to the flow, Figure 1) per second, denoted q_s, is given by:

$$q_s = qc \tag{2}$$

Thus the total sediment loss during an erosion event is obtained by summation over this time period:

$$\Sigma q_s = \Sigma qc \tag{3}$$

To fully interpret Σq_s, we therefore need to know the time history of q and of c.

Equations (2) and (3) indicate that whatever can be done to reduce either water loss or sediment concentration will be equally effective in reducing sediment loss.

Reducing water loss can be achieved by:

(i) Increasing the infiltration rate. Unless the soil profile is saturated, the infiltration rate is increased quite generally by the application of soil cover, for example by mulch (Figure 2), or by intercropping. Active transpiration by a growing crop reduces the amount of water stored in the soil profile, and this leads to a greater fraction of rainfall infiltrating and less running off the plot as overland flow.

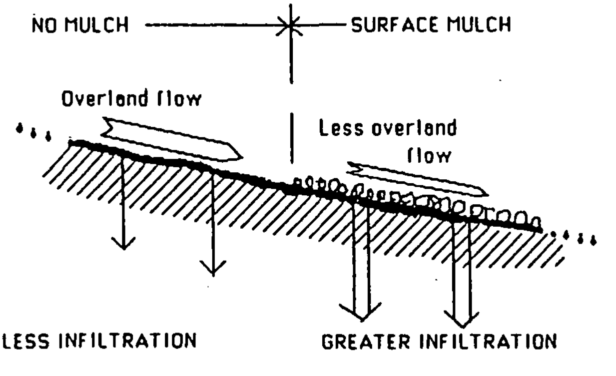

Figure 2. Illustrating the general finding that surface mulch results in greater infiltration and hence less runoff compared with bare soil.

(ii) Increasing the amount of water which can be stored in depressions on the land surface.

Some possible applications of these principles will be considered later in this paper.

The second alternative in erosion control lies in reducing the sediment concentration (c). The factors on which sediment concentration depend will emerge from a consideration of soil-erosion processes undertaken in the next section.

SOIL-EROSION PROCESSES

It is assumed here that soil loss is in the form of either sheet or rill erosion, or some combination of these forms, and that erosion has not formed gullies, and tunnel erosion does not occur. It is assumed that land slopes and soil strength relationships are such that landslides and landslips do not occur. The theoretical framework outlined below provides a means of indicating whether or not such gravity-aided mass movement of soil has occurred: it is not always clear, especially in "mudflows", whether or not such mass movement has occurred.

This assumed context is likely to be appropriate in considering erosion in cropping-system experiments, except in the most extreme situations where gravity-aided mudflows may occur. Mudflows are conceived as a situation where cultivated soil becomes so high in water content that on adequate slopes it can flow due to its very low shear strength.

However, restricting the discussion to a consideration of sheet and rill erosion, there are two processes whereby sediment can be added to the shallow sheet of overland flow assumed to be moving over the soil surface of the experiment.

Rainfall Detachment

Firstly, intense rainfall especially breaks down even relatively stable soil aggregates into much finer aggregates or into the ultimate soil particles, and the splashing process stirs this fine material into the overland flow, which itself is initiated by the excess of rainfall over infiltration. This is illustrated in the upper sketch of Figure 3. The resulting sediment-laden water can clog channels in the soil into which it infiltrates, thus increasing runoff (and soil loss, eqn. (2)). This process can be of dominant importance for some distance (x_*) from the top of the experiment plot, where it is assumed runoff onto the experiment plot is prevented (Figure 1).

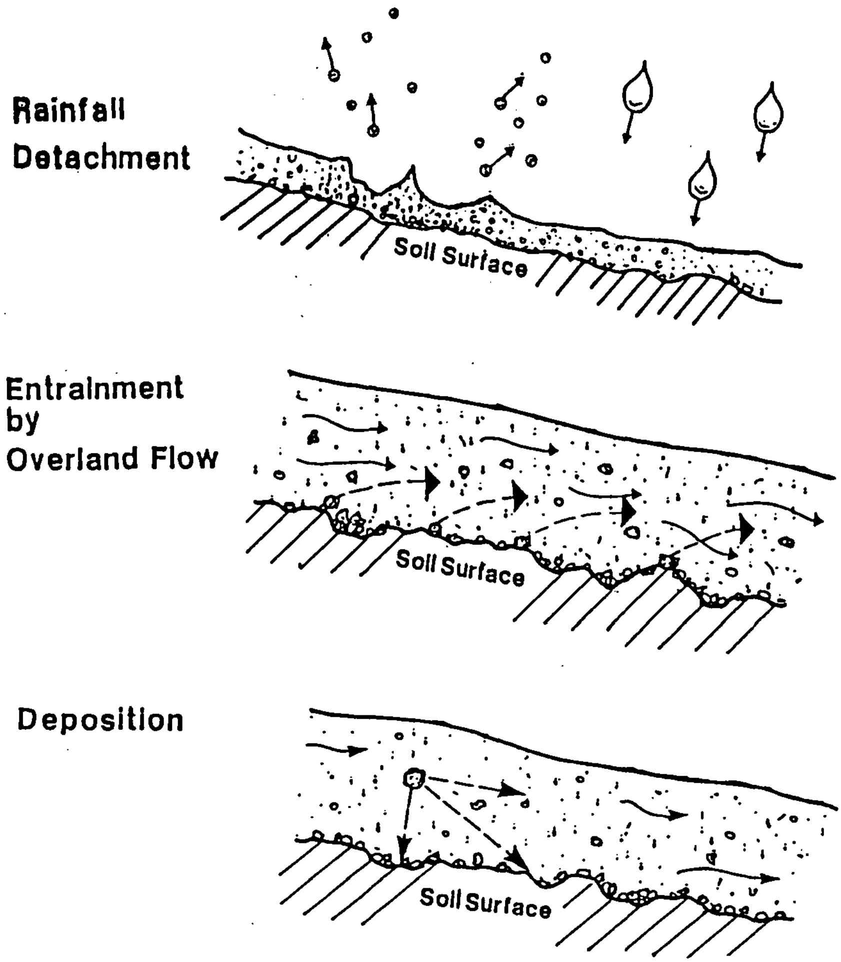

Figure 3. Schematically illustrating the three processes which affect sediment concentration. Rainfall detachment and entrainment both add to the sediment concentration in overload flow; deposition reduces it. The resulting concentration depends on the rate of these three processes.

Let e = rate at which the mass of soil detached by rainfall leaves a unit area of the soil surface. Then experiments have shown that e can be expressed as:

$$e = a\, C_e P \ (kg\ m^{-2} s^{-1}), \qquad (4)$$

where 'a' is a measure of the ease with which the particular soil is detached by rainfall; C_e is the fraction of the soil surface exposed to the detaching action of raindrops; and P is the rainfall rate. (Note that I have expressed P in eqn. (4) as P^2 (e.g. Rose, 1985a, 1985b). However recent experimental work at Griffith University has shown that the power on P in eqn. (4) is much closer to one than two. Whilst it is not of great practical significance exactly what power on P is used, it is of great practical utility if a single standard value is adopted, and unity is recommended on experimental grounds as well as simplicity).

Deposition

Since nearly all sediment has a density greater than water, it falls continuously whilst being carried along in the flow, resulting in the continuous process of deposition illustrated in the lowest sketch in Figure 3. The velocity of fall in water (v_i) of sediment of any size range i is not significantly influenced by the concentration of the sediment for the range of concentration which occurs in the field (Lovell, personal communication). Hence the deposition behaviour of any particular sediment can be described in terms of its fall-velocity characteristic. This characteristic can be measured using bottom withdrawal tube or other techniques.

Let d_i = rate of deposition of sediment mass per unit area of soil surface (kg m^{-2} s^{-2}) for sediment of size-rage i, and

c_i = concentration of sediment in the size range i (kg m^{-3}). Then it follows from the definition of the quantities involved that:

$$d_i = v_i c_i \ (kg\ m^{-2} s^{-1}). \qquad (5)$$

Entrainment

Entrainment, the second process which can add sediment to overland flow, is illustrated in the second sketch in Figure 3. Entrainment is the removal of soil from the soil surface (or surface layers) due to the mutually-shared shear stresses which exist between the flow and soil surface which forms its lower boundary.

Much of sediment entrained in a given runoff event is deposited further downslope, and is likely to be removed again from the soil surface - a process which can be called "re-entrainment". Both processes, entrainment and re-entrainment, are due to the shear stress exerted on the soil surface by the overland flow, and these conceptually separable processes will not be further distinguished in this paper, but referred to simply as entrainment.

For any particular soil type, slope, and runoff rate per unit area (Q), there is a particular threshold distance downslope from the top of the experiment plot (x_*), beyond which the entrainment of sediment commences (cf. Figure 1). The threshold condition has been expressed both in terms of a critical shear stress or a critical stream power (Ω). (Stream power is the rate of working of the shear stress, and is the product of shear stress and flow velocity). The threshold value would be expected to increase with soil shear strength, which is much reduced by cultivation. The threshold stream power for entrainment to commence will be denoted Ω_o, corresponding to $x = x_*$

Thus entrainment commences when:

$$x > x_*, \text{ or } \Omega > \Omega_o \qquad (6)$$

at the bottom of the experiment plot (Figure 1), at $x = L$, $\Omega = \Omega(L)$, and:

$$\frac{x_*}{L} = \frac{\Omega_o}{\Omega(L)} \qquad (7)$$

Sediment Concentration Resulting from Rainfall Detachment and Sediment Deposition

At distance x downslope from the top of the experiment plots such that:

$$x < x_* \quad (m),$$

entrainment has not developed. Hence the sediment concentration results from the balance between the rate of rainfall detachment and the rate of deposition. The resultant sediment concentration varies with time and may be shown (Rose *et al.*, 1983a; Rose, 1983b) to be given by:

$$c(t) = \frac{a\, C_e P}{QI} \sum_{i=1}^{I} \left(\frac{1}{1 + v_i/Q}\right), \quad (x < x_*) \ (\text{kg m}^{-3}), \tag{8}$$

where Q is the runoff rate per unit area of ground. Note that c varies directly with P and inversely with Q, both of which vary with time. Hence c is written c(t).

The total sediment concentration C in eqn. (8) is obtained by summing up over the arbitrary number (I) of size classes into which the fall velocity distribution has been divided. Note that the summation involves v_i/Q, the ratio of fall velocity to Q which is related to the water flux q by:

$$q = Qx \ (\text{m}^3 \text{m}^{-1} \text{s}^{-1}). \tag{9}$$

If v_i/Q is large, as it is for larger particles or aggregates, then their sediment concentration will not be as high as for finer particles, where v_i/Q is smaller.

The sediment concentration resulting from rainfall detachment will be richer in fine material compared to the original soil (as confirmed by experiment). However note that eqn. (8) predicts no variation in c with distance x down the plane. This will be so provided the depth of water further downslope is not sufficient to give some protection to the soil surface from the detaching action of raindrops. That is, the rainfall detachability ('a' in eqn. (8)) is reduced when flow depth exceeds some critical depth, likely to be greater than the median drop size by a factor of the order of two or three.

Whilst the effect of water depth on detachment rate can be readily investigated with a level soil surface, this is a rare situation in the field, where water depth is typically variable.

Sediment Concentration Resulting from Entrainment and Sediment Deposition

Sediment deposition is unavoidable, but for $x > x_*$, the entrainment processes get under way. If plot length L is large compared to x_* (Figure 1), then the contribution to sediment concentration resulting from this process may become larger, perhaps substantially larger, than that due to rainfall detachment. However in weakly aggregated soil the contribution to sediment concentration by rainfall detachment may remain substantial, even for large values of (L/x_*).

The sediment concentration due to interaction of entrainment and deposition processes (without attempting to distinguish between entrainment processes) is given (Rose *et al.*, 1983a; Rose, 1985b) at the bottom of the plot (x = L) by:

$$c(L,t) = 2700\ S\eta\ C_r(1-x_*/L),\ (L > x_*)(\mathrm{kg\ m^{-3}}), \qquad (10)$$

where S is the slope of the land (the sine of the slope angle); η is a measure of the efficiency of the net entrainment process; and C_r is the fraction of the soil surface exposed to overland flow and hence exposed to entrainment. (Note that C_r, and C_e in eqn. (4), are in general different, though for stubble in good contact with the soil surface, $C_r = C_e$.)

The dependence of c on L and t comes explicitly through the threshold term x_*/L, which is equal to $\Omega_o/\Omega(L)$ (see eqn. (7)). Length x_* fluctuates markedly with time under natural rainfall, so it is impossible to speak to a 'typical' value; it also is affected by the land slope (as is $\Omega(L)$). For soils that exhibit rilling, a rough guide to a typical value of x_* for a bare soil plot is the distance from the top of the plot to where there is evidence of rills starting to form. (Rills require entrainment for their formation).

The net efficiency η depends on soil type and condition. For the same soil type η is greatly increased by cultivation; it is much affected by the type of cultivation and the water content at cultivation (if this is wet enough to produce clods, for example). Minimizing tillage tends to lead to a fall in η. Thus η is a composite measure of soil erodibility.

Further implications of this analysis for erosion control will be considered below.

Erosion Control by Reducing Runoff

Reducing runoff by maintaining infiltration rate

It is very well documented that rainfall damage to a soil surface rapidly reduces the infiltration rate (Morin and Benyamini, 1977; McIntyre, 1958; Rose, 1962), thus increasing runoff and erosion (eqn. (2)). There is also very extensive evidence for the complementary result, namely that protecting the soil surface from raindrop action by some form of cover increases infiltration and reduces runoff. Sometimes the reduction in runoff is approximately linearly related to cover fraction (Rose, 1985a).

The aboveground leaves and stalk of vegetation can be effective in protecting the soil by intercepting raindrops. However drops falling from vegetation with a fall height of more than a metre or so can still cause aggregate breakdown. Plant residue or stubble on the soil is also effective in protecting the soil surface from raindrop action, but has the double advantage of also protecting the soil from entrainment.

Reducing runoff by measuring depression storage

Producing furrows or ridges by cross-slope cultivation has the effect of increasing the depth of water which can be stored on the soil surface, giving it more time to infiltrate than if such surface storage was not there. This example is perhaps the most commonly practiced of a wide range of mechanical soil protection measures usefully described and reviewed by Hudson (1973).

Especially in the semi-arid zone, or whenever rainfall amounts are not too great relative to the surface storage available, depression storage techniques can be used successfully. Morin *et al.* (1984) have recently provided a more adequate theoretical background to help interpret the effectiveness of tillage practices, such as basin tillage (or tie ridging).

However, surface depression storage has limits, and the design of any surface storage system needs to be such that if overtopping occurs, the damage caused by failure is not greater than if this mechanical protection had not been carried out (Hudson, 1973). Tie ridging, for example, whilst very suitable for nearly level land and typical semi-arid climate conditions, becomes increasingly dangerous in sloping humid tropical climates.

Another type of mechanical protection is to break up a slope by terracing. Irrigation and rice terraces are one example. Using tropical leguminous trees in a hedgerow layout also leads to a natural terrace formation (Clestino, 1985).

Erosion Control by Reducing Sediment Concentration

When rainfall detachment is the dominant erosion mechanism

With $x < x_*$, eqn. (8) describes the way in which various factors affect the sediment concentration $c(t)$. Rainfall detachability ('a') and the fall velocity distribution are soil characteristics, though these characteristics are improved, in the sense of $c(t)$ being reduced in any situation, by cultural practices which increase the stability and size of aggregation. Thus maintaining an adequately high level of organic matter will tend to reduce 'a' and increase the fraction of soil with a high v_i, both of which lead to lower values of $c(t)$ (eqn. (8)).

The major management method of reducing $c(t)$ is by reducing the fraction (C_e) of the soil surface exposed to the destructive beating action of raindrops. The fraction C_e may be called the exposure fraction to rainfall detachment or the detachment exposure fraction. Sediment concentration decreases directly proportional to the increase in the detachment *cover* fraction, which is $(1 - C_e)$.

Taller vegetation, such as a tree crop, can be less effective than a low-growing crop of the same leaf-area-index in reducing sediment concentration due to rainfall detachment. One reason for this is that larger drops can form from larger tree leaves, and when these fall from canopy-height they can achieve a substantial fraction of their terminal velocity. Such drops from a tree canopy are capable of significant erosion. Fortunately, of course, leaf fall from trees commonly occurs at a sufficient rate for shed leaf and twigs to make a significant contribution to cover on the soil surface.

When runoff entrainment is the dominant erosion mechanism.

When the threshold distance, $_*$, or threshold streampower, Ω_o, is exceeded, entrainment gradually, but fairly rapidly, increases in importance as a contributor to sediment concentration. Whilst in short slope-length plots, say of the order of 4 m, rainfall detachment may be the dominant erosion mechanism, for long plots, say of the order of 40 m, entrainment is likely to be the dominant mechanism. It is not plot length (x) itself which determines this relative importance, but rather stream power Ω, where at distance x downslope:

$$\Omega(x) = pgSQx \quad (Wm^{-2}), \tag{11}$$

where p is water density (1000 kg m^{-3}), g the acceleration due to gravity (9.8 ms^{-2}), S the sine of the slope angle in radius, and Q the runoff rate per unit plot area.

From eqn. (11) it can be seen that Ω depends on S and Q, and not only on distance x. For cultivated soils the threshold streampower (Ω_o) for entrainment to begin is often of the order of 0.02 Wm^{-2}. Assuming this figure to be approximately appropriate, then eqn. (11) can be used to solve for x_* in any particular situation, since from eqn. (11)

$$\Omega_o = pgSQx_* \quad (Wm^{-2}). \tag{12}$$

The contribution to sediment concentration, measured at x = L, when entrainment is the erosive mechanism, is given by eqn. (10).

Note that c is predicted to increase linearly with slope S, underlining the well-known fact that erosion danger increases with slope.

The parameter η has to be evaluated for any particular soil type and soil condition. Experience is being gathered as to its value for various soil types and management methods. Synthesis of this experience could be made in terms of soil groups and management types. Thus in the near future some ability to provide approximate estimates of likely values of η should emerge. In the meantime, it is best to evaluate η (and Ω_o) for the soil type and management method of concern.

By definition, $0<\eta<1$, and the value of η is substantially increased by cultivation. For cultivated soils, values of η over the range 0.1 to 0.8 have been reported for bare soil ($C_r=1$). If, following a period of cultivation, minimum tillage practices are adopted, then evidence is beginning to emerge from Australian research that η tends to fall, perhaps to approximately 1/3 of its cultivated value, in a period of a year or two.

Again, as was the case for rainfall detachment, the relative degree of exposure of the surface to the erosion process, here entrainment is the dominant factor determining sediment concentration c, and so soil loss in erosion. The fraction C_r may be called the exposure fraction to entrainment or the entrainment exposure fraction. The corresponding cover fraction is $(1-C_r)$. Protection against entrainment is provided only by material (such as plant residue) which is in close or intimate contact with the soil surface. Thus fraction $(1-C_r)$ can usefully be termed "surface contact cover". Hence the aerial cover provided by the leaves and stalk of a standing crop, which contributes to aerial cover $(1-C_e)$, does not contribute at all to surface contact cover $(1-C_r)$. This is a most important distinction with significant practical implications.

The major implication is that it is only cover in close contact with the soil surface which is effective in reducing sediment concentration and soil loss when such loss is due *both* to runoff entrainment and rainfall detachment. It appears the value of η decreases rapidly with increasing surface contact cover, as is illustrated in Figure 4. Thus the effectiveness of surface-contact cover in reducing c in eqn. (10) is both directly through reduction in the exposure fraction C_r (eqn. (10)), and through the strong dependence of η on C_r (Figure 4).

The humid tropics is in a favorable situation in terms of the ability to maintain high levels of surface-contact cover. If the fairly high levels of potential plant productivity not uncommon regionally can be achieved, then there is also the potential for keeping the exposure fraction C_r at a minimum. Indeed, with hand-planting of crops, it may well be possible to maintain effectively 100% cover without this leading to difficulty in planting, especially if planting is by hand or with simple equipment.

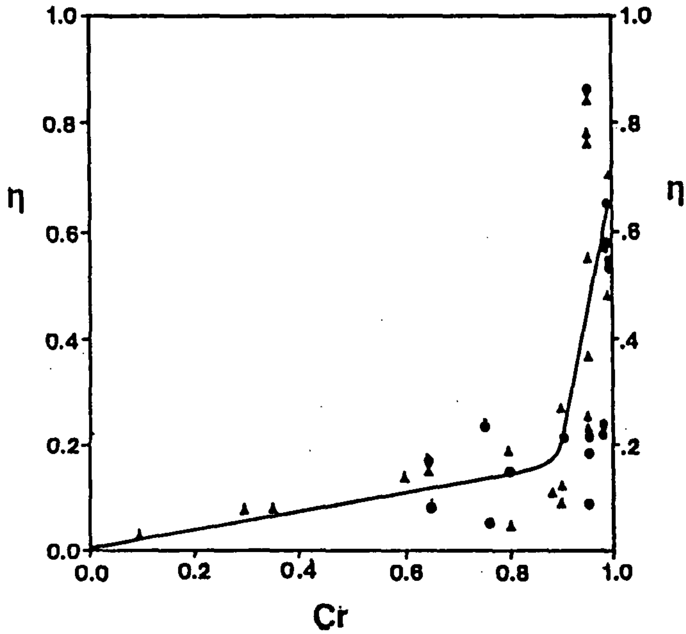

Figure 4. Efficiency of entrainment vs. soil exposure fraction for two Vertisols in the Darling Downs, Queensland. ▲ represents a Pellustert; • a Chromustert (Freerbairn and Rose, 1982).

There is little doubt that soil erosion can be kept to acceptable levels, even on high slopes, given high levels of surface-contact cover ($1 - C_r$), provided landslips or some other form of instability failure does not occur.

The Effect of Slope-length in Erosion

Figure 5 illustrates the combined effect of both erosion processes on soil loss per unit area as the length of slope increases. The figure results from assuming particular feasible values in eqns. (8) and (10), and clearly it is only the form of the relationship that has any generality. The threshold component $(1-x_*/L)$ in eqn. (10) is responsible for the rather rapid rise in sediment concentration downslope of the threshold distance x_*. The contribution of eqn. (8) to soil loss per unit area (m_a) is constant upslope of x_* (Figure 5), but is shown as declining downslope of x_* due to increasing water depth protecting the soil surface from raindrop detachment.

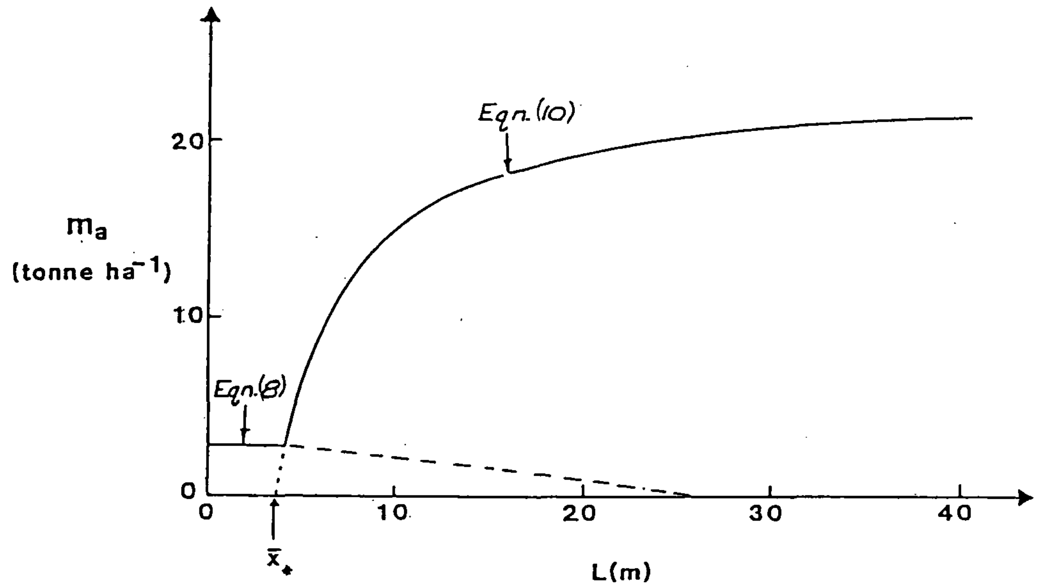

Figure 5. One possible relationship between soil loss per unit area (,,$_a$) and length of plot (L) for a particular combination of relevant variables. Other possible relationships have a generally similar form.

Whilst the particularities of the relationship shown in Figure 5 vary with the values of the relevant quantities and parameters involved, the broad characteristics of a rapid rise towards an asymptotic plateau of soil loss per unit area have been observed. Also it is clear from Figure 5 that adopting as short as possible a slope length consistent with other management and economic constraints will help to reduce soil loss per unit area. However, slope length compatible with acceptable rates of soil loss in any particular environment can be increased if higher levels of surface-contact cover can be maintained.

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FERTILITY CAPABILITY CLASSIFICATION SYSTEM AND ITS UTILIZATION

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ABSTRACT

The incompatibility between the requirements of soil scientists, viz. permanent soil characters found essentially in the subsoil, and those of the agronomists, viz. fertility parameters found in the topsoil, are explained. The dilemma is between the type of information given by the soil scientist which is often not directly relevant to immediate practical issues and the agronomist's hope of finding a universal soil test, which is unrealistic if not related to other soil properties.

Most of the data needed by the agronomist could be found from a soil map. However, essential properties such as surface texture or pH are not specifically expressed in soil classifications. Soil fertility parameters are mostly found in the topsoil and have been listed to form the Fertility Capability Classification (FCC) system. Using and testing the FCC in the last ten years has proved a rewarding exercise. It has made if possible to group together soils which are homogeneous enough in these properties to allow soil management decisions to be taken. The interactive computer software programs now available for personal computers should greatly facilitate its use in the future.

INTRODUCTION

The development of the Fertility Capability Classification System (FCC) was started in response to a perceived under-utilization of soil survey information by agronomists. In this discussion, the rationale and objectives of the FCC system are explained, the components of the system are outlined, and brief comments are given on some of the uses that have been made of the system. Interactive software programs of the FCC system are being developed for micro personal computers and an opportunity to run the system will contribute to a better understanding of the possibilities and limitations involved.

NATURE OF AGRONOMIC-SOIL CLASSIFICATION INCOMPATIBILITY

A critical look at the fundamental concerns of both groups, soil scientists vs. agronomists, goes a long way in explaining the lack of mutual reinforcement. First, the soil scientist is rightfully concerned with being able to correctly identify and locate identifiable kinds of soils. He would like to be able to go back the next year and find the same things. To accomplish this, soil scientists have selected soil properties as criteria for soil classification that are somewhat insensitive to change by expected soil management techniques. We are not totally successful in this respect, but as one example, the 1.8 m from the surface or 1.25 m below the top of the argillic of the Alfisol-Ultisol base saturation limit is deeply placed to avoid the recharge of bases from long-term use of lime, a common practice on acid soils (Soil Survey Staff, 1985). In effect, to the soil scientist a soil is primarily defined by properties that are difficult to alter.

The agronomist's objective is to manage soil properties. He or she is concerned with properties that can be changed. In many cases the actual measurement is not different in kind from that made by the soil scientist, but almost without exception the two professions sample different parts of the profile. Soil management is almost exclusively limited to the upper few centimeters of the soil, with some notable exceptions of drainage and irrigation.

In like fashion, the upper few centimeters are excluded from soil taxonomic consideration, again with a few notable exceptions such as categories that utilize various epipedons for class criteria. The family category of Soil Taxonomy specifically avoids the surface layer in most soils by defining a control section from 25 cm to 100 cm.

It is really not very useful to argue about whether or not more attention needs to be paid to the subsoil by the agronomist. In several regression studies of variables affecting row crop yields, the properties of the topsoil are always more significant to crop growth than subsoil properties. It can be argued that only satisfactory subsoil properties are incorporated in the selection of suitable sites. The folly of prolonging the argument is that the agronomist has almost no technology to change most soil properties below plow depth or subsoiling depths of perhaps 50 cm. Although soil scientists are fond of pointing out the completely controlling influence that shallow bedrock, fragipans, duripans, etc. have on land use, we have to remember that these choices of land use have already been made before the working agronomist gets involved. In fact much of the disregard given soil survey information stems from the fact that within any local area most of the soils that are intensively used for a crop are similar in many respects, and those soils not responding to conventional management are not used for cultivation.

SOIL PROPERTIES - AGRONOMIC OPERATIONS

No attempt will be made to create a definitive list of management practices and of how the presence, absence, or degree of a given soil property influences the agronomic operations. However, there are a few categories of problems that I think we can address. One potential area is that of fine-tuning soil test interpretations. All soil test procedures attempt to extract an arbitrary fraction of several elements from a soil sample and then predict how much fertilizer will be needed for 60 to 120 days, or longer. There are many situations where this works very well; but the real problems result when interpretations are made in soil material which is not like the soil where the calibration was developed. The impulse of the agronomist has been to look for a universal extractant, but perhaps by grouping soils according to their management layer, ion release, and/or fixation properties (i.e. texture, mineralogy, etc.) better interpretations can be made by developing soil group-specific conversion factors from soil-test extraction quantities to application rates.

Methods of fertilizer application are very much soil property- as well as crop-related. High P fixation favors banding or slow release formulations. One or two side dress applications of nitrogen as routine or emergency recommendations for supplemental N after excessive leaching conditions are based on texture, depth to impeding layer, etc.

Soil management is not only fertilizer and other amendments, such as lime, but also mechanical operations such as subsoiling, bedding, mulching, no-till, and limited-till planting. One of the objectives of FCC is to attempt to present soil properties that address agronomists' concerns in a manner which is convenient for them.

WHERE IS THE DATA?

It is correct to conclude that most of the data needed by agronomists along with the spatial distribution of soil properties can be found in a soil map - if the scale of the map permits the resolution of management decision areas. All the agronomist needs to know is the classification system used to name the soil in the map unit. Unfortunately, even that probably will not assure him of knowing the surface texture, since that is seldom a criterion for classification.

How much does the agronomist need to know about a soil's properties to formulate management recommendations?

Some years ago I set out to determine how experienced agronomists and soil fertility experts looked at soils. During the early course of the work it consisted entirely of informally questioning leading agronomists and soil fertility professionals as to how they evaluated agronomic needs in a new area. I was, so to speak, professionally insulted in that I did not find the use of soil surveys high on anyone's mode of operation. However, I found I could usually have told them almost everything they wanted to know from what we would expect in a map unit description. I could not do this from a taxonomic placement, regardless of the classification system, primarily because of the question that emerged to be number one among the agronomists. Simply, they wanted to know: What is the surface texture? As one individual put it, "I first give the soil a kick to see what the texture is." I concluded I did not have to be too precise about texture if it could be done with a kick, but I had better lead off a soil description by giving a surface texture if I am to get an agronomist's attention.

After rather unanimous agreement on surface texture, the background of the individuals made for a rather diverse list of concerns. Certainly pH was high on the list, as was subsoil texture, soil test levels, past cultural practices, and rainfall and temperature. It became apparent that what agronomists wanted to know about soils was far less than the soil surveyor had to have to classify a soil. Many of the analytical methods preferred were not the same. The units of expression were different, and there was a host of reasons why they did not relate to the various soil survey reports.

Most of these apparent problems faded, however, when the agronomists were asked to put "quantitative criteria" on their categories of "high P-fixing soils", "rapidly leached soils", "wet soils", etc. It was obvious that they had almost no creditable way of communicating with each other. Consequently, they did not communicate well, and I think evidence of this lack of communication is reflected in verbal and published statements to the effect that "this is the practice to use in state X, while in state Y or county Z another practice is to be preferred." It seems agronomists can usually agree on the political boundaries on a map, but that does not appear to be a scientifically satisfying way to communicate cause and effect of soil management techniques.

What followed was a series of appoximations to express the concerns of agronomists in a formal fashion and with quantitative class limits. As we all now know, essentially all soil properties form a continuous solid series and any class limit is going to fit better in one part of the world than in another. Thus the limits used in FCC have been arrived at either because they can be conveniently borrowed from Soil Taxonomy or they can be agreed to by agronomists as limits that are critical to key agronomic technologies. This relationship to technology, although critical for a technical classification, is always time-dependent because technologies change.

What has evolved is presented in Table 1. There are many questions that have been raised over the years about the system, and perhaps I can address some of the more general ones at this time.

Table 1. FCC system. (Sanchez *et al.*, 1982).

Type. Texture of plow-layer or surface 20 cm, whichever is shallower:

S = sandy topsoils: loamy sands and sands (by USDA definition);
L = loamy topsoils: 35% clay but not loamy sand or sand;
C = clayey topsoils: 35% clay;
O = organic soils: 30% O.M. to a depth of 50 cm or more.

Substrata type (texture of subsoil). Used only if there is a marked textural change from the surface, or if a hard root-restricting layer is encountered within 50 cm:

S = sandy subsoil: texture as in type;
L = loamy subsoil: texture as in type;
C = clayey subsoil: texture as in type;
R = rock or other hard root-restricting layer.

Modifiers. Where more than one criterion is listed for each modifier, only one needs to be met. The criterion listed first is the most desirable one and should be used if data are available. Subsequent criteria are presented for use where data are limited.

g' = (constant saturation): Soil is constantly saturated with no evidence of brownish or reddish mottles, except around root channels, in the top 50 cm.
g = (gley): soil or mottles 2 chroma within 60 cm of the soil surface and below all A horizons, or soil saturated with water for 60 days in most years;
d = (dry): ustic, aridic or xeric soil moisture regimes (subsoil dry 90 cumulative days per year within 20-60 cm depth);

e = (low cation exchange capacity): applies only to plow layer or surface 20 cm, whichever is shallower: CEC 4 meq./100 g soil by bases + KCl-extractable Al (effective CEC), or CEC 7 meq./100 g soil by cations at pH 7, or CEC 10 meq./100 g soil by cations + Al + H at pH 8.2;

a = (aluminum-toxicity): 60% Al-saturation of the effective CEC within 50 cm of the soil surface, or 67% acidity saturation of CEC by cations at pH 7 within 50 cm of the soil surface, or 86% acidity saturation of CEC by cations at pH 8.2 within 50 cm of the soil surface, or pH 5.0 in 1:1 H_2O within 50 cm, except in organic soils where pH must be less than 4.7;

h = (acid): 10-60% Al-saturation of the effective CEC within 50 cm of soil surface, or pH in 1:1 H_2O between 5.0 and 6.0;

i = (high P-fixation by iron): % free Fe_2O_3/% clay 0.15 and more than 35% clay, or hues of 7.5 YR or redder and granular structure. This modifier is used only in clay (C) types; it applies only to plow-layer or surface 20 cm of soil surface, whichever is shallower;

x = (X-ray amorphous): more than 1.4% oxalate extractable Al or a pH 10.6 in 1N NaF in the top 20 cm;

v = (Vertisol): very sticky plastic clay: 35% clay and 50% of 2:1 expanding clays, or severe topsoil shrinking and swelling;

k = (low K reserves): 10% weatherable minerals in silt and sand fraction within 50 cm of the soil surface, or exchangeable K 0.20 meq./100 g, or K 2% of bases, if bases 10 meq./100 g;

b = (basic reaction): free $CaCO_3$ within 50 cm of soil surface (effervescence with HCl), or pH 7.3;

s = (salinity): 4 mmhos/cm of electrical conductivity of saturated extract at 25°C within 1 m of the soil surface;

n = (natric): 15% Na-saturation of CEC within 50 cm of the soil surface;

c = (cat clay): pH in 1:1 H_2O is 3.5 after drying and jarosite mottles with hues of 2.5 Y or yellower and chromas 6 or more are present within 60 cm of the soil surface; (only used in Cg and Cg' substrata);

' = (gravel): a prime (') denotes 15-35% gravel or coarser (2 mm) particles by volume to any type or substrata type texture (example: S'L = gravelly, sand over loamy; SL' = sandy over gravelly loam); two prime marks (") denote more than 35% gravel or coarser particles (2 mm) by volume in any type or substrata type (example: LC" = loamy over clayey skeletal; L'C" = gravelly loam over clayey skeletal);

% = (slope): where it is desirable to show slope with the FCC, the slope range percentage can be placed in parentheses after the last condition modifier (example: Sb (1-6%) = uniformly sandy soil, calcareous in reaction, 1-6% slope).

> The soils are classified by determining whether the characteristic is present or not. Most of the quantitative limits are criteria present in Soil Taxonomy (Soil Survey Staff, 1975). The FCC unit then lists the type and substrata type (if present) in capital letters, and the modifiers in lower case letters, the gravel modifier as a prime (') and the slope, if desired, in parentheses. For example, many Oxisols belong to the FCC unit C aeik (i.e., clayey, Al-toxic, low CEC, high P-fixation by iron, low K-reserves), many Vertisols to C bdv (i.e., clayey, dry season, vertic calcareous), whereas a young alluvial Entisol with no fertility limitations is simply classified as L (loamy soil). The absence of modifiers suggests no major fertility limitations, other than nitrogen deficiency.

First, the rationale for the system was simply to provide a framework within which problems of soil management, primarily correctable problems, and fertility problems could be quantified for better communication. This always leads to the question: Why is it called "capability" rather than a "problem" or limitation classification? Well, quite simply, that is "Madison Avenue" or "sex appeal". Fertility sounds better than another list of problems.

Whenever you create class limits, procedures have to be specified. Rigid requirements can severely limit the use of a system. Thus, over the years we have added "alternative" methods to define many of the condition modifiers. These are designed to allow the FCC system to be compatible with existing soil surveys and systems of soil characterization. Note that the system is open-ended and additional features considered of local importance can be added as prime (′) or perhaps asterisks (*). I have resisted adding a multitude of other condition modifiers, not because they may not be important, but because it is already a bit longer than I consider ideal.

OUTPUT FROM FCC

The objective of a technical classification system is not to classify but to create identifiable groups of soils about which more precise statements can be made than when discussing the entire soil population. With FCC the attempt is to group soils about which agronomists feel comfortable in making statements and transferring *their* technology. Sample interpretive statements about each FCC condition modifier have been suggested for upland agriculture (Table 2) and paddy rice cultivation (Table 3). However, in an operational setting local editing and modification by local agronomists are highly desirable.

Table 2. FCC sample interpretation. (Sanchez *et al.*, 1982)

S: high rate of infiltration, low water-holding capacity.

L: medium infiltration rate, good water-holding capacity.

C: low infiltration rates, good water-holding capacity, potential high runoff if sloping, difficult to till; when i modifier is present, these (Ci) soils are easy to till, have high infiltration rates and low water-holding capacity.

O: artificial drainage is needed and subsidence will occur; possible micronutrient deficiencies; high herbicide rates usually required.

SC, LC, LR, SR: susceptible to severe soil degradation from erosion exposing undesirable subsoil; high priority should be given to erosion control.

Interpretation of modifiers:

When only one modifier is included in FCC unit, the following limitations or management requirements apply to the soil. Interpretations may differ when two or more modifiers are present simultaneously or when textural types are different.

g': too wet for upland use unless expensive protection is provided.

g: denitrification frequently occurs in anaerobic subsoil; tillage operations and certain crops may be adversely affected by excess rain unless drainage is improved by tilling or other drainage procedures; good soil moisture regime for rice production.

d: moisture is limiting during the dry season unless soil is irrigated; planting date should take into account the flush of N at onset of rains, germination problems are often experienced if first rains are sporadic.

e: low ability to retain nutrients against leaching, mainly K, Ca and Mg; heavy applications of these nutrients and of N fertilizers should be split; potential danger of overliming.

a: plants sensitive to Al-toxicity will be affected unless lime is applied; extraction of soil water below depth of lime incorporation will be restricted; lime requirements are high unless an e modifier is also indicated; this modifier is desirable for rapid dissolution of phosphate rocks h: low to medium soil acidity; requires liming for Al-sensitive crops, such as cotton and alfalfa. and for good latex flow in rubber. Mn-toxicity may occur on some of these soils.

i: high P-fixation capacity; requires initial application of 5-10 kg P per hectare for each % clay; sources and method of P fertilizer application should be considered carefully; with C texture, these soils have granular soil structure.

x: high P-fixation capacity; banding or pelletized P fertilizers are recommended; low organic N mineralization rates.

v: clayey textured topsoil with shrink and swell properties; tillage is difficult when too dry or too moist, but soils can be highly productive; P-deficiency common.

k: low ability to supply K; availability of K should be monitored and K fertilizers may be required frequently; potential K-Mg-Ca imbalances.

b: calcareous soils; rock phosphate and other non-water-soluble phosphates should be avoided; potential deficiency of certain micronutrients, principally iron and zinc.

s: presence of soluble salts; requires drainage and special management for salt-sensitive crops or the use of salt-tolerant species and cultivars.

n: high levels of sodium requires special soil management practices for alkaline soils, including use of gypsum amendments and drainage.

c: potential acid sulfate soil; drainage is not recommended without special practices; should be managed with plants tolerant to high water table level.

By using the individual guides for each type, substrata type, and modifiers, it is possible to prepare composite interpretation guidelines for all of the possible FCC-units. More comprehensive interpretative statements are possible when interactions of two or more soil conditions are considered. No necessity is seen for a complete listing of all possible combinations because only a limited number of FCC-units will be found in any area under consideration. At the local level, however, interpretation of the FCC-units found in relation to the main crops and specific farming systems used would be a valuable extension tool and local expertise is expected to supplement the following brief statements where experience warrants.

Sample interpretations of FCC-units:

Lehk: good water-holding capacity, medium infiltration capacity; low ability to retain nutrients for plants mainly K, Ca, Mg; heavy applications of these nutrients and N fertilizers should be split; requires liming for Al-sensitive crops; potential danger of overliming because of low

	CEC, low ability to supply K; availability of K should be monitored and K-fertilizers may be required frequently for plants requiring high levels of K.
Lgth:	good waterholding capacity, medium infiltration capacity;limitations in drainage so that tillage operations and some crops may be adversely affected unless drainage is improved by tilling or other procedures; strong to medium acid soil; liming required for some crops; excellent soil for flooded rice, as acidity will be eliminated by flooding.
LCaegk:	erosion or other removal of surface soil will expose undesirable clay-textured subsoil; drainage limited so that tillage operations and some crops may be adversely affected unless drainage is improved by tilling or other procedures; low ability to retain nutrients for plants, mainly K, Ca, Mg; heavy application of these nutrients and N fertilizer should be split; plants sensitive to Al-toxicity will be affected unless lime is deeply incorporated; however, deep liming practices are difficult because of clay-textured substrata; low ability to supply K; availability of K should be monitored and K fertilizers may be required frequently for plants requiring high levels of K.
L:	excellent soil with no major fertility constraints; N deficiency likely with intensive use.

Table 3. Sample interpretations of FCC condition modifiers for rice cultivation in aquic soil moisture regime. (Sanchez and Buol, 1985).

Modifier	Limitations or management requirements
g	= Defines wetland soils. Preferred moisture regime for rice cultivation.
g'	= Prolonged submergence causes Zn deficiency.
d	= Topsoil moisture limited during dry season unless irrigated. Generally only one rain-fed rice crop can be grown a year. Irrigated rice during the dry season has higher yield potential and responds to higher N rates.
k	= Low inherent fertility because of low reserves of weatherable minerals. Management levels higher than in soils without this modifier. Potential K deficiency depending on base contents of irrigation water.
e	= Low ECEC reflects less gradual N release, more exacting N management. Identifies degraded paddy soils with SLa or LCa and low organic matter

contents. If so, potential H2S toxicity can occur if (NH4)2SO4 is used as N source. Potential Fetoxicity if adjacent uplands have Fe-rich soils.

a = Aluminum toxicity will occur in aerobic layers. Soil test for identifying P deficiency recommended.

h = Optimum aerobic pH for flooded rice production. Potential P deficiency with continuous rice cropping.

b = High pH may induce Fe deficiency when aerobic and Zn deficiency when waterlogged. High N volatilization loss potential from broadcast N applications. NH4+ fixation by 2:1 clays possible. Mollusk shells indicative of Zn deficiency.

i = High P fixation by Fe; P deficiency likely; Fe toxicity potential; soils difficult to puddle and will regenerate original structure rapidly. Interflow from Ci uplands may cause Fe toxicity to e soils with lower topographic position.

x = Volcanic materials indicate high inherent fertility with no potential Si deficiency; N and P deficiencies common and soil may fix large quantities of P; soils difficult to puddle and will regenerate original structure rapidly.

v = Soils will shrink and crack when dry, causing excessive percolation losses afterwards. Easy to puddle but difficult to regenerate structure. P deficiency suspect and should be determined by soil tests. Soils fix applied NH4 and release it later to the rice crop (a positive-attribute). Cracks, however, may not close after drying and subsequent flooding, increasing percolation and exacerbating N losses.

s = Defines saline soils. Drainage needed but must consider conductivity of irrigation water.

n = Defines alkali soils. Reclaiming with drainage and gypsum applications may be needed.

c = Acid-sulfate soils causing Fe and S toxicity when anaerobic and Al toxicity when aerobic. Depth at which c modifier occurs determines feasibility of rice production. Strong P deficiency likely and Al toxicity when aerobic.

TESTING AND USING THE SYSTEM

No doubt "testing and using" mean very contrasting things to different people. Soils have been grouped according to FCC criteria for many different reasons in the last few years. Data from general soil maps and other studies were assembled by FCC criteria in the recent three-volume publication of "Land in Tropical America" by Cochrane *et al*., 1985. All of the FAO world soil map units in Africa have been converted to FCC units in preparation for compiling interpretive maps of Africa. FCC groupings have been tested as guides for N fertilization of lowland rice (Lin, 1984) and P and K fertilization of lowland rice (Lin, 1985) in Taiwan. FCC has been used to evaluate the extent of soil constraints (Sanchez and Cochrane, 1980; Trangmar *et al*., 1984) and as a basis for evaluating future fertilizer manufacturing requirements (T. Kaddar, 1981, personal communications). Several studies have used FCC to group soils in smaller regions as the basis for further technology transfer and research (Oliveira, 1978; Avilan *et al*., 1979; Avilan *et al*., 1978; Avilan *et al*., 1977; Brito *et al*., 1979; Paredes Arce, 1986).

Not all users found that their needs were fully satisfied by FCC; however, only slight modifications were suggested. Concepts of what a technical classification system should and can do certainly vary from scientist to scientist. In my opinion, there is a tendency to expect too much in the way of interpretations from almost every classification system. In the case of FCC, I do not expect that it will serve well as a predictor of yield. The criteria are not selected with this in mind. What is hoped for are groups of soils that are homogeneous enough in properties that soil management decisions are the same in kind, if not totally in quantity, within groups and different between groups. While rigorous testing of response to management inputs is appropriate, the ultimate test appears to be in an evaluation of the use of the system in the delivery of soil management information to the user. In almost every country the delivery of advice to farmers follows a path of researcher - extension specialist - farmer. Often soil science is but one of several disciplines an extension specialist is expected to communicate to the farmer. If FCC groups permit clearer and more precise information to be transmitted while requiring a less sophisticated comprehension of soils terminology, often not relevant to the area, the more inclined the extension specialist is to get the job done properly.

PERSPECTIVE ON FCC USE

The FCC system as presently structured seems less detailed than many soil scientists (classifiers) would like and a bit more complicated than agronomists feel comfortable using. The use of the interactive FCC software program for personal computers greatly facilitates using the system. As with any technical classification, the most important feature is the usefulness of the technology. The classification aspect of the system is only the vehicle by which the technology is transferred.

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ACID SOILS IN THE HUMID TROPICS: MANAGING THE SOIL SURFACE

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ABSTRACT

Acid soils in the humid tropics represent the largest potential for the future development of agriculture. The climate in the humid tropics is an asset to plant growth but a constraint to lasting soil fertility. To maintain soil fertility, cropping systems have to be used that minimize exposure of the bare soil to the elements. Legumes play a key role in providing a soil cover and in maintaining soil fertility.

INTRODUCTION

Acid soils in the humid tropics represent the largest potential for future agricultural development. So far most permanent human settlements in the tropics have been confined to areas with high base saturation soils.

With the exception of tree-crop cultivation, sustained agriculture based on row crops has rarely been successful. To the present day their successful management poses serious problems to soil scientists, agronomists and farmers alike.

The predominant management form on acid soils is shifting cultivation in which the land is cropped for short periods in alternation with long periods of (secondary forest) fallow. Shifting cultivation can sustain subsistence agriculture as long as population pressure is low and the people practicing shifting agriculture have a long historical experience in this form of land use. But once population pressure builds up, shifting agriculture has to give way to more intensive, permanent management systems. And it is here where the problems arise. The discussion in this paper will be limited to the soil orders of Ultisols, Oxisols, Alfisols and some Inceptisols. Acid sulphate soils (Sulphaquepts and Sulphaquents), peat soils (Tropofibrists) and Andepts will be left out, as they require a very different management approach. Similarly, the most efficient system of managing the soil surface - to cover the soil surface with water for paddy rice cultivation (on soils where water can be impounded) - will not be discussed because the impounded water which prevails in the rice paddy raises soil pH to a level close to the neutral point.

FERTILITY CONSTRAINTS IN THE ACID SOILS OF THE TROPICS

Most acid soils presently not under permanent cultivation have a low and highly fragile fertility. Von Uexkull (1982) listed the following constraints:

- a low pH
- a low cation exchange capacity
- a low level of total and available nutrients
- a low base saturation percentage
- a high aluminum saturation percentage
- a high, often toxic, concentration of manganese
- a high phosphorus fixation capacity
- a clay fraction consisting of minerals with a low and partly pH-dependent surface charge density
- a low water-retention capacity
- an organic matter fraction consisting largely of coarse, purely dispersed material
- absence of stable organo-mineral complexes (exception: Andepts)
- a low level of microbiological activity
- sensitivity to compaction (especially Ultisols) and slow recovery from compaction
- sensitivity to erosion

This catalogue of constraints could be expanded, but it is sufficient to explain why most acid soils have so far been left uncultivated.

CLIMATE - AS AN ASSET AND CONSTRAINT

The climate of the humid tropics is an asset to plant growth and a constraint to soil fertility. The apparent productivity of tropical rain forests is not based on enduring soil fertility, but rather on nearly year-round favorable climatic factors such as an optimal temperature range, high rainfall, and reasonably high solar radiation. Such factors also increase the rate of weathering of soil minerals and the release of nutrients into the soil-plant system.

But it is also climatic factors that are largely responsible for the rapid deterioration of soil fertility where the bare soil is exposed to the elements. The two main factors are the amount and type of rainfall and high temperatures. By contrast, wind that can have a strong effect in temperate or arid sub-tropical regions has little significance as a factor influencing soil fertility in the humid tropics.

Rainfall causes erosion and leaching of nutrients, and can destroy topsoil structure. Rainfall tends to be more destructive in the tropics than in the temperate regions because it frequently comes in very intense showers with individual raindrops larger than in temperate regions. It is this type of rainfall that makes the tropical rain forest or the rice paddy (with a protective water cover) the ideal ecosystem to maintain soil fertility.

The surface temperatures of unprotected soil in the tropics can exceed 50°C, resulting in rapid desiccation of the surface soil and the death of surface feeder roots. They also contribute to the more rapid fixation of nutrients, and in alternation with rainfall produce crusts that reduce water infiltration rates and increase the danger of erosion.

"Sound management systems applied to the fragile acid soils must aim at optimizing the positive aspects of a tropical climate while minimizing the negative ones" (Dowdle and Von Uexkull, 1986).

SOIL COVER AND SOIL PRODUCTIVITY

The lush growth of the tropical rain forests, even on very poor soils, is ample evidence that as long as the entire nutrient cycle is intact, soil fertility is maintained. The following factors explain the lush growth of the rain forest vegetation, even on very poor soils:

- A very rapid and efficient cycling of nutrients (Table 1). In many cases up to 60% of the total available nutrients can be found in the live or dead vegetable matter.

- A dense and closed canopy that:
  . reduces the total amount of rainfall reaching the soil surface;
  . reduces the kinetic energy of raindrops reaching the ground;
  . constantly deposits a protective layer of litter on the ground; and
  . keeps the soil surface shaded, cool and moist.

- A vegetation that absorbs some nutrients from the subsoil and deposits them on the soil surface.

Table 1. Nutrient cycle in high forest at Kade, Ghana.

	Wt. of material (oven dry) kg/ha	Nutrient elements (kg/ha/annum) N	P	K	Ca	Mg
Rainfall in open - (1854 mm in 12 months)		15	0.4	18	12	11
Rainfall under forest - (1575 mm in same period)		27	4.1	238	41	29
Rain wash from leaves		12	3.7	220	29	18
Timber fall	11.210	36	2.9	6	82	8
Litter fall (on 12 months' record)	10.540	200	7.3	68	206	45
Total addition to soil surface		248	13.9	294	317	71

Source: Calculated from Nye and Greenland (1960).

Once the cycle is broken when the forest is cleared, both soil productivity and soil fertility usually decline steeply. Injection of nutrients alone into the broken cycle in the form of fertilizers slows down but rarely arrests the productivity and fertility decline. This means that it is more than just the interrupted nutrient cycle that is responsible for the decline.

Whenever a tropical rain forest is cleared the following chain reaction is set in motion and is largely responsible for the loss in fertility: (Dowdle and von Uexkull, 1986)

- loss of the original protective canopy cover
- interrupted deposition of plant biomass on and in the soil
- increased amount of rainfall hitting the ground directly with increased kinetic energy
- increased erosion of the topsoil
- decreased topsoil organic matter
- decreased activity of soil fauna and flora
- decreased rates of water infiltration
- decreased water-holding capacity of the soil
- increased surface runoff and increased erosion
- increased surface soil temperature maxima
- frequent variations in surface soil moisture, ranging from excess to severe stress
- decreased availability of plant nutrients
- decreased plant growth
- decreased (secondary) protective canopy cover
- increased erosion - and so on.....

Over time this sequence tends to lead from primary forest to savanna and finally to barren land. The main factors responsible for the stable soil conditions under forest are the protective canopy and the uninterrupted deposition of organic matter (and nutrients) on the soil surface. Loss of protective cover, decomposition and loss of organic matter, and topsoil erosion are the three main factors that initiate the degradation of the soil once the forest cover is removed.

THE ROLE OF ORGANIC MATTER

In high base saturation soils there is usually a gradual fertility drop from the topsoil to the subsoil.

By contrast, in the acid soils of the tropics most of the fertility is accumulated in the topsoil, with the subsoil contributing very little to the overall productivity that cannot be easily overcome by (increased) fertilizer application.

Organic matter affects or interacts with most soil fertility parameters. Greenland and Dart (1972) have pointed out the following benefits of organic matter:

- Organic matter supplies most of the nitrogen and sulphur and half of the phosphorus taken up by unfertilized crops. The slow-release pattern of nitrogen and sulphur mineralization in organic matter offers a definite advantage over soluble fertilizers.

- Organic matter supplies most of the cation exchange capacity of acid, highly weathered soils. Rapid decreases in organic matter result in sharp reduction in the CEC.[1]

- By forming complexes with organic matter, amorphous oxides do not crystallize. Phosphorus fixation by these oxides is decreased by organic radicals blocking the fixation charges.

- Organic matter contributes to soil aggregation, and thus improves physical properties and reduces susceptibility to erosion.

- Organic matter modifies water-retention properties, particularly in sandy soils. In Ghana, the soil water-holding capacity decreased from 57% to 37% when the soil organic matter decreased from 5% to 3%.

- Organic matter may form complexes with micronutrients which prevent their leaching. The availability of micronutrients is also improved.

In addition, the following other effects are of importance:

- Organic matter forms complexes with aluminum and manganese, thereby decreasing their concentration in the soil solution.

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1. The CEC of organic matter is highly pH dependent.

- Organic matter stimulates activity of the soil flora and fauna. This in turn further improves physical properties through the formation of more stable soil aggregates and aeration channels.

- By keeping the soil surface covered, organic matter prevents the build up of high temperatures in the topsoil.

Because of rapid decomposition, and because clay minerals with a low surface charge (like kaolinite) do not form stable organo-mineral complexes,[2] the effect of the bulk of the organic matter is rather short-lived. Under forest there is a continuous supply of organic matter. Clearing the forest and cropping the land interrupts the supply of organic matter, while at the same time often speeding up its decomposition.

What makes organic matter so important is the fact that it is the only soil amendment that can be produced on or near the farm. For upland soils in the tropics cycling of organic matter is a precondition for efficient use of chemical fertilizers. Organic matter in all its forms is essential to preserve and protect the topsoil. Loss of topsoil due to erosion is probably the largest single factor responsible for the decline in soil fertility whenever a natural vegetation is replaced by arable crops. Lal (1979) has shown that removal of 2.5 cm of topsoil can result in yield losses of 40 to 50%.

The rate of soil erosion will depend on topography, soil, climate, crops grown, type and timing of land preparation, etc: With good management, soil erosion can usually be kept within tolerable limits when topography is good. The amounts of soil and nutrients lost under different types of soil cover and management are shown in Table 2. Soil erosion as a constraint to crop production has been discussed in detail by Lal (1980) and Lal and Greenland (1979).

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2. Allophane on the other hand reacts with organic radicals to form complexes with organic complexes that remain relatively resistant to mineralization. The same applies to some other amorphous sesquioxide compounds.

Table 2. Loss of topsoil and calculated nutrient losses as affected by different types of land utilization in Chinchina, Colombia (18 locations, 6 years).

Type of soil cover	Topsoil loss mt/ha	Nutrient loss, kg/ha N	P	K
Old coffee	0.5	0.5	0.3	1.0
Young coffee	2.2	0.7	1.1	3.0
Grass mulch	32.1	9.4	16.1	48.0
Grass vegetation	37.7	11.3	19.0	55.0
Corn-Fallow-Corn	166.0	49.8	83.0	249.0
Continuous corn	798.0	239.4	120.0	1197.0

Source: Pagel, 1981.

MANAGING THE SOIL SURFACE

General

Successful and sustained use of the acid soils in the tropics is largely a function of managing the soil surface in a way that most closely resembles conditions prevailing under forest cover.

While limitations due to nutrient deficiencies can be easily overcome by proper manuring, limitations due to physical factors are less amenable to improved management practices. Sanchez (1981) reported that biomass production by rain forests was more related to physical than to chemical and plant nutrient aspects. When the forest is cleared, crop productivity is initially and temporarily related more to chemical than physical parameters, but as the latter tend to deteriorate faster, this relationship is reversed and soil physical parameters become the main constraint. Chan and Pushparajah (1972) showed that differences in soil structure could account for up to 405 yield difference in rubber. Preserving and maintaining good physical soil properties is essential to any efficient soil management system for acid soils.

For tree crops such as oil palm, rubber, etc. highly successful management practices based on the initial use of creeping legumes that protect the soil surface during the immature phase of the crop have been developed (Pushparajah, 1987).

For row crops the use of the fertility-maintaining and fertility-regenerating properties of leguminous creepers is more limited and not yet sufficiently researched and explored.

Successful management systems should aim at:

- preservation and minimum disturbance of the soil surface properties on land clearing; and

- use of cropping and soil management systems that aim at maximizing the presence of a protective cover (canopy of a growing crop and live or dead mulch), and minimize practices that could lead to erosion, soil compaction or loss of organic matter.

LAND CLEARING

Whenever possible, good soil surface management should already start with land clearing. Conventional methods pay little attention to what happens to the soil surface during the process of land clearing. The standard procedure is to slash the undergrowth, fell the remaining trees, wait until the foliage dries up sufficiently to give a good burn, cut up the ramaining tree trunks, stack them and re-burn. This procedure leads to a rather "clean" soil surface. The process of burning usually results in the loss of the forest biomass which might usefully be retained, leaving behind the dried, sterilized and surface-carbonized trunks of the larger trees, which are the only item one really would like to burn. While conventional land clearing methods may be acceptable where the land subsequently is sown to a leguminous cover crop and planted to tree crops like rubber or oil palm, such methods cannot be advocated where the land is to be used for row crops. Von Uexkull (1982, 1984) suggested land clearing techniques aimed at minimum disturbance of the soil surface and a smooth transition from forest to agricultural use.

The basic components of this technique are:

- zero or minimum burn;
- poisoning rather than burning the large trees for their rapid decomposition; and
- planting or seeding of a fast-growing legumin-

ous cover crop to take over the protective functions of the forest cover *before* the forest cover is totally removed.

LEGUMES IN SOIL CONSERVATION AND SOIL REGENERATION

Leguminosae are one of the three largest families of plants, with some 690 genera and about 18 000 spp. of herbs, shrubs, trees and climbers (Purseglove, 1974). Although the value of legumes in improving and sustaining soil fertility has been known since ancient times (Chen, 1983), it was not until the end of the 19th century that it was found out that they added nitrogen to the soil (Hellriegel and Willfarth, 1888).

For a long time after this discovery, the beneficial effect of legumes was largely credited to their nitrogen-fixing properties. But in actual fact, their beneficial effect often goes far beyond this trait:

- many leguminous plants are tolerant to acid soils;
- they are fast growing and provide a quick and effective soil cover;
- they are often resistant to pest and disease attacks;
- they are deep rooted and thus help to bring up nutrients to the soil surface;
- they improve soil structure and water infiltration;
- they provide food and/or fodder to man and animals;
- they can easily be removed either by hand, mechanical means or by chemical spray; and
- they can help to keep grassy weeds under control.

On account of their large number, suitable species can be found adapted to a very wide spectrum of soils, climates and management practices.

While the use of legumes as green manure in temperate regions and as cover crops for plantation crops has a long history, the importance of legumes for upland agriculture in the tropics, especially on acid soils, is still grossly understated. In fact, sustained use of most acid soils for arable crops may not be possible without the use of soil fertility regenerating legumes in the cropping system.

In temperate regions and in structurally stable soils having a topography and rainfall pattern that permits plowing, the legumes can and should be used as "green manure" to be plowed under. In the structurally labile and often shallow acid tropical soils, legumes should be principally used as shade trees, soil cover, and as a source of live or dead mulch in minimum-tillage systems.

- Tree or shrub species (*Leucaena leucocepala*. *Gliricidia maculata*, *G. sepium*, *Cajanus cajan*, *Sesbania* spp. *Thephrosia* spp., *Moghania macrophylla* - syn. *Flemingia congesta*).

  The above species can be used as shade or temporary shade or for "alley cropping". This agroforestry type of technique combines the soil restorative attributes of the bush fallow with arable cropping by growing arable crops and fast growing (perennial) trees or shrubs side by side (Wijewardene and Waidyanatha, 1984). Leguminous trees or shrubs are established in rows 3 to 5 m apart and at the time of seedbed preparations the trees are lopped. After removal of the woody material for use as fuel, the green materials from the loppings are used in situ as a mulch and a source of nutrients (Figures 1 to 3).

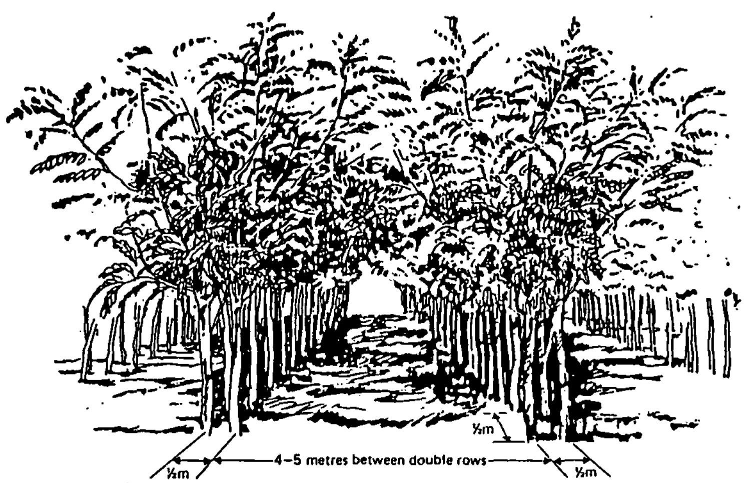

Figure 1 Double hedges of *Gliricidia* or Leucaena forming dense shade over the alleys during the dry (non-cropping) season (IITA, 1979-81).

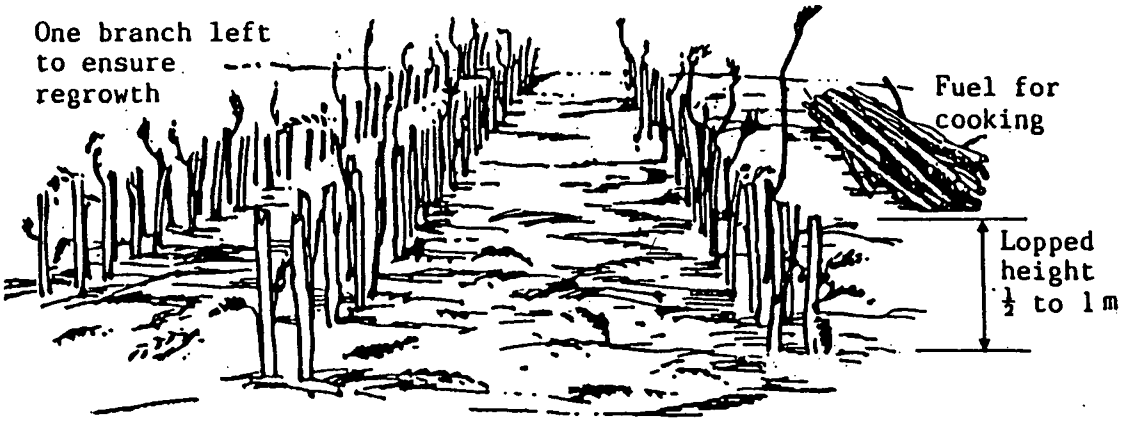

Figure 2 Hedgerows lopped and mulch laid in the alleys (IITA, 1979-81).

Figure 3 Crops growing in the alleys in light shade from the hedgerows which are lopped periodically during the growing season to provide further mulch and optimum light for the maturing crop (IITA, 1979-81).

- Prostrate herbs (*Arachis prostrata*, *Desmodium* spp., *Crotalaria* spp. *Stylosanthes erecta*, *S. guianensis*, etc.)

Prostrate herbs can be used as soil cover, live or dead mulch.

As shown in Figure 4, maize yields could be maintained under a system of no-till on live mulch, whereas there was a steep decline in yields under conventional till.

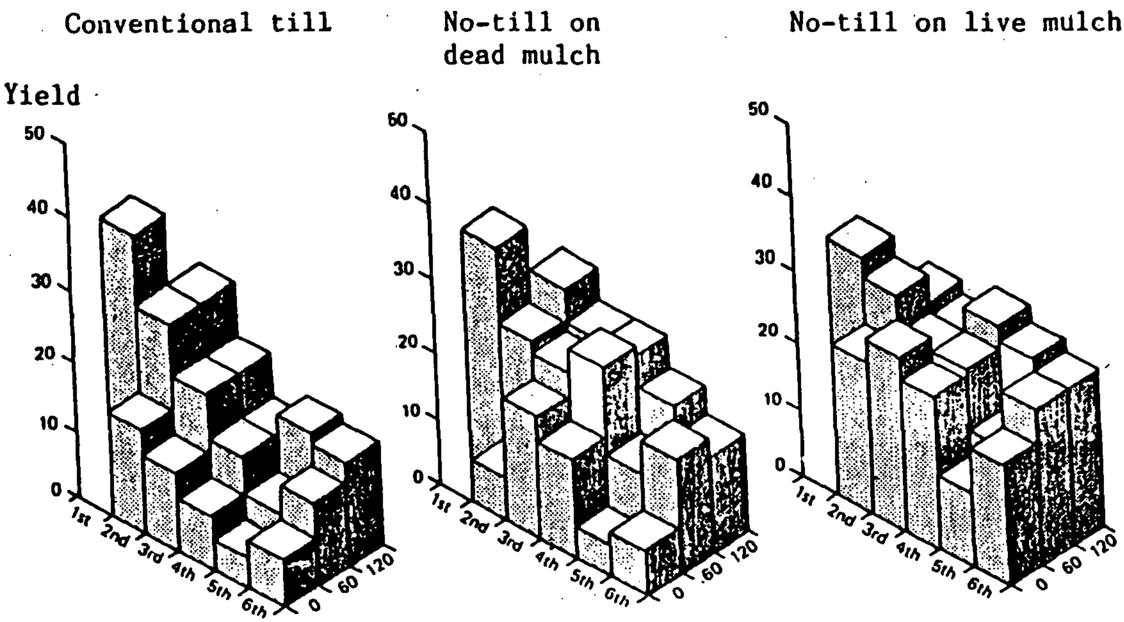

Figure 4 Effect on maize yields over six successive cropping seasons of three land management systems at 0, 60 and 120 kg/ha fertilizer N (IITA, 1979-81).

- Leguminous creepers (*Calopogonium caeruleum*, *C. mucunoides*, *Centrosema pubscens*, *Mucuna cocciniensis*, *Phosphocarpus palustris*, *P. tetragonolobus*, *Pueraria phaseoloides*, *P. triloba*, etc.)

Among all leguminous species the creepers are the most effective in providing a good soil cover. Unfortunately they are not liked by farmers on account of their very fast growth and climbing habits. Unless constant care is given, they tend to climb and stifle other plants. Unfortunately creeping covers have received very little attention as a soil-protecting and fertility-regenerating cover for food crops, although they have become a mainstay for many tree crops.

On the basis of their excellent properties as an effective soil cover and as a source of good mulch, von Uexkull (1982, 1984) suggested a system of "strip cropping" where strips of cover crops would alternate with strips of row crops planted into the dead mulch left behind after the cover crop has been killed by sprays (2-4-D) or by manual pulling (Figure 5). Preliminary investigations have shown that this system has considerable potential, but it would need more research to make it acceptible to farmers.

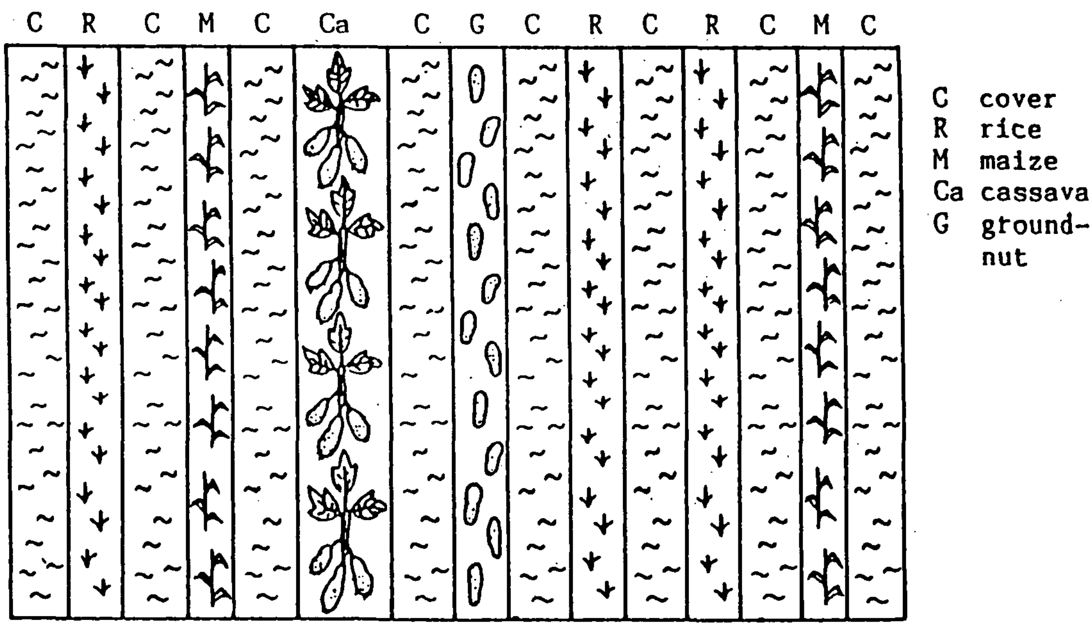

Figure 5 Suggested cropping system based on the alternation of food crops and cover crops (von Uexkull, 1984).

DISCUSSION

The nature of the climate in the humid tropics is such that unless properly protected, the topsoil is easily lost due to erosion or degraded through loss of organic matter. For the sustained use of acid soils protection and proper management of the topsoil and the soil surface is most critical. Any management system for the above soils should aim at providing some form of soil cover - moist, if not all, of the time. Such cover can consist of the canopy of a growing crop, shadetrees and their loppings, a live or a dead mulch. Traffic on the land as well as tillage has to be kept to a bare minimum.

Fertilizer and lime, though not discussed in this paper, are absolutely essential because of the low inherent fertility of most acid soils. Lime and phosphate are often needed for the speedy establishment of a good cover crop. To maintain soil fertility a large amount of vegetable matter has to be produced and circulated. As in any agricultural system, a certain amount of organic matter and nutrients will be removed, so injection of nutrients into the cycle is essential. But to be effective nutrients must be injected into a functional cycle. A continuous and functional cycle can only be maintained if good topsoil properties are maintained. For acid soils, proper management of the soil surface is the key to lasting success.

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Sixth Session: Cropping systems

Chairmen: M. Velayutham
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LOW-INPUT SYSTEMS AND MANAGED FALLOWS FOR ACID SOILS IN THE HUMID TROPICS

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ABSTRACT

A low-input cropping option was tested using acid-tolerant germplasms of upland rice and cowpea, with a return of the crop residues and no fertilizers, and compared with higher-input practices with fertilizer. No response to fertilizer was shown during the first six crops, but sharp differences appeared in the seventh crop. Topsoil fertility showed little change after 34 months, apart from 0.25% decline in organic matter on the fertilized plots.

The major problem was the incidence of weeds which makes these technologies more transitional than really sustainable. In an attempt to find a solution to this problem, an experiment with managed fallows using kudzu was carried out, and the results proved to be interesting. However, this procedure did not stop the decline in soil fertility on the Ultisols concerned, which had a very acid and infertile subsoil.

LOW-INPUT SYSTEMS

Intensive, fertilizer-based continuous cropping is likely to be limited to humid tropical areas with relatively good access to inputs and markets. A low-input cropping option has been studied at Yurimaguas, Peru, as a transition between shifting and continuous cultivation. This option is based on the selection of crop varieties tolerant to relatively high levels of aluminum saturation.

Germplasm collected from various institutions, believed to have high yield potential under humid tropical conditions, was tested in limed and non-limed plots in Yurimaguas at aluminum saturation levels of about 20 and 80% respectively. Germplasm was considered highly tolerant if its yields in acid soils were 85% or more of those obtained in the limed plots, and moderately tolerant if the relative yields were between 65 and 85% (Nicholaides and Piha, 1985). The overall results indicate a high degree of acid tolerance in upland rice and cowpea, an absence of acid tolerance in the corn, soybean and winged bean germplasm tested, and evidence of moderate tolerance in peanuts and sweet potatoes. Some local peanut cultivars appear highly aluminum-tolerant in growth vigor, but not in yields.

A one-hectare plot of a 10-year old secondary forest fallow was cleared by slash-and-burn in July, 1982. In August 1982, a low-input trial consisting of upland rice and cowpea was initiated with two treatments: one half of the hectare with fertilization (30 kg N, 22 kg P and 48 kg K ha^{-1} per rice crop) and the other half of the hectare without fertilization. This trial was planted according to the following procedure:

1. After slash-and-burn, the traditional upland rice variety was sown with a planting stick ("tacarpo") at conventional wide spacing, using a post-emergence herbicide for broad-leaved weeds, as is conventionally done.

2. Improvements are then introduced at the time farmers normally abandon the field, which is after the rice harvest, namely:

   - All the rice straw is cut low and spread evenly.

   - The acid-tolerant improved rice variety "Africano Desonocido" is planted by tacarpo at 30 x 50 cm spacing.

- It is then followed by acid-tolerant cowpeas (cv. Vita 6 or Vita 7), also planted with tacarpo.

- After threshing, all the rice straw or cowpea stover is spread evenly, in spite of the extra labor involved.

- The rotation is continued for 34 months, fertilizing only the rice crop, except the first rice crop.

- Chemical weed control, using 2-4 D (1.5 L ha^{-1}) and Paraquat (2.5 L ha^{-1}) preplant.

Yields of seven continuous crops harvested within three years are shown in Table 1. A total of 13.8 t ha^{-1} of rice and cowpea grain was produced during this period without any fertilizer or lime additions. These results contrast sharply with the experience with high-input cropping systems where crop yields approached zero without fertilizers. The use of Al-tolerant cultivars, maximum residue return and zero tillage are believed to be responsible for this difference. No responses to the 30-22-48 kg N-P-K ha^{-1} applications to the rice crops were observed during the first six crops. Both upland rice and cowpea yields are considered high.

Table 1. Productivity of a low input system during the first 34 months. Expt. Y-210.

Crop sequence	Planting date	Grain yields	
		Not fertilized	fertilized*
	month	t ha^{-1}	
1. Rice cv. Carolina	Sept. 82	2.4	2.4
2. Rice cv. Africano	Feb. 83	3.0	3.1
3. Cowpea cv. Vita 7	Sept. 83	1.1	1.2
4. Rice cv. Africano	Dec. 83	2.8	3.2
5. Cowpea cv. Vita 7	May. 84	1.2	0.9
6. Rice cv. Africano	Sept. 84	1.8	2.0
7. Rice cv. Africano	Feb. 85	1.5	2.5
Total	34	13.8	15.3

* 30 kg N ha^{-1}, 22 kg P ha^{-1}, 48 kg K ha^{-1} to rice crops 2, 4, 6, 7.

A sharp yield response to fertilizer was observed in crop 7, rice, indicating a fertility decline in the check plots. Modest NPK applications, therefore, became important at the end of the third year.

Topsoil chemical properties, shown in Table 2, indicate the favorable changes from 3 to 14 months after clearing in response to the fertilizer value of the ash, particularly in increasing base status. From 14 to 34 months little changes in pH, organic matter and exchangeable bases took place, maintaining a more favorable Al saturation level. It is noteworthy that there were slight decreases in soil organic matter, which is in sharp contrast with a 25% decrease observed in similar soils under a high-input system. The residue return and absence of tillage are probably responsible for this less drastic soil fertility decline.

Table 2. Topsoil (0-15 cm) fertility dynamics within the first 34 months of the low-input cropping system at Yurimaguas. Expt. Y-210.

Months after clearing	Fertilized[1]	pH	Exchangeable Al	Ca	Mg	K	ECEC	Al Sat.	Avail. P	OM
			----c mol L^{-1}				----------	%	mg kg^{-1}	%
3	No	4.4	1.10	0.30	0.09	0.13	1.62	68	20	2.12
14	No	4.6	1.46	0.92	0.28	0.19	2.85	51	13	2.06
	Yes	4.7	1.14	0.97	0.27	0.19	2.58	45	18	2.07
34	No	4.6	1.65	1.00	0.23	0.10	2.99	53	5	1.92
	Yes	4.6	1.23	1.16	0.20	0.16	2.76	44	16	1.77
CV%[2]		6	46	46	41	43	9	37	39	20
LSD		0.1	0.25	0.17	0.04	0.03	0.20	7	2	0.15

0.52[2]

1 Cumulative amount over 34 months: 120 kg N^{-1}, 88 kg P ha^{-1} as OSP, 192 kg ha^{-1} as KCl.

2 Comparisons do not include sampling at 3 months after clearing.

Although less drastic, a soil fertility decline pattern with time is evident in the check plots. Available P and exchangeable K decreased below the critical levels (12 ppm for P and 0.15 cmol L^{-1} for K). The small P and K additions were apparently sufficient to offset this decrease. It seems reasonable to assume, therefore that this system could be sustained by modest fertilizer applications. The crucial limiting factor, however, is a gradual grassy weed buildup, particularly during the rice crops. The effect of fertilizer application on weed growth does not seem important, at least visually. The studies on weed control for low-input systems show that we do not know how to control these weeds economically by herbicides; the absence of tillage does not help in this case. It is possible at an unrealistic cost. Consequently, we have reached the crossroads of this transition technology.

If the transition from shifting agriculture to a more permanent management system is to succeed, effective and affordable weed control measures for bridging the "year-two-to-year-five" gap are needed.

Results are promising for the low-input strategy as a transition technology from shifting agriculture to a more permanent management. With relatively simple practices, farmers can grow seven crops where they were able to grow one. This system cannot be considered stable at this time and is viewed as a transition technology.

When the system breaks down the farmer may have the following alternatives: 1) a managed fallow, primarily to suppress weeds and start the cycle again, albeit at a lower fertility level; 2) shift to fertilizer and lime-based continuous cropping; 3) plant pastures; and 4) agroforestry systems. These alternatives are illustrated in Figure 1.

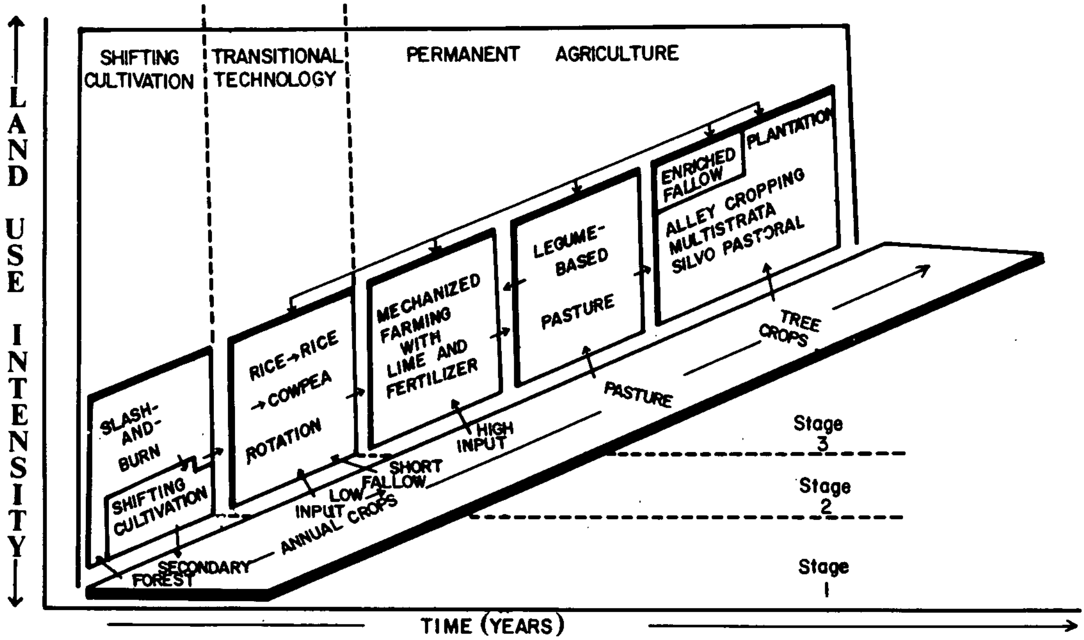

Figure 1. Soil management options for the Peruvian Amazon.

MANAGED FALLOWS

Managed fallows provide another alternative, giving farmers a safe way to rest the soil without major weed encroachment. Research with kudzu (*Pueraria phaseoloides*) fallows at Yurimaguas show some advantages as well as limitations. Kudzu grows luxuriously in the Amazon and, contrary to temperate-region experience, it is relatively easy to eliminate by cutting and burning it during the drier part of the year. Alternating one year of cropping with one year of kudzu fallow has produced respectable yields, while providing total soil protection during the fallow period. Crop yields, however, are declining with time (Table 3) and the decline seems to be related to potassium deficiency.

Table 3. Performance of minimum-input system with kudzu fallow rotation with no lime or fertilizer addition.

Year	Management	Corn Yields (1st crop after burn)	Rice Yields (2nd crop after burn)
		-------tons/ha-------	
1977	Burn 20 year old secondary treat., plant	4.0	3.3
1978	First kudzu fallow	-	-
1979	Burn kudzu, plant	1.1	1.7
1980	Second kudzu fallow	-	-
1981	Burn kudzu, plant	0.7	1.5

Source: Bandy (unpublished paper).

The effect of kudzu fallows in pumping nutrients from Ultisol subsoils, however, has been of little relevance (Bandy and Sanchez, 1981). In these very acid and infertile subsoils, no significant nutrient recycling occurred, in contrast to areas with high base status subsoils. Nevertheless, cutting and burning two to three years' growth of kudzu fallow produced similar crop yields as cutting and burning a 25-year old secondary forest fallow. Additional advantages of kudzu fallows include the maintenance of the residual effects of previous liming and fertilization, and its grazing potential as a "protein-bank" combined with adjacent grass pastures. Also, kudzu fallows provide virtually total protection against erosion.

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FARMING SYSTEMS AND SOILS IN NORTHEAST THAILAND

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ABSTRACT

This paper analyzes the influence of soils on the farming systems of northeast Thailand. The farming systems are viewed as agroecosystems, and the important properties of these systems include productivity, stability, and sustainability. In this paper only the cropping systems component of the farming systems is considered, since the northeast farming systems are crop-based, with rice as the subsistence crop and field crops as cash crops.

Soils have profound effects on the productivity (crop yield) and stability (the reliability of type yield) of the northeast agroecosystems. The generally low fertility of the northeast soils results in low crop productivity, while the low water-holding capacity of these soils in conjunction with the erratic rainfall lead to instability of rice yields, i.e. the yields fluctuate from one growing season to another. Researchers try to improve productivity and stability by resorting to the use of chemical fertilizers, but the farmers use little chemical fertilizer of any kind. Farmers tend to maintain the soil fertility by applying organic matter. They

also try to make efficient use of water by designing cropping systems which have many minor crops growing before or after the main crops, namely rice in the lowland and cassava or kenaf on the upland.

Farmers appear to give priority to maintaining sustainability, rather than improving the productivity and/or stability of the system at the risk of losing the sustainability. Fertilizer is costly, and the crop price is low. Moreover, farmers in rainfed agriculture are always faced with many uncertainties, especially drought, which may occur in the rainy season and cause them to risk losing part or all of their crops. Their farming systems cannot be made sustainable if they have to purchase fertilizer at a high price while their income from crops is low. This paper suggests that the sustainability property of the agroecosystems should be investigated in future research designed to study the influence of physical and biological factors on the farming systems of the northeast.

INTRODUCTION

Farming is the way of life for most people in northeast Thailand. The northeast farming system is traditionally crop-based, consisting of paddy rice and upland crops. A farming system is influenced by factors internal and external to the system. These factors interact with each other and can be divided into physical, biological and socioeconomic factors (Prakongsri and Jintawet, 1986). Physical factors include geography, climate, rainfall/irrigation, soils and transportation. These factors change slowly and are not easily modified. Biological factors include types of crops and animals raised in the area, cultural practices, seasons, fertilizers and pesticides. These factors are variable, depending on the physical and socioeconomic factors in the area. Socioeconomic factors include dependency relationships in the area, beliefs, decision-making in day to day activities, festivals and merit-making, the market system, labor, and capital. These factors also change with time. When one attempts to study a farming system, one cannot reach a complete understanding of the activity without studying, or at least acknowledging, all three interacting factors.

Soil is both a physical and biological factor which significantly influences the northeast farming system. The four important properties of an ecosystem are: productivity (e.g. crop yields), stability (the reliability of the yield), sustainability (the prospect for maintaining it in the long term), and resilience (the ability to function under unexpected and possibly disastrous changes in the social and environmental conditions) (Conway, 1985; Marten, 1986). All these properties are affected by soil and soil management. Soil *per se* is a physical factor, but the various technologies, both traditional and modern, which are used to modify the soils so as to produce a better growing medium are biological factors. Most soils in the region are not considered productive because they produce low crop yields. This is attributed to their low fertility, though the farmers have managed to make it sustainable by their traditional technologies for centuries.

Researchers are of the opinion that the farmers in the northeast resist new technology designed to improve productivity, such as the application of fertilizer. Studies have pointed out that the farmers have reasons for not accepting some introduced technologies, and they do in fact realize the importance of maintaining soil fertility. Rainfall is another physical factor considered most influential with regard to the stability of crop production and the northeast farming system as a whole. Crop production in the northeast is unstable because the yield fluctuates from season to season. This is due mainly to the erratic nature of the rainfall in the region.

The aim of this paper is to discuss soils and some soil fertility management techniques in the northeast with reference to the important physical and biological factors which influence the farming system, and to describe the serious limiting factors of these soils which mitigate against crop productivity and stability. The farming system of the northeast is viewed in this paper from the standpoint of the crops, which in turn are viewed in relation to the soils. A discussion of the reasons why the farmers do not accept some introduced technology is also presented.

CHARACTERISTICS OF SOILS IN THE NORTHEAST

The northeast is an undulating plateau bordered by hill ranges to the west and south and by the Mekong River to the north and east (Figure 1). The elevation is 100 to 300 m. Geographically, five types of landform can be observed: flood plains, low terraces, middle terraces, high terraces and hills (Figure 2).

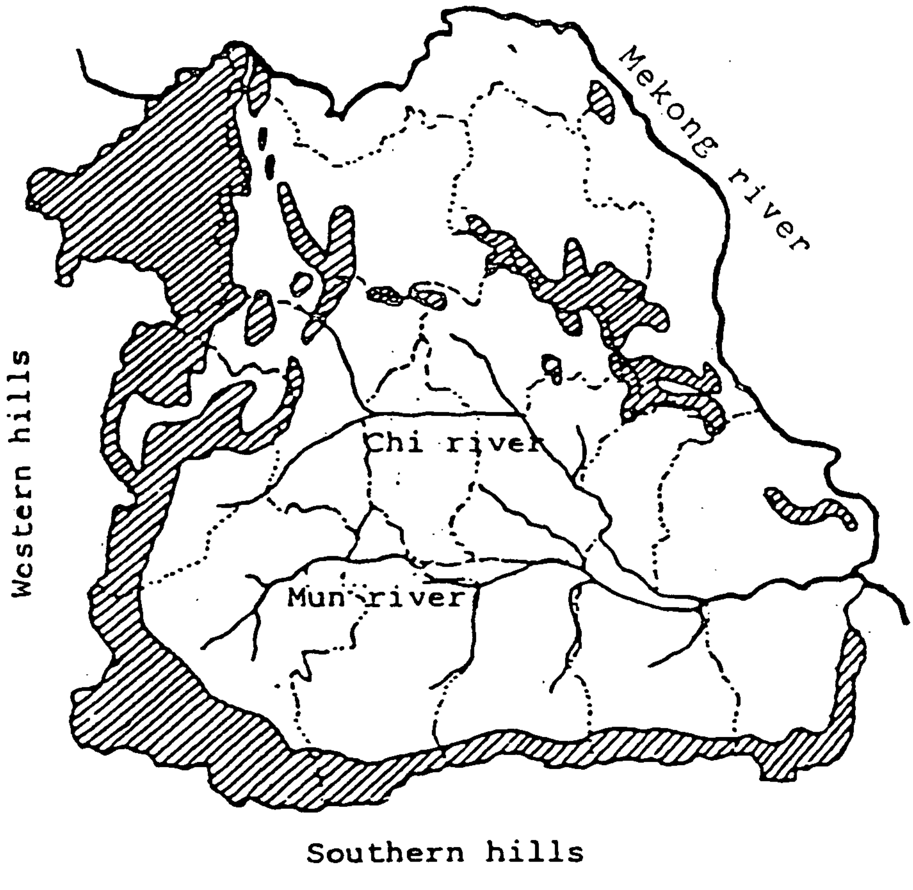


Figure 1. Topography of the northeast showing hill ranges (approximately 300 m contour) and major rivers. The boundaries of the 16 provinces of the region are shown in dotted lines (adapted from KKU-Ford Cropping Systems Project, 1982).

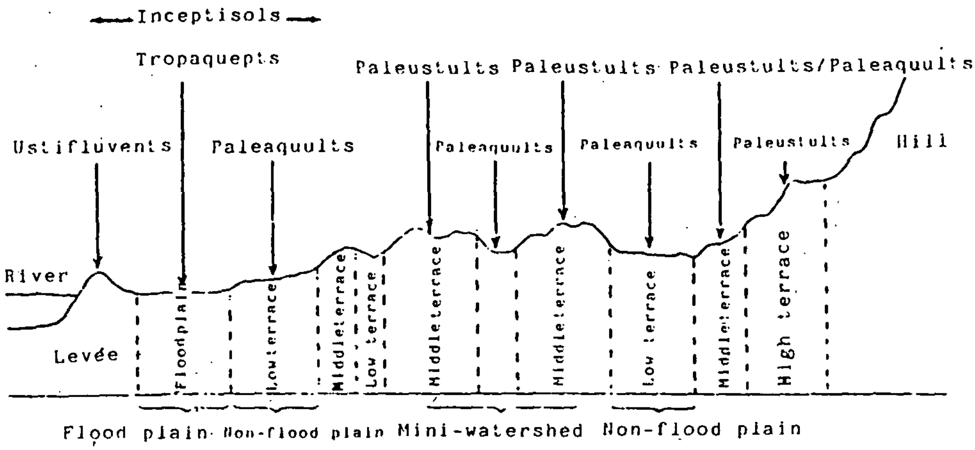
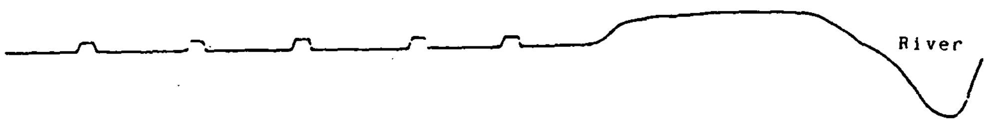


Figure 2. Schematic cross section of topography and soils in the northeast (after KKU-Ford Cropping Systems Project, 1982).

The flood plains (Figure 3) occur along the rivers. These systems are flooded each year by the annual flood caused by the overflowing of the river banks. Most of the soils belong to two groups - Ustifluvents on the river levee, and Tropaquepts along the river basin (Table 1).



	Flood plain	Levee	
Soils	Paleaquults or Dystropepts or Tropaquepts	Ustifluvents	
Crops	Rice Rice followed by vegetables	Vegetables	
Problems	Flooding		

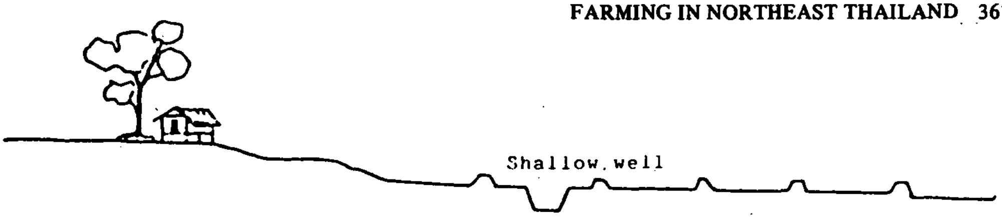
Figure 3. Schematic cross section of a flood plain (after KKU-Ford Cropping Systems Project, 1982).

Table 1. Types of soils occuring on different physiographic positions in northeast Thailand.

Physiographic position	Great Group (Soil Taxonomy)	Important soil series
Flood plain	Ustifluvents Tropaquepts	Chiang Mai, Sanphaya Phimai, Ratchaburi
Low terrace	Paleaquults	Roi-Et
Middle terrace	Paleustults Quartzipsamments	Korat, Satuk, Warin Nam Phong
High terrace	Paleustults	Yasothon
Hill	Paleustults Haplustoxs Haplustalfs	Pak Chong Chok Chai Chatturat

The low terraces (Figure 2) are at a slightly higher elevation than the flood plains, so they are rarely fooded from the rivers. The soils are mostly of the great group Paleaquults (Table 1, Figure 2), which are good paddy soils. The low terraces usually rise gradually up to the middle terraces (Figure 4) in the undulating terrain of this region. This particular agroecosystem, which was called "non-flood plain" by the KKU-Ford Cropping Systems Project (1982), can be divided into two parts: (i) upland, and (ii) lower or flat paddy fields (Figure 4). The villages are usually situated on the upland areas, and small areas are grown to field crops such as cassava, kenaf, sugarcane, peanuts and watermelons.

Gently undulating areas between the middle terraces, also consisting of low terraces in the depressions of the terrain and high terraces in the relatively higher elevations, are commonly found throughout the region (Figure 2). The depth of the undulating terrain varies from shallow to fairly deep, and the width from ridge to ridge may be from a half to several kilometers. The distance from the lower paddy field to the top of the ridge varies from 5 to 30 m. The agroecosystem of this terrain type is classified as a "mini-watershed" (KKU-Ford Cropping Systems Project, 1982) (Figure 5) because water availability in the



	Upland	Flat paddy
Soils	Paleustult	Paleaquult or Dystropept
Crops	Cassava Kenaf Sugarcane Peanut Watermelon	Rice In limited areas { Rice followed by peanut or tobacco Sesame followed by rice Rice followed by vegetables

Figure 4. Schematic cross section of a non-flood plain (after KKU-Ford Cropping Systems Project, 1982).

	Upland	Upper paddy	Lower paddy	Upper paddy	Upland
Soils	Paleustult	Paleaquult/ Paleustult	Paleaquult		
Crops	Cassava Kenaf Sugarcane Watermelon	Cassava Rice	Rice followed by vegetables		
Problems	Drought Erosion	Insufficient water			

Figure 5. Schematic cross section of a mini watershed (after KKU-Ford Cropping Systems Project, 1982).

downslope areas is partially regulated by the upslope areas in this undulating terrain.

The soils in the depression at the bottom of a unit of undulating terrain usually belong to the great group Paleaquults and are used as paddies in the rainy season (Figure 5). Almost every year enough water accumulates, both directly and by runoff from the upper paddy field and upland areas, to allow transplanting in July or August.

The upper paddy fields (Figure 5) are cultivated only when there is sufficient rain by August/September to permit rice transplanting. In drier years, it is usually left idle. The upland areas are planted each year with cassava, kenaf, sugarcane, watermelons, or some other field crops. The soils, being mostly Paleustults (Table 1), have low fertility and low water-holding capacity.

The hills of the northeast are theoretically protected as forest reserves, but they have long been invaded and field crops have been established. The soils in the hill areas are relatively more complex in their distribution than those in the undulating areas because they have a wider range of parent materials. Those along the foothills of the ranges in the west, southwest, and south of the region have relatively fertile soils. Some great groups of more fertile, deep, and well-drained soils in this terrain are shown in Table 1. The foothill zone contributes less to farming in the northeast than the flood plains and the terraces.

To illustrate the characteristic locations (excluding those which occur on hill and foothill areas), the properties of some representative soil series are shown in Tables 2 and 3. Generally, the soils on the flood plains, as exemplified by the Phimai series, have higher clay and organic matter contents, which results in a higher cation exchange capacity (CEC) in these soils than in those on the terraces. A higher base saturation is also found in the soils from the flood plains than in those from the terraces. Usually, the terrace soils have sandy-textured topsoils which become loamy or clayey in the subsoils (B horizon). The low pH values, which are below 5 in some soils, suggest that problems due to acidity, such as Al-toxicity, are possible. Al-toxicity can be a limiting factor for crop productivity. Ratanarat *et al.*, (1977) demonstrated that the factors associated with acid soil infertility in the Roi-Et soil series growing soybean were high tissue Al and Mn and low tissue Ca and Mg. Katawetin (1982) showed that Al toxicity in sorghum could be expected in some Yasothon soils (Oxic Paleustults on high terraces).

A low cation exchange capacity (CEC) results in the low buffering capacity of these soils. Ragland and Boonpuckdee (1986) have shown that the pH of the Renu soil series, which is a low terrace paddy soil similar in classification to the Roi-Et series, can decrease quite dramatically with the addition of ammonium sulfate to rice plants (Figure 6).

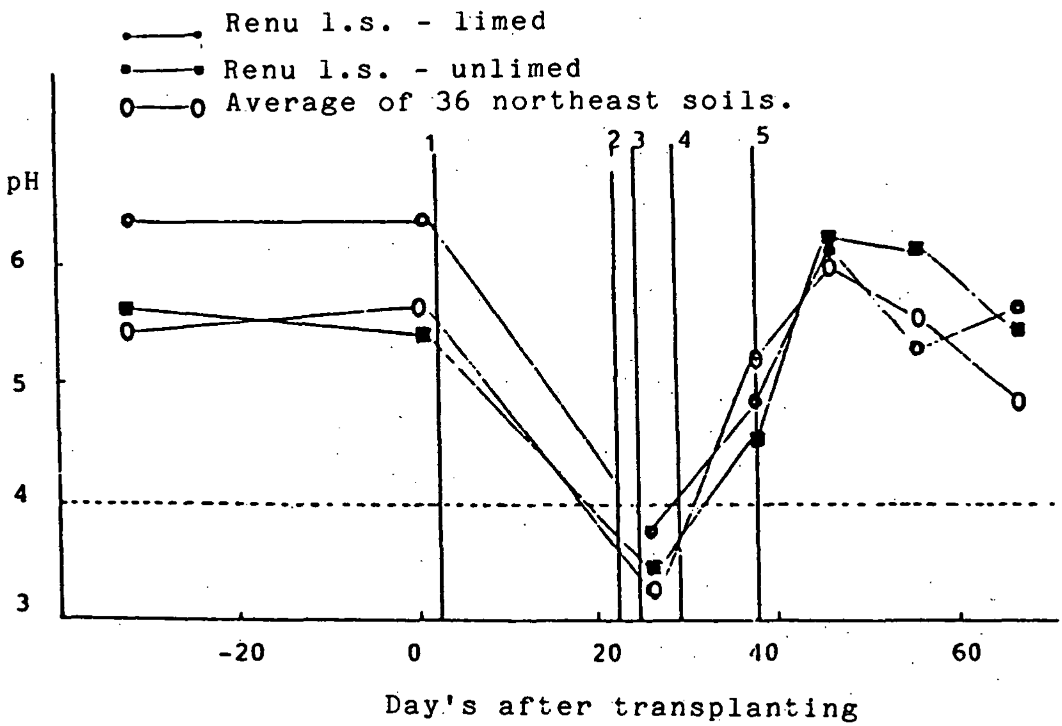


Figure 6. Changes in pH of 1:1 soil-water mixtures with respect to days after transplanting two rice seedlings per pot.

1. Marks the time of adding 50 kg N per ha as ammonium sulfate,
2. Marks time of another 50 kg N added,
3. Time when 112 kg lime added per ha,
4. Time when another 112 kg lime added, and
5. Time when 225 kg lime added per ha (after Ragland and Boonpuckdee, 1986).

Table 2. Some chemical and physical properties of some representative soil series of different landforms in the northeast region of Thailand.

Soil series	Soil subgroup	Land form	Horizon	Depth (cm)	Sand	Silt	Clay	pH 1:1 H_2O	% OM*	Exchange capacity and cations: Ca	Mg	K	Na	Extr. acidity	CEC soil	% BS	P ppm Bray 2	K ppm ammon. acetate
Pimai	Vertic	Flood	Apg	0-11	5.3	31.6	63.1	4.9	1.5	16.4	6.8	0.8	1.7	13.6	31.0	66	14.5	192
(Pm)	Tropaquept	plain	C_{1g}	11-25	6.1	31.0	63.2	4.8	1.0	17.0	7.0	0.6	2.0	13.2	31.4	67	9.2	129
			C_{2g}	25-65	8.1	31.2	60.8	4.8	0.5	15.5	7.5	0.4	2.2	10.3	30.1	71	7.6	111
			C_{3g}	65-102	14.0	38.2	47.9	5.3	0.3	13.1	7.5	0.3	2.3	7.0	26.3	76	7.1	96
Roi Et	Aeric	Low	A_{pg}	0-7	68.0	26.5	5.5	4.8	0.9	0.2	0.1	0.1	0.2	1.2	1.6	33	2.2	32
(Re)	Paleaquult	terrace	A_{3g}	7-23	59.5	32.0	8.5	5.2	0.4	0.3	0.1	0.1	0.1	0.8	1.5	43	2.0	29
			B_{21tg}	23-60	58.0	26.5	15.5	5.1	0.3	0.2	0.2	0.1	0.1	2.9	2.9	17	1.9	32
			B_{22tg}	60-98	52.0	29.0	19.0	5.2	0.7	0.3	0.4	0.1	0.1	3.3	3.5	21	1.9	32
Korat	Oxic	Middle	A_1	0-8	77.0	75.0	8.0	5.8	2.1	3.1	1.3	0.1	0.1	3.0	6.7	61	19.2	62
(Kt)	Paleustult	terrace	A_2	8-37	77.0	10.0	13.0	5.4	1.6	0.9	0.6	0.1	0.1	2.8	3.3	36	10.8	24
			B_1	37-80	75.0	13.5	11.5	5.5	1.3	0.6	0.5	0.1	0.1	2.6	2.8	32	16.3	15
			B_2	80-105	72.0	15.0	13.0	5.5	0.8	1.0	0.6	0.2	0.2	3.0	3.6	28	27.3	18

Source : Chotimon and Hermsrichart (1982).
* % OM = % C x 1.72

Table 3. Water-holding capacity of some northeast soils of Thailand.

Soil series	Soil subgroup	Land form	Horizon	Depth (cm)	% Water: Air-dry	% Water: Wilting coefficient (15 atm.)	% Water: Field capacity (1/3 atm.)	% Water: Avail. water-holding capacity	O.M. %	Clay %
Roi Et	Aeric	Low	A_p	0-18	2.2	7.6	19.0	11.4	1.3	14.6
	Paleaquult	terrace	B_1	18-37	3.0	8.4	15.3	6.9	0.15	14.7
			B_2	37-128	3.3	9.8	16.9	7.1	0.06	17.8
Korat	Oxic	Middle	A_p	0-31	2.5	4.2	7.3	3.1	0.48	4.5
	Paleustult	terrace	A_3	31-56	1.3	5.5	10.9	3.4	0.41	4.5
			B_1	56-82	1.9	5.2	10.8	5.6	0.44	9.1
Warin	Oxic	Middle	A_p	0-32	2.3	5.0	9.2	4.2	0.75	9.5
	Paleustult	terrace	B_1	32-64	2.1	5.9	10.9	5.0	0.56	12.1
			B_2	64-120	2.3	5.9	10.6	4.7	0.37	11.1
Yasothon	Oxic	High	A_p	0-26	2.3	5.8	11.2	5.4	1.0	10.1
	Paleustult	terrace	B_1	26-70	2.2	6.4	11.4	5.0	0.44	11.6
			B_2	70-125	2.6	6.4	11.4	5.0	0.29	16.1

Source : Boonsompoppunth, 1981.

Some different findings have been reported by Keerati-Kasikorn (1986). Peanuts gave a significant threefold yield increase in response to complete fertilizer treatment as compared to untreated peanuts in a Quartzipsamment soil which had only 2% clay within a 60 cm depth and a CEC of 0.3-0.7 me/100 g, while those grown in Paluestult soil with 4-10% clay within a 60 cm depth did not respond in the first crop, but did in the second crop. No conclusion can be offered with regard to the fertilizer response in the northeast agricultural soils until more decisive evidence has been obtained. Nevertheless, there is a need to understand this phenomenon so that strategies for fertilizer application in the northeast soils can be developed which would make fertilizing more profitable to northeast farmers.

Organic matter has been shown to reduce the adverse effects due to acidity of some northeast soils. Ratanarat *et al.* (1977) showed that the application of lime together with compost resulted in the highest yield of soybean being grown on acid Roi-Et soil, as compared to soybean grown on the same soil receiving lime without compost. They demonstrated that the lower tissue concentrations of Al and Mn in the plants treated with lime-compost resulted in superior growth over the other treatments.

Organic matter has been shown to reduce the adverse effects of soil acidity in a good many ways. It can increase the CEC of soils (Kapland and Estes, 1985) and hence increase the sorption capacity of the soils to some cations which can be toxic if present in high concentrations in soil solution. The organic acids produced from organic matter decomposition can also form a complex with soil solution Al and render it inactive (Hue *et al.*, 1986). The evidence presented indicates that crop productivity is limited by low soil fertility due to low nutrient content and various other factors, resulting in nutrient imbalances.

Water stress is considered to be another limiting factor to productivity. It could have a significant effect on the fertilizer responses in the northeast. Erratic rainfall, together with the low water-holding capacity of soils due to the sandy texture in this region (Table 3), could create serious problems for farmers. Crops grown in the high and middle terraces undergo drought stress at times during the rainy season when a dry spell sets in.

Various researchers have demonstrated through their pot and field trials that a wide range of soil series taken from Khon Kaen province are deficient in P, S, K, Ca, and B (Gibson, 1984; Keerati-Kasikorn, 1984). Omission field trials on Paleustult and Quartzipsamment soils, the latter being a sandy-textured soil found on middle terraces growing peanuts, have also shown K, Cu and B deficiencies (Keerati-Kasikorn, 1986).

Fertilizer responses of northeast soils appear to be inconsistent. Fugli (1985) has shown that there is hardly any yield response of rice to nitrogen fertilizer in a typical northeast paddy soil (Roi-Et series). Moreover, there appears to be an adverse effect of the nitrogen fertilizer on rice grown in the Ubon Soil series, an Aquic Dystropepts of coarser texture than the Roi-Et series. On the other hand, a relatively larger response was observed in those grown in the Pimai series (Figure 7). Ragland and Boonpuckdee (1986) suggested that the difference in the rice responses among the soils could be attributed to the difference in clay and organic matter contents in these soils, i.e. the Roi-Et and Ubon series had lower clay and organic matter contents than the Phimai series. They further indicated that Roi-Et soil had a 10 times less active iron content than Phimai soil. The active iron content can cause the pH to increase when the soils are inundated through a ferrolysis process (Brinkman, 1970).

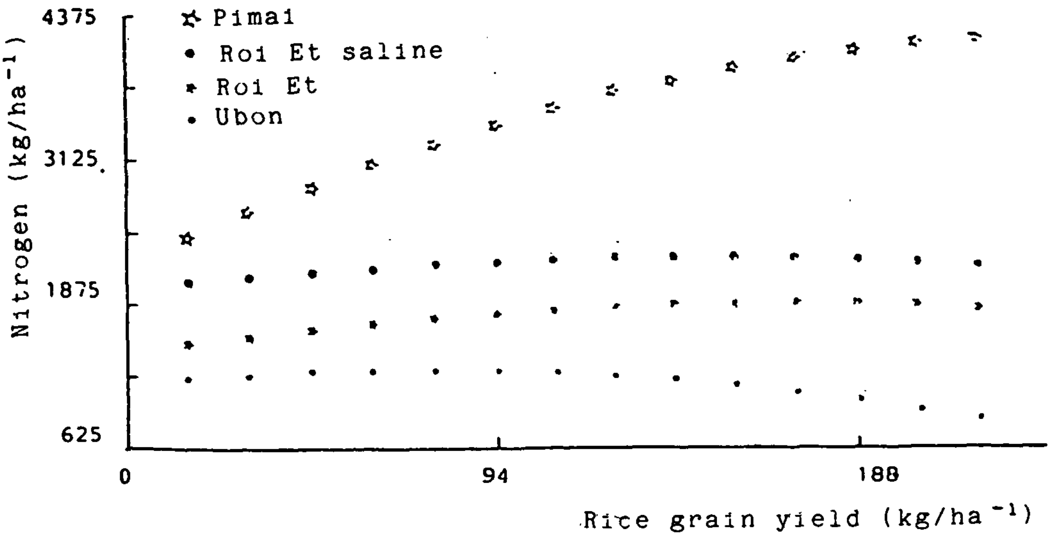


Figure 7. Rice response to nitrogen by soil series in northeast Thailand (after Fugli, 1985).

In the northeast, rainfall is considered the most influential factor affecting the stability of rice production and other crops. The erratic nature of the rainfall pattern in the region results in yearly fluctuations in the quantity of the harvest, which is most vividly demonstrated in the rice crop. Data on rice production have shown that areas along the Mekong river (to the north and east of the region), which are under high and evenly distributed rainfall, produce a stable yield. On the other hand, rice production tends to be either unstable and/or low in areas away from the Mekong river towards the mountain ranges in the west and southwest (KKU-Ford Cropping Systems Project, 1982). This pattern of rice production not only correlates with the difference in mean annual rainfall in different parts of the region (refer to the isohytes in Figure 8 for the main annual rainfall), but also with the degree of irregularity in rainfall in these different parts (refer to the use of total drought days from May to October in Figure 9 as an indicator of the rainfall irregularity.

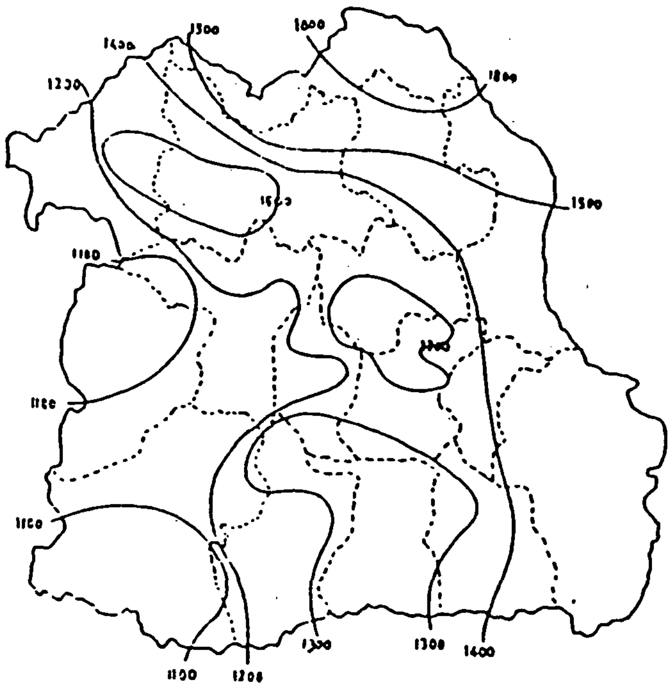


Figure 8. Isohytes for mean annual rainfall of the northeast which indicate three distinct regions: above 1400 mm to the north and east, below 1200 mm to the west, and a central band of 1200-1400 mm. (after KKU-Ford Cropping Systems Project, 1982).

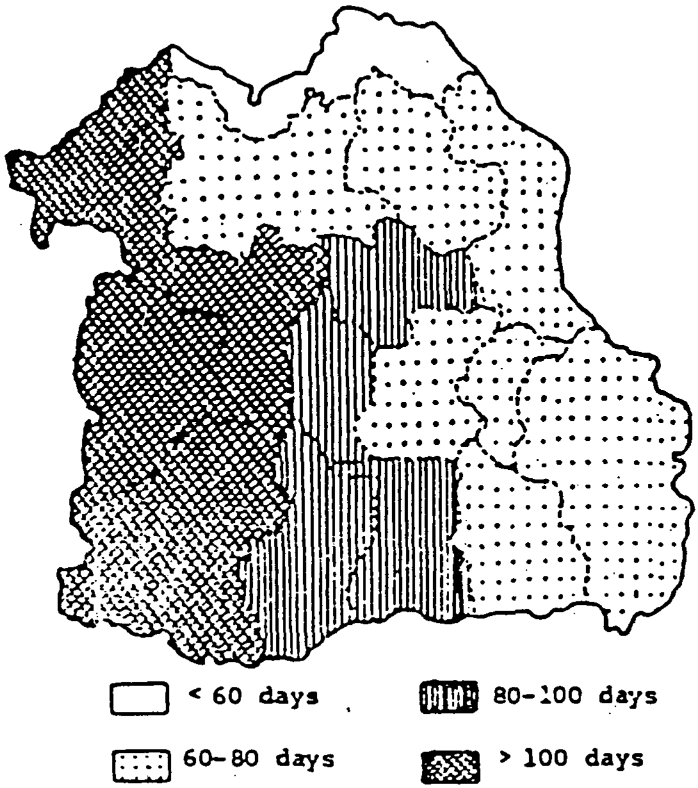


Figure 9. Number of total drought days (calculated for paddy) in the northeast for the period from May to October, which indicates three distinct zones with less than 80 days to the north and east, more than 100 drought days to the west, and a central zone of 80-100 drought days (after KKU-Ford Cropping Systems Project, 1982).

Soils, in conjunction with the rainfall pattern of the region, contribute in some degree to the instability of the rice and field crop production systems because of their coarse texture and low organic matter content, with the resulting low water-holding capacity (Table 3). It appears from much of the evidence which has been presented that low soil fertility limits crop productivity, while the poor physical properties of the soil limit crop stability.

FARMING SYSTEMS IN THE NORTHEAST

Farming systems in the northeast are crop-based, with rice as the subsistence crop (a surplus of which is produced for sale), and upland or field crops as cash crops. Rice is the center of the northeast farming system around which other activities, such as the production of field crops, animal husbandry, and various social activities, revolve. Farmers value their rice highly: producing enough rice at each growing season for yearly home consumption is the main goal that every farmer strives to meet. In certain years, however, this basic goal is not met due to the erratic rainfall, which has a profound influence on the stability of the rainfed agriculture of this region.

Rice is the most cultivated crop in the region. It is grown on 74% of the agricultural land of the region (1983 statistics). Field crops amount to approximately 23%, with the four most important upland crops being cassava (10%), corn (6%), kenaf (3%), and sugarcane (1%). The rest are less prominent field crops, and include peanut, soybean, cotton, pineapple, and mungbean. Fruit trees and vegetables occupy a small portion of agricultural land (Office of Agricultural Economics, 1985).

Rice is grown in relatively lower lying areas than field crops, i.e. on flood plains and low terraces, because water accumulation in paddies is required for rice culture. This is not always possible on the upland or even the upper paddy fields. Many observers, however, have pointed out that farmers also convert upland areas, which are more suitable for field crops, to paddy fields, using the so-called upper paddy fields, apparently because of an increase in population pressure (Limpinuntana, 1985). In addition, rice is their staple food and they try to expand its cultivation as much as possible. Traditionally, the social and economic status of a household is also assessed by their rice harvest.

Limpinuntana (1985) has identified two basic problems in rice production in the northeast:

- low stability of production on the upper paddy due to rainfall inadequacy for three out of every five years, and

- low productivity (yield) per unit area due to low soil fertility.

Farmers have adapted to the unfavorable conditions of upper paddy land, which are mainly due to low water availability, by growing short duration varieties to utilize the short period of water accumulation in the upper paddy fields (Limpinuntana, 1985). In addition, some farmers also improve their rice-based cropping system by incorporating field crops into the system. For example, farmers grow sesame before rice in Buriram and Mahasarakam provinces, peanut after rice in Surin and Buriram provinces, tobacco after rice in Roi-Et province, cassava after rice in Khon Kaen province, vegetables before rice in Roi-Et and Khon Kaen provinces, and vegetables after rice in most areas in northeast Thailand (Polthanee and Marten, 1986) (Figure 10). Labor availability is a factor determining the degree to which growing minor field crops can be practiced. Sometimes there is a labor shortage because of additional work, which precludes this kind of cropping system in some places.

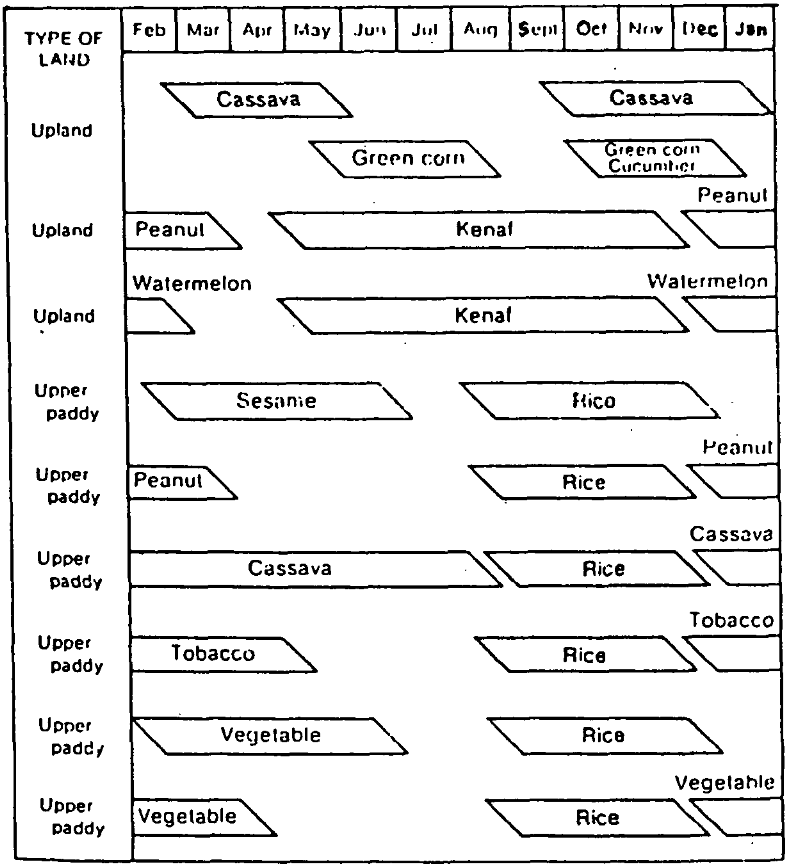


Figure 10. Farmers' improved cropping systems in northeast Thailand (after Polthanee and Marten, 1986).

The problem of how to deal with the low soil fertility of paddy fields is also of great concern to the farmers. The average rice yield in the northeast was less than 2 tons per hectare in the 1984/85 growing season (Office of Agricultural Economics, 1985), which is the lowest of all the regions in the country, and very low by any standard. Many observers have indicated that the northeast farmers realize the importance of maintaining soil fertility, and they use such techniques as applying animal manure or fertile soils from termite mounds or from under the canopies of large trees (Marten and Vityakon, 1986), and also use other organic residues such as ash from rice husks to maintain soil fertility. Trees standing at various densities in the northeast paddy fields have also been thought of as "nutrient pumps." The roots tap nutrients below the level reached by the roots of rice and other crops and return them to the soil surface through litter fall. The effects on rice growth of having trees in paddy fields, and the farmers' perception of the effects, have not yet been determined (Grandstaff *et al.*, 1986).

A case study done in one of the villages in Khon Kaen province (Ban Dorn Por Daeng Village) on the use of animal manure and plant residue by the farmers in cultivating land (Palaraksh *et al.*, 1984) provides evidence of the soil fertility maintenance done traditionally by the farmers. It was reported that in the village a large amount of animal manure was used for crop production and, on the other hand, little chemical fertilizer was used. Some of the farmer informants were of the opinion that chemical fertilizer had to be applied yearly, while animal manure could be applied in alternate years because of its long-term effects. Another interesting observation revealed by the farmers was that the long-term (10 years) application of the manure helped to decrease soil salinity in the area. Animal manure was highly valued in the village, and in certain years some farmers had to purchase it from other farmers when they did not have enough. It was also reported that the village children collected the manure to sell the buyers who visited the village with their trucks.

Palaraksh *et al.* (1984) reported a village tradition concerning soil fertility maintenance. This is called "Aork Mai" Day, which is a day in mid-February when the farmers have finished rice harvesting and started putting fertilizer on their fields. To the northeasterner, this is an auspicious day, a day of peace and high productivity. On this day, each farmer carries a containerful of animal manure to be emptied in the paddy field, which he believes will result in high productivity.

In this village, crop residues from rice, corn, peanut, and cassava were used both as animal feed and as green manure or mulch. The most important crop residue was rice straw, followed by corn stover (Palaraksh *et al.*, 1984). The northeast farming system exhibits intimate relationships between soil, plant, and animal components, as illustrated by the use of crop residues for both animal feed and for maintaining soil fertility.

As regards the use of chemical fertilizers, it appears to researchers that the northeast farmers use little chemical fertilizer of any kind. Statistics obtained for the 1983/84 growing season show that approximately 33 kg/ha of combined NPK fertilizer was applied to rice, and approximately 5 kg/ha to upland crops (Office of Agricultural Statistics, 1985).

Farmers do in fact realize the merit of applying chemical fertilizer with regard to increasing crop yields. The criteria as to whether to apply chemical fertilizer or not at first appear to be many and varied. Limpinuntana (1985) has pointed out that farmers want to be certain that water is consistently available so as not to risk a drought. Fertilizer is used intensively for the establishment of rice seedlings in the nursery beds, and some farmers explained that application of fertilizer to rice seedlings makes it possible to pluck them out easily at transplanting time.

Where crops are grown in rotation, the farmers prefer to use a heavy application of fertilizer on the high-value cash crops grown after rice, e.g. watermelon and tobacco in Roi-Et province, and green corn in Khon Kaen province. Subsequent rice is grown on the residual fertilizer. The farmers also rotate the plots planted with high-value cash crops from year to year so that nearly every paddy field can be restored to fertility every few years (Limpinuntana, 1985). It appears that the main criterion for using chemical fertilizer lies in making the most economical use of it as possible since it is an expensive material.

The costliness of chemical fertilizers relative to the price the farmers receive for their rice makes it uneconomical for them to apply fertilizers. Fugli (1986) demonstrated that at 1982 price levels, the application of nitrogen fertilizer was economical only in rice paddies situated in flood plain areas, and not on the upper paddy areas where the adequacy of water could not be assured.

While rice is mainly for subsistence in the northeast, field crops are for cash. The latter are grown in two major zones: the fertile foothills, and the top part of the undulating topography (Figures 2, 4, and 5). Foothill areas are grown to crops like corn, sorghum, cotton, and soybean, which require relatively more fertile soils. Since the top part of the undulating topography has soils with low fertility and low water-holding capacity, the crops grown in these areas are long-duration and drought-tolerant crops which require only a low input, namely cassava and kenaf. They are the two major crops on the upland, and are mostly grown as a monoculture. However, in some areas they are grown in rotation with minor crops such as corn, watermelon, and peanuts, depending on the soil moisture regimes in each location (Polthanee and Marten, 1986) (Figure 10). Little fertilizer is used for field crops, however, where crop rotation is practiced, and the residual fertilizer from high-priced crops such as watermelons will affect the subsequent growth of cassava or kenaf.

CONCLUSION

The farmers of the northeast have been making a living out of the land that researchers and outsiders have regarded as marginal for a long time. Their traditional farming systems have been changed and modified through their experience in order to maintain the sustainability and resilience of the system. These two properties of an ecosystem were not discussed in this paper because the trend of research at present is to aim for high productivity and stability. The farmers, however, cannot accept this trend because if they do they can risk losing system sustainability. Their farming systems have been sustainable for centuries and obviously they want them to remain so. Today, with the introduction of new technologies such as fertilizer application, the farmers are dealing with traditional practices and modern technologies by blending them together in the best possible way they can. The degree to which the farmers will accept new technologies is probably determined by the limitations imposed by the need to ensure that the sustainability of the system is not disturbed.

Soils in the northeast are poor. The various soil and crop management practices that the farmers employ are basically designed to sustain the system, and are called "low-input technologies." With low fertility and low water-holding capacity soils, together with the erratic nature of the rainfall pattern, high-input technologies increase the risks taken by the farmers. Future research concerning the effects of various physical and biological factors on the productivity for the northeast farming system should attempt to incorporate studies of their effect on system sustainability as well. This will result in the development of technologies appropriate to the farmers' needs.

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ALLEY CROPPING IN THE PHILIPPINES

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ABSTRACT

Comparative tests alley cropping vs. the traditional shifting cultivation system in the Philippines have recently been carried out successfully. The main plants to be tested were *Leucaena leucocephala*, *Gliricidia sepium*, and *Alnus japonicum*, and food crops were normally used between the hedgerows. An account is given of the establishment and management of the alley crops, and their beneficial effects on erosion and nutrient inputs.

Alley cropping has proved attractive to farmers, providing as it does natural leveling, increased yields and an alternative source of income from the sale of dried leaves. However, the investment involved is a problem. Research is needed to assess the long-term sustainability of specific alley-cropping practices, to determine the effect of alley width and alternative alley managements on soil erosion, to screen acid-tolerant shrub legumes, and to make a socioeconomic evaluation.

INTRODUCTION

Hillylands constitute a major portion of the Philippines' total land area. According to Lawas *et al.* (1986), of about 9 million ha of land classified as hillyland, 4 million ha are presently under cultivation. Due to a lack of sufficient flatlands and increasing population pressure for more food, clothing and shelter, more and more farmers are encroaching into these ecologically fragile lands. With the prevailing heavy rainfall intensities on slopes of between 18-50%, and with reduced vegetative cover, the cultivated hillylands are the most severely eroded and marginally productive farming-system sites in the country.

The hillyland farmers are among the more numerous farming groups, but also among the least endowed in terms of livelihood resources (Lawas *et al.*, 1986). Many of them are squatters with a very low farm income. Poor soil conditions, a lack of farm inputs, such as fertilizers, pesticides and seeds of improved variety, and improper farming practices are among the reasons for the very low crop productivity. Their traditional "slash-and-burn" agriculture, improper cultivation practices (plowing, harrowing and furrowing along the slopes), indiscriminate cutting of trees for firewood, all contribute to serious erosion and very fast degradation of the land. Unless appropriate farming technologies become available to them, their impoverished living conditions will continue to get worse.

The magnitude of soil erosion is very alarming and has been identified as the most serious environmental problem in the country. More than a half of the country's land area is susceptible to, if not already under, severe erosion (NEDA, 1982). Some studies conducted using soil erosion plots, as cited by Sajise (1984), showed that on bare plots (no vegetation) with slopes of 27 to 29%, soil loss ranged from 23 to 218 ton/ha/yr. The "kaingin" or slash-and-burn farming practices in the hillylands were estimated by David (1984), using the Universal Soil Loss Equation (USLE), to cause an annual soil loss of 100 ton/ha. Not only are the hillylands destroyed at a very fast rate, but also the very stability of the lowland ecosystem is endangered.

Promising production technologies appropriate for the hillylands are now being identified, tested, and disseminated to the farmers in order to stop or even reverse this trend. The acute need is for more improved crop production practices which encourage soil conservation. This paper presents a discussion on alley cropping as one of the promising appropriate farming technologies for the hillylands of the Philippines.

TRADITIONAL HILLYLAND FARMING

"Shifting cultivation", locally known as "kaingin", is the traditional and dominant farming practice in the hillylands. With this system, forestland is initially cleared, the trees are felled, and some are used later for lumber. The vegetation underneath the forest canopy is also cut down, allowed to dry, and burned. At the start of the rainy season, the area is further cleared of unburned materials, and the seeds of rice, corn and other annual food crops are dibbled into the soil using only a pointed stick.

In the second year of planting, the same field is cleared again - this time of weeds and residues from the previous crop. Cropping is repeated successively for a few years, depending on the productivity of the land. Farmers admit that after 2 to 3 years of cropping, harvests sharply decline to substandard levels and they have to shift to other areas. Usually the fallow period ranges from 5 to 10 years and the cropping cycle is then repeated.

In most cases hillyland soils belong to the soil order Ultisol, which is highly leached, acidic and nutrient-depleted. When still under forest vegetation, the original nutrient resources of the system are concentrated in the forest biomass, and when this biomass is cut down and burned, the ashes become fertilizer. However, the loss of the forest cover and extensive cultivation result in excessive soil erosion. Both the well-structured topsoil and nutrients are lost, resulting in a sharp decline in soil productivity, and forcing the farmer to move to other areas.

ALLEY CROPPING

Alley cropping, as a promising alternative to shifting cultivation, involves the establishment of hedgerows planted along the contours. In the contour bay in between the hedgerows, annual crops (usually food crops such as corn, upland rice, mungbeans, peanuts, etc.) are planted. The hedgerows provide a biophysical infrastructure within which cropping, using ordinary existing practices, can be carried out without so much danger of massive soil erosion (Celestino, 1985).

Ipil-ipil (*Leucaena leucocephala*) is commonly used as hedgerows, and is planted in either double or triple rows (with about 50 cm between the rows). *Gliricidia sepium* and *Alnus japonicum* are other plants used for the same purpose. To ensure thick hedgerows, the ipil-ipil seeds are drilled along the furrows at the rate of 60-100 seeds per linear meter. The plants are thinned to about 50 plants per meter. When fully grown, they are cut periodically with a large handknife every 45 to 60 days, depending on herbage growth, to a cutting height of about 0.4 to 1 m. The cuttings are chopped into smaller pieces and either spread as mulch or incorporated into the soil in the alleyways (the spaces between the hedgerows) to decompose.

The width of the alleyways varies from 4 m to more than 10 m, depending on the degree of slope and the amount of herbage production desired. The steeper the slope the narrower the alleyways. Complementary soil conservation techniques, such as contour plowing, furrowing and planting, strip cropping, cover cropping, crop rotation, minimum tillage, and tree farming could be practiced in the alleyways.

Ipil-ipil hedgerows serve several purposes: they check excessive erosion, provide a source of renewable organic fertilizer, produce feed for poultry and livestock, and can be used as firewood. According to Celestino (1985), it is generally observed that in about 3 years of continuous cultivation and cropping, the strips between hedgerows level off, becoming a series of natural terraces with the ipil-ipil hedgerows serving as risers. Piles of straws, rocks and stones on the base of the ipil-ipil strip and napier grass or other similar crops planted near or within the double hedgerows can build a strong and permanent vegetative terrace. Besides stabilizing the slope, the formed terrace facilitates land preparation and other farm operations.

When used as mulch, the cut ipil-ipil leaves, midribs and twigs, along with crop stubbles, reduce soil detachment by rain and entrainment by runoff, particularly during the early stages of crop growth. Also, when the organic residues decompose, the soil structure is improved, enhancing the infiltration rate. This means that runoff and soil loss are considerably reduced, as shown in Table 1.

Table 1. Runoff and soil losses during 7 months at Carcar and Barili in Cebu province in the Philippines (Pacardo and Montecillo, 1983).

Treatment	Runoff (mm)	Soil loss (g/plot)	Runoff (mm)	Soil loss (g/plot)
	Carcar		Barili	
Bare	87	3156	56	5667
Corn alone (stubbles removed)	30	680	33	2214
Corn/ipil-ipil (stubbles retained)	2	14	13	712
Corn/ipil-ipil (stubbles removed)	4	8	16	820

Ipil-ipil hedgerow herbage is a renewable source of organic fertilizer. Recent findings by several researchers have indicated that ipil-ipil leaves can be successfully applied to corn either as green manure or dried leaves incorporated into the soil during planting and at the hilling-up stage. They may be applied alone or in combination with inorganic fertilizer.

On the average about 5 tons of dry herbage could be harvested per year in double hedgerows of ipil-ipil occupying an equivalent of about 1/5 of the land or 2000 m^2/ha. The nutrient content of the leaves (dry basis) is 4.1% N and 1.4% K, and of the twigs and midribs 2.1% N, 0.3% P and 1.7% K. These figures were reported by Maniego (1986), and are very close to those previously reported elsewhere. With two-fifths leaves and three-fifths midribs and twigs, an equivalent of 5 tons dry ipil-ipil herbage cuttings can give 145 kg N, 15 kg P and 75 kg K per ha, which could be enough to supply the fertilizer needs of two cropping seasons. The Sloping Agricultural Land Technology or SALT project (Watson and Laquihon, 1985) reported that a one-year cropping of hedgerows (10 harvests of ipil-ipil), occupying 20% of the land area, produced about 290 kg N and 100 kg K per ha.

The fertilizing effect of ipil-ipil hedgerow cuttings on corn is shown in Tables 2, 3 and 4. In all the experiments ipil-ipil herbage significantly increased corn grain yield by more than 100% over the control treatment. The inorganic fertilizers, however, tended to be used more efficiently by the corn than the ipil-ipil.

Table 2. Effect of nitrogen source on corn DMR-2 yield over eight croppings. (Watson and Laquihon, 1985).

Fertilizer source	Average yield (ton/ha)
No fertilizer	1.3
Ipil-ipil from hedgerow	2.7
Commercial fertilizer[1] + ipil-ipil from hedgerow	3.7
Ipil-ipil equivalent to commercial fertilizer rate	2.6
Commercial fertilizer[1]	3.7

1. Commercial fertilizer applied at a rate of 100 kg N and 50 kg P per ha.

Table 3. Yield of corn DMR Comp 2 in erosion plots in Carcar and Barili in Cebu province in the Philippines (Pacardo and Montecillo, 1983).

Treatment	Yield kg/ha	
	Carcar	Barili
Corn alone (stubbles removed)	130	1242
Corn/ipil-ipil (stubbles retained)	499	1771
Corn/ipil-ipil (stubbles removed)	483	1738

Table 4. Effect of intercropping and mulching ipil-ipil on corn yield: average of 5 croppings (O'Sullivan, 1985).

Treatment	Yield (ton/ha)
Corn intercropped with ipil-ipil mulch	
+ N, P[1]	2.41
- N, P[2]	1.19
Corn without ipil-ipil mulch	
+ N, P	2.11
- N, P	0.53

1. + N, P-fertilizer treatment of 100 kg N and 50 kg P_2O_5/ha
2. - N, P-no inorganic fertilizer applied.

Very low corn yield is quite noticeable in the control treatments, indicating low productivity using traditional hillyland cropping practices. The use of ipil-ipil and other tree legumes as hedgerow in alley cropping tends to enhance soil productivity and improve sustainability. In the SALT experience (Watson and Loquihon, 1985), corn was continuously planted for ten consecutive croppings (about 3 crops of corn per year) on the same piece of land using ipil-ipil leaves produced from the hedgerows as fertilizer. The yields from the third to the tenth cropping tended to stabilize at about 2 ton/ha/cropping. This is significantly higher than the national average of 1 ton/ha, or the local average of 500 kg/ha. This is a good indication of the sustainability of the cropping system.

TECHNOLOGY ADOPTION BY FARMERS

Adoption of the alley cropping technology by upland farmers has been very encouraging. Primary sources of information on the technology are from agricultural extension workers, various government development programs, SALT, and the farmers themselves. SALT, for example, had 1110 farmer cooperators from 1981 to 1984. The Philippine-Australian Development Assistance Program (PADAP) carried out a massive campaign in the province of Zamboanga del Sur and had about 700 farmer cooperators. In one catchment area in Leyte province, 16 out of 48 respondents practiced the technology within two years of the introduction (Maniego, 1986).

The high adoption rate of ipil-ipil-based alley cropping in hillyland farming is attributed to the benefits perceived by the farmers. Some of these benefits are (1) natural leveling of the alleyway, which makes farm operations more convenient; (2) production of renewable green manure, which serves as a fertilizer; (3) increased yield; (4) an alternative source of income from the sale of dried ipil-ipil leaves as part of poultry and livestock feeds; and (5) it conserves the soil and improves soil fertility.

Other elements are necessary to further improve the adoption of the technology. These are, as pointed out by Sajise (1984): (1) the land tenure situation - farmers are hesitant to invest time and resources in soil conservation because of the uncertain tenurial status in public lands where such technology is very necessary; (2) the need for an appropriate sociocultural and political support structure; and (3) the need for appropriate long-term budget allocations from the government. In fact, credit facilities have now been opened to corn and rice farmers in the hillylands.

In the past, hillside farming was strictly illegal. Recently the government introduced the Integrated Social Forestry Program which provides security of tenure to shifting cultivators. A stewardship lease is granted for three to seven ha to each farmer on occupied land for a period of 25 years, and is renewable for another 25 years. One of the major objectives of the program is the identification and dissemination of information concerning applicable technologies that are economically feasible, socially acceptable, and environmentally sound. Indications are that alley cropping as a system meets these three requirements.

RESEARCHABLE AREAS

During the Soil Erosion Management Workshop held at PCARRD, Los Banos, Laguna, Philippines, in 1984 (Craswell *et al.*, 1984), alley cropping was identified as an alternative technology for uplands/hillylands. Researchable areas relevant to this system of cropping which are still in need of investigation today are:

- assessment of the long-term stability and sustainability of specific alley-cropping practices in different topographic, meteorological and soil environments;

- the effect of alley width and alternative alley managements on soil erosion and soil movement;

- the establishment problem with shrub legumes in relation to site characteristics: for example, ipil-ipil does not grow well on highly acidic soils, and late last year ipil-ipil in the Philippines was devastated by psyllids (*Heteropsylla* spp.) or jumping lice; so there is a need to search for alternative shrub legumes.

- site-specific socioeconomic evaluation of this farming method.

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ALANG-ALANG LAND IN INDONESIA: PROBLEMS AND PROSPECTS

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ABSTRACT

In 1986, alang-alang (*Imperata cylindrica*) covered approximately 18 million ha of the land area in Indonesia. Studies have shown that alang-alang has no adverse effects on the soil, but land covered with alang-alang is not only unproductive for agriculture but also prone to fire.

Three methods have been tested to control alang-alang: mechanical, biological, and chemical. Of these, the chemical method is by far the most efficient for annual crops. Round up has proved to be the best herbicide, but is quite expensive. In fact, the most effective control is to have appropriate cropping systems and soil management technologies which prevent the proliferation of alang-alang. Further research is needed to address the problem of small farmers so that they will not be induced to infringe unduly on forestland.

INTRODUCTION

The value of alang-alang [*Imperata cylindrica* (L.) Beauv.] may be viewed from two different perspectives.

Agronomists and foresters consider alang-alang as a noxious, troublesome weed. Animal husbandry specialists consider it as a useful source of feedstuff. Other possible uses of alang-alang, e.g. for ethanol production and for medicine (traditional), have also been noted. In the past, many rural people used alang-alang for making roofs, and this is still one of its uses nowadays, though it is only occasionally used for this purpose.

The occurrence of alang-alang land is primarily due to shifting cultivation. The shifting cultivators open the forest and cultivate it with food crops without any input either of fertilizer or pesticides, and soil conservation is also ignored. Usually after 2-3 years, the yield declines sharply and hence they leave the site and clear another forest area, and so forth. The abandoned site is then invaded by alang-alang.

In Indonesia the exact acreage of land predominantly under alang-alang vegetation is not known. In 1975 it was calculated that it covered approximately 16 million ha with an annual increase of 200 000 ha (Muljadi and Soepraptohardjo, 1975; Sudarma, 1975). If this is in fact the case, the 1986 figure would be approximately 18 million ha. But according to the most recent data obtained from another source (Anonymous, 1984), the land under shrubs/alang-alang is only 7.5 million ha.

In order to make a proper plan to deal with alang-alang problems, reliable data are required regarding both its extent and related issues. The aim of this paper is to review the state of research on alang-alang undertaken in Indonesia, particularly with regard to its adverse effects. However, the paper does not cover all the work which has been reported, and only deals with some of the more salient topics.

EFFECT OF ALANG-ALANG VEGETATION ON SOIL

Information about the effect of alang-alang vegetation on soil characteristics in Indonesia is very limited. The work carried out by Satari (1968) was to determine the differences occurring in a soil (yellowish-red Latosol) under alang-alang and one under shrubs or secondary forest. He found that some differences existed between the properties of the soils under these two different types of vegetation. Table 1 shows that the soil under shrub vegetation has a higher content of C, N, and P and also a higher C:N ratio. Satari pointed out that the alang-alang requirement for No.3 is very high as compared to that of shrubs. Furthermore, his results indicate that no significant differences exist between either the bulk density or the infiltration rate of the soils under these two vegetations. On a reddish-yellow podsolic soil, Sukmana (1977) observed no differences in bulk density and pore size distribution in soils under alang-alang and under food crops (Table 2).

Table 1. Soil characteristics under alang-alang and shrub vegetation (Satari, 1968)

Vegetation	pH	Org.C %	Tot.N %	C/N	P_2O_5 * %	CEC me/100g	BD g/cm3
Alang-alang	5.0	2.31	0.17	13.6	0.022	32.7	1.58
Shrubs	4.7	3.97	0.20	19.8	0.079	31.6	1.56

*** 25% HCl extractable**

Table 2. Bulk density and pore-size distribution of a reddish-yellow podsolic soil under alang-alang and food crops (Sukmana, 1977).

Vegetation	BD g/cm^3	TPS %	Aeration porosity %	Slow-draining pores %	Available water % vol.
Alang-alang (7)	1.29	51.7	12.0	4.5	9.4
Food crops (4)	1.28	51.7	13.2	2.8	9.9

* Figure between brackets means total sample.

The uptake of nutrients by alang-alang was reported by Soepardi (1976) (see Table 3). However, he suspected that the figures on this table are on the high side, because the sample was collected from a plot where alang-alang grew together with young rubber trees - and these trees had been fertilized. In general, the concentration of macroelements and Si in the leafblade is higher than in the leafsheat or rhizomes. On the other hand, the microelement concentration in the rhizomes is higher than in the two leafy parts.

Table 3. Chemical composition of leafblade, leafsheet, and rhizomes of alang-alang on a reddish-brown Latosol in Darmaga, Bogor (Soepardi, 1976).

Chemical composition*	Leafblade	Leafsheet	Rhizomes
1. Nitrogen	0.59	0.17	0.35
2. Phosphorus	0.39	0.33	0.17
3. Potassium	0.51	0.56	0.38
4. Calcium	0.41	0.35	0.19
5. Magnesium	0.27	0.28	0.20
6. Silicon	2.66	2.66	1.90
7. Iron	0.05	0.13	0.10
8. Manganese	91.7	97.8	105.9
9. Zinc	4.2	9.0	33.4
10. Copper	5.5	6.3	19.7

* Numbers 1 to 7 expressed in percent and 8 to 10 in ppm of its elemental form.

A study on the effect of alang-alang vegetation on soil loss and runoff has been conducted on a reddish-yellow podsolic soil in Baturaja, South Sumatra, on a 15% slope (Barus *et al*., 1986). Their results indicate that clearing the alang-alang and replacing it with food crops increased the rate of both runoff and soil loss. The annual runoff and soil loss occurring under alang-alang were 422 mm and 18 t/ha respectively, whereas those which occurred under food crops were 774 mm and 25 t/ha respectively.

Based on these findings, it might be concluded that land covered with alang-alang does not result in such adverse effects as many people think. However, the occurrence and expansion of alang-alang land are not desirable trends since the land is not only unproductive but also prone to fire.

EFFECTS OF ALANG-ALANG ON CROP PRODUCTION

Like other weeds, the presence of alang-alang in cultivated crops is undesirable. Due to its hardy growth, alang-alang is considered as the most difficult weed to control. The most striking characteristics of alang-alang are its fast regeneration both by vegetative (rhizome) and generative (seed) mechanisms, its allelophatic reactions, and its high evapotranspiration rates, which may cause water stress (Sajise, 1976). Besides, the competition for nutrients between crops and alang-alang represents an impediment to food-crop production.

Data pertaining to the loss of food-crop production due to alang-alang infestation are practically nonexistent, except for the work conducted by Eussen *et al*. (1976) and Bacon and Subagyo (1985). Eussen *et al*. (1976) carried out a pot experiment to study the effect of the plant density produced by alang-alang on the growth of maize and of sorghum by mixing alang-alang with these two crops. They found that the harmful effect of alang-alang upon maize and sorghum, expressed in its competition value, increased logarithmically with increasing alang-alang plant density. These authors concluded that a part of the competition value of alang-alang is performed by an allelophatic value.

In a study to test some herbicides and additives for controlling alang-alang, Bacon and Subagyo (1985) observed the tiller formation of upland rice was retarded when alang-alang was not controlled (check plot), but no attempt was made to measure the grain-yield losses. However, the yield losses of some food crops due to weeds other than alang-alang are indicative. Nangoensoekardjo and Kadnan (1971a) reported that unweeded treatment produced 0.68 t/ha of corn in comparison to weeded treatment which produced 1.18 t/ha. In another work, Mangoensoekardjo and Kadnan (1971b) reported a grain yield of rice of 3.03, 2.35, and 0.88 respectively from plots with two-weeding, one-weeding, and unweeding treatments.

Estate-crop production losses due to alang-alang have frequently been reported in the literature. Mangoensoekardjo (1976) observed a severe retarding effect on the growth of young mature rubber, and as much as 40-50% retardation in growth in immature trees over a 5-year period. In oil palm plantations, alang-alang also decreases the yield (Garot and Soebadi, 1960). The bad effect of alang-alang on coffee plantations has also been reported (Danhof, 1940).

ALANG-ALANG CONTROL

Basically, measures to control alang-alang can be divided into three categories: mechanical, biological, and chemical. Combinations of these methods are also often used.

Mechanical Method

The mechanical method is the oldest means of alang-alang control, and is still practiced by most farmers in Indonesia. The effectiveness achieved and the cost of the procedure depend on the type of mechanical method used. Chopping the alang-alang down and then burning it can even stimulate its regrowth (Bustami *et al.*, 1982). These authors also reported that clearing the ground by pulling out the alang-alang was the most successful treatment, and with this method there was no evidence of regrowth until 4 months after clearing.

Chozin and Ibrahim (1981) suggested cutting the rhizomes of alang-alang as short as possible during tillage operations and burying them to a depth of 20 cm or deeper. Rhizome cutting to yield 2 to 8 internodes was employed in their study. When buried at a depth of 20 cm none of the internodes emerged to the soil surface since their carbohydrate reserve was utilized before they were able to undergo photosynthetic activities. They also emphasized the importance of plowing and harrowing the soil intensively in the right direction in order to cut the rhizomes into small pieces. This might be a useful practice for clearing land of alang-alang.

Biological Method

A widely used biological method is the growing of plants, which affects alang-alang primarily because it is intolerant of shade. In this connection, Eussen (1981) found that an 80% reduction in daylight intensity resulted in about 50% reduction of the mean relative growth rate of alang-alang due to a decline in the mean relative growth rate of the aerial plantpart and that of rhizomes. This characteristic can be exploited successfully in a number of ways.

The application of *Gliricidia maculata*, with a planting distance of 1 m x 1 m, 2 m x 2 m, and 3 m x 3 m has been studied by Sukartaatmadja and Siregar (1971). The study suggested that shading with *G. maculata* was effective only at the 1 m x 1 m planting distance.

Bustami *et al.* (1982) compared the effectiveness of two cover crops, i.e. *Stylosanthes guyanensis* and *Dolichos lablab*. The best results were obtained from the plot treated with *S. guyanensis*. This plant was able to cover 88% of the ground surface after 5 months, whereas *D. lablab* covered only 20% at the same age.

The most commonly recommended plant species according to Mangoensoekardjo (1976) are as follows:

Legume creepers:

Calopogonium mucunoides Desv.
Centrosema pubescens BTH
Pueraria phaseoloides (Roxb.) BTH
Pueraria triloba (= kudzu)
Psophocarphus palustris Desv.

Leguminous shrubs:

Crotalaria spp.
Stylosanthes spp.
Moghania macrophylla (wild)

The biological method is in fact practicable only in tree-crop plantations or in farming systems when the annual food crop is not included in the system. Mulching techniques using crop residues might be applicable and inexpensive for food-crop-based farming systems.

Chemical Method

The use of chemicals for weed control in general and for alang-alang in particular has been of interest mainly to estate-crop enterprises. Although mechanical methods as a means of clearing (pulling out or plowing the soil, either preceeded by cutting the alang-alang stands or not) has been found effective, it is often time-consuming and uneconomical (Butar-Butar and Kartono, 1975).

Chemical control was probably not practiced in Indonesia prior to 1930 (Mangoensoekardjo, 1976). The most widely used herbicide in the past, particularly in Malaysia, was sodium arsenite. In Indonesia it was not used until 1950 (Mangoensoekardjo, 1976), and due to its several disadvantages (i.e. the danger to human beings, animals, and soil microorganisms, the risk of damage to crops, and the possibility of contamination of the drinking water supply), it was not approved as a herbicide in Indonesia (Soedarsan, 1976).

Dalapon was recommended to replace sodium arsenite, and is available in Indonesia under the trade names Agropon, Basfapon, Dalapon, Dowpon, Granevin, and Pelitapon, usually with 74% a.e. or an 85% sodium salt of 2.2-dichloropropionic acid. The average dose used is 8-10 kg/ha, repeated once and followed by spot spraying with 4 kg/ha at intervals of 3 to 4 weeks, combining 0.1 to 0.05% wetting agent (Mangoensoekardjo, 1976).

Later on, glyphosate [N-(phosphonomethyl) glycine] under the trade name Round up, was recommended in Indonesia for alang-alang control in rubber, oil palm, tea, coffee and cocoa plantations at a dosage of 3 kg a.e./ha followed by the same dose after one to two months (Soedarsan *et al.*, 1975).

Recently, imazaphyr [2-(4,5 dihdro-4-methyl-(1-methyl-ethyl) 5 oxo-1 maimidazol 2-yl)-3 pyridine carboxylic acid], under the trade name Arsenal has also been studied (Bacon and Subagyo, 1985). The results indicate that this herbicide has a very long residual effect. Bacon and Subagyo (1985) also studied the efficiency of dalapon and glyphosate by introducing additives, either Frigate or Hyspray. They found that those additives did not increase the efficacy of either of these two herbicides.

LAND CLEARING OF ALANG-ALANG

Mechanical land clearing with heavy machinery has been widely used in Indonesia, mostly for transmigration projects. Using this method, a fast clearing operation can be achieved, but, much care should be taken to avoid or to minimize soil deterioration which can come about as a result of compaction and removal of the topsoil. Most soils in Indonesia are fine-textured and have low organic-matter contents. Because of this, they are easily compacted when they are worked at the wet range of moisture content.

Soemangat (1984) observed that a higher soil erosion rate occurred on the soil after it was cleared with heavy equipment as compared to erosion caused by the manual method. The use of heavy equipment causes soil compaction which results in a low infiltration rate.

Most of the lands which have been cleared were previously under forest vegetation, and the soils of the forestlands were, in general, more fertile than those under alang-alang vegetation. When alang-alang land is cleared with less care or with improper methods, the soil will be in worse condition. Therefore, studies to investigate the possibility of applying herbicides for clearing alang-alang land are justified.

A study to compare the effectiveness of Gramoxone, Dowpon, and Round up for clearing land dominated by alang-alang was conducted on a reddish-yellow podsolic soil at Baturaja, South Sumatra in 1981-1984 (Suwardjo *et al.*, 1985). It was found that Round up was the most effective; but Round up was also the most expensive. The cost of Round up, Downpon, and Gramozone for one hectare was Rp. 187 500, Rp. 100 000, and Rp. 15 000 respectively. Based on the yield data obtained for rice and maize, the study suggested that after clearing with herbicide tillage is unnecessary.

Another study on the application of dalapon and glyphosate in combination with biological methods was proposed, and was expected to be conducted in the transmigration area at Betung Supod, South Sumatra (Mangoensokardjo and Tjitrosoedardjo, 1984), Food crops, hybrid coconuts, legume cover crops, and forage crops (*Stylosanthes*) were to be used as test crops after clearing It was proposed that this study should be financed by the Agricultural Research to Support Transmigration Project, but since this project was terminated in the 1985/1986 fiscal year, its fate is not known.

POST-LAND-CLEARING MANAGEMENT PERTAINING TO ALANG-ALANG CONTROL

In Indonesia rice is one of the most important commodities, as it is the staple food of most people in the country. In Java Island, rice is grown almost entirely on "sawah" (paddy rice), either irrigated or rainfed. Being cultivated in flooded conditions, weeds do not usually pose a serious problem, since certain weeds are intolerant to excessive water; and even though the weeds exist, they can be easily controlled using manual methods.

In the transmigration areas, most of the lands are cultivated in upland conditions, except in tidal swamp areas where water is excessive. In the former conditions, farmers grow rice either by itself or intercropped with maize, peanut, cassava, etc. during the wet season. During the dry season, shortage crops like soybean, mungbean, cowpea, etc. are often planted when rainfall is sufficient.

An alang-alang invasion of either a food-crop-based or tree-crop-based cropping system usually takes place at the initial stage of crop growth, as long as there is enough light for the alang-alang to develop. A severe invasion of a newly cleared area usually takes place when weeding is ignored or not done properly. By practicing an appropriate cropping system and soil management technologies, alang-alang can be suppressed (Suryatna and McIntosh, 1976).

THE NEED FOR FURTHER RESEARCH

So far, research on alang-alang control has been directed mainly to estate-crop management, and for this purpose more attention has been paid to the chemical method since it is considered the cheapest. After being kept under control with chemicals, a biological control was then applied mostly in the form of cover crops, in order to prevent a regrowth or new infestation of alang-alang and to help in soil conservation. This technology, however, cannot be adopted by farmers whose cropping system is food-crop-based.

Alang-alang generally develops on poor soils because the land has been abandoned; but it can also grow and develop on fertile soils when the soils are not in use. On fertile soils, however, the cultivated crops are able to grow and develop so well that there is no chance for alang-alang to develop, largely because of the shading effect of the crops. On poor soils, like those found in transmigration areas which are, mainly used to grow annual food crops, these crops are not able to develop well unless the soil condition is corrected. Due to the poor growth of the cultivated crops the alang-alang receives enough light to develop and to compete with the crops as a result of its allelophatic reaction.

As was mentioned at the beginning of this paper, vast areas of alang-alang are found in Indonesia. These areas were formed as a result of shifting cultivation, and presumably they occupy the flat to undulating terrains because the shifting cultivators have selected such terrains rather than the steeper ones. These alang-alang areas have an agricultural potential if the fertility status of the soil is improved. This is an important consideration in the context of the transmigration programs in Indonesia, in pursuance of which large areas of forest with topographic conditions suitable for agricultural uses have been cleared. During the third 5-year development plan (Pelita III) from 1978 to 1983, about 500 000 families transmigrated from Java to the outer islands (Sumatra, Kalimantan, Sulawesi, Irian Jaya). According to the provisions of Pelita IV, a further 750 000 families are expected to transmigrate from 1983 to 1988. Since the average land acreage for each family is about 2 ha, it is now becoming increasingly difficult to find forestland suitable for transmigration purposes.

Some people consider that the alang-alang lands are in such a critical state that they should be given low-priority status with regards to agricultural use and development, and this view is understandable in a situation where research on clearing and post-clearing management of alang-alang land has been neglected.

However, in response to the ever-increasing demand for land which can be used for agricultural development, alang-alang land should now be given more attention so that its agricultural potential can be developed. Investigations on ways of dealing with clearing and post-clearing management problems of alang-alang are now urgently needed.

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Seventh Session: Design of experiments

Chairmen: E. Craswell
N. Tuivavalagi

DESIGN AND ANALYSIS OF EXPERIMENTS ON HOMOGENEOUS/ HETEROGENEOUS SOIL CONDITIONS

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ABSTRACT

Agronomic experiments have to take soil heterogenity into account, and it must be an integral aspect affecting the choice of the size and shape of plots and blocks and the number of replications to be used. In the case of agronomic trials, randomized complete blocks and other statistical methods are used; and in the case of land and water management trials, split-plot or strip-plot designs are preferred. Data is generally analyzed by fitting general linear models with eventual covariate adjustments.

INTRODUCTION

The availability of homogeneous soil conditions definitely provides flexibility in experimentation for obtaining treatment estimates with the desired high degree of accuracy. The results obtained help make valid comparisons due to low experimental error and there is a larger scope of randomization over the experimental area. But in the real world of field experimentation, hardly any experimental field or area could be considered satisfactorily homogeneous. The heterogeneity in the experimental area is due to variations in the soil slope, texture, water-retention capacity, fertility status, and soil depth. The soil characteristics interact with other biological yield reducers and condition/influence the response of treatments. There are a number of statistical techniques that can be applied to obtain fair estimates of applied treatments in heterogeneous soil conditions. Generally blocking systems are used in cases of variability in one or more directions in the field for a given soil parameter, e.g. slope, soil depth, availability of N, etc. During the current decade, a lot of emphasis has been given to designing experiments to account for the effects of the various types of local fertility variation or spatial variation in soil and to make adjustments for neighbouring plot effects (Pearce, 1983; Kempton, 1984).

RESOURCE CHARACTERIZATION

In this review, experiments based on resources and their management for optimized production will be briefly discussed. Resource characterization involves the choice of an experimental site, keeping in view its taxonomic, agrometeorological, and biological environment. An idea of the soil heterogeneity can be obtained by using soil productivity contours, variograms, and other geostatistics for spatial variations (Vieira *et al.*, 1983). The choice of size and shape of the plots and blocks, and the number of replications to be used should be decided with reference to the soil heterogeneity. The management parameters generally consist of land and water management and crop management. The crop-management studies include cropping systems, tillage, the selection of adaptable crop cultivars, seeding and spacings, weeds, fertility, and pests and diseases. For this presentation we shall only consider designs for two types of agronomic studies: (i) agronomic trials, and (ii) land-and water-management trials.

1. Agronomic trials: In this case, in trials with a small number of factorial combinations, ICRISAT uses RBD (randomized complete blocks), and for a large number of combinations, we use confounded factorial and fractional factorial experiment designs. Where only quantitative factors are being investigated (e.g. fertility x water) with the purpose of fitting quadratic surfaces and of determining the optimum dose

combination, response surface designs are considered most useful.

2. Land and water management trials: Experiments on the land and water management aspects of watershed-based research generally require a comparatively large plot area (compared to the plots needed for evaluating genotypes or cultivars in crop improvement) to get a fair representation on response and for ease of operation. The split-plot design or strip-plot design are often found suitable. It may be worth listing the experimental designs adopted for land and water studies at ICRISAT:

   - The effect of three slopes and three lengths of plot to study the soil erosion and surface water runoff is being evaluated in a strip-plot design with two replications.

   - The effects of soil texture on productivity levels on four different types of soils are being studied. The treatments have been arranged in an RBD. Further, three different dates were taken for sowing in order to simulate three cropping-season environments in the same year.

   - The effects of primary tillage and soil amendments on Vertisols have been studied with the help of eleven treatments consisting of variable depths of tillage. Configurations and soil amendments were arranged in an RBD. The cropping system was maize, followed by chickpea (1983-84). In this experiment, land pieces with uniform soil depth and slope were selected to form the plots of the blocks.

DATA ANALYSIS

The analysis of data is generally done by fitting general linear models, with or without checking the assumptions underlying the analysis of variance. To improve the precision of the treatment effects, one might consider using the previous status of the plot (before the application of the treatment) with possible coveriates to account for residual effects, competition effects from neighbours, etc.

TECHNOLOGY TRANSFER

Another important area of the agricultural experiment is to determine the transferability of the results to other sites. It was decided (ICRISAT, 1984) that there is a need to collect minimum data sets for the study of response-input relations or model testing for agrotechnology transfers. For testing the operational models, data sets should be collected on weather, soils, crops, management, pest damage, and other such crop-related parameters. For model development, data on soil fertility parameters and on crop phenology will also be required.

In on-farm trials, the choice of the number of farmers' fields, and the sampling schemes for measurement of the responses will require attention.

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ACCOUNTING FOR SOIL MICROVARIABILITY AFTER LAND CLEARING

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ABSTRACT

Tropical soils often exhibit high variability over short distances after clearing. Knowledge of this microvariability is essential both at the research level, for efficient design and analysis of experiments, and at the farm level, for efficient management practices.

Methods of accounting for micro-variability by means of experimental design are discussed. These include blocking, the use of covariates, and nearest-neighbour adjustments. The mapping of key soil parameters over a site, either by geostatistical or less sophisticated techniques, is shown to be a useful aid in the design and analysis of experiments. Various methods are outlined for improving the efficiency of soil sampling of recently cleared land in the tropics. Finally, the effect of spatial autocorrelation on the estimated precision of a sample mean is examined.

INTRODUCTION

The principles used in the design and analysis of agricultural field experiments were devised over 50 years ago by Fisher and Yates at Rothamsted. While these methods have proved enormously successful, they had their origins in temperate regions for land which had been farmed for centuries. In tropical regions such uniform tracts of land are rare, and for recently cleared land soil properties are much more variable. In these circumstances the wisdom of blindly following the traditional statistical methods needs to be questioned.

The heterogeneity of tropical rainforest soils increases after clearing to varying degrees, depending on the method of clearing. Ruts from bulldozer tracts, for example, can leave infertile patches, while bonfire sites provide fertile spots, at least in the short term. When agronomic expriments investigating such treatments as different crop varieties, or levels of lime or fertilizer application, are being conducted on recently cleared land, a poor treatment may appear to be performing well simply because it has been applied to a plot on a highly fertile patch. Similarly a sterile patch can hide the effect of a good treatment. The site microvariability, that is the variability over distances as small as one or two meters, needs to be understood, and accounted for in the analysis of the results.

In this paper, some consideration is given to ways of overcoming the soil microvariability in the tropical environment. Blocking, analysis of covariance, and nearest-neighbor analysis are all discussed as means of accounting for spatial variability in the design and analysis of experiments.

Geostatistical techniques for mapping relevant soil properties over the area of interest are briefly discussed. The mapped patterns can be used to identify relatively homogeneous areas for blocking in the design of an experiment, to form covariates for use in the analysis, or to aid generally in the interpretation of results.

Finally, some relevant statistical aspects of soil sampling are discussed. Various methods are proposed for increasing the efficiency of sampling schemes for recently cleared land in the tropical environment. The effect of assuming observations to be independent when they are in fact autocorrelated is demonstrated.

The individual farmer should benefit from the research results through the establishment of improved management techniques, both in the identification of microvariability and in its treatment.

EXPERIMENTAL DESIGN

The principal aim of experimental design is the removal of as much extraneous variation as possible, to allow precise comparison of treatment effects. As I explain below, the high variability inherent in cleared tropical soils seems best accommodated by simple designs. This is fortunate as, for ease of management and to comply with the desirability of comparable designs at different sites within a network, experimental designs should be kept as simple as possible. Also, on-site statistical analysis of data on a microcomputer is highly desirable, and most statistical packages for microcomputers are not geared to handle complex designs.

Randomized Blocks

One of the simplest, and often most effective, experimental designs is the randomized complete block design. The treatments are randomly allocated to the plots within a block, and the treatments are replicated in several blocks. The amount of replication varies with the circumstances, but should be sufficient to allow at least 10 degrees of freedom for the estimation of experimental error.

The purpose of blocking is to remove the effect of site heterogeneity from random error. Blocks should be chosen to be as homogeneous as possible, while the differences between blocks should be as large as possible. In the standard textbook example, in which there is a known fertility gradient across the site, the blocks should be situated along the gradient; plots should be as similar to each other as possible, of rectangular shape, and oriented in the direction of the fertility gradient. In real life, situations are rarely this clear-cut and knowledge of site variability is often scant.

Many experiments have been poorly laid out in the field due to a blind adoption of textbook 'recipes' for randomized block rather than a careful consideration of their implementation (Preece, 1982). An experiment cannot be satisfactorily designed from afar. As Pearce (1978) puts it:

> "A lot must depend on the experimenter's knowledge of the site. Ideally he should be able to walk over it and study its features, in which case he may well be able to form effective blocks."

Poor blocking can, in fact, have an adverse effect on the efficiency of an experiment, as would be the case, for example, if blocks were unwittingly placed in the direction of a fertility gradient. If the fertility pattern is unknown, and likely to be very patchy, as in the case of newly cleared tropical forest, blocking is unlikely to be effective. Pearce (1986) argues that blocks in the tropics on balance do not contribute much to the precision of experiments. Thus in experiments following land clearing it may be more appropriate to adopt the even simpler completely randomized design, in which treatments, suitably replicated, are randomly allocated to plots across the whole site.

One other aspect of block experiments is particularly relevant in the IBSRAM context, in which similar, or even identical, experiments are to be carried out at contrasting sites. Each site can be regarded as a block, and the group of experiments regarded as one randomized block experiment. The interaction of treatments and sites can then be tested. If it turns out that treatment differences are uniform across sites, then recommendations can be made across a range of environments; when an experiment is performed in isolation at one site, generalizations to other environments become more an act of faith.

Covariates

An alternative method of accounting for site variability is by the use of covariates - subsidiary observations taken prior to the application of treatments. For example, in an experiment in which the treatments are different varieties of maize, possible covariates could be available P or bulk density of soil samples taken from each plot. Another useful covariate is the yield per plot from a 'uniformity trial', in which one variety is grown across the entire site before the treatments are applied (a luxury which is, unfortunately, rarely afforded).

The idea is that the treatment means are 'adjusted' to allow for the effect of the covariates, which reflect site heterogeneity. The aim is a reduction in the error variance, and a consequent increased precision for treatment comparisons. This 'analysis of covariance' can also be used in conjunction with randomized blocks when blocks are suspected of not being entirely homogeneous.

Nearest-Neighbour Analysis

Analysis of field trials can incorporate information from the yield of neighbouring plots. It has been claimed that such 'nearest-neighbour' models are substantially more efficient than randomized block designs. The prototype nearest-neighbour analysis was that of Papadakis (1937) which used covariance analysis to adjust the yield of a plot by taking into account the yields of its neighbouring plots. The philosophy behind the approach is that if a plot is producing a high yield purely because it is situated on a fertile patch of soil, its neighbours are also likely to be yielding well, and its estimated yield due to treatment should be downgraded accordingly. Similarly, a poorly yielding plot may be due to infertile soil rather than an inferior treatment, and its yield is adjusted in accordance to its neighbours' performances.

There has been a renewed interest in neighbour analysis in recent years (e.g. Bartlett, 1978; Wilkinson *et al*., 1983; Green *et al*., 1985). It appears to be an area of significant value in the tropical environment. Pearce (1986) cited a potential application of nearest-neighbour analysis in which an experiment placed on a terrace may wind its way around a hillside with no obvious blocking system available. Several terraces could be used, each regarded as a block, and the nearest-neighbour adjustment should be made within each. In the situation following land clearing in the tropics, where soil chemical and physical properties would be expected to be higly variable with no clear pattern, a potentially effective nearest-neighbour design would be one in which plots would be very long-edge adjoining. Because of the narrow plots, any high or low fertility patches are likely to cross into two or more plots; neighbour analysis is designed to increase precision in such situations.

GEOSTATISTICS

There has been great interest shown recently by soil scientists in the use of geostatistical techniques to map and compare soil properties. Geostatistics evolved in the mining industry as a means of ore estimation, based on information from a sample of (usually) irregularly spaced drill-holes. The main aim of geostatistical techniqes, of which 'kriging' is probably the best known to soil scientists, was to estimate the ore content at an unsampled location.

In soil surveys of large areas a similar aim applies - to predict soil properties at a location not on the sampling grid (Trangmar *et al.*, 1985). But at the smaller scale of an agricultural field experiment, perhaps the greatest contribution of geostatistical techniques is in the mapping of the soil properties across an experimental site. For the interested reader, Laslett *et al.* (1986) provide a detailed comparison of 9 spatial prediction methods which can be used for mapping purposes. My own feeling is that in the field-experiment environment, in which the sampling is usually done on a regular grid, it makes little difference which method is used to map the soil properties. Even the simple contour map computed from the 3 x 3 moving average, as described in Gomez and Gomez (1984, pp. 480-485), would be sufficient for most purposes.

Once a site is mapped with respect to a particular soil property, what use is to be made of this information? From the point of view of experimental design, it may be possible to identify homogeneous areas within a site, and to use them as blocks in a subsequent experiment. The site variability demonstrated in the map may also be useful in interpreting yield results. More formally, the mapped soil property can be used in covariate analysis, as described in the discussion on covariates above.

It is difficult to see much practical value in mapping the variability at the within-plot scale. The experimenter is more interested in the mean value of plot yield than the microvariability within a plot. This is not to discount the basic interest in understanding the underlying sources of microvariability which a detailed geostatistical analysis can help to provide.

SAMPLING

The basic principles of sampling, and soil sampling in particular, are well-established (Cline, 1944; Cochran, 1963; Petersen and Calvin, 1965). A few techniques which have proved particularly useful for sampling in a tropical environment will now be mentioned, and a more general problem regarding the estimation of precision when the observations in the field are not independent, as the classical methods of sampling assume, but are 'autocorrelated', such that observations a small distance apart are more similar than those far apart will also be discussed.

Pilot Survey

When designing a sampling program, the key question to be answered is: 'How many samples do we need to take to achieve the desired precision?' If little is known of the variability of the site (and hence the approximate variance of the sample mean of the property being studied), a small pilot survey can provide the necessary information.

In a study investigating the effect on some soil chemical properties of the selective logging of a tropical rainforest, Gillman *et al.* (1985) conducted a pilot survey whereby pairs of 5 cm diameter 0-10 cm cores (30 cm apart) were taken from 20 randomly selected sites in the undisturbed sections of the study area. The samples were analysed for organic C, N, Ca, Mg, K, Na, Al, available P, cation exchange capacity and pH. For each of these chemical properties the 'within-' and 'between-' sampling location components of variance could be estimated (Snedecor and Cochran, 1967, p. 280). Assuming that soil variability below

10 cm was less than that in the topsoil, and that the variability in the disturbed sections of the rainforest would be greater than that in the undisturbed area, an appropriate sampling scheme was devised (see Gilman *et al.*, 1985, for full details).

Site Stratification and Pairing

Precision, as measured by the standard error of the mean of the property being considered, can be improved if the site can be divided into clearly defined strata. In the case of recently cleared land, it may be possible to stratify according to such things as bulldozer tracks, bonfire sites, stump holes and relatively undisturbed ground. If this is the case, a stratified sampling approach (Cochran, 1963, p. 87) should be considered.

In the aforementioned study of Gillman *et al.* (1985), a stratified sampling approach was adopted, whereby samples were taken from the closest locations in each of four 'disturbance classes' (snig track depressions, snig track humps, crown litter, and areas beneath openings in the canopy) to 10 reference points. The proportion of the forest in each disturbance class was used to obtain an estimate of the mean nutrient levels on each sampling occasion.

As a further endeavour to increase precision, a 'paired-location' procedure was adopted, whereby soil cores were taken in the undistrubed forest as near as practicable to a location in a disturbance class. The undisturbed samples provided a 'base level' for nutrient status at each site reference point, and the pairing of disturbed and undisturbed locations allowed an analysis of their differences. This served to minimize the variability between sampling points as well as to account for seasonal variability due to climatic factors. Gillman *et al*. (1985) calculated an average increase in efficiency due to pairing over random sampling of about 70%. That is to say, 70% more observations would have ben needed to achieve the same precision. Comparable savings could be expected if a similar pairing scheme were adopted when sampling highly variable tropical soils following land clearing.

Repeated Sampling

The patches of highly fertile soil present after clearing are likely to diminish in quality relatively quickly with cropping (Kang and Juo, 1986). Thus the high variability in recently cleared land would be expected to be short-lived. The change in chemical or physical status of a soil from one year to the next, and the effect of different management practices on that change, is a very important aspect of experimentation. When the same site is to be sampled repeatedly, substantial gains in precision can be made by returning to the same sampling locations each time.

In the Gillman *et al.* (1985) study, a principal aim was to track the change in nutrient levels in the logged rainforest over time. Each year the same sampling strategy was followed, and core samples were taken as close as practicable (within about 30 cm) to the previous year's core. This removed the effect of site heterogeneity, and increased precision in the comparison of the nutrient levels between years. The average gain in efficiency due to resampling the same locations as opposed to obtaining different random locations each year was about 150%. So, when interest lies in the change from one sampling time to the next, as it often will in post-clearing experiments, fixed sampling points are strongly recommended.

Autocorrelation

The traditional soil sampling techniques (e.g. Cline, 1944) have always assumed the sample observations to be independent. The realization that points closer together in space are likely to be more similar than those far apart led soil scientists to embrace the new technology of geostatistics, briefly discussed earlier, which is designed to take account of the dependencies, or 'autocorrelation' between observations.

The primary aim of most sampling schemes is to estimate a mean value of some property of interest. The precision of the sample mean is given by its standard error. When the observations are independent the standard error of the mean is well known and easily calculated, and given in any elementary statistics textbook. But what effect does autocorrelation have on the standard error?

Let $X_1, X_2, \ldots, X_n$ be observations of some soil property at n sampling points over a site. The estimate of the sample mean is:

$$\bar{X} = \frac{\Sigma X_i}{n},$$

and the classical estimate of variance, assuming independent observations, is

$$S^2 = \frac{\Sigma (X_i - \bar{X})^2}{n - 1}$$

This gives an estimate of the variances of $\bar{X}$ of S^2/n, and a standard error of $S/\sqrt{n}$. The estimate of the variance of $\bar{X}$ is unbiased as long as the observations are independent. But suppose now that they are correlated, and that the correlation between X_i and X_j is given by ρ_{ij}. Then it can be shown that the expected value of $S\sqrt{}/n$ is

$$E(S^2/n) = \frac{\sigma^2}{n} \left[1 - \frac{2}{n(n-1)} \sum_{i<j}\sum \rho_{ij}\right],$$

where σ^2 is the true population variance.

It can also be shown that in the presence of autocorrelation, the actual variance of $\bar{X}$ is given by:

$$\mathrm{Var}(\bar{X}) = \frac{\sigma^2}{n}\left(1 + \frac{2}{n} \sum_{i<j}\sum \rho_{ij}\right).$$

Thus it follows that S^2/n underestimates Var $(\bar{X})$ by $\frac{2}{n-1} \sum_{i<j}\sum \rho_{ij}$.

If $\rho_{ij} = 0$ for all i, j, the observations are independent and S^2/n is an unbiased estimate of Var $(\bar{X})$; at the other extreme, if $\rho_{ij} = 1$ for all i, j, Var $(\bar{X}) = \sigma^2$ and the effective sample size is one.

The important point, which is not widely appreciated among soil scientists, is that if observations are not independent, as may be the case in soil sampling, the traditional estimate of Var $(\bar{X})$, S^2/n, is biased: the actual variance of $\bar{X}$ may be considerably higher. Thus if S^2/n is incorrectly used as the estimate of Var $(\bar{X})$, a false impression is given of the precision of $\bar{X}$.

The precision of $\bar{X}$ increases as $\Sigma\Sigma\rho_{ij}$ decreases. Thus a network design which minimizes autocorrelation is desirable. In soil studies ρ_{ij} is realistically modelled as a decreasing function of the distance between sample points i and j. Thus a sampling scheme which maximizes the distance between sampling points is to be preferred. These considerations led Matern (1960) and McBratney *et al.* (1981) to recommend sampling on triangular or square grids. Other sampling schemes require more observations to be taken to achieve the same level of precision.

It has been established over a wide range of soils (e.g. Talsma and Flint, 1958; Hammond *et al.*, 1958; Beckett and Webster, 1971) that small-scale variability of soil properties is often of the same order of magnitude as large-scale variability. This means that sampling points do not need to be very far apart to be considered independent. Thus in many situations a grid sampling scheme with the requisite number of points for the desired precision will yield independent samples.

The indedendence assumption can be examined by means of the variogram (see e.g., Trangmar *et al.*, 1985), which I will not go into here. A constant variogram indicates zero autocorrelation. Various methods have been proposed to test for autocorrelation, and for the distance sampling points need to be apart for autocorrelation to be zero (e.g. Vauclin *et al.*, 1982).

After land clearing no clear pattern of microvariability, such as fertility gradients, would be expected. In this highly patchy environment, sampling points well spaced on a regular grid may be expected to be effectively independent, so that fears of the effects of autocorrelation could well be unfounded. Nevertheless, it is worth appreciating in general the dangers of assuming independence in the presence of autocorrelation.

CONCLUSION

I have illustrated how an appreciation of the sources and scale of variability of tropical soil following land clearing can influence the design of experiments and the sampling strategy. As a statistician, I have concentrated on the statistical aspects of the subject, but unless due attention is paid to the practical aspects of experimentation, the statistical considerations may be worthless. Dyke (1964) provides an excellent manual on the conduct of agricultural field trials.

With poor soils predominating in large areas of the humid tropics, land has traditionally been farmed for only a few seasons after clearing (Lal et al, 1986). As soil microvariability is likely to be greatest immediately after clearing, it must obviously play a crucial role in field experimentation on newly cleared land in the humid tropics. Learning firstly how to measure the microvariability, and secondly how to account for it, is of prime importance.

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DATA BASE FOR SOIL MANAGEMENT NETWORK

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ABSTRACT

The paper describes the types of data collected in, and the type of data analysis and management required by, regional or international agricultural networks, and proposes a data-base structure that can effectively and efficiently handle data from such networks. The major feature of the proposed system is that it is decentralized in that each network participant is responsible for the management (data entry, editing, analysis, storage, and retrieval) of his or her data - utilizing a common microcomputer-based data-base management system with programming support provided by the network coordinator. The network coordinator, on the other hand, is responsible for the management of a central integrated data base and for the aggregate analysis of data across test sites and across trials. Advantages and disadvantages of the proposed structure over the centralized system, currently used by most international agricultural networks, are discussed.

INTRODUCTION

The term "data base" has been defined and used in different ways by different people, ranging from the very liberal definition: "Any collection of information stored in a computer is a data base," to the more rigid and formal definition exemplified by the following:

> "A data base is a shared collection of interrelated data designed to meet the needs of multiple types of end-users. The data are stored so that they are independent of the programs which use them. A common and controlled approach is used in adding new data and modifying and retrieving existing data." (Martin and James, 1981).

A data base and its related technology are generally applied to data that possess one or more of the following characteristics:

- Data are voluminous.
- There is a variety of data that are interrelated.
- Data come from several sources.
- Data are to be shared and used by several entities.
- A high level of accuracy and speed in data analysis and management is required.
- Data need to be stored for future use.

The purpose of this paper is to discuss the usefulness of an efficient data-base management system for agricultural research networks, such as the one to be planned during this conference (i.e. a soil management network). More specifically, the topics to be covered are:

- The common features of networks.
- The types of data generated in a network.
- The types of data analysis and management required by a network.
- The proposed structure of a data base and its associated management system for the soil management network.

In discussing these topics, I shall rely heavily on my experience with the three networks coordinated by the International Rice Research Institute (IRRI), namely the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network (ARFSN).

COMMON FEATURES OF NETWORKS

All networks share the common goal of increasing the effectiveness of research through bringing national and regional research institutions out of isolation and widening their resource base and range of activities. Thus, the sharing of technology, research methodology, and experimental results are key ingredients for the success of a network.

The following features, common to all networks, are necessary in order to enhance the network's concept of "sharing":

1. More than one trial (or nursery) is tested in order to evaluate the diverse technologies and cover a wide range of target environments. For example, the six trials currently tested in INSFFER are:

   - Nitrogen fertilizer efficiency in irrigated rice

   - Nitrogen fertilizer efficiency in rainfed wetland rice

   - Integrated use of inorganic and organic nitrogen fertilizer in irrigated wetland rice

   - Comparison of hand- and machine-applied prilled urea and urea supergranules in irrigated wetland rice

   - Long-term fertility trials in irrigated wetland rice

   - Sources of phosphorus and their residual effects in flooded rice

2. A standard set of treatments and experimental

procedures is followed for each trial. For the six INSFFER trials, for example, while the objective, treatments, experimental procedure, data collection, and data analysis vary from one trial to another, they are standardized within a particular trial. In fact, for any IRRI network, the standard practice is that, once agreements on the details of each trial have been reached among the participants at their annual conference, a copy of the "Field Book" (outlining the objectives of the trial, the management and cultural practices of the rice crop, the experimental design and layout, the method for implementing the treatments, the definitions of the data to be collected, and associated data-collection procedures) and a standard set of data sheets are provided to each network participant.

3. The system for data mangement and analysis is common. Following from feature #2 - standard procedures in all aspects of experimentation are being followed by everyone in the network - it is natural that data collected by each participant can, and should, be analyzed and managed in the same way. Because of this uniformity in experimental procedure and data gathering, the data-management system developed and employed for IRRI networks is a centralized system. In such a system, each network participant submits completed data sheets to IRRI, which is responsible for data entry, editing, data analysis, and information storage and retrieval. There are, of course, other alternatives, and I shall discuss one of them together with its advantages and disadvantages relative to the centralized system in a later section.

4. Information sharing is accomplished through formal and informal channels. Published reports, joint monitoring programs, regular conferences and workshops are some of the common mechanisms for enhancing information sharing in a network. For each of the three IRRI networks, progress reports are usually produced annually and used as discussion papers during the annual conference of network participants. A monitoring program is occasionally held to provide an opportunity

for network participants to visit and review one another's ongoing experiments; it provides an excellent forum for the exchange of views and problems.

DATA: TYPE AND ANALYSIS

Even though specific sets of data are not yet prescribed for the soil management network, it is worthwhile to examine the broad type of data that are normally collected and the broad types of data analysis that are normally performed in such a network.

1. Types of data. Data generated in a network can be broadly classified into three categories based on the "basic unit" that the data describe:

   - Site characteristics, in which the test site is the basic unit. This type of data is not expected to change with time, with the treatments being tested, or with the experiments being conducted (in cases where several experiments are conducted at the same site) - such as latitude/longitude, long-term climatic data, and initial taxonomic characteristization - and hence should be collected only once. Data on site characterization are used to aid in (1) interpretation of analysis of data pooled across test sites, (2) grouping of homogeneous test sites based on similarity of technology performances, and (3) generalization of results to cover areas not under tests (agrotechnology transfer).

   - Experimental conditions, where the experiment is the basic unit. Data on experimental conditions include all environmental factors that are not already included in the site characterization, and management factors that are not part of treatments to be tested, such as rainfall, solar radiation, pest incidence, and method of land preparation.

   - Experimental data, where the experiment plot is the basic unit. These are data representing the performance variables, based on which the test technologies are being evaluated (such as crop yield or physical and chemical properties of the soil), and other variables that are anticipated to assist in a better understanding of how and why technologies perform the way they do, under a given environmental condition.

2. Minimum data set. For a given trial in a network a "minimum data set" (MDS) is usually prescribed for each of the above data types. This is essential for the sharing of information among members of the network. An MDS concept requires that each network participant must (1) include all data prescribed in the MDS as a part of the data collection scheme (i.e. each participant can collect more, but not less, than what is prescribed in the MDS); and (2) follow the standard definition and sampling/measurement technique prescribed for each and every character in the MDS.

The MDS concept should be applied not only to the experimental data but also to the data on site characteristics and experimental conditions. This is needed to allow sharing of information across trials and test sites, and thus achievement of the total goal of the network.

3. Analysis and management of data. Data processing and analysis are done at three levels: the participant level, the country level, and the network level.

- Participant level. Data in a network originate with each participant (or participating agency) conducting one or more experiments at one or more test sites in a country. Thus the first level of data analysis and management is on a participant basis. It involves the following processes:

  * data entry
  * data editing
  * analysis and summary of data

* information storage and retrieval

Data analysis at this level is usually in the form of standard statistical analyses of individual experiments (such as analysis of variance, mean comparison, and regression/correlation analysis). A sample format for summarizing results of an experiment is shown in Appendix 1.

- Country level. This represents the first aggregate level wherein data from all participants, all test sites and all trials in a particular country are combined, and wherein aggregate analyses are performed. Examination of the experimental results at the country level provides useful information for national agricultural research and development institutions.

- Network level. At this level, data from all participants, covering all test sites and all trials, are deposited and maintained, usually by the network coordinator, for the aggregate analysis. The aim of aggregate analysis is to:

  * examine, for a given trial, variation of results across test sites and to relate the results to the environmental and management factors; and

  * relate results, whenever feasible and meaningful, across the various trials of the network.

PROPOSED STRUCTURE OF DATA BASE FOR A SOIL MANAGEMENT NETWORK

The structure of a data base suited to a particular network depends on (1) the nature of data generated in, and the type of data analysis, storage, and retrieval required by, the network; and (2) computer facilities available to the network participants and to the network coordinator.

With the rapid reduction in the cost of microcomputers and their increased availability in developing countries in recent years, microcomputers have become an affordable tool of research in many national research systems. Thus the present proposal assumes that (1) each network participant (or participating agency) will either have a microcomputer or have access to one for use in the management of network data, and (2) that the network coordinator can provide a sufficiently large computer facility for the management of, and the performance of aggregate analysis on, data accumulated from all network participants, as well as expertise in the development and maintenance of the common data entry/data analysis system for use by all network participants.

It is further assumed (1) that the network data are diverse and contain all the three types given above in discussing the type of data generated in a network; (2) that the data are voluminous, since many trials and test sites are involved; (3) that data management for MDS is similar, but added analysis may be made for those data specific to a particular participant or test site; and (4) that aggregate analysis across all test sites and/or trials is desirable.

On the basis of these assumptions, the data-base structure that I suggest for the soil management network is described below:

- It is decentralized. Each network participant is responsible for the management of his or her own data, including such tasks as:

  * data entry,
  * data editing,
  * standard data analysis and summary (common to all network participants),
  * data storage and retrieval,
  * transmission of a copy of each participant's database to the network coordinator,
  * specialized data analysis unique to individual participants, and
  * coordination with other participants in the country for the aggregate country data analysis and management.

- It is supported, at the network coordinator level, by a software development team that provides the following services to network participants:

* Choose a commercially available microcomputer data base management system (DBMS) to be used as the basis for the tailor-made system for the participants. The choice of only one DBMS would facilitate the development and maintenance of the system and enhance compatibility of data format and medium. The choice should be made based on its portability (i.e. compatible with a large number of microcomputers), flexibility, and scope of features needed for system development. A possible candidate here is the dBase software (dBase II, dBase III or dBase III Plus).

* With the chosen DBMS software as the base, develop support programs that will provide each participant with the capability to perform the following data management tasks easily: data entry, data editing, and data summary. An essential feature of the data entry system is that it must be compatible with the standard field books and data sheets prescribed for use by the participants. This will greatly facilitate and speed up the data entry operation as well as minimize errors.

* Conduct a training program on the use of the data entry/editing/summary system, during which time diskettes containing the relevant programs developed by the network software development team will be distributed to participants. Such a training program can be done separately or as a part of the overall training program of the network (on research mothodologies, implementation of test technologies, etc.).

* Perform system maintenance and provide system support to all participants.

- It is supported by an aggregated data storage, analysis, and retrieval service provided by the network coordinator. Activities at this level are:

* Manage a central integrated data base containing all data-bases received from network participants.

* Perform aggregate analysis of data pooled

over all test sites of a given trial, as well as across different trials.

* Provide linkages with other data bases (outside the network itself) having information relevant to the needs of the network.

* Maintain an information storage and retrieval system that can provide end-users with rapid and accurate retrieval of the desired information.

The advantages of a decentralized system over a centralized system, which is currently used by most international agricultural networks, are as follows:

- Participants are responsible for the entry of their own data and for its accuracy. Since they are the ones who understand the data best, the tasks of error detection and correction are greatly facilitated.

- Data entry and editing can be done as soon as data are available. In the centralized system, data are generally submitted to the network coordinator only at the end of each experiment.

- Data are readily available to individual participants as needed.

- Participants are free to analyze and manipulate their data in a way that can best satisfy their unique requirements. Such flexibility will not only encourage maximum usage of data by individual participants (even for purposes beyond those of the network) but will also increase the level of imagination and initiation in the performance of data analysis.

- Participants submit to the network coordinator copies of their respective data bases, instead of raw data. This removes the burden placed on the network coordinator in the centralized system of being responsible for the data entry and editing of a large volume of data in a short time.

On the other hand, the disadvantages of a decentralized system are as follows:

- The data management support program used by the network participants must have provision for a high level of control (to ensure correctness of data).

- More people need to be trained.

- On-site program maintenance and trouble-shooting must be provided.

I feel that the advantages of the decentralized system outweigh its disadvantages; and, in fact, this alternative promotes the development of local expertise, which is a desirable outcome that must be tackled and considered as an end in itself.

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APPENDIX I : THE THIRD INTERNATIONAL TRIAL ON NITROGEN FERTILIZER EFFICIENCY IN RAINFED WETLAND RICE

MITHAPUR
COOPERATORS : MITHAPUR

COUNTRY : INDIA
DATE SEEDED : 13 JUN 84
AMOUNT OF RAIN (MM) : 1151
VARIETY USED : PANKAJ
WATER DEPTH (CM) :
LOWEST : 30
NO. OF REPLICATIONS : 4

STATE : BIHAR
DATE TRANSPLANTED : 05 JUL 84
SOLAR RADIATION (K-CAL/ 45 DAYS BEFORE HARVEST) : NOT STATED
HIGHEST : 33
PLANT SPACING (CM) : 20 x 10

DATE HARVESTED : 20 NOV 84
SUNSHINE HOURS (45 DAYS BEFORE HARVEST) : NOT STATED
MEAN : 32

NO.	N-LEVEL	FORM OF UREA	METHOD OF APPLICATION	GRAIN YIELD (T/HA)	PLANT HEIGHT (CM) 30DT	PLANT HEIGHT (CM) HARVEST	TILLER/SQ.M. 30DT	TILLER/SQ.M. HARVEST	PANICLE NO./SQ.M.	SPIKE-LET NO. /SQ.M.	UNFILLED GRAINS (%)	100-GRAIN WEIGHT (G.)
1	0	CHECK	-	4.3	51	103	240	329	315	532	14.2	2.43
2	29	UREA	BEST SPLIT	5.0	56	107	248	361	347	520	11.8	2.52
3	29	SCU	BROADCAST	5.2	62	111	254	380	361	237	10.4	2.59
4	29	SUPERGRANULE	PLACEMENT	5.7	60	107	297	396	381	671	10.1	2.57
5	58	UREA	BEST SPLIT	4.9	59	106	256	358	340	669	11.4	2.51
6	58	SCU	BROADCAST	5.6	60	111	297	385	368	306	10.2	2.59
7	58	SUPERGRANULE	PLACEMENT	6.0	63	111	262	422	405	710	9.8	2.62
8	87	UREA	BEST SPLIT	4.9	60	105	254	388	372	476	11.5	2.52
9	87	SCU	BROADCAST	5.9	65	111	301	388	375	609	9.2	2.63
10	87	SUPERGRANULE	PLACEMENT	6.2	68	113	267	414	397	486	8.7	2.65
		GRAND MEAN		5.4	60	108	268	382	366	522	10.7	2.56
STANDARD ERROR OF THE MEAN				0.3	1	1	21	8	8	130	0.2	0.02
COEFFICIENT OF VARIATION (%)				11.9	3.9	2.3	15.7	4.4	4.5	49.8	3.7	1.5
LSD (5%)				0.9	3	4	NS	25	24	NS	0.6	0.06
F-TESTS :												
ALL TREATMENTS				3.6**	15.4**	7.3**	1.2NS	10.3**	10.4**	1.4NS	62.7**	11.6**
CONTROL VS. TREATED				12.8**	68.0**	20.0**	-	43.0**	41.6**	-	337.7**	48.6**
AMONG TREATED				2.4*	8.8**	5.7**	-	6.3**	6.5**	-	28.3**	6.9**
RATE				<1	13.3**	1.5NS	-	3.3NS	3.8*	-	18.2**	2.9NS
FORM				7.8**	17.8**	14.7**	-	18.5**	19.1**	-	88.3**	22.6**
RATE x FORM				<1	2.0NS	3.3*	-	1.6NS	1.6NS	-	3.4*	1.1NS

APPENDIXES

APPENDIX I

SEMINAR RESOLUTIONS

Proposed ASIALAND Regional Network

The network organization has been described in other IBSRAM publications, mainly in the reports of the inaugural workshops, the IBSRAM highlights and the newsletter. By and large these descriptions remain valid, but in order to achieve better efficiency a regional approach is taking place in conjunction with a common coordination for the three networks - tropical land clearing for sustainable agriculture, the management of acid tropical soils, and the management of Vertisols. The title of the proposed network program should be: "Land Development and Soil Management in Asia and the Pacific (ASIALAND) "

This network will not destroy the integrity of the three original networks, but should help to foster links between them while at the same time facilitating the coordination process. It is recognized that some projects will focus on tropical land clearing, others will be mainly concerned with the management of acid tropical soils and Vertisols, and others again may integrate the objectives of more than one network.

Organization of the Regional Network Program

The proposed organization of this network regional program will be similar to that envisaged for the initial network. It will comprise three components, namely:

- Cooperators, who will initiate and operate the soil management program activities. Four types of participation are possible:

  * simple participation in the different program activities, mainly with a view to sharing information;
  * active participation - both by having an accepted program, and by participating in all the various program activities;

* basic participation - by having an approved program, some basic research related to the objectives of the network, and also participation in all the programs;
* support participation by international and other research agencies, by undertaking some part of the basic research related to the objective of the network, either alone or in conjunction with other cooperators.

- IBSRAM, through a program coordinator backed by the Network Coordinating Committee, will catalyze, coordinate, and assist cooperators in conducting their activities. IBSRAM provides assistance in the preparation and in the presentation of the projects to donor agencies. the coordinator acts as a link between the cooperators and IBSRAM. He helps strengthen the national cooperators program by regular visits and consultations and by backstopping the following network activities:

  * site characterization;
  * exchange of control soil samples and analytical methods;
  * design of experiments, analyses, and interpretation of the data arising from the experiments;
  * technical assistance;
  * regular meetings, during which programs will be reviewed and eventually revised;
  * monitoring tours;
  * training courses;
  * creation of a data base;
  * review of past and ongoing research and bibliographic information services;
  * program newsletter, publications, and documentation.

- Donors, who will fund the program coordination and, in part, the activities of the individual national cooperators.

Mechanism of Approval of National Project Proposals

One of the main objectives of this meeting was to revise and approve national project proposals in order to establish the regional network program. The mechanism of approval, which has already been put into effect, consists of the following steps:

- A project proposal on soil management is presented to IBSRAM by a national institution. Coordination between national organizations is favoured. More than twenty projects have been presented for this Asian Program.

- The project is reviewed by the Network Coordinating Committee (NCC). Until now, the initial interim NCC formed during the inaugural workshops has been used. The NCC consists of the active. basic, and support cooperators, the main donors, and the IBSRAM coordinator. The IBSRAM Board must then endorse its acceptance of the project proposals.

- After approval, an official letter of acceptance is sent to the cooperators, who may use it as a letter of support for fund-seeking. During the regular meetings of the network, cooperators will present their results, and these will be discussed and reviewed by the participants in order to maintain a high scientific and development standard in the program.

Criteria of Approval for National Project Proposals

The criteria for the approval of a national project proposal are as follows:

- The project must fulfill the network objectives as defined during the inaugural workshops and as clarified during the present seminar.

- The project must be technically acceptable, i.e. it must follow the approach and methodology defined during this seminar.

- The project must be economically acceptable.

- The country must already be involved in research of the type proposed, or be willing to invest in training for its personnel to achieve worthwhile participation.

- If a basic research project is proposed, it should have implications on a wider scale. This criterion will not apply to validation projects.

Network Implementation

Immediate action will be taken by the director of IBSRAM to gain donor support for the program. The requested funds include those needed for the employment of a coordinator, the cost of meetings and monitoring tours, and the requested external funding of the accepted national project proposals. To be effectively implemented, it is felt that the program coordination is the first priority, as without a coordinator there is no network.

So as not to lose momentum in the period before the program coordinator is appointed, the director of IBSRAM will keep in close contact with cooperators and relevant organizations to carry out the various functions set out below:

- Cooperators - to redraft their project proposals in accordance with the discussions which took place during the seminar, and with the guidelines provided.

- IBSRAM - to prepare comprehensive project proposals on "Land Development and Soil Management in Asia and the Pacific" to be presented to donor agencies.

- Cooperators - to follow up activities in the proposed project which have already started, or to start activities as soon as is agreed upon even on a small scale.

- Cooperators - to send IBSRAM an inventory of their available laboratory equipment and to list their needs regarding soil and plant analyses.

- Cooperators - to send their training plans and a list of available facilities at different levels in order to organize training sessions. IBSRAM will encourage cooperators to send participants to ICRISAT and IRRI soil management training sessions.

APPENDIX II

PROGRAM OF THE SEMINAR AND FIELD TOUR

Monday October 13

Opening session: Introductory addresses

- Welcoming address
  Governor of Khon Kaen Province
  Sakda Orpong
- Opening statement
  IBSRAM Director
  Marc Latham
- Formal address
  Director General, Department of Land Development
  Sanarn Rimwanich
- Inaugural address
  Deputy Minister, Ministry of Agriculture and Cooperatives
  H.E. Prayuth Siripanich
- Emcee
  IBSRAM Administrative Officer
  Chalinee Niamskul

First session: IBSRAM and its networks
Chairmen: Dr. R.J. Millington
Dr. S. Panichapong

The IBSRAM land development and soil management network program in monsoon Asia	M. Latham
Management of acid tropical soils	P. Sanchez
Tropical land clearing for sustainable agriculture	R. Lal
Management of Vertisols for improved agricultural production in the tropics ICRISAT experience	S. Virmani
ACIAR role in supporting IBSRAM-backed research programs	E. Craswell
Soil management research: a suggested approach	D. Nangju

Second session: Site selection
Chairmen: Prof. S. Buol
Dr. F. Hj Ahmad

Physical and socioeconomic considerations in site selection	N.F.C. Ranaweera
Site selection for agricultural research or experimentation in Thailand	S. Panichapong
Site selection for agronomic experimentation: Malaysian experience	E. Pushparajah

Third session: Site characterization
Chairmen: Dr. A.J. Smyth
Dr. Vo Tong Xuan

Soil vertical and lateral variation	A. Ruellan
Soil and site characterization for soil-based research networks	H. Eswaran
Agroclimatic parameters for site characterization	R. Yost G. Tsuji P. Kilham

General discussion
Chairmen: Dr. H. Eswaran
Prof. A. Ruellan

Tuesday October 14

Fourth session: Chemical aspects
Chairmen: Dr. H.R. von Uexkull
Dr. Tian Ren Yu

Acidity-Al toxicity	L.C. Bell
Soil acidity management	R. Yost S. Itoga Z. Cheng Li P. Kilham
Organic matter - crop residues and green manure management	I. Kheoruenromne
Dynamic behaviour of plant nutrient in upland soil in northeast Thailand	S. Yoshioka

Fifth session: Physical aspects - FCC
Chairmen: Dr. A. Maglinao
Dr. Paitoon Ponsana

Soil compaction - soil moisture control	R. Lal
Controlling erosion for cropping system experiments	C.W. Rose
The FCC system and its utilization	S. Buol
Land management in Indonesia	H.R. von Uexkull

Sixth session: Cropping systems
Chairmen: Dr. M. Velayutham
Dr. G.M. Hashim

Low-input technologies and managed fallow systems	P. Sanchez
Farming systems and soils in northeast Thailand	P. Keerati-Kasikorn
Alley cropping	E. Paningbatan

Seventh session: Design of experiments
Chairmen: Dr. E. Craswell
Mr. N. Tuivavalagi

Design and analysis of experiments on homogeneous/heterogeneous soil conditions	S.M. Virmani
Microvariability after land clearing	D. Sinclair
Data base for soil management networks	K. Gomez

Wednesday October 15

Country reports and national project proposals
Eighth session: Presentation of proposals on tropical land clearing for sustainable agriculture
Chairman: Dr. D. Nangju
Discussion Leader: Dr. R. Lal

Philippines
Thailand
Indonesia
Nepal
Western Samoa
China
Papua New Guinea
Malaysia
India

Ninth session: Presentation of proposals on the management of acid tropical soils
Chairman: Dr. E. Craswell
Discussion Leader: Prof. P. Sanchez

Thailand
Vietnam
Philippines
Malaysia
Western Samoa
China

Tenth session: Presentation of proposals on the management of Vertisols
Chairman: Dr. S. Panichapong
Discussion Leader: Dr. S.M. Virmani
Philippines
Thailand
Pakistan

Thursday October 16

Eleventh session: Country project proposals and discussion (cont.)

Friday October 17

Twelfth session: Working group discussions
Group A: Morphological, structural, and taxonomic characterization
Group B: Physico-chemical characterization
Group C: Sampling and the design of experiments
Group D: Evaluation of cropping systems

Demonstration of computer programs
The use of the FCC system
The soil acidity and lime requirement expert system

Network Coordinating Committee meeting
NCC discussions with individual cooperators

Saturday October 18

Field trip
Stop 1: DLD Regional Center
Stop 2: Khon Kaen Field Crops Research Center
Stop 3: Nam Nao National Park
Stop 4: The King's residence at Khao Kho

Sunday October 19

Stop 5: Hilly slope soil profile (Ban Chong series) observations of land-use pattern, soil management and cultivation practices on the hilly terrain along the roadside.
Stop 6: B.N. Farm
Stop 7: Phitsanulok Province

Monday October 20

Thirteenth session: Summaries of project proposals and network reports

Chairman: Dr. D. Nangju

Individual project proposals

- China
- Indonesia
- Nepal
- Pakistan
- Philippines
- Thailand
- Western Samoa
- Vietnam
- India
- Papua New Guinea

Network reports

- Management of Vertisols	S.M. Virmani
- Management of ATS	P. Sanchez
- Tropical land clearing	R. Lal

Fourthteen session: Working group reports

Chairman: Dr. S. Panichapong

- A. Smyth	Group A
- Vo Tong Xuan	Group B
- D. Sinclair	Group C
- N. Ranaweera	Group D

Colsing session: Concluding remarks and formalities

Chairman: Dr. R.J. Millington

Formation of the Asian program	M. Latham, IBSRAM Director
Summary of the seminar	Chalinee Niamskul, IBSRAM Administrative Officer
IBSRAM closing remarks	R.J. Millington, Vice-Chairman, IBSRAM Board
	H.A.H. Sharifuddin, Representative of participants
Seminar closing	Mr. Noparatana Vechasart, Governor of Phitsanulok

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Closing Remarks

by H.A.H. Sharifuddin

Representative of the participants

Madam Chairman,
Your Excellency, Mr. Noparatana Vechasart, Governor of Phitsanulok, Dr. R.J. Millington, Vice-Chairman of the IBSRAM Board, Dr. Marc Latham, Director of IBSRAM, Dr. Samarn Panichapong, fellow participants, ladies and gentlemen:

I am greatly honoured to be able to say a few words today on behalf of the participants of this First Regional Seminar on Soil Management under Humid Conditions in Asia, which has enabled us to be together since 13th October till today to discuss ways and means of tackling the problem of managing one of our invaluable resources - i.e. the soils - particularly acid soils, the Vertisols, and those on the slopes.

For the last 10 days we have had good and fruitful discussions and interaction, and I am sure all participants agree that this is mainly due to the excellent and efficient organization of the organizing committee. The participants have been put to hard work with no wastage of time at all. In fact, if the pace of this seminar is any indication of the pace to be achieved by the research programs, we will soon be in possession of a good deal of meaningful data to solve our soil management problems for sustained food crop production.

To the secretariat and the organizing committee we would like to express our sincere gratitude and appreciation for the efficient arrangements in running this seminar. Ms. Chalinee and the core personnel at the secretariat have really given us all an excellent example of how a good seminar should be run. Not to be forgotten are all those who have worked behind the scene to make this seminar and tour successful. To them we convey our thanks and appreciation.

The tour arrangements enabled us to have a very educating and enjoyable trip. I am sure the experience will linger long in our memory. The cooperation from other agencies, like the Infantry Division, was greatly appreciated. Personally, the seriousness of the problem faced by the people of the northeast never dawned on me until we saw them during this field tour.

The warmth and hospitality of the people of Thailand are greatly appreciated, and will certainly be missed by all of us when we go home to our different countries. This hospitality will be cherished by us all. In fact, if a vote were taken now on where we should have our 2nd Regional Seminar, I am sure all participants would unanimously vote for Thailand, and this says a lot about the hospitality and goodwill showed us by our host country.

I would also like to thank our sponsors, namely IBSRAM, ACIAR, the Asian Development Bank and the Ministry of Agriculture and Cooperatives of Thailand, for making this First Regional Seminar possible. Their support has enabled us to be gathered here to discuss problems which greatly affect the well-being of our people, and finally to come up with practical proposals that we feel will certainly not present too much of a problem in getting support from agencies.

The participants have worked hard to eventually come up with 25 proposals worth about US$2 million for the first three years, and I think this is a good indication of the willingness of the participating countries to put in hard work to achieve their objectives. The enthusiasm shown should be an encouraging sign to IBSRAM and potential donors like ADB, USA, Japan, etc.

To the discussion leaders, particularly Dr. Rattan Lal, Dr. Pedro Sanchez and Dr. S.M. Virmani, who have ably led us on fruitful discussion and enlightened us on many issues to be faced, we thank you for sharing with us your rich knowledge and experience.

Lastly, but certainly not least, we would like to thank Dr. Marc Latham for his leadership and enthusiasm in making this seminar a fantastic success.

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