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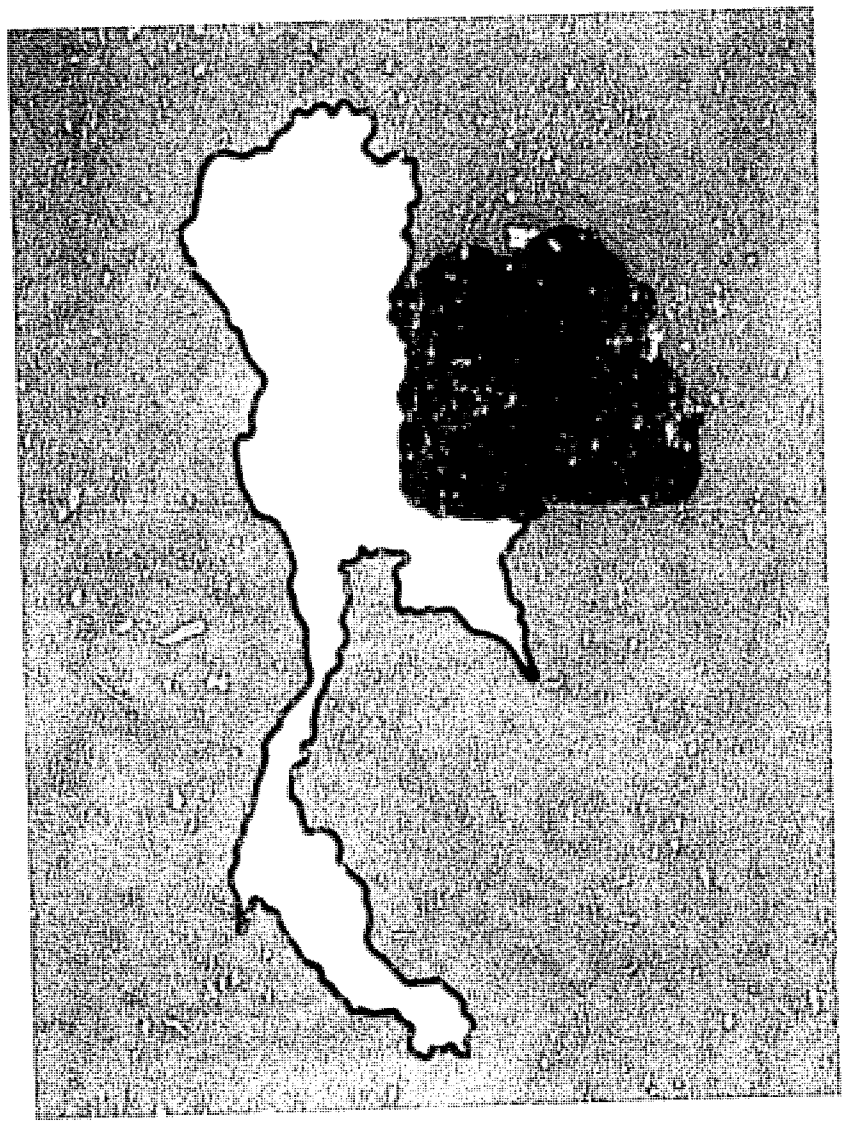
Soil, Water and Crop Management Systems

Rainfed Agriculture in Northeast Thailand



Khon Kaen University

U.S. Department of Agriculture

U.S. Agency for International Development

The First KKU-USAID International Seminar

Soil, Water and Crop Management Systems for Rainfed Agriculture In Northeast Thailand

Proceedings of the workshop
at
Khon Kaen University
Khon Kaen, Thailand

February 25—March 1, 1985

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KKU
Cooperative Research Project

USDA/USAID
Dryland Agriculture Project

The opinions expressed here are those of the authors and do not necessarily reflect the policies or views of the United States Department of Agriculture.

Washington, DC
August 1988

Foreword

Late in 1983, an agreement was reached between the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) and the U.S. Agency for International Development (USAID) whereby ARS would provide technical input to USAID projects in need of expertise for improving soil and water management in dryland or rainfed agricultural systems. This decision reflects not only a growing awareness that such systems provide most of the world's basic food crops, but that increased production is often limited by constraints in soil and water management. It also indicates renewed interest in improving the productivity of subsistence level farmers in semiarid regions where dryland and rainfed agriculture is practiced. The USDA/USAID Dryland Agriculture Project emphasizes the technology for soil moisture management, and is directed toward three geographic regions where there is a critical need to increase the production of diversified agricultural crops, i.e., the Near East (or Middle East), Sub-Saharan Africa and Southeast Asia.

The Northeast Region of Thailand, which encompasses the Korat Plateau and 17 Provinces, is the poorest region in the Kingdom, both agriculturally and economically. The major constraints to agriculture in this region are coarse-textured, sandy soils that are inherently low in fertility, low in soil organic matter, and low in their water holding capacity. Rainfall patterns are erratic and crops are subject to moisture deficits and stress from drought that can occur even during the rainy season. It is logical then that USAID should be concerned with improving soil, water and crop management systems for rainfed agriculture in Northeast Thailand. We seek to accomplish this through cooperative research with Khon Kaen University and the Ministry of Agriculture and Cooperatives, and its Department of Agriculture and Department of Land Development. More specifically, we hope to foster research projects that will lead to improved soil management techniques, increased water conservation and storage, and improved crop calendars that would allow the selection and/or sequencing of crops for more efficient use of water.

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Preface

The workshop on "Soil and Crop Management Systems for Rainfed Agriculture in Northeast Thailand" was held at Khon Kaen University, Khon Kaen, Thailand on February 25-March 1, 1985. It was co-sponsored by Khon Kaen University (the official host institution), the Department of Agriculture (DOA), the Department of Land Development (DLD), Kasetsart University, the Northeast Rainfed Agricultural Development Project (NERAD), and the USDA/USAID Dryland Agriculture Project. The objectives of the workshop were threefold:

1. To review and discuss major problems and constraints in soil/water/crop management in rainfed agricultural systems with particular reference to Northeast Thailand. Regional experiences from Sri Lanka and India were also presented.
2. To review available data bases and current research activities, and to develop strategies for resolving major problems through research and agrotechnology transfer.
3. To consider the development of an effective and comprehensive research and training network which includes scientist-to-scientist linkages between national/regional scientists and with U.S. scientists working on similar problems of dryland or rainfed agriculture.

The data base document, distributed to the workshop/seminar participants, was compiled by the Department of Soil Science, Kasetsart University, Bangkok. It summarizes the research which has been done in Thailand in various aspects of soil, water and crop management that are relevant to future agricultural research and development projects in the Northeast region. Hopefully, this document, as well as the technical papers in these proceedings, will be of considerable value to those scientists who will be working on high priority problems of the Northeast. Such problems and constraints to agricultural production and stability in the Northeast region can best be overcome through meaningful cooperation among Thai University scientists and those researchers in the Ministry of Agriculture and Cooperatives. It is hoped that linkages with U.S. scientists working on similar problems will also contribute to this goal of increasing the productivity and stability of rainfed agriculture in Northeast Thailand.

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We would also like to thank Jean Newcomb, Information Staff, Agricultural Research Service, USDA, for her many significant contributions during the course of publication. These include designing the cover, assisting with the format, supervising the final layout, and serving as a technical consultant to the printers and contractors.

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Abbreviations

AICRPDA	All-India Coordinated Research Project for Dryland Agriculture
CIDA	Canadian International Development Agency
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico
CPD	Cooperatives Promotion Department, Thailand
DOA	Department of Agriculture, Thailand
DOAE	Department of Agricultural Extension, Thailand
DLD	Department of Land Development, Thailand
DZRI	Dry Zone Research Institute, Sri Lanka
FAO	Food and Agriculture Organization, United Nations
FSRE	Farming Systems Research and Extension, Thailand
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer, USAID
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas, Syria
ICRISAT	International Crops Research Institute for the Semiarid Tropics, India
ILO	International Labor Organization, United Nations
IRRI	International Rice Research Institute, Philippines
JICA	Japanese International Cooperative Agency
KKU	Khon Kaen University, Thailand
MKG	Mekong Committee, Thailand
MOAC	Ministry of Agriculture and Cooperatives, Thailand
MRD	Mineral Resource Department, Thailand
NERAD	Northeast Rainfed Agricultural Development Project, Thailand
NEROA	Northeast Regional Office of Agriculture, Thailand
OAE	Office of Agricultural Economics, Thailand
RTG	Royal Thai Government
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WHO	World Health Organization, United Nations

Section I
Background Information on Northeast Thailand

Soil and Water Resources in Northeast Thailand

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ABSTRACT. This paper presents information about soil conditions and availability of water resources for agricultural production in Northeast Thailand. Soil constraints and possible methods to alleviate them are discussed.

Introduction

Northeast Thailand is comprised of 17 provinces covering 168,854 km^2 or about one-third of the total country area. It is considered to be a region of limited resources, although 57 percent of the region is currently under agricultural production. The main problems are poor quality soils, the scarcity of water resources, and erratic rainfall patterns. This paper discusses the soil and water resource status of the region and suggests some approaches for improving soil productivity and increasing crop yields.

Physiography of the Northeast

The Northeast, commonly known as Korat Plateau, is a saucer-shaped shallow basin which tilts slightly in an easterly direction. The plateau consists of flat-topped mountains and undulating dissected peneplain surfaces. Its elevation ranges from 100 to 200 m above MSL. Along the southern and western edges of the plateau are mountains of the cuestas type and cliffs with elevations of 200 to 1000 m above MSL. The middle of the northern part of the plateau is folded, forming the Phu Phan Mountain Range in a NW to SE direction. It has an elevation of 600 m above MSL. Based on this information and geological structure, six physiographic areas of the Northeast region are differentiated, as shown in Figure 1, and described briefly as follows:

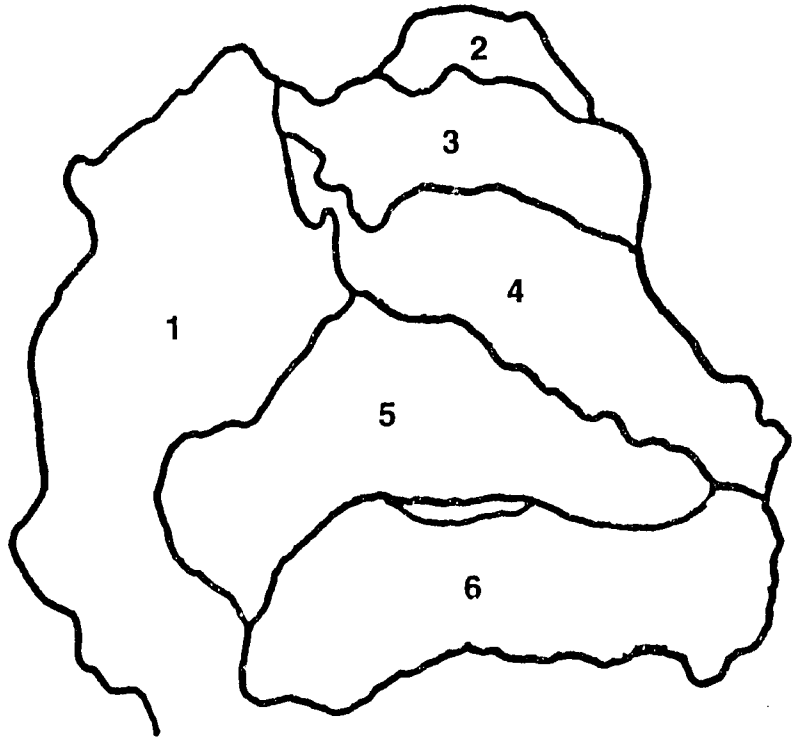
1) *Western Highland.* The area is comprised of a mountain range lying in a north-south direction. The area east of the mountains is an undulating to rolling landscape.

2) *Northern Highland.* The area is a narrow strip located in the extreme north of the region. It has undulating to hilly topography underlain by rocks of the Lower and Middle Korat Group.

3) *Sakon Nakhon Basin.* This basin is in the north of the region with Sakon Nakhon Province in the center and extends to Nakon Phanom to the east and Nong Khai and Udorn to the west. The surface of the basin has flat to undulating topography, underlain by the evaporite bearing salt formation. The largest fresh water lake of the region, Nong Harn, is located at the middle of the basin. Water from the major streams north of the Phu Phan Range drains into Nong Harn and then to the Mekong River via the Songkram River in the northern part of Nakon Phanom Province.

4) *Central Highland.* The area is composed of the Phu Phan Mountain Range and has hilly to undulating topography. It is underlain by the rocks of the Lower and Middle Korat Group.

5) *Korat Basin* The Korat Basin is located south of the Central Highland. It is the largest basin and covers all or part of 11 provinces (17 provinces in the NE), including Buriram, Surin, Srisaket, Nakon Ratchasima, Ubon, Roi Et, Yasothon, Maha Sarakham, Khon Kaen and Kalasin. The two major rivers of the Northeast that flow through the basin are the Chi River in the Central portion and the Mun River in the south (Figure 2). These rivers join together at Rasri Salai District, Srisaket Province, before draining into the Mekong River southeast of Ubon Province.



1. Western Highland
2. Northern Highland
3. Sakon Nakhon Basin
4. Central Highland
5. Korat Basin
6. Southern Lowland

Figure 1. Physiographic Regions of Northeast Thailand.

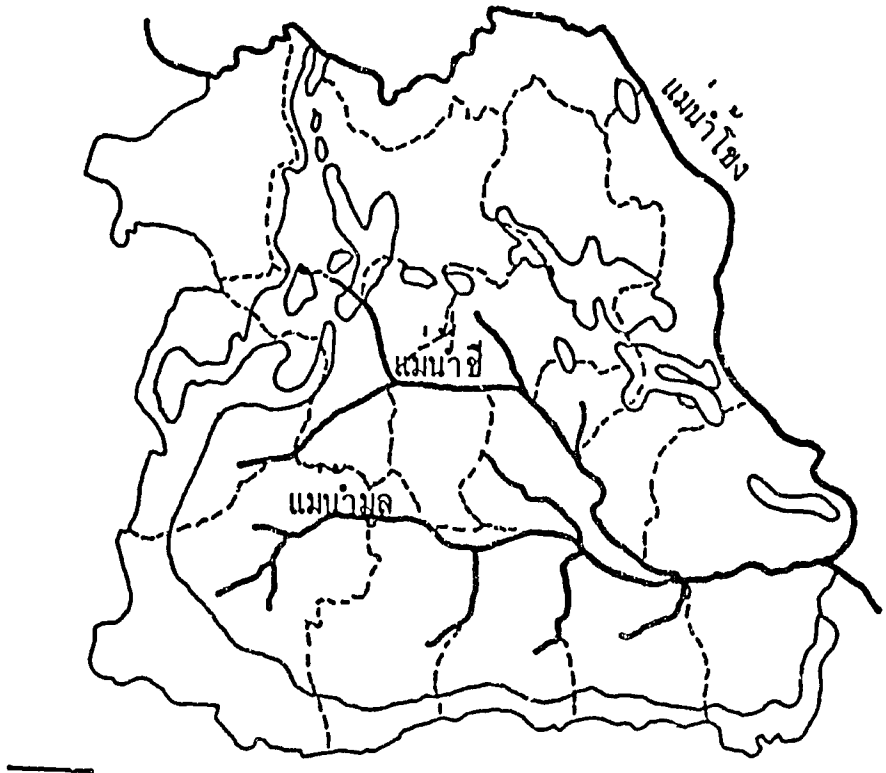
6) *Southern Lowland.* This area is located in the southern part of the region with the Dangrek Mountain Range on the extreme south forming the border between Thailand and Cambodia. The area north of the Dangrek Mountain Range is undulating to flat, grading toward the north to the Mun River. Tertiary basalt hills are found scattered in the area, especially in Surin and Buriram Provinces.

Soils

Soils in the Northeast region are derived from three major groups of parent material: (1) alluvium, mainly sandstone origin, (2) colluvium, mainly sandstone origin, and (3) residual sandstone and basic rock such as basalt. Some scientists believe that many soils originally thought to be derived from alluvium may actually have formed from eolian or residual material. However, this concept has yet to be proved.

The Soil Survey Division, Land Development Department, has shown that the Northeast region consists of seven soil orders, of which 21 great groups have been identified. A brief description of these groups follows:

1) *Quartzipsamments.* These soils are found on alluvial terraces having undulating topography with slopes ranging from three to eight percent. They have A-C profiles with sandy texture throughout. Sand grains are composed of greater than 95 percent SiO_2. These soils are rapidly to excessively drained. Water holding capacity is very low. Fertility status is low to very low.



Mountain

Figure 2. Mountain Ranges and Main Drainage Patterns of Northeast Thailand.

2) *Ustipsamments.* These soils are similar to the Quartzipsamments except that the sand grains are less than 95 percent SiO_2.

3) *Ustifluvents.* These soils are found on the levees of the major rivers such as the Chi, Mun and Mekong, and, in general, have less than a five percent slope. They have A-C profiles but the texture of each horizon is varied. Profiles can be sand alternating with loam texture. Drainage of the soils is good to moderate. Fertility level is medium.

4) *Ustorthents.* These soils are found along the base of hills or mountains. They are shallow with rocks or rock fragments found at less than 50 cm depths. They can have either A-C-R or A-R profiles and are not considered suitable for agricultural purposes.

5) *Chromusterts.* These soils are found on slightly sloping topography and are derived from basalt. They have A-C profiles with heavy clay texture throughout. They crack deeply for a period longer than 90 days a year. The surface soils, less than 30 cm deep, have a pale color. They normally have a high fertility level but their suitability for agriculture is outweighed by their poor physical characteristics.

6) *Pellusterts.* These soils are similar to Chromusterts except that the color of the upper 30 cm of the surface soil is very dark or black.

7) *Tropaquepts.* These soils are found in backswamps or low terrace positions having flat topography and slopes less than two percent. They have A-B (cambic) profiles. Soil texture is clay or loam with a predominantly gray color. Brownish, reddish or yellowish mottles are found throughout the profile. They are poorly drained; during rainy seasons, water stagnates for a long period. Water holding capacity is moderately high to high. The fertility level is low to moderate.

8) *Halaquepts*. These soils are found on the low terraces having flat topography with slopes less than two percent. They have A-B (cambic) profiles. Soil texture is loamy and the soil matrix color is gray with mottles throughout. These soils often have a high salt content. SAR is $\geqslant 13$ (or sodium saturation $\geqslant 15$ percent) in most of the upper 50 cm and decreases below this depth. Salt crust can be observed on the soil surface during the dry season.

9) *Ustropepts*. Typically these soils are formed from weathered basic rocks on undulating topography. They are well-drained with A-B (cambic) profiles. Their texture is clayey throughout and lime concretions are often found in the subsoil, which can reach a base saturation percentage of more than 50 percent. Their fertility level is medium to high.

10) *Dystropepts*. These soils are found on nearly flat to undulating topography with slopes ranging from two to eight percent. They also have A-B (cambic) profiles with sandy loam or sandy clay loam texture. Drainage is moderate to good. Their fertility level is low or somewhat low.

11) *Haplustolls*. It is believed that these soils are formed from marl on undulating terrain with slopes from three to eight percent. They are shallow soils with marl or carbonate at a depth of less than 50 cm. Surface soil is black and very thick. Soil texture is fine clayey to clayey. They have a high water holding capacity and are well-drained. They have a high fertility level.

12) *Natraqualfs*. These soils are derived from alluvium on flat to nearly flat topography. They have A-Btg (argillic B) profiles. Surface soil texture is either sandy loam or loamy sand with the clay content increasing in the argillic horizon. Subsoils contain high sodium. In general, they have a gray matrix color with brown and yellow mottles in the subsoil. During the dry season white salt crusts are commonly found on the soil surface. This group is one of the major problem soils in the Northeast, requiring special attention from all disciplines concerned.

13) *Tropaqualfs*. These soils are found on recent or low terraces having flat to nearly flat topography. They have A-Btg (argillic B) profiles. Soil texture is fine clayey or fine loamy. Matrix color is gray with brown, yellow or red mottles throughout the soil profile. Percent base saturation in the subsoil is higher than 35 percent. They are poorly drained and water stagnates on the soil surface throughout the rainy season.

14) *Paleustalfs*. These soils are found on undulating terrain and have A-Bt (argillic B) profiles. Soil texture is mostly loamy. The soils have a reddish brown color and are well-drained. Percent base saturation in the subsoil is more than 35 percent. Carbonate concretions may be found in the B horizon or below. They have a medium fertility level.

15) *Haplustalfs*. These soils are found on undulating to rolling topography. They are somewhat shallow with A-Bt (argillic B) profiles. Soil texture is clayey throughout. Soil color is mostly brownish or brownish yellow indicating well-drained conditions. Rock or rock fragments, resulting from weathering of the rock beneath, are present at depths of 50 cm or more. Percent base saturation in the subsoil is more than 35 percent. These soils are rated as medium in fertility.

16) *Plinthaquults*. These soils are found on old alluvial terraces that have flat to nearly flat topography. In general, the soils have A-Bt (argillic B) profiles with loamy to clayey soil texture. These soils have a gray colored matrix with mottles throughout. Laterite gravels are found in the subsoil and below that the plinthite layer is present. They are poorly drained and water normally stagnates on the soil surface for much of the rainy season. They are rated low to somewhat low in fertility.

17) *Paleaquults*. These soils are formed on old alluvial terraces that have flat to nearly flat topography. Their profile orientation is A-Bt (argillic B). They can have either clay or sandy loam texture. Matrix color is gray with brown, yellow or red mottles throughout the profile. They are poorly drained with water stagnant on the soil surface during most of the rainy season. They are low or somewhat low in fertility.

18) *Plinthustults*. These soils are found on ailuvial terraces that are undulating. They are shallow with A-Bt (argillic B) profiles. Laterite gravels or rock fragments are present at depths of 50 cm or less The horizon immediately below this is plinthite in nature. The soils are well to moderately well-drained. Fertility status is somewhat low to low.

19) *Paleustults*. These soils are found on undulating to rolling topography, and on footslopes of less than 30 percent. They are deep soils with A-Bt (argillic B) profiles. Soil texture varies from clay to loam. Matrix soil color is yellowish red or red, and soils are moderately well to well-drained. Fertility status is moderately low to low.

20) *Haplustults*. These soils have characteristics resembling Paleustults except that the argillic horizon is thinner and the subsoil contains more than ten percent weatherable minerals.

21) *Haplustox*. These soils are found on high alluvial terraces with undulating or rolling topography. They have A-Box profile characteristics. Soil texture varies from loamy sand to sandy loam and sandy clay loam. Their color is red or yellowish red throughout. representing well-drained situations. The soils have undergone strong leaching processes, leaving only trace amounts of plant nutrients in the upper profile. Hence, their fertility status is low.

Many of the soils are considered to be problem soils as recognized by Panichapong (1982). Of his seven types of so-called problem soils, four of them, sandy textured soils, vertisols, saline and sodic soils, and skeletal soils, are found in the Northeast. Saline and sodic soils have received the most attention and publicity because they are utilized to produce the most important food crop, i.e., paddy rice. Table 1 illustrates the extent of the problem soils in the region.

Table 1. Types and Extent of Problem Soils in Northeast Thailand (Panichapong, 1982).

Soil Type	Area	
	rais	*km²*
Sandy texture soils	3,300,000	6,100
Vertisols	290,000	470
Saline and sodic soils	1,500,000	2,300
Skeletal soils	18,000,000	20,000
Total†	24,000,000	29,000

† Totals may not be precise due to rounding.

In addition, there are about 12,000,000 rais or 19,000 km^2 of land with slopes in excess of 35 percent. Such lands are not suitable for agricultural purposes.

A 1:500,000 scale soil map of the Northeast region was used to estimate the approximate area of each phase of the great groups. The results are reported in Table 2. This provides a good understanding of the soil resources of the region.

Table 2. Soils in Northeast Thailand.

Phase of Great Group	Area		
	rais	*km^2*	*%*
Sandy Quartzipsamments	3,300,000	5,300	3.1
Sandy Quartzipsamments/Loamy Dystropepts	720,000	1,200	0.69
Sandy Ustisamments	41,000	65	0.039
Loamy Ustifluvents	260,000	410	0.24
Skeletal Ustorthents	25,000	40	0.024
Clayey Chromusterts	13,000	20	0.012
Clayey Pellusterts	280,000	450	0.27
Clayey Tropaquepts	6,800,000	11,000	6.5
Loamy Halaquepts	460,000	730	0.44
Clayey Ustropepts	140,000	230	0.14
Loamy Dystropepts	1,900,000	3,000	1.8
Loamy Dystropepts/Loamy Paleaquults	320,000	520	0.31
Clayey Calciustolls	320,000	520	0.31
Loamy Natraqualfs	1,000,000	1,600	0.95
Clayey Tropaqualfs	470,000	750	0.44
Clayey Paleustalfs	36,000	58	0.034
Loamy Paleustalfs	230,000	380	0.22
Clayey Haplustalfs	900,000	1,400	0.86
Loamy Haplustalfs	330,000	500	0.31
Skeletal Haplustalfs	2,200,000	3,600	2.1
Skeletal Haplustalfs/Loamy Paleaquults	29,000	47	0.028
Skeletal Plinthaquults	450,000	710	0.42
Clayey Paleaquults	1,800,000	2,900	1.7
Clayey Paleaquults/Loamy Paleaquults	230,000	370	0.22
Clayey Paleaquults/Loamy Paleaquults	26,000	41	0.024
Loamy Paleaquults	15,000,000	24,000	14

Table 2. (Continued)

Phase of Great Group	Area		
	rais	*km²*	%
Skeletal Paleaquults	20,000	32	0.019
Loamy Plinthustults	45,000	72	0.043
Skeletal Plinthustults	10,000,000	17,000	10
Skeletal Plinthustults/Skeletal Plinthaquults	550,000	880	0.52
Skeletal Plinthustults/Loamy Paleaquults	920,000	1,500	0.88
Skeletal Plinthustults/Loamy Paleustults	200,000	310	0.18
Clayey Paleustults	2,200,000	3,500	2.1
Loamy Paleustults	22,000,000	34,000	20
Loamy Paleustults/Clayey Tropaquepts	61,000	98	0.058
Loamy Paleustults/Loamy Dystropepts	710,000	1,100	0.67
Loamy Paleustults/Clayey Paleaquults	220,000	360	0.21
Loamy Paleustults/Loamy Paleaquults	14,000,000	22,000	13
Loamy Paleustults/Skeletal Paleaquults	150,000	240	0.14
Loamy Paleustults/Skeletal Paleust lts	760,000	1,200	0.72
Loamy Paleustults/Skeletal Haplustults	34,000	54	0.032
Skeletal Paleustults	1,900,000	3,000	1.8
Skeletal Haplustults	450,000	710	0.42
Skeletal Haplustults/Skeletal Ustorthents	140,000	220	0.13
Skeletal Haplustults/Skeletal Plinthaquults	210,000	330	0.20
Clayey Haplustox	730,000	1,200	0.69
Slope Complex	12,000,000	19,000	11
Water	980,000	1,600	0.92
Total†	100,000,000	170,000	100

† Totals may not be precise due to rounding.

Water

Sources of water for crop cultivation are 1) rainfall and 2) irrigation.

Rainfall

The climate of Northeast Thailand is classified as tropical savanna. From November to February the northeast monsoon brings cool and dry weather to the region, while from May to September the southwest monsoon brings warm and moist weather from the Indian Ocean. Most of the rainfall occurs during this period. Average annual rainfall varies from one area to another. The areas in the west and the south, including Loei, Khon Kaen,

Surin, Korat, Chaiyaphum, Buriram and Maha Sarakham Provinces, are the driest. Their average annual rainfall is from 1200 to 1400 mm with 107 to 132 rainy days. The areas in the north and east of the region, including Sakon Nakhon, Srisaket, Roi Et, Ubon, Udorn, Kalasin, Yasothon and Mukdahan Provinces, receive moderate amounts of rainfall, ranging from 1400 to 1800 mm per annum, with 120 to 125 rainy days per year. The areas in the extreme north of the region near the Mekong River, including Nakon Phanom and Nong Khai Provinces, receive more than 1800 mm per annum with about 132 rainy days.

The total amount or average annual rainfall is not that important. Rather, erratic rainfall patterns and poor distribution coupled with sandy soils which are low in fertility, highly erodible, low in organic matter, and have low water holding capacity, create more problems for farmers in the region because they depend on rainwater for their cultivation. The low lying areas normally suffer from flooding after intense rainfall while the highlands are generally water deficient.

Irrigation

The government recognizes the problem of water deficiency in the Northeast, hence, a large amount of the budget has been used for constructing reservoirs and ponds of varying capacity. Although the government is willing to spend more money for this purpose, the construction of dams, reservoirs or ponds is limited by a lack of suitable sites. Some 210 irrigation projects have now been completed and many farm ponds are under construction. Figure 3 shows the types and approximate locations of the completed irrigation projects. These projects will irrigate about 3.2 million rais, which is only 2.3 percent of the land classified as suitable for crop cultivation (Table 3). It is impossible to irrigate all of the agricultural land. Moreover, the completed projects need better maintenance which also requires a large capital input. It is inevitable that a large part of the land in the Northeast will rely on rainfall for crop cultivation. What has been accomplished thus far on irrigation is mainly that farmers' attitudes have improved. This is important in building a firm foundation for future development schemes.

Table 3. Irrigation Projects in the Northeast Region of Thailand (Statistics and Report Section, Planning and Budget Division, Oct. 1982).

Irrigation Region	No. of Projects	Capacity	Area
		m^3	*rais*
4th Irrigation Region, Khon Kaen	65	330	690,000
5th Irrigation Region, Ubon	70	2,200	1,300,000
6th Irrigation Region, Nakon Ratchasima	75	1,500	1,200,000
Total Projects†	210	4,000	3,200,000

† Totals may not be precise due to rounding.

Small reservoirs and farm ponds

Pumping irrigation projects for dry season

Pumping irrigation projects for wet season

Large dam and irrigation projects

Irrigation systems

Figure 3. Irrigation Projects in the Northeast Region of Thailand.

Constraints In Agricultural Production

Constraints derived from soil and water resources can be summarized as follows:

Soil

1) Soils are low in organic matter and low in plant nutrients.
2) Some soils have special characteristics that hinder crop cultivation such as saline and sodic soils, very heavy clay soils (vertisols), very sandy textured soils and skeletal soils. Remedial measures or special management practices are necessary before they can be farmed effectively and productively. Thus, these soils are called problem soils.
3) Low water holding capacity, low cation exchange capacity, low pH (acidity), and low base saturation.

4) Some soils are highly erodible, especially those with a low organic matter content and light sandy texture. During a rainstorm the clay particles are easily dispersed and move downward with water to settle in between the rows of the crop or low spots, leaving almost pure sand particles on the ridges where the crops are transplanted. The clay particles settle and often form a sheet that hardens into a surface crust which can impede water infiltration, aeration, drainage and seedling emergence.

5) Low biological activity in the soils due to the lack of available carbon (or energy) and the presence of factors unfavorable for microbial activity.

Water

1) The total amount of annual rainfall is not much different from other parts of the country, but due to high evapotranspiration rates coupled with low water holding capacity of the soils, the crops grown in this region require more water and have a greater risk of water stress and drought. The climatic analysis shows that surplus water occurs only between August and October. Rainfall may exceed the evapotranspiration rate for a short period in May, but it is not long enough for most crops to survive and reach maturity.

2) Irrigable land is limited.

3) The risk of salinity increases when the land is put under irrigation because most of the existing irrigation system is designed for paddy rice; hence, the drainage system is ignored. Without a proper drainage system the groundwater level, which has a high salt content, will gradually be raised until it reaches the root zone, after which the crop will be adversely affected.

Panichapong and Hemsrichart (1982) prepared an agroclimatological map of Thailand using soil suitability and moisture availability index (MAI) values as criteria for classification. The results of their study showed that the Northeast can be separated into agroclimatological regions as listed in Table 4.

Recommendations

1) Salinity will continue to be a major research topic but more attention should be given to (a) movement of salt in relation to groundwater, (b) distribution of salt-affected soils in relation to movement of groundwater, and landscape and rainfall distribution, and (c) crop varieties tolerant to saline conditions.

2) Research to develop appropriate technologies for the management of other problem soils, such as skeletal soils and sandy textured soils, must be accelerated.

3) Development of cropping systems or crop varieties that are adaptable to conditions in the Northeast Region is of utmost importance.

4) Water consumption and water use efficiency by each crop must be determined.

5) Technology for managing acid soils must be developed and transferred to critical areas to minimize research costs.

6) Conservation tillage systems must be developed that can be easily and successfully adopted so as to effectively minimize soil erosion.

Table 4. Agroclimatological Zones of the Northeast Region of Thailand (Panichapong and Hemsrichart, 1982).

Map Legend	Description	Area
		rais
AU-L-M	Areas with a long rainy season (≥5 months) suited for most annual crops, biennial crops and some fruit trees. Growing season starts in May.	45,000,000
AU-M-Mr1	Areas with a medium rainy season (3-4 months) suited for most annual crops and some biennial crops. Growing season begins in May but a dry spell may occur for one month during June or July.	11,000,000
AU-M-Mr2	Similar to AU-M-Mr1 except that the dry spell period is two months between June and August.	11,000,000
AU-M-Ju	Areas with a medium rainy season (3-4 months); suitable for most annual crops and some biennial crops. Growing season starts in July.	240,000
AP-L-M	Suitable areas for late rice varieties. Growing season starts in May.	16,000,000
AP-L-J	Suitable areas for late rice varieties. Growing season starts in June.	3,600,000
AP-M-Mr	Suitable areas for medium rice varieties. Growing season starts in May but dry spell may occur between June and August.	6,400,000
NA-F	Nonagricultural land including steep lands and watershed areas.	11,000,000
Water		980,000
	Total†	100,000,000

† Total may not be precise due to rounding.

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Physical Environments and Soil Profile Characteristics of Northeast Thailand

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ABSTRACT. The objective of this paper is to provide some information on physical environments for discussion during the field trip. It also describes profile characteristics of the representative soils in the Northeast. The physical environments as described here were extracted from several publications.

Excursion Route

The schematic map of the excursion route is shown in Figure 1.

Stop 1 Maha Sarakham Field Crop Experiment Station.

The route first passes along the Friendship Highway and turns left to Maha Sarakham. We will stop at Maha Sarakham Field Crop Experiment Station where the experiments on soil, water and crop management have been conducted for several years. The results and activities of the Station will be explained to overview the agricultural problems existing in the region.

Stop 2 Kalasin Land Development Station (see map).

The profile characteristics of the most extensive upland soil in the Northeast will be shown. The discussion will be concentrated on the management practices of this soil. Moreover, the research activities conducted at the Station will be explained to help point out the existing problems.

Stop 3 Profile of the paddy soil.

The profile is characteristic of paddy soil. The discussion will cover the practical management of this soil under rainfed conditions.

Stop 4 Huai Srithon Experiment Center.

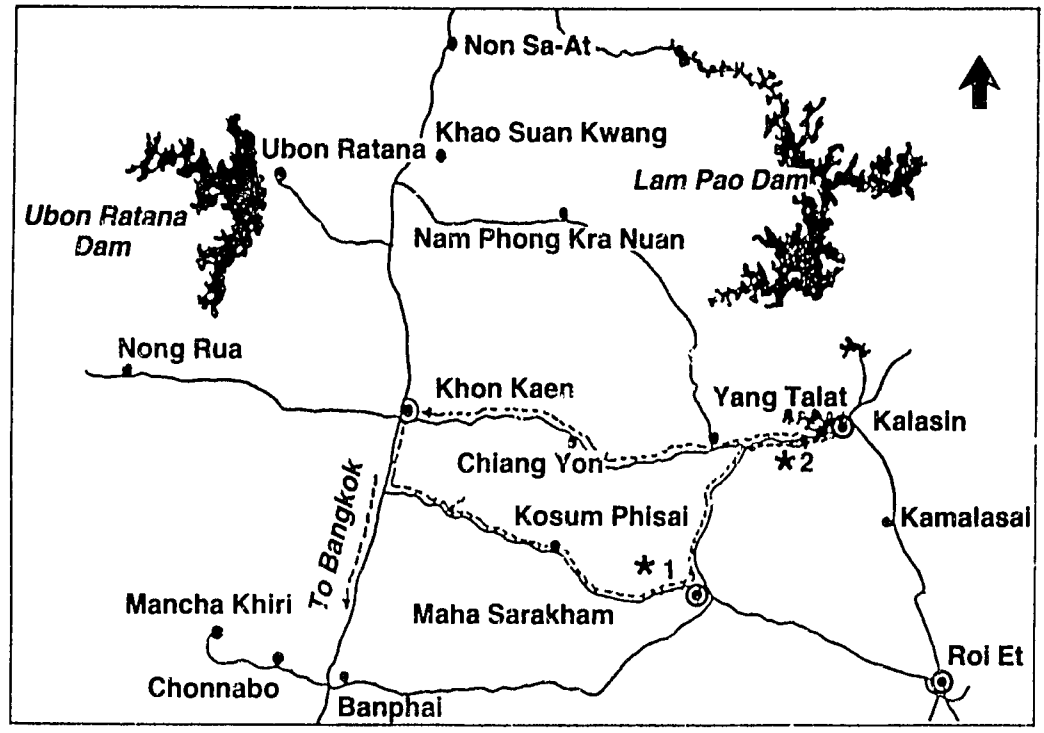
The activities of the Center mainly deal with soil, water and crop management under irrigation.

Physical Environment of Northeast Thailand

Climate

The dominant feature of the climate of Northeast Thailand is the marked seasonality in rainfall distribution with nearly 80 percent of the total rainfall being recorded in the wet season from May to October. The controlling mechanism for this is the seasonal shift of the low pressure belt of the Intertropical Zone of Convergence (ITC) with the apparent movement of the sun and corresponding changes in wind patterns. Superimposed onto this is the development of a marked zone of high pressure over the Asian continent during the winter and of low pressure during the summer.

The main seasons are a relatively cool, dry season from November to February and a wet season from May to September with an intermediate warm to hot season from March to April, and again in October.



Legend

Excursion route

Highway

Scale 1: 1,000,000

20 10 0 10 20 km

* 1 Stop 1

* 2 Stop 2

* 3 Stop 3

* 4 Stop 4

⊙ • Changwat, Amphoe

Figure 1. Schematic Map of the Excursion Route.

The dry season is associated with the extensive high pressure system over the cold Asian continent and the ITC over the Indian Ocean slightly to the south of the equator. The resulting north-south pressure gradient causes fresh, dry northerly to northeasterly winds over Southeast Asia.

The premonsoon season from March to April is characterized by changing wind systems and a marked increase in temperature. Unsettled conditions and thunderstorms mark the approaching wet season. It is associated with a low pressure belt over the Asian land mass resulting in a pressure gradient opposite to the one dominating the dry season. Wet season winds are southwesterly moisture bearing winds from the sea which bring heavy rainfall to the area. Tropical cyclones originating in the Pacific contribute erratically to the rainfall. The postmonsoon period in October marks the change in the predominant wind and pressure systems.

There is some spatial variation in rainfall and evaporation across the Korat Plateau. The lowest rainfall occurs in a rain shadow zone east of the ranges dividing the plateau from the Central Plains and the highest evaporation occurs in a zone across the southern part of the plateau. These two zones coincide in Korat and Chaiyaphum.

While these characteristics reflect the general long-term weather pattern, the actual year-to-year situation may vary considerably with below or above average rainfalls. Delays in the start of the wet season and dry spells within the wet season can seriously affect agricultural activities.

Most serious for agricultural activities, and in particular for rainfed, lowland rice agriculture, are rainfall variability at the beginning of the wet season and dry spells within the wet season. Variability in the onset of the wet season can result in a considerable range in planting date for rice nurseries and time of transplanting with resultant yield variations. Dry spells within the wet season result in significantly lower yields or even crop loss due to the drying out of freshly transplanted rice fields. No detailed study has been made of the extent of dry spells or drought days but general information indicates that dry spells of three weeks are possible. The total number of dry days in the months from May to July is, with 50 percent probability, 44 at Roi Et and 35 at Surin. Since dry spells are identified merely by the number of consecutive days without rain, the actual effect of dry spells can be expected to be much more significant if one looks at the total water balance and identifies dry spells in terms of moisture stress.

Geology, Geomorphology and Soil

The Northeast region of Thailand is virtually identical with the Korat Plateau, a large saucer-shaped basin with prominent raised margins to the south, southeast and west formed by outward facing escarpments. The boundaries to the north and east follow more or less the course of the Mekong River. Apart from the steep and high margins, the only other prominent topographic feature of the Korat Plateau is the Phu Phan Range, a southeasterly row of hills which separates the plateau into two basins, the larger Korat Basin to the south and the smaller Sakon Nakhon Basin to the north. Due to the predominantly horizontal structure of the sedimentary sequence which underlies the plateau and the generally low elevation (100 to 200 m MSL), the landscape is relatively featureless and consists of low hills and ridges separated by broad, shallow valleys.

The central areas of the two basins are formed by flat to gently undulating alluvial plains which are drained by easterly flowing drainage systems. The Korat Basin, covering some 33,000 km^2, is drained by two major rivers, the Mun and Chi Rivers, which join at Ubon Ratchathani. The smaller Sakon Nakhon Basin, extending only over some 10,000 km^2, is drained by a number of disconnected shorter rivers most of which drain directly into the Mekong River. Of great significance for the development of the Korat Basin is the presence of a series of rapids near the junction of the Mun River and the Mekong River since these control the local base levels of erosion and are largely responsible for the very low gradients of the Mun and Chi Rivers. The geological map of Northeast Thailand is shown in Figure 2.

Geologically, the Korat Plateau is formed by a thick sequence of Mesozoic sediments, the Korat Group, ranging in age from upper Triassic to Tertiary and attaining a maximum thickness of about 5000 m. This sequence unconformably overlies a relatively rigid folded Palaeozoic basement block. The Mesozoic sequence has been subdivided into numerous formations; however, only the upper Korat (subgroup), consisting of the Phu Phan, the Khok Kruat and, above all, the Maha Sarakham Formation, is of significance for the land salinization studies.

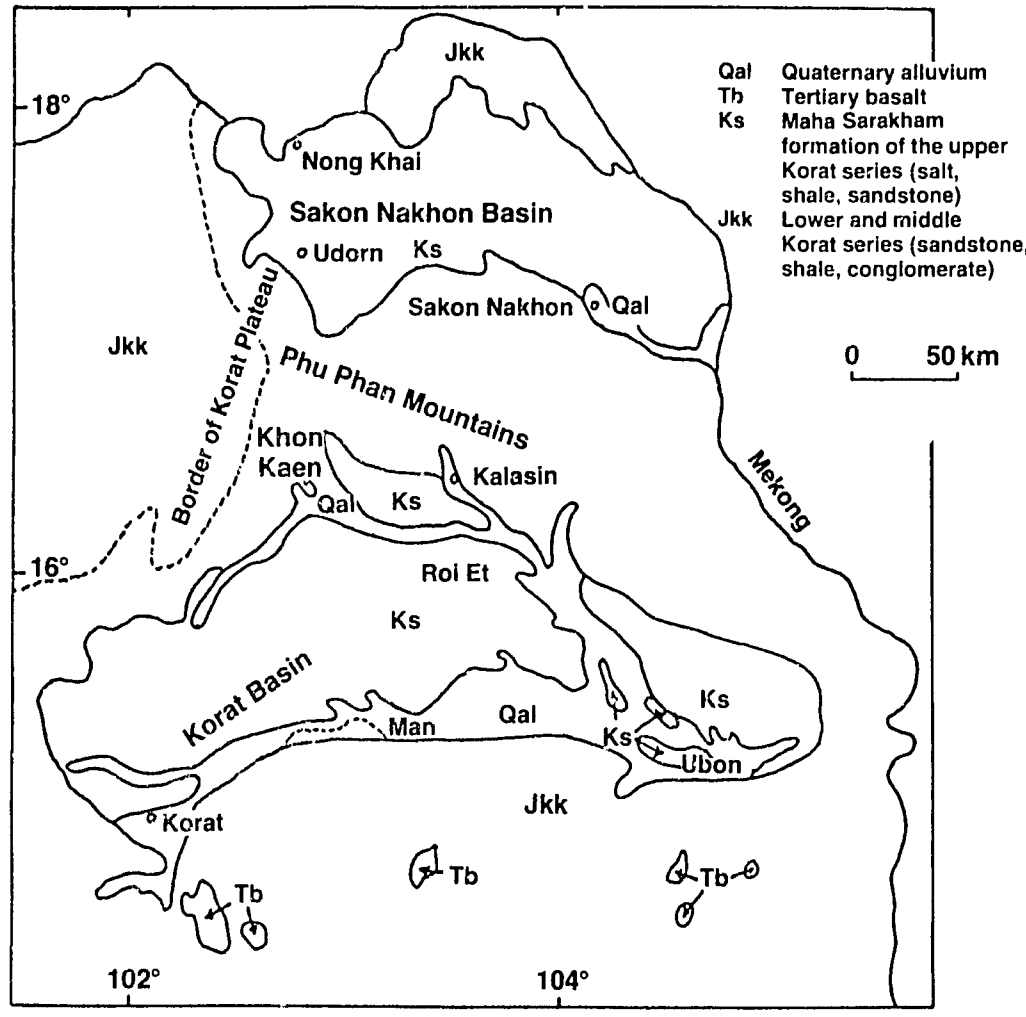


Figure 2. Geology of Northeast Thailand (After Jacobson *et al.*, 1969).

The Phu Phan Formation is a relatively thin (100 to 140 m), but resistant layer of hard sandstone capping the steep escarpments surrounding the Korat Plateau. It is overlain by the Khok Kruat Formation, a series of interbedded siltstones, shales and minor sandstones with the sandstone beds decreasing in thickness upwards in the sequence. The Khok Kruat Formation is relatively nonresistant and contains a few small salt beds in the upper parts of the sequence.

The most important formation, the one which underlies the entire excursion area, is the Maha Sarakham Formation. Formerly called the Salt Formation, it contains considerable quantities of evaporites (salt beds) in the form of rock salts, halite, gypsum and potassium minerals. The sequence consists of interbedded siltstones, sandy shales, mudstones and sandstones. The rocks are nonresistant and surface outcrops are rare since they are invariably deeply weathered. Occasionally, sandstone outcrops occur near ridges and along road cuts. The distribution of saline soils in the Korat Plateau closely coincides with the occurrence of the Maha Sarakham.

The salt deposits within the formation are of variable thickness and range from salt veins or thin layers of salt of only a few centimeters thickness to bodies of salt exceeding 250 m in thickness. Recently, it has been reported by the Economic Geology Division of MRD that salt domes hundreds of meters thick have been discovered extending to within 80 m of the land surface. The salt deposits are not found at depths of less than 60 m due to leaching of the salt.

The Maha Sarakham Formation was deeply weathered in the Tertiary period. In some areas the weathered mantle is fully preserved, but in others it has been partially or wholly stripped. During the Pleistocene, a deep valley system was incised into this weathered landscape. Uplift along the margins subsequently caused its filling with sediments.

Most of the present-day landscape is more easily explained as an erosional landscape which developed over the near horizontal to gentle warped bedrock. At least two major periods of erosion and incision can be recognized. The Tertiary period was characterized by deep weathering of the bedrock and a gently undulating landscape. Low, flat-topped plateaus of gravelly remnants with deep weathering profiles (high terrace) which occur along the margin of the Mun and Chi River basin may also be remnants of this period. During the early Quaternary period, a lowering of base level caused this landscape to be dissected and the main valleys were deepened to 150 m below their present levels. This was followed by a major period of sedimentation in the basins leading to filling of the valleys and the formation of the extensive plains.

Superimposed on these events were climatic changes associated with worldwide cooling and warming during the Pleistocene. We have evidence that in Northeast Thailand this cooling was associated with drier conditions probably resulting from the greatly extended land area during the glacial low sea level stage. At that time, the entire Gulf of Thailand, the Sunda Shelf and the Malacca Straits were dry land and the west coast lay some 150 km west of the present coast. These drier environments resulted in reduced vegetative cover in the catchment areas and increased supply of sandy sediments into the rivers causing braided flood plain conditions. This led to widespread accumulation of sand in the lower lying, low energy basins. The landforms of the Korat Plateau have generally been fitted into the model of landscape-evolution as described by Moormann *et al.* (1964) and Scholten *et al.* (1973). Moormann *et al.* (1964) distinguished several terraces extending over much of the plateau area and regarded the present day undulating to low hilly landscape as essentially alluvial in origin. During several stages of erosion, this alluvial landscape was dissected and, as a result, a series of terraces developed which they termed high, middle and low terrace. Scholten *et al.* (1973), in a more recent study, proposed that eolian activity was associated with these processes and Moormann's middle terrace deposit may have originated from this activity (Figure 3).

The general physiography, including the main quaternary formation of the Korat Plateau, is shown in Figure 4 (after Mekhong Committee, 1978).

The identification of landforms helps to identify the soil boundaries since their relationships are intimately associated. The terrace landscapes and corresponding soil series in the Northeast are illustrated in Figure 3.

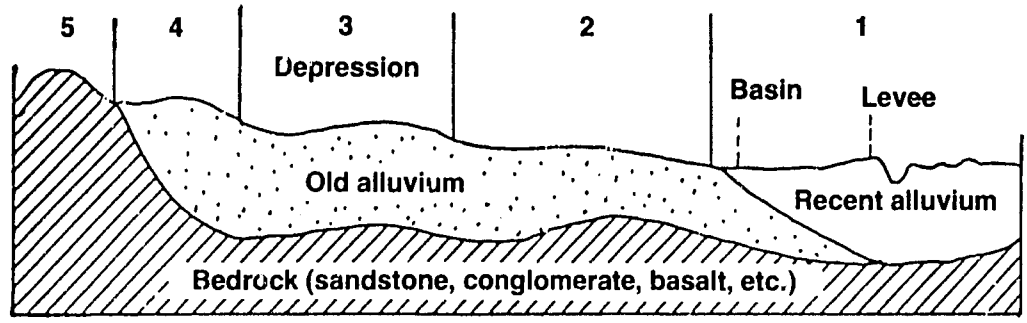


Figure 3. Schematic Cross-Section of the Terrace Landscape in Northeast Thailand (After Scholten *et al.*, 1973).

1. Flood plain of recent river alluvium with Tha Muang, Chiang Mai and Sanphaya soils on levees, and Chainat, Ratchaburi and Phimai soils in the basins.
2. Low alluvial terrace of old alluvium with Roi Et, Tha Tum, On, Phen, Kula Ronghai and Ubon soils, and also Tha Phanom soils on old levees.
3. Middle alluvial terrace of old alluvium with Korat, Satuk, Nam Phong and Phon Phisai soils, and also Ubon and Kenu soils in depressions and lower parts.
4. High alluvial terrace of old alluvium with Warin and Yasothon soils.
5. Hills with Tha Yang, Lat Ya, Phu Sana, Borabu, Buriram, Surin, Chok Chai and Chatturat.

Description of Soil Profile Characteristics (Stop 2 and Stop 3)

Stop 2

I Information on the Site

Soil name: Fine loamy, mixed, isohyperthermic aeric Paleustults

Date of examination: February 17, 1985

Authors: C. Mongkolsawat, R. Katawetin and T. Tulapitak

Location: Southern part of the area belonging to Kalasin Land Development Station. About 15 km west of Kalasin Province at approximately 16°24′N 103°25′E.

Elevation: 155 meters

Landform: Physiographic position: Middle terrace
Surrounding landform: Undulating
Microtopography: Nil

Slope: Gentle slope

Vegetation and land use: Mainly used for field crops

Climate: Annual rainfall about 1300 mm, mainly in the rainy season. Average temperature 26 to 28°C.

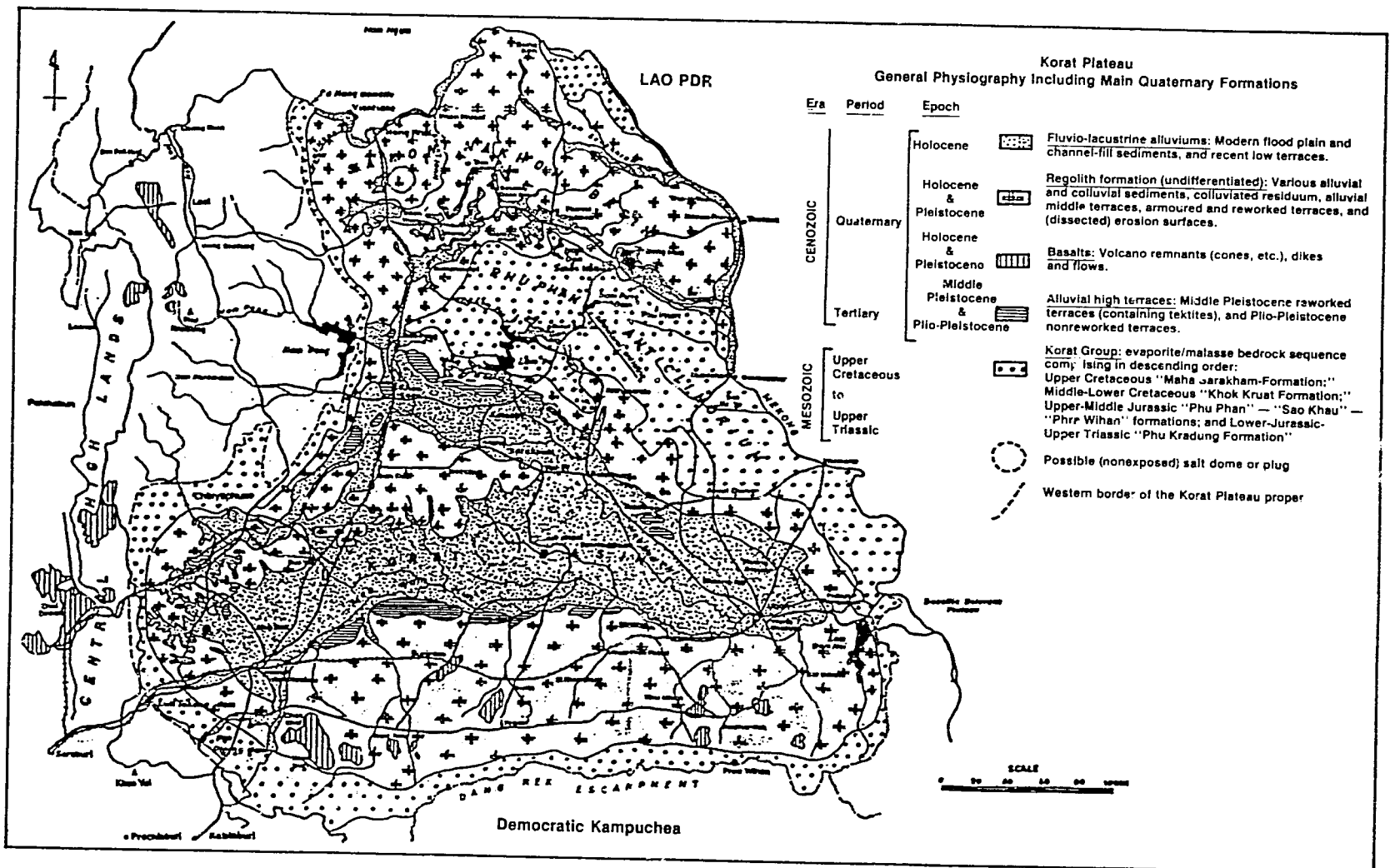


Figure 4. Korat Plateau. General Physiography Including Main Quaternary Formations (After Mekhong Committee, 1978).

II General Information on the Soil

Parent material: Old alluvium

Drainage: Well-drained

Moisture condition in profile: Dry

Presence of surface stones and rock outcrops: Nil

Evidence of erosion: Nil

Presence of salt and alkali: Apparently free

Human influence: Plow pan created by agricultural machines

III Profile Description

Ap 0-34 cm	Reddish brown (5 YR 4/3) moist; loamy sand; weak fine subangular blocky structure; nonsticky, nonplastic; few fine roots, smooth boundary to B1t; medium acid (pH 5.0)
B1t 34-74 cm	Reddish brown (5 YR 5/4) moist; sandy loam; weak fine subangular blocky structure; slightly sticky, slightly plastic; broken thin clay coating in pores; very few fine roots; clear smooth boundary to B22t; medium acid (pH 5.5)
B22t 74-110 cm	Reddish brown (5 YR 5/4) moist; sandy loam; weak fine subangular blocky structure; slightly sticky, slightly plastic; common interstitial pores; broken thin clay coating in pores; very few fine roots; clear smooth boundary to B23t; medium acid (pH 5.5)
B23t 100+ cm	Reddish brown (5 YR 5/4) moist; sandy clay loam; weak fine subangular blocky structure; slightly sticky, slightly plastic; broken moderately thick clay coating in pores; strongly acid (pH 5.0)

IV Inferred Characteristics of the Soil

The land has been generally used for field crop experiments, probably with high fertilizer application.

Stop 3

I Information on the Site

Soil name: Clayey, mixed, isohyperthermic aeric Paleaquult

Date of examination: February 17, 1985

Authors: C. Mongkolsawat, R. Katawetin and T. Tulapitak

Location: 200 m north of road from Kalasin to Khon Kaen. About 12 km west of Kalasin Province at approximately 16°24'W 103°26'E.

Elevation: 140 m

Landform: Physiographic position: On low terrace
Surrounding landform: Flat
Microtopography: Nil

Slope: Flat

Vegetation and land use: Mainly used for paddy field

Climate: Annual rainfall about 1300 mm, mainly in the rainy season. Average temperature 26 to 28 °C.

II General Information on the Soil

Parent material: Old alluvium

Drainage: Poorly drained

Presence of surface stones and rock outcrops: Nil

Evidence of erosion: Nil

Presence of salt and alkali: Apparently free

III Profile Description

Ap 0-17 cm	Brown (7.5 YR 5/4) moist; strong brown (7.5 YR 5/8) mottles; sandy loam; weak fine subangular blocky structure; nonsticky, nonplastic; few fine roots, gradual smooth boundary to B1tg; medium acid (pH 5.5)
B1tg 17-34 cm	Brown (7.5 YR 5/4) moist; strong brown (7.5 YR 5/8) mottles; loam; weak fine subangular blocky structure; slightly sticky, slightly plastic; common interstitial pores; continuous moderately thick clay coating on ped faces and in pores; few to frequent iron concentrations; few fine roots; gradual smooth boundary to B21tg; strongly acid (pH 5.0)
B21tg 34-64 cm	Light brown (7.5 YR 6/4) moist; yellowish red (5 YB 5/8) mottles; loam; moderate medium subangular blocky structure; sticky, plastic; common interstitial pores; continuous moderately thick clay coating on ped faces and in pores; few to frequent iron concretions; few fine roots; gradual smooth boundary to B22tg; very strongly acid (pH 4.5)
B22tg 64-90 cm	Light brown (7.55 YR 6/4) moist: red (25 YB 5/6) mottles; clay loam; moderate medium subangular blocky structure; sticky, plastic; many tubular and interstitial pores; continuous moderately thick clay coating in pores and ped faces; few to frequent iron nodules; smooth boundary to B23tg; extremely acid (pH 4.0)
B23tg 90+ cm	Gray (5 YR 6/1) moist; dark reddish brown (10 YR 4/6) mottles; clay; moderate medium subangular blocky structure; sticky, plastic; many tubular and interstitial pores; continuous moderately thick clay coating in pores and ped faces; few to frequent iron nodules; very strongly acid (pH 4.5)

IV Some Information on Agricultural Practices Used by the Farmers

Rice has been cultivated during the rainy season with

Fertilizer: 16-20-0, 150 kg/ha
Pesticide: Furadan
Variety: RD 6, Sanpathong
Yield: 3000 kg/ha

During the dry season watermelon, peanut and vegetables have been planted.

Watermelon: Variety: Cristone, Sugar Baby
Fertilizer: 15-15-15, 150 kg/ha
Pesticide: Lannate
Irrigation: Twice

Net Income: 20,000 B/ha (dependent on marketing price)

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Overview of Rainfed Agriculture in Northeast Thailand

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ABSTRACT. This paper provides background information about the Northeast at the region level and makes comparisons with Thailand as a whole. Data are presented on the physical, agroecological and socioeconomic conditions in the region, and national agricultural policy and its implications for the Northeast are briefly reviewed. Agricultural production patterns, trends and yield levels are summarized and comparisons are made with other regions and Thailand as a whole. Agroecological parameters are used to define the five major agroecosystems of the region and the critical crop production constraints in each are identified and discussed.

An attempt is made to assess the variability of production at the region, the agroecosystem and the farm levels. The importance of stability at the farm level is described and its implications for farmer decision-making, technology-adoption and technology-design are discussed. Finally, the perspective for agricultural production in the region is considered and the major critical constraints to development are summarized.

Introduction

The purpose of this paper is to provide background information concerning rainfed agriculture in Northeast Thailand. This revie cannot hope to be complete and, therefore, focuses on the agricultural characteristics of the region that have important implications for the objectives of this workshop and presents information that will not be directly addressed in other papers.

The Northeast Region

The Northeast region covers 170,000 km^2 and is bounded on the north and east by the Mekong River which forms the common border with Laos, on the west by the Phetchabun Mountain Range and on the south by the Dangrek Mountain Range where it borders with Kampuchea. The Phu Phan Mountains run in a northwest to southeast direction dividing the region into the Sakon Nakhon and Korat Basins. The former is drained by the Songkram River directly into the Mekong while the Korat Basin or Triangle is drained by two major rivers, the Chi and the Mun, which flow into the Mekong in Ubon (Figure 1). Both basins are at an elevation of approximately 200 m and are characterized by a gently rolling topography which slopes toward the southeast. A schematic cross-section of the region is shown in Figure 2.

Rainfall patterns are dominated by both the southwest monsoon and tropical cyclones originating over the Indian Ocean. There is a distinct rainy season from May to October exhibiting a bimodal pattern with peaks in June and September. Average annual rainfall varies from less than 1000 mm in the rain shadow in the west to over 2300 mm along the Mekong in the northeast giving three distinct rainfall regimes (Figure 3). The critical factor affecting agriculture, however, is the extreme variability both within and between years rather than the total amount of rainfall received.

There are 35 different soil types in the Northeast but the majority fall into one of four great groups (Table 1).

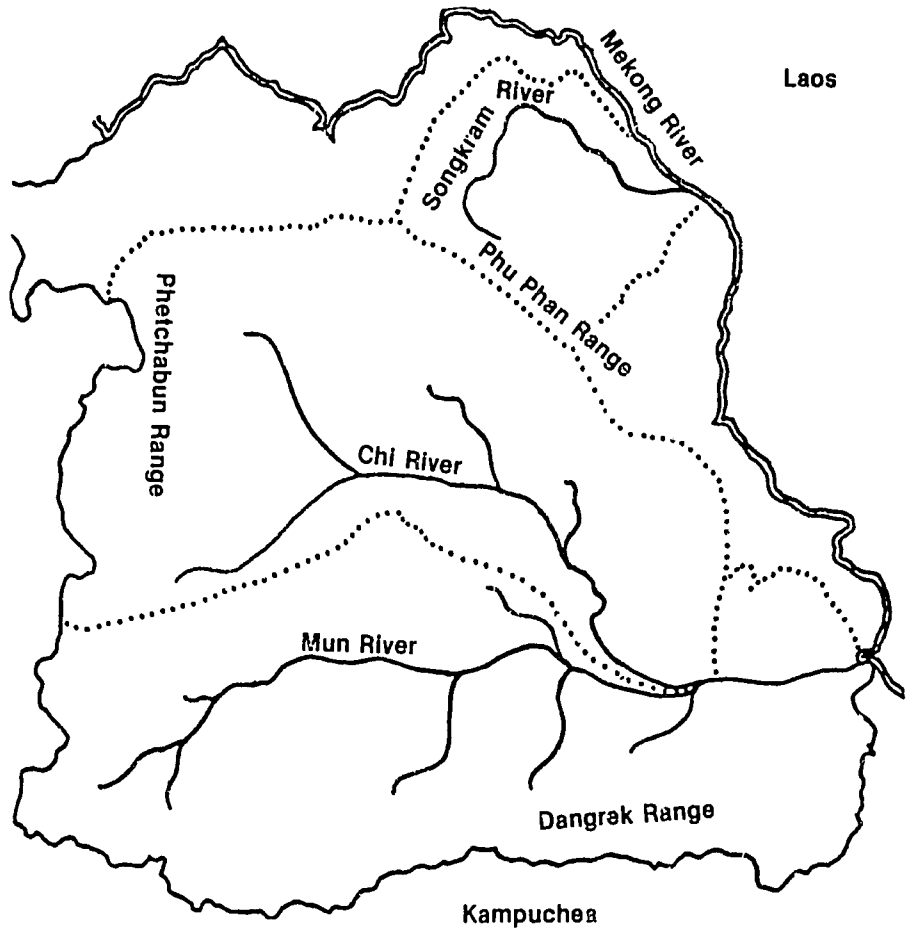


Figure 1. Topography of Northeast Thailand.

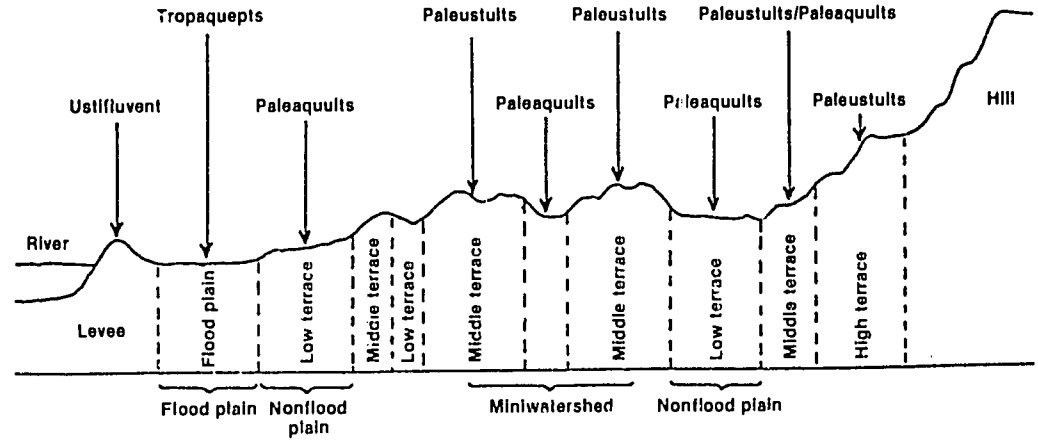


Figure 2. Schematic Cross-Section of Topography and Soils in the Northeast.

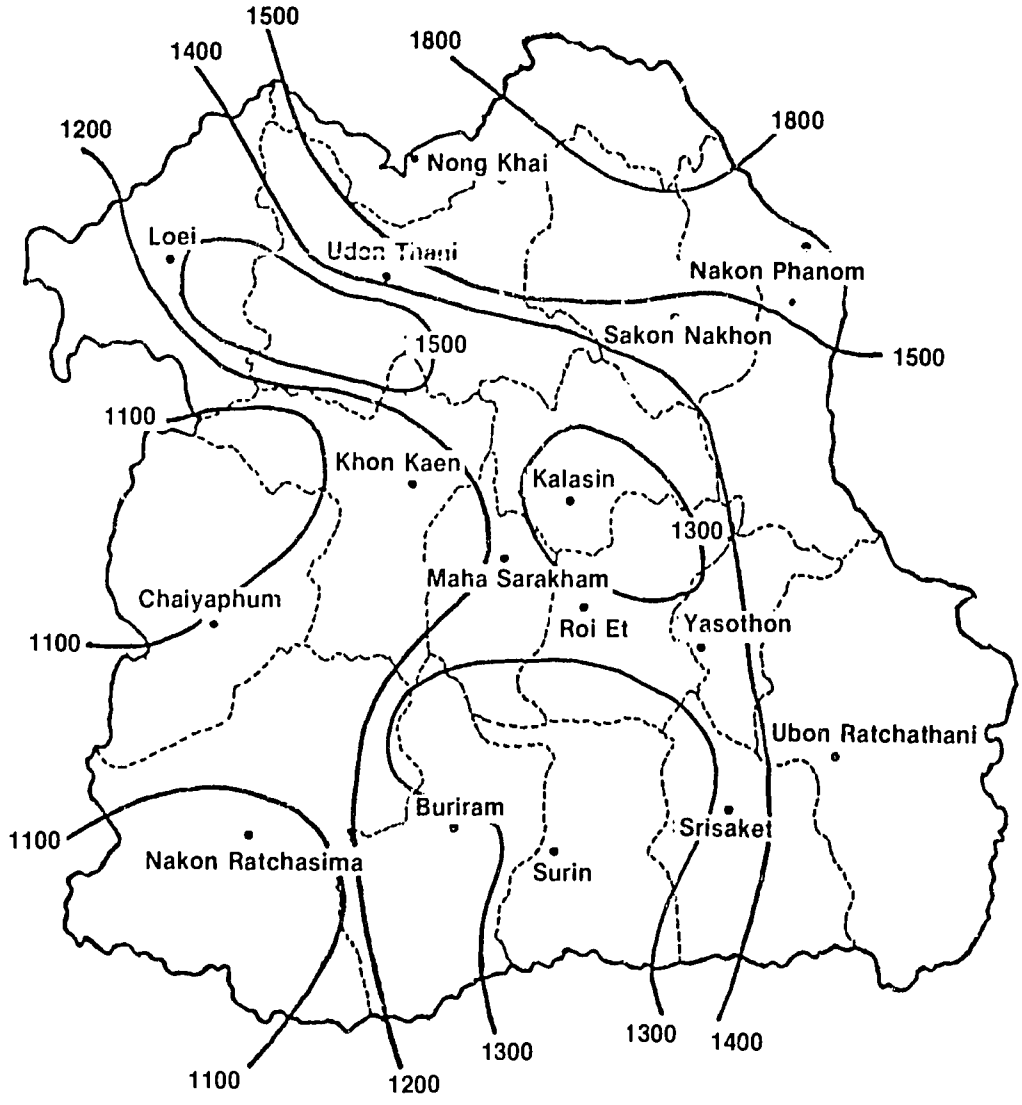


Figure 3. Rainfall Isohyets and Major Rainfall Regimes.

With the exception of some limestone areas in the hills, virtually all soils in the Northeast are derived from sandstone, shale or siltstone and, therefore, are inherently low in potassium, calcium, magnesium and phosphorus (Ragland *et al.*, 1984). Being highly weathered, they are extremely sandy and have low organic matter and clay (predominantly kaolinitic) contents. Low clay contents combined with the low acidity of kaolinitic minerals give rise to soils with extremely low cation exchange and buffering capacities which are often extremely acidic, especially when dry. In addition, parts of the region are underlain by salt bearing rock, often quite close to the surface, resulting in geologically induced salinity problems (Mitsuchi, 1984).

Table 1. Major Soils of Northeast Thailand (KKU, 1982 and Mitsuchi, 1984).

USDA Classification	National Systems	Major Series
Ustifluvents	Semirecent alluvial	Tha Muang, Sanphaya
Tropaquepts	Recent alluvial	Ratchaburi, Phimai
Paleaquults	Low-Humic Gley	Roi Et, Tha Tum
Paleustults	Red-Yellow/Gray Podzolic	Korat, Warin, Satuk, Yasothon

The region contains approximately 17 million people or about one-third of the total population of Thailand and has an annual population growth rate of 2.3 percent. The majority are "Thai Issan" who migrated from Laos across the northeast bank of the Mekong over the past several hundred years (KKU, 1982). There are also many ethnic subgroups including Laos-Wieng, Thai Korat, Khmer in the southern provinces, recently migrated Vietnamese and long established ethnic Chinese mainly in the towns and larger villages.

Farming is the major occupation of 80 percent of the population and, on average, 75 percent of household income comes directly from farming (USAID, 1981). The average agricultural household income for the region is 15,000 Baht, or approximately $540 per year, which represents only 65 percent of the national average (OAE, 1983). The Northeasterners are extremely mobile and will often migrate to the provincial centers, Bangkok or other regions to find work in the off-season to supplement their incomes. A significant number also migrate to Singapore or the Middle East to find work mainly as laborers for periods of one to three years.

The region is well served with air, rail and road systems linking the major market towns and the region as a whole with Bangkok. Laterite roads link most of the villages directly with market centers or at least provide access to the highway system. Small-scale industry and construction in the Changwat centers provide some off-farm employment in the region.

Administratively, the Northeast is organized according to Table 2. Agriculture receives high priority in the nation's economic policy and greater attention is now being given to rainfed and poverty areas than in the past with obvious positive implications for the Northeast. The region includes 60 percent of the nation's government-designated poverty areas with over 75 percent of the region's Districts falling into this category. Such Districts receive additional aid through various development programs. A major policy shift in recent years is towards greater reliance on local initiative and participation in development programs which should, as a consequence, solve locally important problems and thus better serve the real needs of the farmers. This should greatly benefit the Northeast which in the past has suffered from inappropriate programs administered from Bangkok. Specific agricultural policies which will help the Northeast include the promotion of export crop commodities, reforestation, small-scale water resource development and improvement of problem soil areas (saline, acid and eroded soils).

Table 2. Administrative Organization of the Northeast.

Total area	17 Mha
Provinces	17
Districts	193
(Poverty Districts)	(147)
Tambons	1981
Villages	20,828
Farms	1,840,184
Average farm size	4.5 ha
Average household members	6.6 people
Population	17 million
Population growth rate	2.37%

Production Patterns

Total cropped area in the Northeast is increasing as population pressure causes the farmers to cut the forest and bring it under cultivation. Deforestation is occurring at an alarming rate and currently stands at seven percent per year (Table 3). Most of the forest clearance is not for permanent agriculture. Farmers are exploiting the initially high organic matter and nutrient levels for two to three years after which the land is abandoned as fertility levels and yields decline. This is adding significantly to the region's problems through increased flooding in the rainy season and reduced river flow in the dry season.

Permanent agriculture in the region is essentially small, predominantly crop-based, mixed-farming with 80 percent of agricultural income obtained from cropping activities. The remainder accrues from the sale of livestock and fish, production of silk and charcoal, sale of forest products, etc.

A variety of cropping systems have been evolved by farmers in response to their local agroecological conditions and family requirements. Ninety-five percent of the region has no irrigation and the crop production environment is characterized by rainfall with extremely high annual variability. Staggered planting dates, cultural practices and the crops grown are the most common farmer strategies for dealing with this variability.

Cropping patterns in the region can best be summarized according to five generalized land types: lower paddy, middle paddy, upper paddy, upland and hill land. Most farms are composed of a mixture of two, three or more of these land types in varying proportions depending on their location.

The lower paddy land is bunded and planted to long-duration rice every year in the wet season. Rice seedling nurseries are also generally established on this land type as soon as sufficient water is available. Other crops grown in part of this area include kenaf before rice and a variety of vegetables for home consumption with sale of the surplus in local markets. The major problems on the lower paddy land are occasional flooding of the rice in wet years and difficulty in establishing prerice upland crops due to temporary waterlogging of the soil.

Table 3. Land Use in Northeast Thailand (OAE, 1983).

Land Use	Area	Percent of Total Area	Percent Change in Last 5 Years
	Mha		
Total area	17	100	Unchanged
Forest land	2.7	16	- 35
Farm holding	8.3	49	+ 6
Unclassified	5.9	35	+20
Farm holding	8.3	100	+ 6
Irrigated area	0.4	4.8	+44
Paddy land	5.8	70	+ 5
Field crops	1.7	20	+31
Others	0.8	10	Unchanged
Head of cattle	6 million	-	+ 7
No. of pigs	1.1 million	-	+24

The middle paddy is probably the most productive land in the region, as it combines reasonable water control with a reduced risk of flooding. A medium-duration rice crop is produced in the rainy season in most years, sometimes with vegetable, legume or tobacco crops before and/or after the rice.

The upper paddy is also bunded but may be planted to short-duration rice in only three or four years out of ten with a successful harvest occurring even less frequently. This land has the potential for producing one or two upland crops during the rainy season. Farmers will plant rice whenever possible, however, and by the time the decision is made that there will be insufficient rainfall for rice, it is generally too late to plant an upland crop. Weed problems are severe on this land since it often lies fallow for two to three consecutive years allowing weed populations to build up.

The uplands account for 20 to 30 percent of the cultivated land in the Northeast and consist of unbunded fields, often on land reopened from a short bush fallow. The major crops grown on this land in order of importance are: cassava, kenaf, sugarcane, upland rice and legumes such as peanut or mung bean, which are usually grown as monocrops during the rainy season. The major problems here are rapid reduction in soil nutrient levels, selective soil erosion of clay and organic matter (Mitsuchi, 1984), and disease build-up in the continuously cropped areas.

The hill lands are found in the more mountainous areas in the south, the west and in the Phu Phan Range. The hill soils are usually of higher inherent fertility than those found in the river basins and generally produce good yields of maize, upland rice, cotton and a variety of other crops in the rainy season. The major problems include: sheet and gulley soil erosion, poor water retention due to the shallow nature of the soils in some areas, isolation from markets and market price fluctuations. Farmers in these areas are especially at risk from price fluctuations as they often grow no rice and are, therefore, totally dependent on selling cash crops to buy their subsistence rice supplies.

Production Levels

The crop production data presented in Table 4 illustrates a number of important properties of the agricultural situation in the Northeast.

First, the Northeast is a vital contributor to the successful Thai economy through its contribution to agricultural production, which for Thailand as a whole accounts for 65 percent of total export earnings. The region supplies 36 and 59 percent, respectively, of the country's rice and cassava, Thailand's two largest export earners. It also produces 22 percent of the maize, 11 percent of the sugarcane and 100 percent of the kenaf which are also important export commodities.

Table 4. Crop Production in Northeast Thailand (OAE, 1983).

Land Use			Production			
Crop	**Planted Crop Area**	**Change in Planted Area 1978-83**	**Percent of National Production**	**Mean Yield 1978-83**	**National Mean Yield 1978-83**	**Percent of National Average**
	ha x 10³	.....%	.....	.... *kg ha⁻¹*		%
Rice	4,260	+ 9	36	1,200	1,660	73
Cassava	726	+ 15	59	13,400	13,900	96
Maize	501	+ 53	22	1,780	1,990	90
Kenaf	217	- 31	100	1,040	1,040	100
Sugarcane	104	+124	11	39,800	40,600	98
Peanut	28	+ 25	19	1,020	1,190	86
Cotton	25	+ 13	25	1,270	1,150	112
Mung bean	18	+ 55	4	664	594	112

Second, despite the generally poor soils and erratic rainfall in the region, yield levels are generally comparable with and in some cases exceed national averages. Rice yields are low not only because of soil and water control problems but also because, unlike many larger rice farmers in the Central Plain and elsewhere, rice is produced as a low-input, subsistence crop in the Northeast and produces little or no cash for the purchase of fertilizer and other inputs. Considering the production constraints facing the Northeastern farmers, the yields obtained should dispel any ideas that the farmers are backward or lazy. They are undoubtedly among the most skilled in southeast Asia and are behaving rationally in the face of the constraints facing them.

Third, changes in the planted area of the major crops illustrate that agriculture in the Northeast is extremely dynamic. The rice area varies considerably from year to year in response to rainfall. Changes in planted area of the other crops, however, are more a response to market opportunities and prices received. Cassava is the best example of this. Within the last ten years as demand grew in Europe, cassava, a virtually unknown crop, has become the second most important crop after rice and the largest cash earner for the region. These shifts in production patterns illustrate how farmers will respond to new opportunities and should help to dispel the myth that they are resistant to change.

With the exception of rice and cassava, where planted area has fluctuated annually, and kenaf production which has declined, the area of all the other major crops has increased significantly in recent years. Production levels have also increased due mainly to the expansion of the area planted rather than higher yields; yields have fluctuated from year to year but have not significantly increased. In the future, if production is to continue to expand and the natural resource base of the region is to be maintained, then yields per unit area must be improved.

Agroecosystems of the Northeast

Various attempts have been made to classify the Northeast into zones or domains for agricultural purposes (Pisone, 1984; OAE, 1980; DOA, 1979). These efforts have been based mainly on rainfall, soil type and economic conditions but have generally not been found to be very helpful and have not been widely used. This is probably due to two major reasons. First, local diversity within the various zones or even within villages and individual farms is considerable and probably accounts for larger differences in agricultural practices within the zones than between them. Second, the zoning systems have failed to take sufficient account of the topography of the region which is the main determinant of both hydrology and soil nutrient status, two critical factors for crop production.

Based on topography and water regimes, five major agroecosystems can be identified for Northeast Thailand. These are: hill, miniwatershed, nonflood plain, flood plain and irrigation systems (Limpinuntana, 1984). This is not offered as an alternative form of agroeconomic zoning but rather classifying the region in this way facilitates the description of the major agricultural production patterns and allows conclusions to be drawn regarding the important problems and constraints facing farmers. Figure 4 shows the location of these systems and their major characteristics are summarized in Figure 5.

Stability

Agriculture in the Northeast is subjected to two major types of instability: first, production instability caused mainly by climatic variability, and second, price instability for both marketed products and purchased inputs.

The greatest production variability occurs in the wet season rice crop and is reflected in both the area planted and yield per planted area. Regional production data do not give a true picture of this variability. It is not until the lower levels in the hierarchy are reached that the real variability facing farmers becomes apparent (Figure 6). This is due to internal

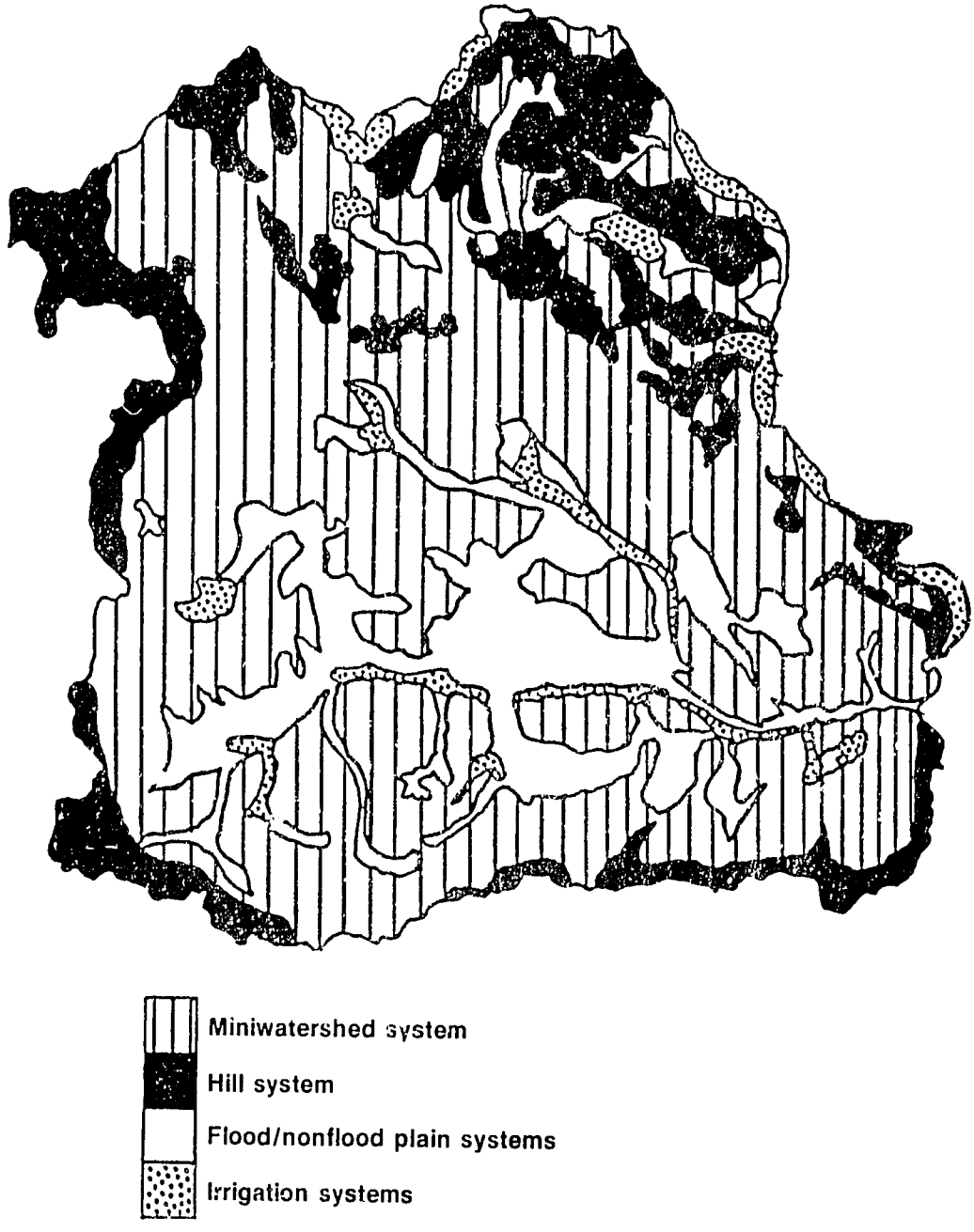
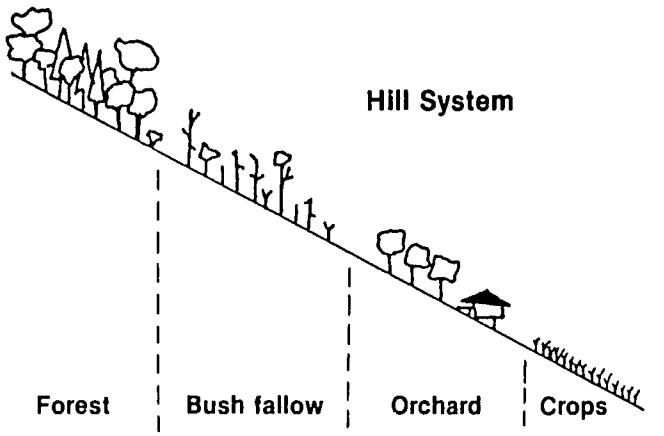
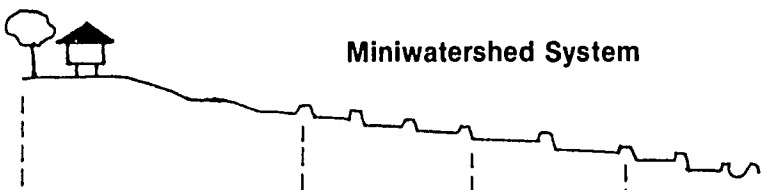


Figure 4. Major Agroecosystems of Northeast Thailand (After KKU, 1982; USAID, 1978).



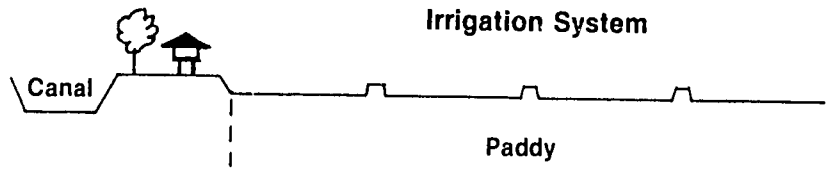
	Forest	Bush fallow	Orchard	Crops
Soils	Paleustults (loamy, fine-clayey), Haplustalfs			
Crops	Gathering, firewood, hunting	Upland rice, cassava, maize	Mango, jackfruit, custard apple	Maize, cassava, mung bean, sorghum
Problems	Diminishing area	Shorter fallows, weeds, erosion	Marketing, prices	Drought, weeds, soil erosion, prices
Location	Western and southern hills and the Phu Phan mountains.			



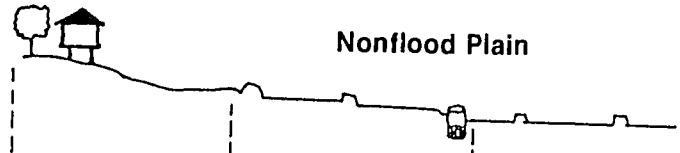
	Upland		Upper Paddy	Middle Paddy	Lower Paddy
Soils		Paleustult	Paleustult/ Paleaquult	Paleaquult	Paleaquult
Crops	Vegetable gardens, mulberry	Cassava, kenaf, sugarcane, watermelon	Rice (short-duration)	Rice (long-duration)	Rice (long-duration)
Problems		Low O.M. content, selective-erosion, marketing	Insufficient water, weeds, drought	Low soil fertility	Low soil fertility, occasional flooding
Location	Throughout the Northeast in areas between the hills and the flood and nonflood plains				

Figure 5. Characteristics of the Major Agroecosystems of Northeast Thailand.

Figure 5. (Continued)



Soils	Paleaquult
Crops	Rice, rice-rice, rice-peanut/corn/vegetables
Problems	Irregular water supplies, salinity, marketing
Locations	Throughout the region in limited area



	Upland	Upper Paddy	Lower Paddy
Soils	Paleustult	Paleaquult or Dystropept	Paleaquult or Dystropept
Crops	Cassava, kenaf, sugarcane, peanut	Rice followed by peanut/tobacco, sesame-rice	Long-duration rice, kenaf-rice-water-melon
Problems	Low soil fertility, marketing	Drought, low soil fertility	Salinity, water-logging of upland crops, marketing
Locations	Throughout the Korat Triangle but predominate in the southern parts of Maha Sarakham, Roi Et and Yasothon and the northern parts of Srisaket, Surin and Buriram.		

	Upland	Paddy
Soils	Ustifluvents	Paleaquults, Dystropepts or Tropaquepts
Crops	Vegetables, fruit trees, mulberry	Long-duration rice, rice-vegetables
Problems	Marketing, limited area	Flooding
Locations	Areas along the Chi, Mun and Songkram Rivers	

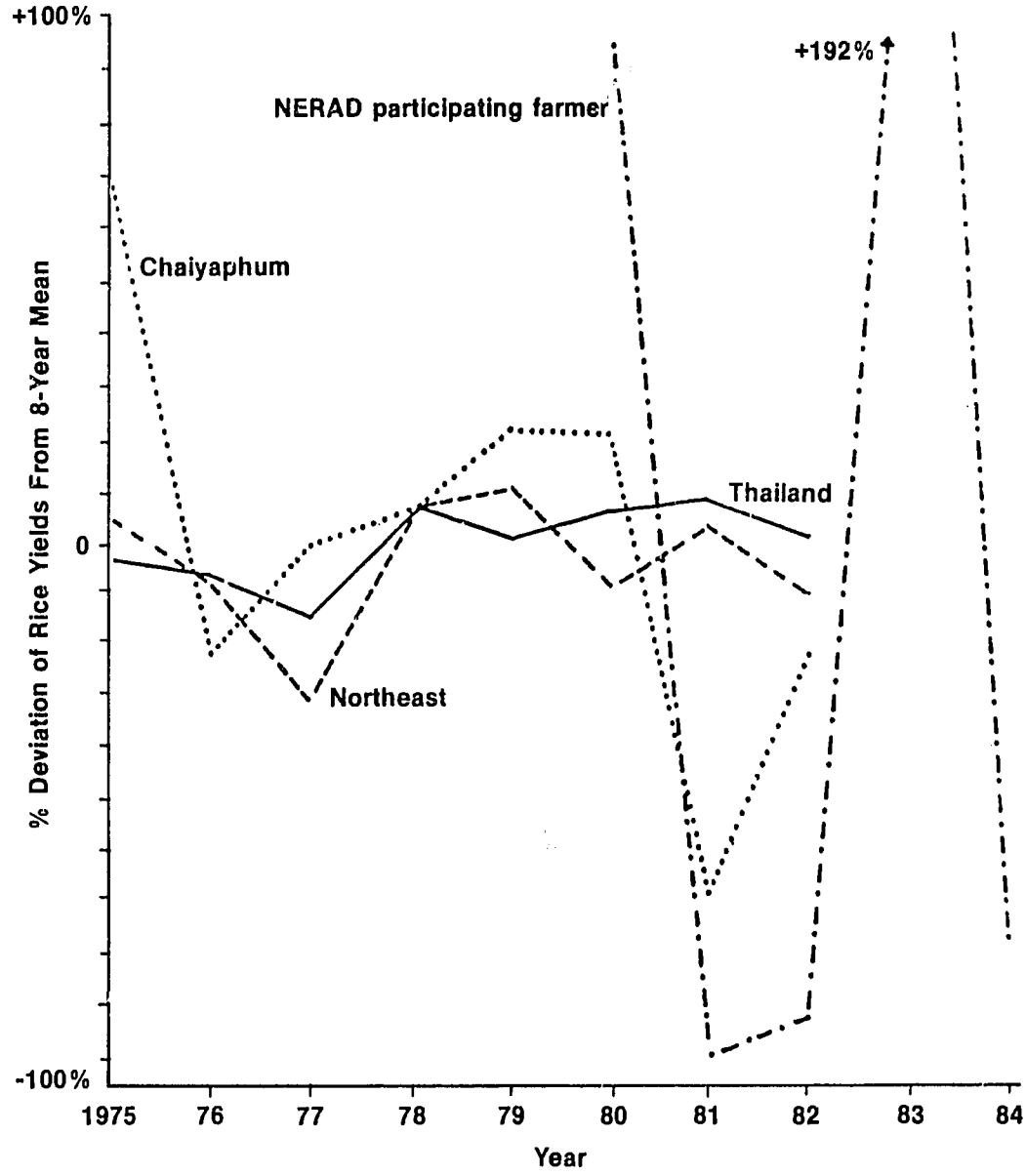


Figure 6. Percent Deviation of Rice Yields From an Eight-Year Mean.

buffering within the region: droughts in one place are compensated by high rain elsewhere; high rainfall reduces yields in the flood plain through flooding but increases yields through better water control in the nonflood plain or miniwatershed systems, etc. Individual farmers still have to cope with the variability, however, and they have developed various strategies for coping with risk. In rice, for instance, they use photosensitive rice varieties so that planting date can be adjusted depending on the availability of sufficient water; they keep a number of years' rice supply in their barns to carry them over years of low production and they use minimal purchased inputs to reduce risk in drought or flood years when they may lose the entire crop.

In cash crops, a further factor of market risk is also introduced. The farmers respond similarly with minimal inputs in these crops; they choose export crops which have more stable prices and plant crops with flexible marketing schedules such as cassava or kenaf which can be left in the ground until prices improve, or choose storable crops such as rice and maize which can be sold when prices are higher.

The inherent instability has a number of important implications for technology design and transfer. First, rice is the key to agricultural development in the region; if rice yields can be stabilized and improved, this will remove many of the constraints currently facing farmers in the Northeast. Second, overemphasis on productivity and insufficient attention to the stability properties of new technologies have led to low adoption rates in the past. Finally, many of the current cropping systems are exploitive in nature and are degrading the production resource base. In the future, if agricultural production is to continue to expand, and the natural resource base of the region is to be maintained or improved, then yields per hectare must be increased. This will not be achieved in the initial phases, however, by dramatic increases in purchased inputs. Rather, attention must focus on low-cost improvements in water control such as small weirs, shallow wells and better leveled paddies, and on low-input systems of soil improvement such as green manuring, liming and more efficient use of animal manure and compost, that the poor subsistence farmers can afford.

Conclusion

The problems facing Northeastern farmers are severe but not unsolvable. However, solutions will come only through a joint effort between research, extension and the farmer. The latter should be considered an active partner in the development process in order that his real needs, the constraints facing him, and the wealth of local knowledge that he has to offer are incorporated into the design of new technology. In conclusion, the problems that need to be addressed, some of which will be considered by this workshop, are as follows:

1) Rapid deforestation
2) Limited opportunity for irrigation: five percent at present; 20 percent maximum
3) Problem soils: Low O.M. and nutrients, acidity, salinity, low water holding capacity
4) Irregular rainfall: drought/flooding
5) Farmers' lack of cash for purchased inputs
6) Farmers' unstable subsistence rice production
7) Low and unstable market prices
8) Lack of area-specific farming system recommendations
9) Poor links between farmer, research and extension.

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Section II
Agroclimatology and Cropping Systems

Agroclimatology in Northeast Thailand

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ABSTRACT. The important factors limiting crop yields in Northeast Thailand are the poor quality soils and erratic rainfall. Soils are sandy with a low moisture holding capacity; they are also of low fertility. The climate is classified as tropical savanna. There are three recognizable seasons, the rainy season with annual rainfall ranging from 1100 to 2300 mm, winter with average temperature of 22° to 25°C and summer with average temperature of 28° to 30°C.

Farming in the Northeast is crop-based; the main crops are rice and a variety of upland crops. Of the 200,000 km² in the region, 54,000 km² are planted to rice and 14,000 km² to upland crops. Vegetables cover 640 km² and fruit trees are planted on 320 km². The remainder of the cultivated land is under grassland pasture or left idle. The success of introducing new cropping patterns such as peanut after rice or sesame before rice is closely dependent upon planning based on a more detailed knowledge of variation in local rainfall.

Introduction

Northeast Thailand is the largest region of the country and covers an area of 200,000 km². Its population is about 17 million which is one-third of the national total. Per capita income of the Northeasterner is about 40 percent of the national average, ranking the lowest among those of the four regions. This can be attributed largely to low agricultural productivity. There are several constraints on farming in the area, but the most important factors are erratic rainfall and the lack of irrigation facilities (KKU-Ford Cropping Systems Project, 1982). At present, over 90 percent of the cultivated land depends entirely upon the monsoonal and cyclonic rains because of inadequate irrigation. Although the amount of rainfall is not as low as that of the semiarid and arid zones, its inconsistency makes it less useful to agricultural development. Either dry spells or flooding generally occur as a result of rainfall irregularity. Since fertile land has become less available due to the high rate of population growth, both the good lands and those which are of marginal quality must be utilized to their full potential. This can be done by increasing the cropping cycles of plants grown on the good quality lands or selecting proper crops to be grown on the marginal lands. This approach requires careful planning to establish a proper cropping pattern suitable for each location in the region. Detailed information on the amount and distribution of annual local rainfall is essential for the development of such a plan.

Location

The Northeast is located between latitude 14° and 18°N and longitude 100° and 106°E (Figure 1). The average elevation ranges from 200 to 300 m above sea level (Meteorology Dept., 1977). It is bordered by a 400 m mountain range to the south, and a 1300 m mountain range in the west; the Mekong River provides the border with Laos in the north and east. Hills in the south define the boundary between Northeast Thailand and Kampuchea (Figure 2).

Topography

The Northeast region consists mostly of undulating plain and plateaus tilted slightly toward the northeastern corner. Rugged hilly areas are also present along the southern and western boundaries of the region, as well as south of Udon Thani and Sakon Nakhon. The Chi and Mun are the two main rivers providing an outlet for four-fifths of the monsoon runoff of the region. The rivers join near the Kampuchean border and flow into the Mekong River.

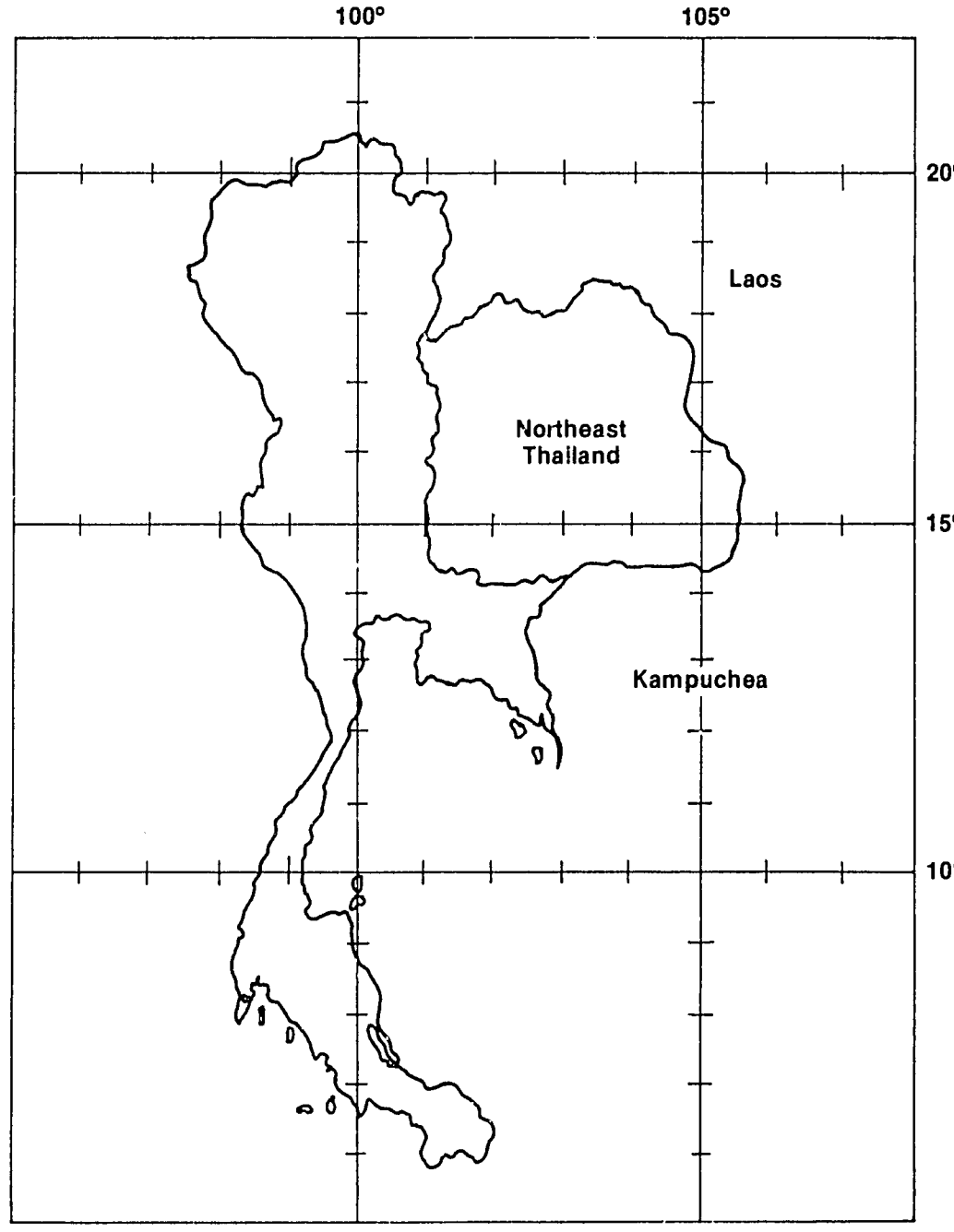

Figure 1. Map of Thailand Showing the Northeast Region.

Geology and Soils

The Northeast region is a high plateau, known as the Korat Plateau. Geologically, the plateau is comprised of sandstone and shale strata overlain in the valley depressions by alluvial and river terrace deposits. Sandstone forms the upper strata and is highly pervious (KKU-Ford Cropping Systems Project, 1982).

Keeratikasikorn (1984) reported that the soils of the region originated from two types of parent material: 1) transported and 2) residual parent material (colluvium).

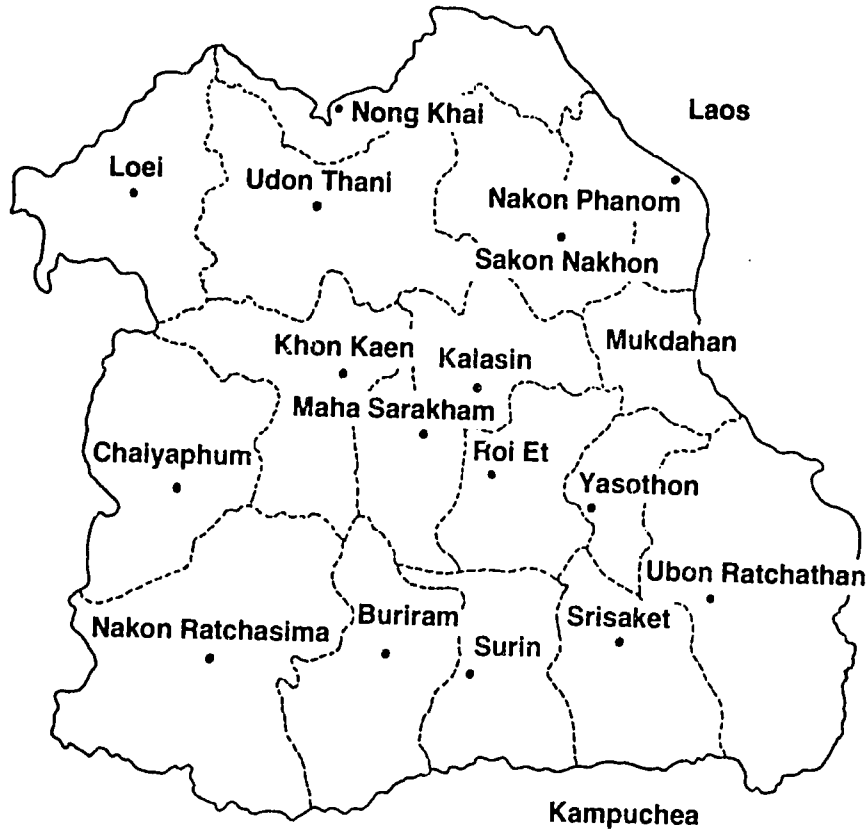

Figure 2. The Northeast Region Showing Changwat (Provincial) Boundaries.

Soils derived from the transported parent material are found in the lower areas of the plateau. These are:

1) Flood plain soils (brown colored soils)
2) Lower terrace soils (brown colored soils)
3) Middle terrace soils (brown and yellow colored soils).

Soils derived from residual parent materials are found in the high terrace and/or the hills. They are mostly red or red-brown in color with good drainage capacity.

The soils found in the Northeast region belong to 22 great soil groups and eight orders (Figure 3).

Climate

The climate of Northeast Thailand is classified according to Koppen's climatic classification (Griffiths, 1978) as tropical savanna. There are three recognizable seasons, namely, the rainy season, winter (or cool season) and summer (Meteorology Dept., 1977). These three seasons are influenced by the southwest and northeast monsoons.

The rainy season extends from May to October. The pattern of rainfall is double-bell shaped or bimodal with the first peak in the period from May to June, and the second peak from July to October. The early season (May to June) rains derive mainly from the southwest monsoon. Total rainfall received in this period is actually less than that obtained during the second phase (July to October). Rains received during this phase are derived

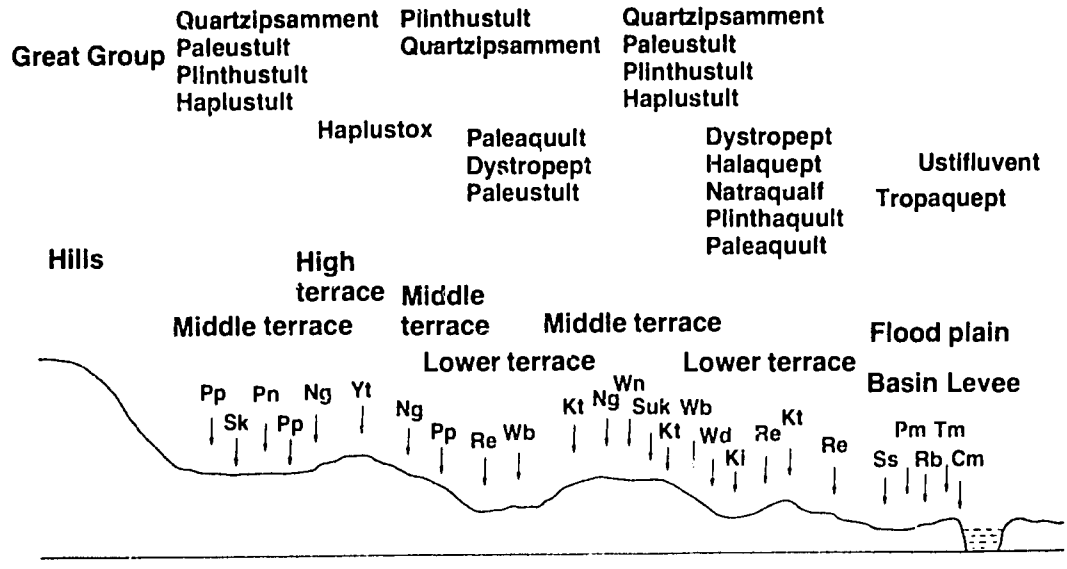

Figure 3. Physiographic Cross-Section and Soil Series of Northeast Thailand (Modified from Keeratikasikorn, 1984).

from the southwest monsoon and cyclonic rain from the South China Sea. Rainfall during the second period is more frequent and heavier than during the first phase. Cyclonic rains occur three to four times annually and annual rainfall is usually determined by the frequency of the cyclonic rains. The average monthly rainfall over 30 years (1951-1980) in each province of the Northeast region (Meteorology Dept., 1982) is given in Table 1. Nakon Ratchasima receives the least, 1100 mm, whereas Nakon Phanom ranks highest, receiving 2300 mm annually.

The region can be divided into three distinct zones according to the average amount of rainfall received annually (Figure 4):

1) Areas receiving more than 1400 mm, i.e., areas located in the northern and eastern parts of the region.

2) Areas receiving less than 1200 mm, i.e., the western band.

3) Areas receiving between 1200 and 1400 mm, i.e., areas between zones 1 and 2.

The winter or cool season extends from November to February. The weather during this period is generally dry and cool and attributed to the northeast monsoon. The monthly means of relative humidity and air temperature of 30 years (1951-1980) in the Northeast provinces are given in Tables 2 and 3, respectively. Average relative humidity during this period is generally low ranging from about 58 percent in Chaiyaphum to 70 percent in Nakon Phanom. The average air temperature is within the range of about 22 °C in Loei to 25 °C in Surin. During this period, frontal rain may occur but contributes relatively little to the total annual rainfall.

The summer extends from March to mid-May. Early in the season, the weather is dry and warm with occasional showers. The average relative humidity ranges from about 62 percent at Chaiyaphum to 71 percent at Nakon Phanom. The temperature gradually increases and reaches a peak in late April. The average summer temperature ranges from 28 °C in Loei to about 30 °C in Chaiyaphum. The intensity and frequency of the rainfall increases with time due to the onset of the southwest monsoon.

Table 1. Monthly Mean Rainfall (mm) of the Provinces in the Northeast for the Period 1951-1980 (Modified from Meteorology Dept., 1982).

Province	Month												Total†
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	mm												
Nong Khai	6	9	28	97	250	290	250	330	300	51	8	4	1600
Loei	6	16	47	88	200	170	160	190	250	95	12	4	1200
Udon Thani	7	20	39	80	220	240	230	290	280	80	7	3	1500
Nakon Phanom	7	19	44	100	240	480	420	590	320	52	5	1	2300
Sakon Nakhon	7	16	42	85	230	260	210	320	260	62	6	2	1500
Khon Kaen	8	15	34	63	170	180	160	190	280	86	14	3	1200
Roi Et	3	15	29	89	190	190	210	260	320	88	9	1	1400
Ubon Ratchathani	1	8	43	79	210	250	280	320	280	92	20	2	1600
Surin	2	9	28	88	180	160	190	200	280	130	22	2	1300
Nakon Ratchasima	4	23	55	70	160	120	130	130	260	160	30	3	1100
Chaiyaphum	4	18	51	84	160	150	150	150	310	120	16	4	1200

† Totals may not be precise due to rounding.

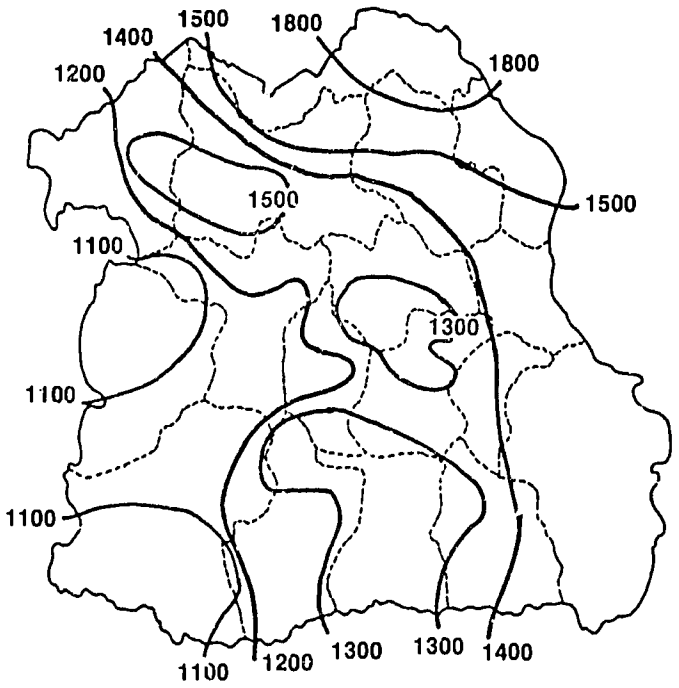

Figure 4. Isohyets for Annual Rainfall (After KKU-Ford Cropping Systems Project, 1982).

Agriculture in the Northeast Thailand

Farming in the Northeast is traditionally crop-based. The main crops are rice and a variety of upland crops. The total area of this region is 200,000 km^2 of which 54,000 km^2 is normally sown to rice and 14,000 km^2 to upland field crops. Vegetable production consists of 640 km^2 and fruit trees are planted on 320 km^2. The remainder of the agricultural land is under grassland pasture or left idle (KKU-Ford Cropping Systems Project, 1982).

Rice in the Northeast is grown mainly for subsistence purposes; only the surplus is left for sale. The highest proportion of cultivated land under rice paddy is found in the eastern provinces on the flood plain along the Mekong River, and in the central and southeastern provinces of Roi Et, Yasothon, Surin and Srisaket (i.e., on the plain along the lower terrace of the Chi and Mun Rivers). The size of the rice planting area, its yield and the total production are the three main factors determining the income level of people in the region. Consequently, those who live in the north and eastern provinces where the annual mean rainfall exceeds 1400 mm seem to have the most stable income. The least stable incomes are found among people who live in the western hilly provinces where the rainfall is less than 1200 mm annually. This region has more than 100 rain-free days in the period from May to October. The proportion of paddy land actually planted in any year depends on the occurrence of drought conditions early in the season, whereas yield is primarily a function of the later rainfall pattern (KKU-Ford Cropping Systems Project, 1982).

Field crops are the most important source of cash income for the Northeast farmers. Most of the area suitable for field crops is in the western provinces where the land is very undulating or mountainous. The mean annual rainfall is less than 1200 mm in this area and is, therefore, more suitable for upland field crops than for paddy. In the central area of the Northeast, 10 to 20 percent of the cultivated land is suitable for field cropping. This area has a gently undulating topography. Paddy rice is normally grown in the depressions and field crops on the higher areas. To the east there are only small areas sown to field crops.

Table 2. Monthly Mean Relative Humidity (%) of the Provinces in the Northeast for the Period 1951-1980 (Modified from Meteorology Dept., 1982).

Province	Month												Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	%												
Nong Khai	67	64	63	68	78	82	83	85	83	76	70	67	74
Loei	65	61	59	64	75	78	78	80	83	79	74	70	72
Udon Thani	69	66	63	66	77	80	80	83	83	77	72	70	74
Nakon Phanom	69	68	66	69	79	85	86	88	85	77	72	71	76
Sakon Nakhon	64	63	62	65	77	80	80	82	82	74	69	67	72
Mukdahan	64	62	60	63	73	79	79	82	82	74	69	67	71
Khon Kaen	63	62	60	63	72	76	77	80	82	76	70	66	70
Roi Et	65	63	62	65	74	78	78	81	83	74	72	68	72
Ubon Ratchathani	66	64	63	67	76	80	81	83	83	77	72	69	73
Surin	65	62	62	66	75	79	80	82	84	80	75	69	73
Nakon Ratchasima	67	65	65	68	76	76	77	78	83	81	76	69	73
Chaiyaphum	55	54	55	60	70	73	75	77	80	72	63	58	66

Table 3. Monthly Mean Air Temperature (°C) of the Provinces in the Northeast for the Period 1951-1980 (Modified from Meteorology Dept., 1982).

Province	Month												Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	°C												
Nong Khai	22	24	28	29	28	28	28	27	27	27	24	22	26
Loei	22	24	27	29	28	28	28	27	26	26	24	22	26
Udon Thani	22	24	27	29	28	28	28	27	27	26	24	22	26
Nakon Phanom	22	24	27	29	28	28	27	27	27	26	24	22	26
Sakon Nakhon	22	25	28	29	29	28	28	27	27	27	25	23	26
Mukdahan	23	25	28	30	29	28	28	27	27	27	25	23	27
Khon Kaen	23	26	29	30	29	29	28	28	27	27	25	23	27
Roi Et	24	26	29	30	29	29	28	28	27	27	25	23	27
Ubon Ratchathani	24	26	29	30	29	28	28	27	27	27	25	24	27
Surin	24	27	29	30	29	28	28	28	27	27	25	24	27
Nakon Ratchasima	23	26	28	29	28	28	28	27	26	26	24	22	26
Chaiyaphum	24	27	29	30	30	29	28	28	27	27	26	24	27

Cassava, kenaf and corn are the most important field crops, sharing about 95 percent of the uplands. Cassava and kenaf are planted throughout the west and in the central area, while corn is more limited to the three provinces of Nakon Ratchasima, Loei and Srisaket. Sugarcane is rapidly replacing kenaf and cassava in those areas having adequate moisture in the dry season. Small acreages of peanuts, cotton, castor bean, sesame, soybean and mung bean are planted in some areas (KKU-Ford Cropping Systems Project, 1982).

Information on the variation of local rainfall can be used for planning cropping cycles and cultural practices. This is illustrated by the rainfall data from Khon Koen and Surin Provinces. These two locations are in somewhat different agroecological zones. Surin has a mean annual rainfall of 1300 mm, which is slightly higher than 1200 mm for Khon Kaen. Annual rainfall for both locations also has a bimodal distribution.

Due to the differences in agroecological conditions, farmers in Khon Kaen and Surin provinces have different types of cropping systems. Khon Kaen farmers grow only paddy rice in the lower areas and kenaf, cassava, or sugarcane in the upland areas as a main crop. In contrast, in certain areas of Surin, farmers practice rainfed double cropping, i.e., they do not only grow rice during the middle of the rainy season but also grow short-duration field crops, either before or after rice and on the same fields. By doing this, they can fully utilize the off-season rain and dry season soil moisture. In the uplands of Surin, peanuts are planted after the early maturing rice or kenaf is harvested. The peanut is planted at the end of rainy season without irrigation. According to the farmers, the late and early rains affect the performance of dry season peanut differently. Off-season rains in late November and December make the soil surface more compact and, therefore, obstruct peg penetration and pod formation, resulting in decreased yields. On the other hand, early rains in February and March markedly increase peanut yield as the rains provide ample moisture during the final pod filling stage. Similarly, in some provinces such as Burirum, farmers grow sesame before rice transplanting. Turkish tobacco is grown after rice in Roi Et.

In order to successfully transfer cropping system technologies from one place to another, the rainfall probability must correspond with the critical growth stages of the introduced crop in that particular location. When growing peanut after rice, crop performance can be expected to be satisfactory in those locations with a chance of receiving little or no rain in late November and December, but with sufficient rain in February and March. However, for peanut, Jintrawet *et al.* (1983) reported that rainfall may not be the only factor influencing the performance of dry season plantings. The results from three years of studies on peanut growth and development in Surin indicate that the level of the subsurface watertable in the postrainy season is also a critical factor affecting peanut growth. High watertable levels can adversely affect the growth of this crop. By checking the level of the subsurface watertable, a suitable area for dry season peanut planting can be located. The final yield, however, will depend almost entirely on the rainfall pattern.

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Recent Advances in Agroclimatological Research in the Semiarid Tropics

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ABSTRACT. The climate of the Northeast region of Thailand is semiarid tropical. It is characterized by high temperatures, low and variable rainfall, and a relatively short growing period. In this region the rainy season ranges from 2 to 4-1/2 months; consequently, the crop growing season lasts from about 70 to 150 days.

The goal of the dryland agricultural research program in Thailand is to evolve techniques for increasing and stabilizing crop production by increasing the rainfall utilization efficiency. The introduction of new cropping systems and soil and water management techniques is envisioned.

A complete and agronomically relevant knowledge of climate is essential for developing strategies for improved dryland agriculture. This includes information on the time and amount of rainfall. An evaluation of the probability of rainfall and soil moisture availability could help define the periods of moisture sufficiency and stress during the crop growing period. The amount of runoff water available for recycling should be estimated. Through proper application of agroclimatological knowledge, an agroecological assessment of selected areas for crop production could be made. Such knowledge would accelerate the process of technology development for rainfed crop production.

Khon Kaen and Chiang Mai Universities have taken a keen interest in the quantification of the climatic environment. Computer programs for Markov chain probability, incomplete Gamma distribution, soil moisture balance and crop weather modeling are available in both of these universities. Khon Kaen University has gone ahead with the analysis of rainfall data of the Northeast region and a publication on the subject is expected shortly.

Introduction

The Semiarid Tropics (SAT) are those regions of the world which are geographically situated 23-1/2° north and south of the equator. These areas have mean annual temperatures which exceed 18°C. They are characterized by seasonal rainfall which may extend from 2 to 4-1/2 months in the drier parts of the SAT and 4-1/2 to 7 months in the somewhat wetter parts. Most of Northeast Thailand has a dry semiarid tropical climate. The annual temperature exceeds 33°C and the main rainy season lasts from June to September. Additionally, some rains are received in May and October.

Although there is a more or less well-defined rainy season in the SAT, the amount of rainfall received and its frequency are highly variable. The coefficient of variability of annual rainfall ranges from 20 to 30 percent. In practical terms this means that at a location receiving an annual average rainfall of 780 mm (e.g., Hyderabad, India), the amount of seasonal rainfall could vary between 400 and 1400 mm. The number of rainy days each year also varies considerably. Thus, in the SAT the moisture environment for crop production can be highly variable. There are periods of excessive rainfall interspersed with periods of unpredictable droughts which often adversely affect the growth and yield of crops.

At the International Crops Research Institute for the Semiarid Tropics (ICRISAT) considerable thought has been given to the question of quantification of the moisture environment of the semiarid tropics in relation to crop water requirements. Much work has been done on the assessment of soil moisture adequacy for crop growth, the pattern of rainfall, and the length and variability of the crop growing season. In this paper some examples of our recent work relevant to Northeast Thailand are discussed.

Estimation of Moisture Adequacy for Crop Production

Estimating moisture adequacy for crops is the first step in the characterization and assessment of a given area for dryland crop production. There are two methods that are generally used. For areas where the available rainfall records exceed 30 or 40 years, it is useful to follow the Hargreaves Moisture Availability Index method (Hargreaves, 1971). It involves estimation of the probabilities of monthly rainfall using incomplete Gamma statistics. The amount of rainfall expected at 75 percent probability is calculated. This is referred to as dependable precipitation or DP. The moisture availability index (MAI) is then assessed as follows:

$$MAI = DP/PE,$$

where PE is the average potential evapotranspiration.

For cases where long-term rainfall records are not available, or where computer facilities are not readily accessible, it is convenient to use the method of Troll (1965) to evaluate moisture adequacy. In this case, a month is designated as a humid month if the amount of rainfall received during the month is adequate for crop production. MAIs calculated by the methods of Hargreaves and Troll for two locations in Niger, West Africa are shown in Table 1. The locations, Maradi and Niamey, are 600 km apart but at approximately the same longitude. The average rainfall at Maradi is slightly higher than at Niamey, but the potential evapotranspiration is somewhat lower. The data period for estimating DP, PE, and MAI for Niamey was 1943 to 1974, and for Maradi 1931 to 1974.

The data (Table 1) shows that July and August are humid months at each location and constitute the core growing season for both locations. The Hargreaves MAI values range between 0.21 and 1.16 for Niamey, and 0.18 and 1.56 for Maradi, respectively. According to Hargreaves (1975), if the value of this index is in excess of 0.34, the moisture supply for the month is adequate for crop growth. Accordingly, both of these locations show moisture adequacy for dryland crop production for the months of July, August and September. According to Hargreaves' classification, the area is semiarid and is suitable for growing crops requiring about three to four months to mature.

It is useful to determine MAIs for a large number of locations in a geographic area when delineating zones of varying moisture adequacy and assessing their suitability for growing crops of different durations. MAI related information could also be used for evaluating differences in climatic moisture balance in various months. For example, data in Table 1 show that at both locations, August has the most favorable moisture balance compared to other months. The results could also be used for interlocation comparisons. The MAI data for Maradi show higher values for all three rainy months than for Niamey (Table 1). This means that, on the average, the moisture environment for growing a 90- to 110-day crop at Maradi is superior relative to Niamey.

Pattern of Rainfall

Markov's chain analytic techniques have been used to estimate rainfall probabilities. A plot of initial and conditional rainfall probabilities, $R/PE \geqslant 0.33$, is shown in Figure 1 for Hyderabad, India. It is assumed that a probability level of 70 percent signifies an acceptable level of risk for dependable dryland production. Figure 1 shows:

(a) that the probability of occurrence of rainfall increases to above 70 percent in week No. 25 (18-24 June) signifying the commencement of the cropping season;

(b) that the probabilities of rainfall exceed 70 percent for a period of about six weeks after the beginning of the cropping season;

(c) that a midseason break in the continuity of rains occurs in the month of August during four to six years of a ten-year period; and finally,

(d) that the rains subside abruptly during week No. 39 (24-30 September).

Table 1. Actual Rainfall, Dependable Precipitation (DP), Potential Evapotranspiration (PE) and Moisture Availability Index at Niamey and Maradi, Niger.

Characteristic	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	..... mm												
Niamey (Lat. 13°29 'N, Long. 02°10 'E)													
Rainfall	0	0	0	0	26	77	159	201	101	15	0	0	580
DP	0	0	0	0	0	44	109	152	64	4	0	0	
PE	163	165	207	202	215	204	157	131	135	172	154	141	2046
MAI†	-	-	-	-		0.21	0.69	1.16	0.47	-	-	-	
Troll's Index‡	D	D	D	D	D	D	H	H	D	D	D	D	
Maradi (Lat. 13°28 'N, Long. 07°25 'E)													
Rainfall	0	0	0	4	32	60	164	260	110	12	0	0	642
DP	0	0	0	0	9	33	126	193	62	0	0	0	
PE	119	126	153	168	189	179	143	123	134	131	125	115	1704
MAI	-	-	-	-	-	0.18	0.88	1.56	0.46		-	-	
Troll's Index	D	D	D	D	D	D	H	H	D	D	D	D	

† Moisture Availability Index after Hargreaves (1971).
‡ Troll index of moisture adequacy. D-Dry month, in which average rainfall is less than the average PE; H-Humid month, in which average rainfall exceeds PE.

In summary, the probability data for Hyderabad exhibit a seasonality of rainfall. The rainy season occurs from 18 June through 30 September with a fair chance of a midseason break in August and the rainfall in July and September is relatively more dependable. This information could be used for developing improved crop calendars and for the introduction and transfer of improved dryland agriculture technologies.

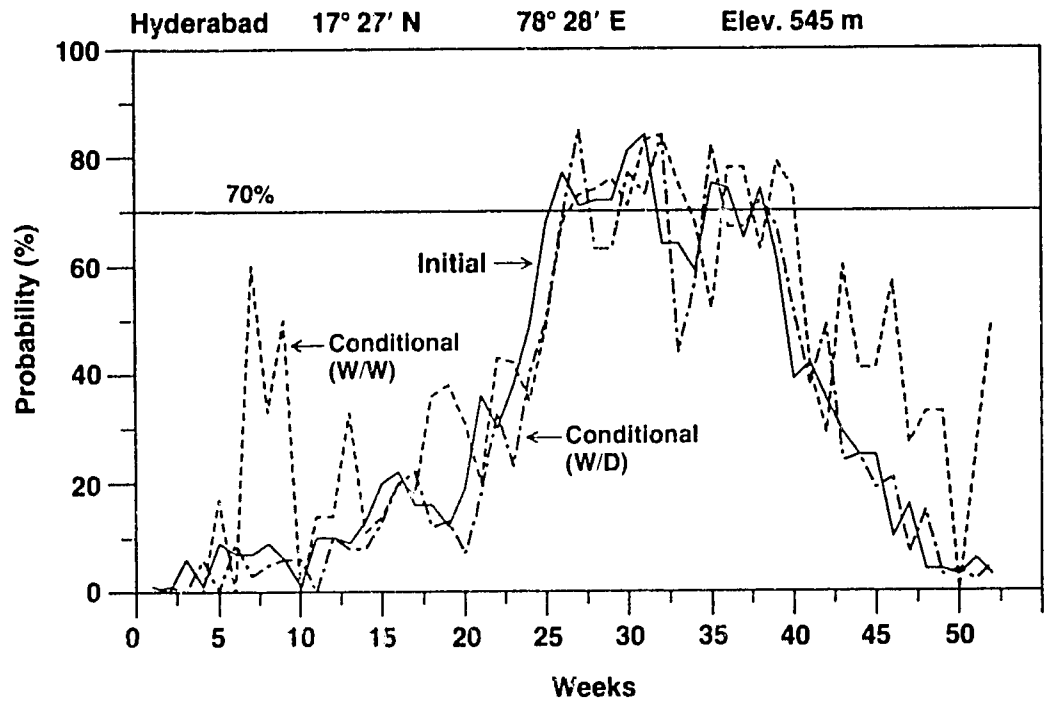

Figure 1. Initial and Conditional Rainfall Probabilities of R/PE ≥ 0.33 at Hyderabad, India (After Virmani *et al.*, 1982).

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Soil and Water Management in a Farming Systems Project

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ABSTRACT. The Northeast region of Thailand shares many of the soil and water constraints found in other semiarid countries. However, the configuration of these constraints, in relation to the biological and socioeconomic environment in which rainfed farmers make a living, is considerably different. The institutional setting from which technological solutions to these constraints arise is also unique. The Northeast Rainfed Agricultural Development (NERAD) Project is one such response. It uses the Farming Systems Research and Extension (FSRE) approach as a framework for interdisciplinary assessment, design and implementation of activities to increase the productivity and income of poor, subsistence-type rainfed farmers. This is accomplished by alleviation of their constraints, among which are soil and water constraints. Many project activities are undertaken as a collaborative effort among farmers, researchers and extension agents. NERAD has found that these constraints can only be removed and productivity increased when farmers are involved in the technology development process. Researchers must have a clear understanding of farmers' resources, cognitive processes and preferences when developing technology to alleviate soil and water constraints. Research methodologies must also be appropriate for Thai institutions to carry out their missions with the human and financial resources available. The resulting technology will only be worthwhile if it can assist the farmer in obtaining better control of his soil and water resources and, consequently, achieving greater productivity and well-being, especially from his own point of view.

Introduction

The Northeast region of Thailand experiences many of the constraints to soil and water management and improved agricultural productivity found in other countries represented here today. The configuration of these constraints in relation to the biological and socioeconomic milieu in which rainfed farmers make a living, however, is considerably different. Likewise, the institutional setting through which the Royal Thai Government (RTG) or, more specifically, the Ministry of Agriculture and Cooperatives (MOAC) develops and delivers technology to respond to these constraints is unique. The purpose of this paper is to share some of the experiences of one project in Northeast Thailand which is making an effort to respond to the problems and needs of rainfed farmers who are confronted with serious soil and water constraints limiting agricultural productivity.

Some of the main soil and water constraints confronted by Northeastern rainfed farmers are:

Water In some years all the following occur:

- highly erratic rainfall patterns
- drought during the rainy season
- flooding.

Soil The following contribute to infertility of the soil:

- low organic matter
- low nutrient levels
- acidity
- salinity.

NERAD: Northeast Rainfed Agricultural Development Project

The Northeast region of Thailand has among the poorest soils in Southeast Asia and highly erratic rainfall patterns. Under optimum conditions, less than 20 percent of the arable land can potentially be irrigated by conventional medium- or large-scale irrigation projects. Thus, it is no surprise that the majority of the farmers in the Northeast are subsistence oriented, rainfed rice farmers—the poorest in the Kingdom. Their farming systems include: some field or vegetable crops in a fraction of paddy land before and/or after rice production; upland fields planted to cassava or kenaf; two or three head of cattle and buffalo along with a few chickens; fishing and hunting/gathering activities which supplement diets and lifestyles; some cottage industry; and off-farm employment. To address these conditions most of the technology developed by the national agricultural programs of MOAC have either been commodity or discipline oriented under the relatively protected conditions of the departmental experiment stations. In this technology development process the linkages between research and extension have also been very tenuous.

The Northeast Rainfed Agricultural Development (NERAD) Project is an effort by MOAC to begin to address this gap in the development and delivery of technology to Northeast rainfed subsistence farmers. The purpose of the Project, as stated in the Loan and Grant Agreements, is "to develop in eight representative tambons a replicable agricultural development program for increasing farm production and income, particularly among lower income farmers in the rainfed agricultural zones." The Project will establish adaptive agricultural research and extension programs which are readily accessible and responsive to the needs of poor farmers.

There are five interrelated themes for implementing the Project:

1) Integration: among and within research and extension programs.

2) Technology development: a collaborative effort between farmers, researchers and extension agents to adapt technology through on-farm trials and demonstrations—the FSRE approach in NERAD.

3) Implementation: a plan to build on lessons learned rather than a blueprint in order to allow the flexibility to respond in a timely manner to farmers' needs.

4) Top-down/bottom-up interaction: the process of articulating rainfed farmers' problems and needs by means of the tambon planning process and matching MOAC's technology and resources to those needs.

5) Institutional development: enhancing the capacity of the participating MOAC departments to deliver more effective agricultural research and extension services.

In the NERAD strategy, the five themes focus on two points for development:

- Farmers' capacity, both as individuals and as members of the community, to confidently and effectively manage their resources. This process begins with tambon planning and extends through the implementation of the various activities.

- MOAC departments' capacity to develop problem-solving, adaptive research and extension programs, and to develop and deliver appropriate and relevant technologies which are responsive to rainfed farmers' needs and are readily accessible to the farmers.

Farming Systems Research and Extension Approach

The Farming Systems Research and Extension (FSRE) approach is used in NERAD to link the agricultural research and extension services to the needs of the farm/village system. FSRE attributes a central role to the farmer, his problems, needs and resources. Farmers seek self-reliance. From their perspective, their understanding of the environment and resources have resulted in reasonable choices of farming activities and practices. Farmers

will alter this mix of activities only when they see that technical innovations have significant advantages over the practices which are to be replaced. They make these decisions within the context of their overall family/farm/village resources and their other on- and off-farm opportunities. Technical innovations are more likely to be adopted by these peasant farmers when they are mixed and matched in step-wise fashion rather than in packages. To build understanding, farmer participation in technology development is encouraged through on-farm trials and demonstrations. Any resulting innovations will be more attractive to other farmers, thus facilitating their possible later adoption.

This integrated FSRE approach requires concerted, coordinated interdisciplinary efforts to help solve the farmer's problems. This reflects the perspective of the farmers who see their problems within the context of their whole farm system. A systems approach is required to help solve systems problems. This means examining physical, biological and socioeconomic interactions, a task for which no single discipline is fully adequate.

Another characteristic of the FSRE approach is the strengthening of linkages between research done on the experiment stations and extension. The technology generated by the various experiment stations is tested in a real farm setting in a collaborative effort among farmer, researcher and extension agents. Extension's active participation is essential in order to better understand and disseminate the new technology.

Finally, the FSRE approach complements and supplements the traditional disciplinary and commodity approaches of the departments. The technology used in FSRE usually is initiated in regular research programs. On-farm testing and feedback from a systems perspective are essential for a more effective technology development and delivery process.

Lessons Learned About Soil/Water Management

The lessons learned about specific technologies will not be discussed here. Those have been covered by Craig (1985) and Ragland (1985). Instead, the lessons here will refer more to techniques of how to approach the problem from the two perspectives mentioned above: the farm/village system and the government system.

NERAD's use of the FSRE approach as a framework to contribute to the solution of the Northeast rainfed farmer's problems is extremely useful in the area of soil and water management. NERAD is making an effort to improve MOAC's agricultural programs in adapting technologies to local conditions. Interdisciplinary methodologies, mechanisms and techniques have been generated and tested to better assess farmers' problems and needs and to marshal the proper resources for their solution.

Farm/Village System

It is almost trite to mention the importance of understanding the farmer's existing system of resource and technology use before we can begin to assist him with more productive, sustainable and equitable technological innovations. But many agricultural development programs, projects and activities are planned and implemented with only a cursory knowledge of the existing system. One mechanism which NERAD has used to increase this understanding is the Rapid Assessment Technique (RAT) Team. It is an interdisciplinary effort to better describe and analyze the farmer's existing cropping systems, his constraints and problems, and his decision-making processes.

From RAT and other experiences NERAD has learned some of the following items about the Northeast rainfed farmer's current circumstances:

The farmer's soil and water constraints are only a subset of his total constraints, which include economic (e.g., policy, markets and credit), biological (e.g., varieties, pests and diseases) and social (e.g., inappropriate innovations and insensitive dissemination techniques) constraints;

- The farmer is an opportunity recognizing decision-maker, that is, reasonable but cautious in his learning and decision-making processes. This means that change is usually weighed carefully;
- The farmer is subsistence oriented, especially with rice production, meaning that his needs come first;
- The farmer is averse to risk in his decision-making, considering rainfall variability, uncertain markets, unsure (in his mind) new technologies, etc.; and
- Contrary to popular opinion, the opportunity costs for family labor on-farm are not zero, which also implies seasonal labor constraints for on-farm activities.

Northeast rainfed farmers have evolved strategies over time to cope with soil and water constraints. NERAD has tried to understand these strategies and build upon them to assist the farmer in improving his well-being. Any proposed interventions must take into account all of the farmer's constraints, in addition to soil/water constraints, and the various attributes which characterize his cognitive (learning and decision-making) processes. Thus, any proposed technical solutions to these constraints are tested with the farmer as a partner, in order to elicit his input into the technology development process which will then hopefully facilitate ultimate dissemination of the final product to other rainfed farmers.

The following are some existing farmer strategies and project technological responses designed to alleviate soil/water constraints:

Constraints	Strategies	Technologies
Erratic rainfall	- Land preparation (Surin technique) - Short maturing upland varieties - Mixture of photoperiod sensitive varieties - Mulching of high value crops - Compensatory system	- Continued testing (Surin technique) - Continued testing with new varieties before and after - Testing planting dates - Shallow and modified shallow wells - Diversion weirs - Submerged dams
Drought	- Larger rice bunds - Drought resistant varieties - Off-farm employment	- Shallow and modified shallow wells - Diversion weirs - Land shaping - No tillage
Flood	- Flood tolerant rice varieties - Use of very marginal upland	- Diversion dikes - Improved upland use
Organic matter	- Limited composting - Prerice and postrice crops	- Extensive compost introduction - Green manuring (cowpeas and swordbeans)

Nutrient levels	- Limited fertilization - Prerice and postrice crops	- Fertility trials
Acidity	- Inundating paddies - Tolerant varieties - Animal manure	- Liming trials
Salinity	- Mildly tolerant varieties - Salt harvest - Water control	

The cropping systems technologies proposed by the Project are based on the farmers' existing systems. Researchers and extension agents examine the proposed changes together with farmers and arrive at a consensus on problem definition and possible solutions from both practical and technical perspectives. From the volunteers, participant farmers are then selected to undertake the ensuing cropping systems trials with researcher and extension collaboration. Cropping patterns and component technologies are tested and refined. Recently, these cropping technologies have been triaged, that is, sorted into those which need more on-farm testing; are presently inappropriate for farmers and need more experiment station testing; are ready to be demonstrated or disseminated by extension; and for which a search may be required to identify those technologies that are not presently released from experiment stations but seem to hold some potential for on-farm testing. Other technologies such as land shaping, shallow wells, submerged dams, etc., are tried and attempts are made to evaluate and improve upon them based on farmer feedback.

Government System

Perhaps the biggest challenge for an institution-building project is the marshalling of common understandings and resources among implementing agencies to attack the technical problems identified. This is especially difficult when multiple agencies are involved, as is the case with NERAD, which involves nine implementing departments. When a new perspective such as FSRE is taken, difficulties in implementation are only compounded.

NERAD has experienced institutional difficulties in undertaking on-farm testing of many of its proposed technologies to improve production. Some of these constraints to using a systems perspective, as it relates to soil, water and plant relationships, are: an understanding of farmers' existing systems, accessing proper personnel for field testing and socioeconomic analysis of proposed technologies. Since the systems perspective is relatively new in Thailand, the understanding of the farmer's indigenous knowledge and behavior is very narrowly viewed from a disciplinary or commodity perspective. Interdisciplinary research among physical, biological and social scientists is needed to better understand farmers' existing soil and water management practices before they can begin to suggest potential technologies for testing and adoption.

When the time comes for field testing, appropriate personnel are not readily available to assist in the trials. For example, there has been difficulty in getting qualified soil physicists and chemists since they were located within another subagency or in the capitol city. Hence, soil/water problems have not been adequately addressed.

Once technologies have been field tested there is too little analysis from a systems perspective. The physical and biological interactions of the tested technology are not only glossed over, but the socioeconomic interactions are almost completely overlooked. This is in part due to the personnel accessing problem previously mentioned, and in part due to questionable methodologies.

Summary and Conclusions

The real challenge in the alleviation of the soil and water constraints in the farmers' cropping systems in Northeast Thailand is to assist in the development of technologies which will allow farmers better control of their land (soil) and water resources for increased production and well-being. Interdisciplinary research methodologies are needed which take into account farmers' resources, knowledge bases and preferences when developing these technologies. These research methodologies must also be appropriate for Thai institutions to execute with the human and financial resources that are available.

Again, we can assist the farmer with better information and decision-making so he can control and manage his soil and water resources more effectively.

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Rainfall Analysis for Rainfed Cropping Systems in Northern Thailand

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ABSTRACT. Daily rainfall records at selected stations in Northern Thailand were analyzed to facilitate cropping systems research and development for rainfed agriculture. The variability of rainfall patterns reflects the differences in the dates of successful onset of rain for crop production. The dates marking the end of the growing season at different locations are affected both by rainfall characteristics at the end of monsoon and available soil water. Variations in the length of the potential growing season and dry season patterns at various locations suggest that different cropping patterns and management strategies must be considered for efficient use of soil and water resources in the Northern region.

Introduction

Research and development programs in rainfed areas must focus on developing technology that increases crop productivity while promoting the stability and sustainability of existing agricultural systems. To achieve this goal, the environments in which proposed programs will be implemented must be characterized prior to the design of cropping systems and management strategies that are in concert with both the physical and socioeconomic environments.

In the semiarid tropics, spatial and temporal variations of rainfall are common features that contribute greatly to variable and unstable crop production under rainfed conditions. Northern Thailand is no exception since a large percentage of the cultivated lands depend solely on rainfall as a source of water for crop production. The importance of rainfall analysis for characterizing the potentials and constraints related to soil management and crop production is widely recognized by researchers at international agricultural research centers, ranging from dry areas at ICARDA (Dennett *et al.*, 1983) and semiarid tropics at ICRISAT (Virmani *et al.*, 1978) to subhumid tropics at IRRI (Morris and Ruumbaoe, 1980). Earlier attempts have been made to utilize rainfall and climatic data for agroclimatological zoning in Thailand by estimating the monthly moisture available index (Panichapong and Hemsrichart, 1982). This technique is useful for characterizing physical resources for agricultural planning at the macro level. However, for planning of the sowing dates for crops at specific locations, the weekly or daily rainfall analyses would be more appropriate. This approach was used in the study described herein.

Data Management

Daily rainfall data for synoptic weather stations in Northern Thailand provided by the Meteorological Department were reorganized and stored on 5-1/4-inch diskettes for use with a microcomputer running on a CP/M-80 operating system. They can be easily updated in the future when more data are available. The sites of these stations are shown in Figure 1.

Rainfall Analysis

Three characteristics related to rainfall, namely, the duration of the dry period, dates at which rain began and the end of the growing season, were analyzed, and the growing season was estimated using the technique of Stern *et al.* (1982) with a slight modification to suit the conditions of Northern Thailand.

Start of Rain

For analysis of the start of rain, the threshold value for differentiating wet and dry days was defined. Days having less than 1 mm of rainfall were considered to be dry days. This small amount of rainfall is subject to measurement errors and is not considered to be of significant benefit to crops. The probability of dry periods occurring at Chiang Rai and

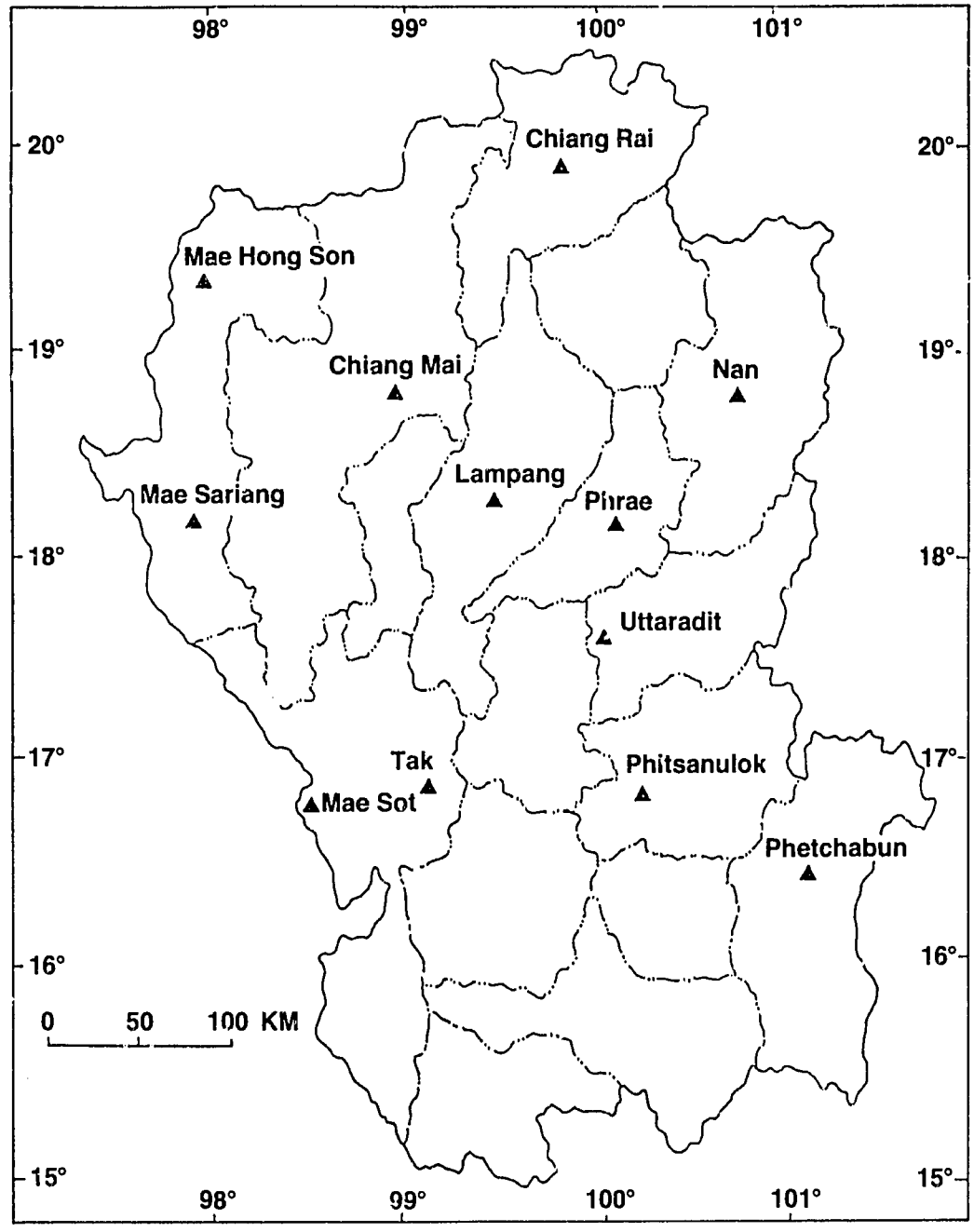

Figure 1. The Sites of Rainfall Stations in Northern Thailand Where Daily Rainfall Records are Analyzed.

Phrae for at least five, seven and ten days within a 30-day period from April to October was calculated and is shown in Figures 2 and 3.

The estimation of the start of rain is achieved by examining the plots of dry periods obtained above. The date after which a dry spell of ten days or more occurred within the following 30 days, with a probability of 0.2 or less, is used as the beginning date for marking the successful start of rain. The first occurrence of 20 mm of rain over two consecutive days, without a dry spell of ten or more days during the following 30 days, is

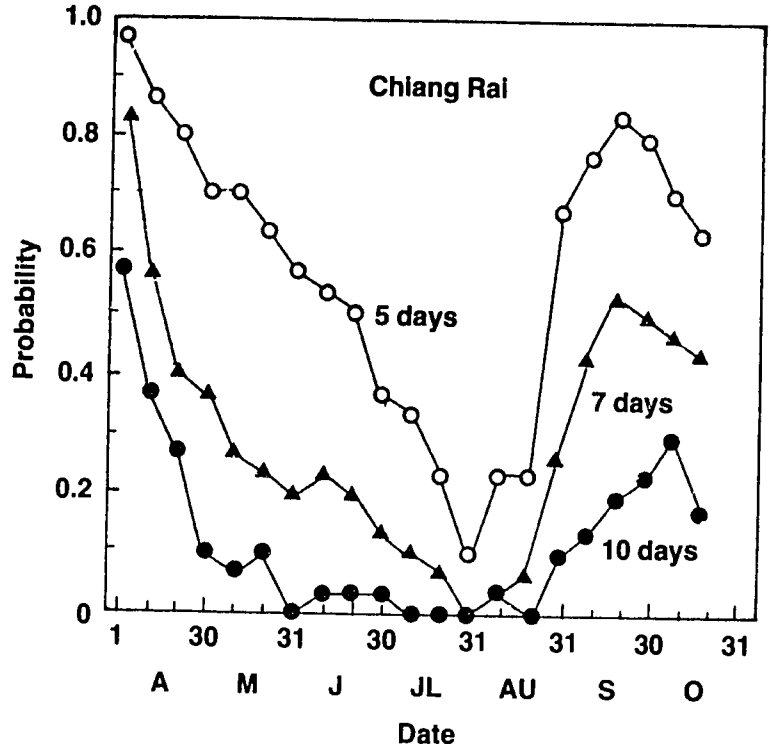

Figure 2. Probability of Dry Spells of at Least Five, Seven and Ten Days Occurring at Chiang Rai in the 30 Days Following Each Date.

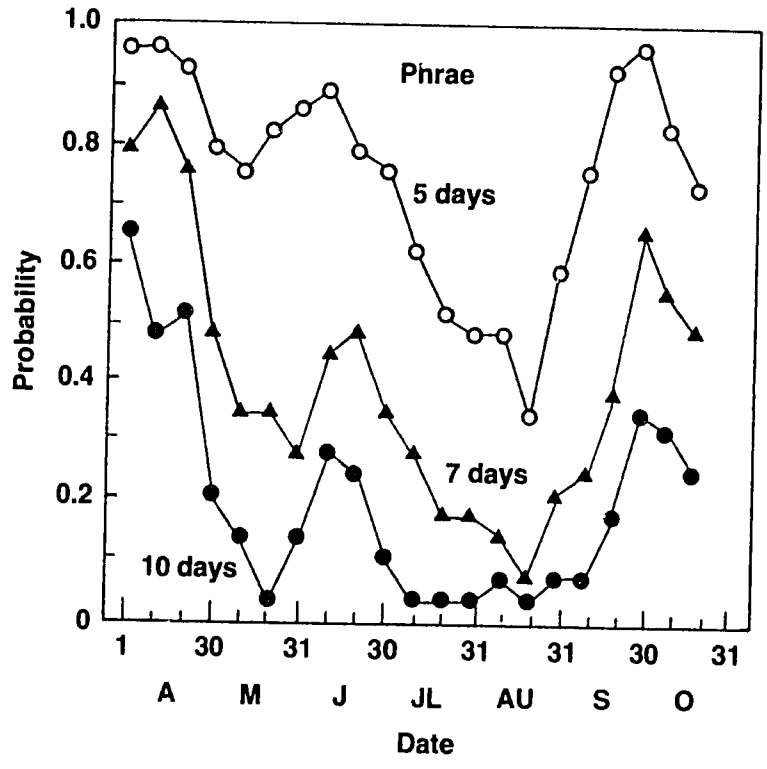

Figure 3. Probability of Dry Periods of at Least Five, Seven and Ten Days Occurring at Phrae in the 30 Days Following Each Date.

used as the date of the successful start of rain for each year. This criterion is considered to be adequate for marking the start of rain for sowing field crops (Stern, 1982). Cumulative probabilities of the starting dates of rain are then calculated.

The median dates for the start of rain (Table 1) range from 5 May at Chiang Rai to 23 May at Tak. The start of rain at Tak is delayed until 4 June at the 80 percent probability level. The start of rain in Table 1 is estimated by using 20 mm of rain within two consecutive days as the criterion. If 50 mm of rain over three consecutive days, without a ten-day dry spell in the following 30 days, is used as a criterion, the onset of the successful start of rain will be different. Morris and Ruumbaoe (1980) suggested that 50 mm of rain over three consecutive days can be used satisfactorily to determine the date for dryseeding of lowland rice under rainfed conditions.

Table 1. Distribution of the Start of Rain at Selected Stations in Northern Thailand Based on the Onset Criterion of 20 mm of Rain in Two Consecutive Days.

Station	Probability Level—%			Standard Deviation
	20	50	80	
	.....	*date*	.....	*days*
Chiang Rai	26 Apr	5 May	15 May	12
Mae Hong Son	4 May	11 May	18 May	7
Chiang Mai	2 May	10 May	18 May	10
Nan	30 Apr	5 May	11 May	7
Lampang	4 May	12 May	20 May	9
Mae Sariang	4 May	11 May	18 May	8
Phrae	3 May	12 May	21 May	11
Uttaradit	6 May	14 May	22 May	10
Tak	11 May	23 May	4 Jun	15
Phitsanulok	7 May	13 May	19 May	8
Mae Sot	16 May	22 May	28 May	7
Phetchabun	3 May	12 May	21 May	11

Based on this criterion, the cumulative probability of dates at which rain will start is shown in Figure 4 for Chiang Mai. When the criterion changes from 20 mm of rain over two days to 50 mm of rain over 30 days at the 80 percent probability level, the start of rain shifts from 18 May to 2 June at this station. Similar delays occur at every station analyzed but the data are not shown.

End of the Growing Season

The simple daily water balance (Stern *et al.*, 1982) is used to mark the end of the growing season. This is defined as the first date on which available water drops to zero. The date is recorded for each year and the cumulative probability of the end of the growing season is computed. In this analysis, two levels of available water capacity (AWC) of soils, 100 and 200 mm, have been used to evaluate the effects of AWC on the end of the growing season. An example of a plot of cumulative probability of the end of the growing season for Chiang Rai is shown in Figure 5.

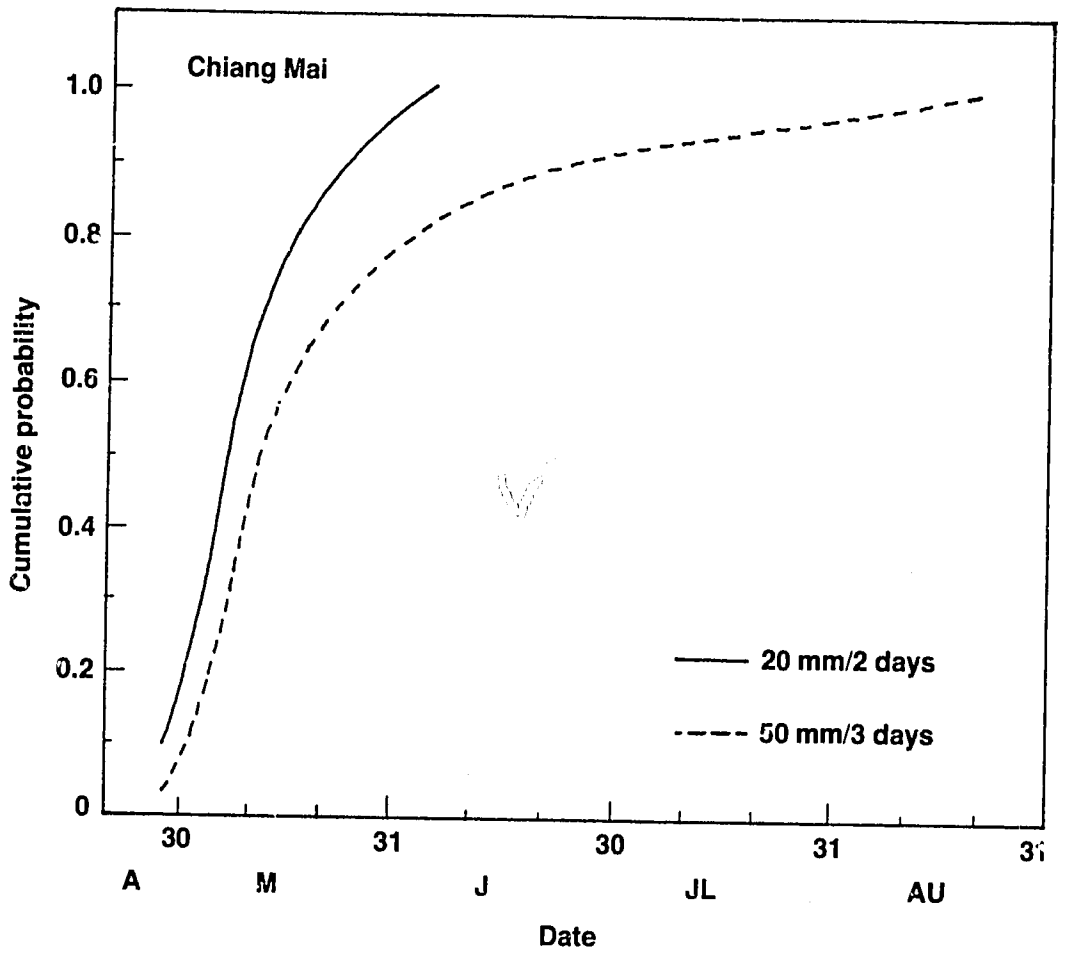

Figure 4. Cumulative Probability of the Starting Date of Rainfall at Chiang Mai Using the Criteria of 20 mm Over Two Consecutive Days and 50 mm Over Three Consecutive Days.

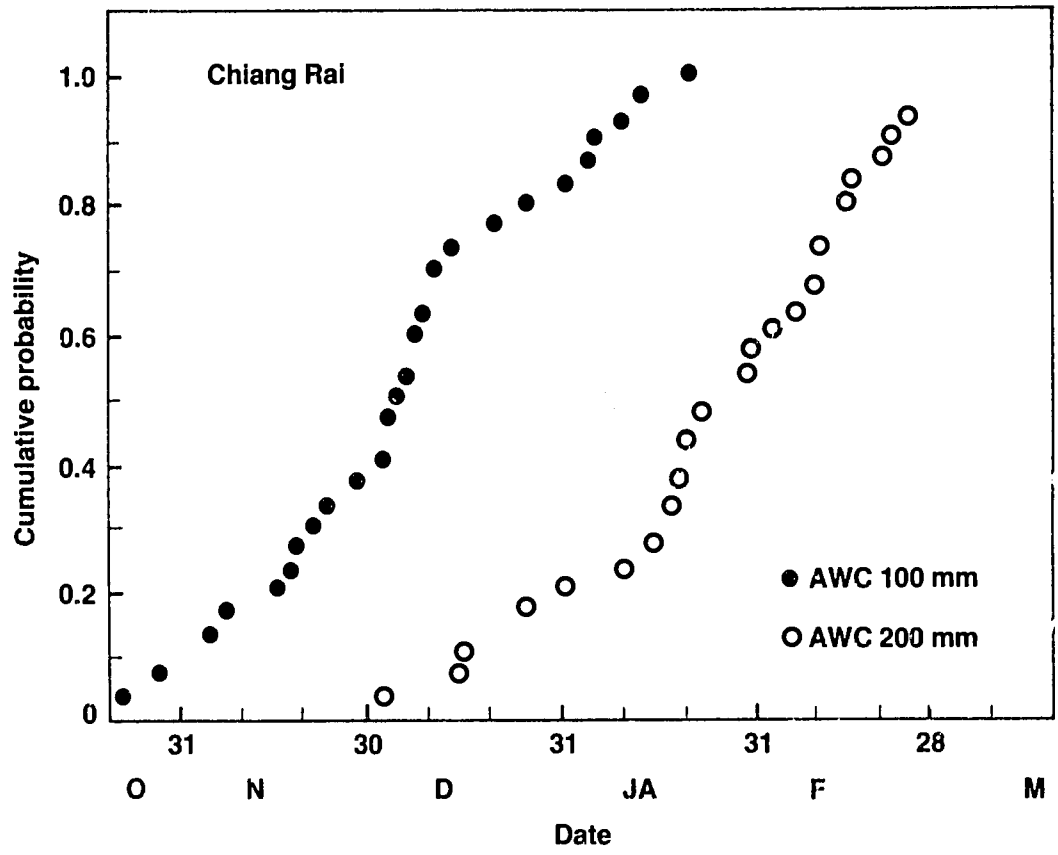

Figure 5. Cumulative Probability of Ending Date of Growing Season at Chiang Rai for Soil with an Available Water Capacity of 100 and 200 mm.

The distribution of the estimated date of the end of the growing season (Table 2) shows variations among stations for the available water capacity of a particular soil. The median date for this parameter ranged from 10 November at Phrae to 6 December at Chiang Rai. Rainfall characteristics at the end of the monsoon contribute significantly to this difference.

The values in Table 3 are the estimated initial and conditional probabilities of weekly rainfall of at least 10 mm calculated by a first order Markov chain model described by Virmani (1978). The results show higher initial and conditional probabilities and mean amounts of rainfall at Chiang Rai than at Phrae in most weeks from October to the end of December. The occurrence of rain during this period recharges soil profiles, maintains availability of soil water and prolongs the end of the growing season.

The AWC of the soil affects the end of growing season differently at the various stations. In this analysis, an increase in AWC from 100 to 200 mm causes the median end of the growing season to be extended from 6 December to 26 January at Chiang Rai, and from 10 November to 15 December at Phrae. The soils with higher AWC can store water to a greater depth and benefit from the wetter years, while shallow soils or soils with low AWC receive relatively little benefit from the occurrence of rain at the end of the monsoon.

Table 2. Distribution of the Estimated Date of the End of the Growing Season on Soils with 100 and 200 mm of Available Water Capacity (AWC) at Selected Stations in Northern Thailand.

Station	AWC					
	100 mm			200 mm		
	Probability level %			Probability level %		
	20	50	80	20	50	80
	..... *date*					
Chiang Rai	16 N†	6 D	25 D	6 J	26 J	17 F
Mae Hong Son	11 N	24 N	8 D	26 D	11 J	28 J
Chiang Mai	15 N	5 D	25 D	1 J	21 J	12 F
Nan	30 O	12 N	26 N	8 D	26 D	17 J
Lampang	15 N	26 N	8 D	23 D	6 J	21 J
Mae Sariang	12 N	26 N	10 D	24 D	11 J	29 J
Phrae	28 O	10 N	23 N	3 D	15 D	28 D
Uttaradit	2 N	14 N	27 N	6 D	19 D	3 J
Tak	18 N	2 D	16 D	23 D	7 J	21 J
Phitsanulok	7 N	21 N	5 D	13 D	27 D	12 J
Mae Sot	5 N	16 N	28 N	10 D	22 D	4 J
Phetchabun	31 O	10 N	21 N	2 D	12 D	22 D

† O, N, D, J and F abbreviate months from October to February.

The correlation coefficients for the starting and ending dates of rain were calculated and found to be nonsignificant with coefficients of less than 0.2 for all stations analyzed. Therefore, independence between the starting and ending dates of rain is assumed.

Table 3. Initial (W) and Conditional (W/W; W/D) Probabilities of Rainfall (%) for Amounts >10 mm at Chiang Rai and Phrae During the Weeks of October through December.

Period		Chiang Rai				Phrae			
		W	W/W†	W/D‡	Mean	W	W/W	W/D	Mean
		..... %			mm	..... %			mm
Oct	01-07	67	55	50	38.0	62	50	46	23.6
	08-14	53	56	36	29.6	48	64	33	19.5
	15-21	47	71	63	17.7	48	43	53	15.3
	22-28	67	40	40	40.3	48	7	27	23.0
	29-04	40	25	28	15.3	17	20	8	6.2
Nov	05-11	27	25	9	11.6	10	0	4	3.9
	12-18	13	0	15	6.9	3	0	7	3.7
	19-25	13	50	12	5.4	7	50	0	1.7
	26-02	17	20	8	7.0	3	0	0	1.3
Dec	03-09	10	33	15	4.1	0	0	7	0.3
	10-16	17	20	16	8.1	7	0	0	1.2
	17-23	17	0	16	5.2	0	0	0	0.3
	24-31	13	50	8	3.0	0	0	0	0.5

† W/W is the probability of this week being wet, given the previous week was wet.
‡ W/D is the probability of this week being wet, given the previous week was dry.

Potential Growing Season

For each year of record, the length of the potential growing season can be computed as the period between the start of rain and the end of the growing season. The mean length of the growing season and the associated standard deviation for each station analyzed are shown in Table 4.

Table 4. Mean Length of Growing Season in Days for Soils with Two Different Available Water Capacities (AWC) at Selected Stations in Northern Thailand.

Station	Annual Rainfall	Mean Growing Season	
		AWC	
		100 mm	200 mm
	mm	..... *days*	
Chiang Rai	1800	216 ± 26	267 ± 26
Mae Hong Son	1280	200 ± 21	249 ± 19
Chiang Mai	1260	210 ± 25	256 ± 26
Nan	1310	193 ± 18	237 ± 23
Lampang	1070	194 ± 27	234 ± 44
Mae Sariang	1220	201 ± 17	246 ± 22
Phrae	1100	183 ± 17	218 ± 15
Uttaradit	1450	186 ± 15	221 ± 17
Tak	1050	194 ± 22	229 ± 22
Phitsanulok	1360	192 ± 15	229 ± 17
Mae Sot	1470	179 ± 16	215 ± 17
Petchabun	1150	184 ± 16	215 ± 16

The results show variations in the mean potential growing season, both within and among stations, and suggests that there are potentials for and constraints to increased cropping intensity and production in those areas. For soils with an AWC of 200 mm at Chiang Rai, the probability of growing a second crop successfully is 80 percent if the crop is harvested before 6 January (Table 2). The probability of success will be reduced to five out of ten years if the second crop reaches maturity after 26 January. However, not every crop can be grown successfully during the cool months of December and January in Northern Thailand even if available water is not seriously limited. Wheat is one of the postrainy season crops that is planted after corn during the last week of October and harvested

during the first week of February. It is grown successfully on the Ban Chong soil series with an AWC of 260 mm and more than 100 cm rooting depth (Norman, 1982). In soils with lower AWC (e.g., 100 mm), a shorter duration crop such as mung bean can be successfully grown in the postrainy season.

In Phrae where the mean growing season is relatively short and the soils have a relatively low AWC, i.e., 100 mm, the probability of having adequate available water for a growing crop is 80 percent if harvest occurs before 28 October (Table 2). In this situation, cropping systems that utilize two three-month crops in sequence will involve high risk due to a lack of available soil water at the end of the rainy season. Rainfall analysis at Phrae also reveals the probability of a dry spell of at least seven days occurring between mid-June and mid-July in five out of ten years (Figure 3). The need for developing strategies to avoid severe stress during this period is obvious. Some of the potentially useful soil and crop management techniques are discussed by Virmani (1983) and Taylor *et al.* (1983). The probability of a dry spell of the same duration at Chiang Rai is significantly less than at Phrae (Figure 2).

High mean annual rainfall does not always extend the mean growing season (Table 4). Mae Sot, for example, has a mean annual rainfall of 1470 mm which allows for 184 days of mean growing season in soils having 100 mm AWC. However, at Chiang Mai where the mean annual rainfall is 1260 mm, a mean growing season of 210 days has been estimated for soils with the same AWC. Heavier rainfall at Mae Sot from mid-July to the end of August (data not shown) results in runoff and deep percolation and does not contribute to increased storage of available water during the postrainy period. The low probability of long dry spells at Mae Sot means that late varieties of crops can be grown to utilize the full growing season with minimum risk of severe stress. Relay cropping of soybean between rows of corn is another strategy that farmers in this area practice in order to maximize the use of stored soil water. It is critical to develop strategies for managing cropping systems under rainfed conditions.

Summary

Daily rainfall records of selected stations in Northern Thailand were analyzed to provide information necessary for identifying potentials and constraints of physical environments that affect cropping systems research and development under rainfed conditions. Variation in the starting and ending dates of rain, coupled with heterogeneous properties of soil in storing maximum available water to plants, produces a range of potential growing seasons among the stations analyzed. The design of crops and cropping systems must take this into consideration to avoid spending unnecessary efforts and risk. This general analysis can be considered the initial step in a systematic approach toward developing cropping systems and related technology for rainfed conditions in Northern Thailand.

Additional research is required to fine-tune the knowledge on soil, water and the plant environment before more accurate predictions can be made. Studies of water storage and movement as affected by properties of major soil types in Northern Thailand are essential. More information is needed on rooting depths and density of major crop varieties in the medium to deep soils of the region. Studies on water use by different cropping systems are essential to effectively design optimal cropping systems and strategies under different rainfall and soil water regimes. Crop improvement programs should be directed toward varieties that can adapt well to postrainy season conditions when water and temperature are suboptimal. Dry periods that occur during the rainy season are of particular concern. Soil, water and crop management techniques that can avoid or minimize the severe stress conditions during these periods will result in a more stable agricultural system. Finally, it should be emphasized that the above activities require a systematic approach for interdisciplinary efforts and cooperation among the researchers and various organizations involved.

Acknowledgements

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Cropping Systems Trial Results From the Northeast Rainfed Agricultural Development Project (NERAD)

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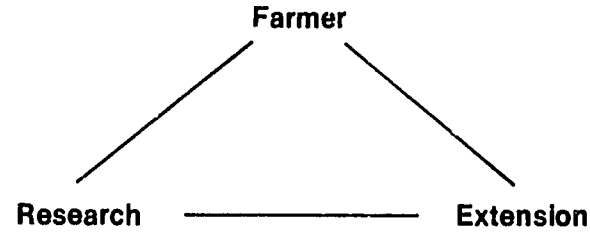
ABSTRACT. The goals, objectives and implementation strategy of the cropping systems component of the Northeast Rainfed Agricultural Development (NERAD) Project are described with emphasis on the "Farming Systems Research and Extension" approach adopted by the Project. The agroecological and socioeconomic conditions in the trial sites are described and an assessment of the major crop production problems and constraints facing the farmers is made. The results of the cropping systems and component technology trials are summarized and the extent to which they met their stated objectives is discussed.

Some traditional cropping systems designed through an evolutionary process by the farmers themselves for optimal management of soils, water and crops are described. These farmer strategies are then related to the cropping system trials conducted by NERAD in an attempt to explain the successes and failures in the Project's cropping trials program. Finally, the major soil and water management problems facing the cropping systems component of the project are summarized.

Introduction

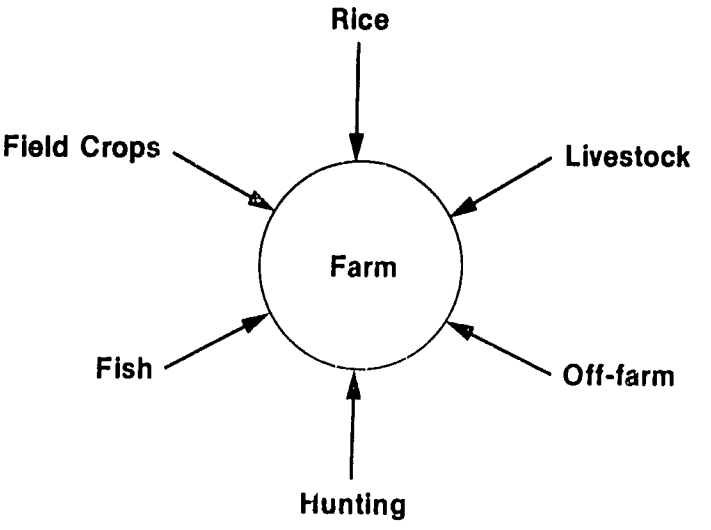
The Northeast Rainfed Agricultural Development (NERAD) Project is developing a Farming Systems Research and Extension (FSRE) approach appropriate for agricultural development in Northeast Thailand. FSRE has different meanings to different people, but as far as the cropping systems component of NERAD is concerned, the major elements of such an approach are (Patanothai, 1984):

Integrated:



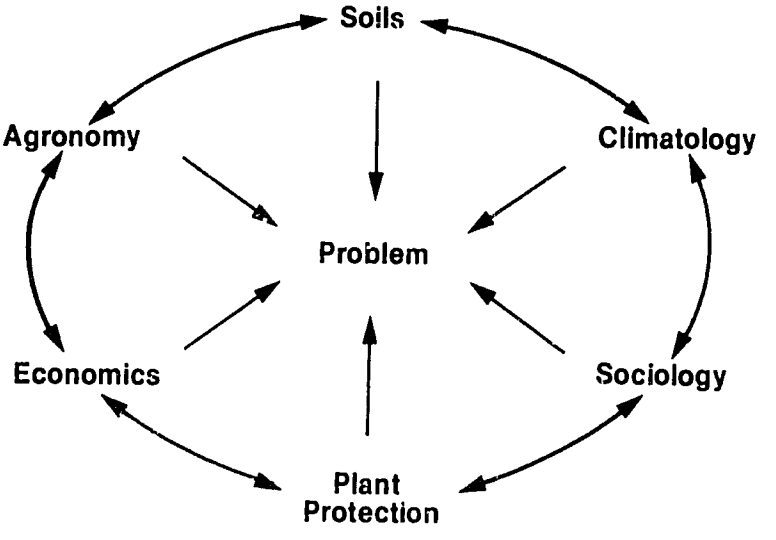
1) An FSRE approach is an integrated effort by research and extension personnel who should be jointly involved during all phases of the work.

Holistic:



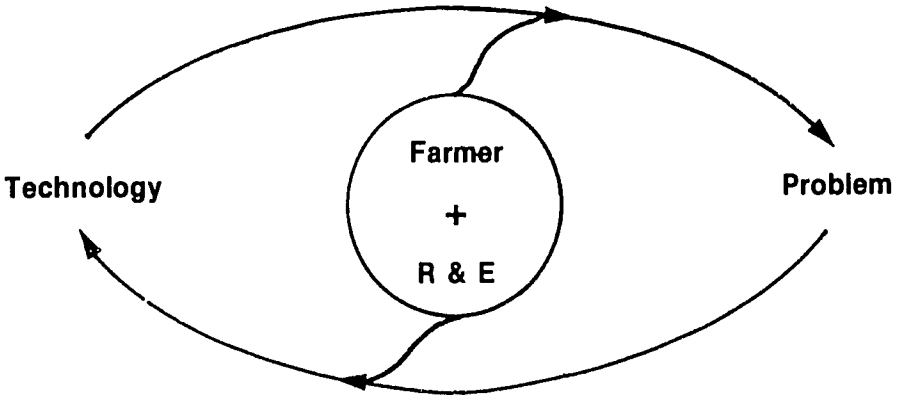
2) FSRE is a holistic approach which should consider all important interactions within the farm-family system.

Interdisciplinary:



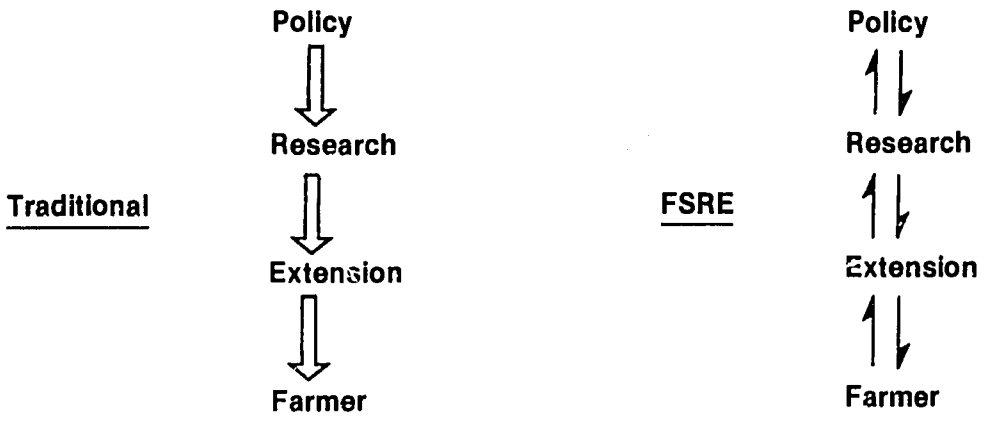
3) FSRE work should be conducted in an interdisciplinary manner that cuts across departmental and divisional boundaries. It does not replace specific, single discipline research, however, but should complement it, especially in the area of assisting in the definition of research priorities.

On-farm:



4) It focuses at the farm level and should include on-farm trials and research where relevant to gain a better understanding of real problems and of the performance of new technologies under actual farm conditions. The farmer should be considered a partner in this phase of the research and should be actively involved throughout.

Bottom-up:



5) It has a stronger bottom-up orientation than the traditional technology-based approach to development and thus requires a greater delegation of responsibility to junior scientists and technicians.

Earlier papers in this workshop have stressed a number of key characteristics of agriculture in the Northeast that have important implications for cropping systems development programs in the region. Some consideration of how these implications are translated into strategic and tactical responses within NERAD's cropping systems component will be made here.

First, it has been stressed that the subsistence rice crop is the key to cropping systems development in the Northeast. If improvements can be made to the rice crop, then constraints will be removed enabling farmers to diversify their cropping activities. Conversely, any cropping system technology which interferes with the subsistence rice crop is unlikely to be successful (Craig and Pisone, 1985). Most of the major advances in rice-based cropping systems development throughout the world have come through the introduction of new rice varieties. In most cases, these have been short duration, nonphotoperiod sensitive varieties enabling planting of rice to be adjusted for timely planting of prerice or postrice crops (Dalrymple, 1971; Carangal, 1977). In rainfed environments such as the Northeast, however, the use of photoperiod sensitive rice is essential to ensure a crop. Thus, this type of breakthrough is unlikely. NERAD's focus has been moving more towards component technology work on rice itself and exploring the potential for stabilizing and increasing rice yields by selective prerice and postrice crops.

Second, it would appear that Northeastern farmers are highly skilled and their traditional practices are already well-tuned to local agroecological conditions (KKU, 1982a). The implication here is that rapid, revolutionary breakthroughs in cropping systems development are unlikely. NERAD has attempted to make small improvements to the farmers' traditional practices in each locality based on the farmers' problems and has taken account of the constraints facing them.

Many papers have stressed the extreme variability of agroecological and economic conditions over both time and space in the Northeast (KKU, 1982b). It is, therefore, unlikely that cropping systems can be developed which will give optimal returns every year or will be suitable for the entire region. Rather, the approach should attempt to identify for each specific location a series of low-risk, robust technologies which give at least adequate returns for all years. These technologies will have to be low-cost and purchased input levels should be adjusted towards risk minimization rather than yield maximization.

Finally, most of the cropping systems development in the world to date has been in irrigated areas and has been a result of increased cropping intensity (Andrews and Kassam, 1976; Anon., 1975; Dalrymple, 1971). There is always the danger, however, of overemphasizing cropping intensification as the major objective of this work especially in rainfed areas where the potential for more than one crop per year is extremely limited. Previous papers have clearly shown that although there is potential for multiple cropping in some situations in the Northeast, many of the current problems with the traditional monocrop systems warrant higher research priority than cropping intensification. It is anticipated that NERAD's cropping systems work in the future will focus more on tackling these problems than attempting to increase cropping intensity *per se*. Hopefully, the results of this workshop will give the project some guidelines on how this may be done as regards soil/water management problems.

Farmer Strategies

It would appear that the majority of the traditional cropping systems in the Northeast are exploitive in nature and the farmers' strategy is essentially one of mining the natural soil fertility established when the land was under forest-cover (Ragland *et al.*, 1983). Purchased fertilizer in the rice crop is zero or minimal and the predominant upland systems of kenaf or cassava also generally receive no fertilizer. A review of the soil fertility levels for four principal villages, shown in Figure 1, gives some idea of how long this exploitation process has been going on in each province.

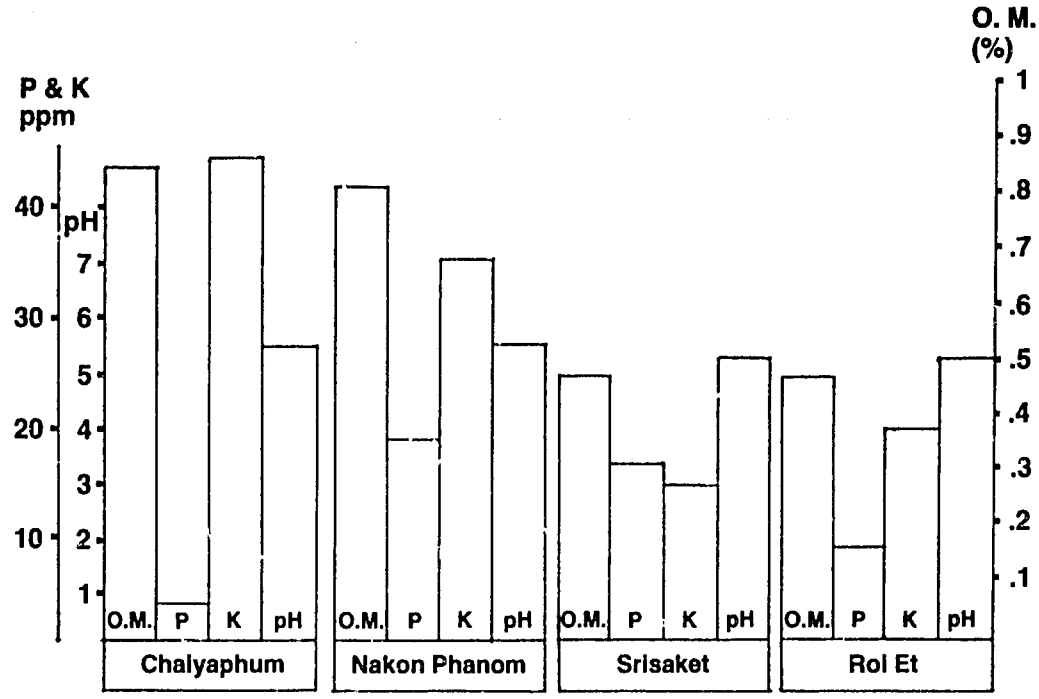


Figure 1. Combined Soil Analysis Data for NERAD Principal Villages, 1983.

In Roi Et, where the land has been cultivated for the longest time and where soil fertility levels are the lowest, cropping intensity (Figure 2) is surprisingly the highest among all the villages. This is due to a locally evolved strategy for dealing with declining nutrient levels and decreasing rice yields. Farmers commonly plant watermelon after rice, not with the primary objective of earning cash but more as a means of stabilizing rice yields. Manure and fertilizer are applied to the watermelon plots resulting in residual fertility. The plots are rotated between fields from year to year in order to spread the benefit over all the paddy land.

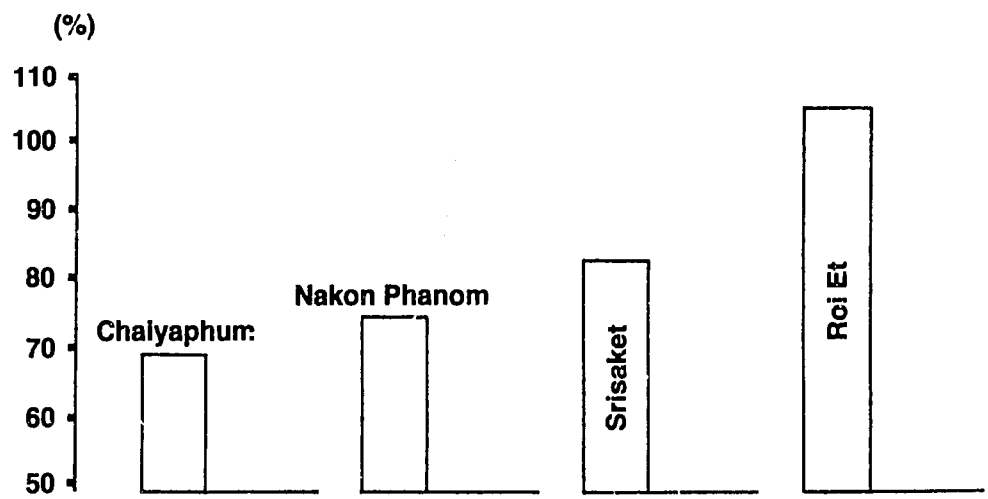


Figure 2. Cropping Intensity Indices for NERAD Principal Villages, 1983.

In Srisaket where fertility levels have also declined markedly, the strategy appears to be to spend more money on fertilizer applied directly to the rice crop (Figure 3). This has probably been made possible by the higher proportion of the rice harvest which is sold, thus generating cash to purchase the fertilizer (Figure 4).

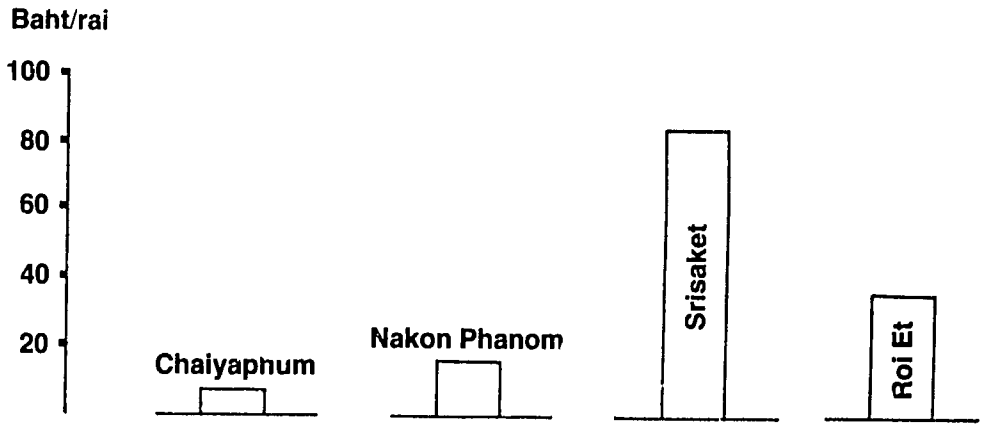


Figure 3. Money Spent on Fertilizer Applied to Rice for the NERAD Principal Villages, 1983.

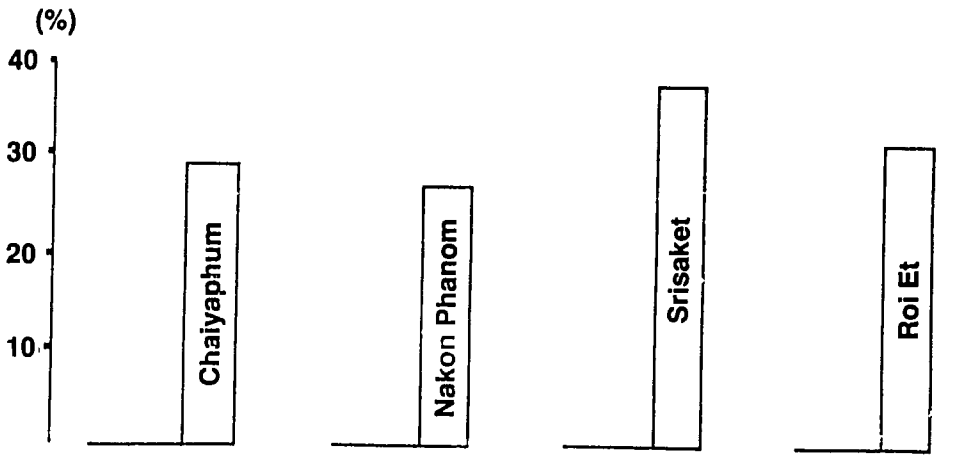


Figure 4. Percent of Rice Harvest Sold in the NERAD Principal Villages, 1983.

In Chaiyaphum and Nakon Phanom, where the land has been cropped for a shorter period, soil nutrients have not yet declined to such low levels and farmers are following the strategy of mining soil nutrients with continuous low-input monocropping. Figure 5 indicates that all three strategies produce approximately equivalent rice yields. However, the dominant strategy in Chaiyaphum and Nakon Phanom of mining natural fertility is not sustainable in the long term.

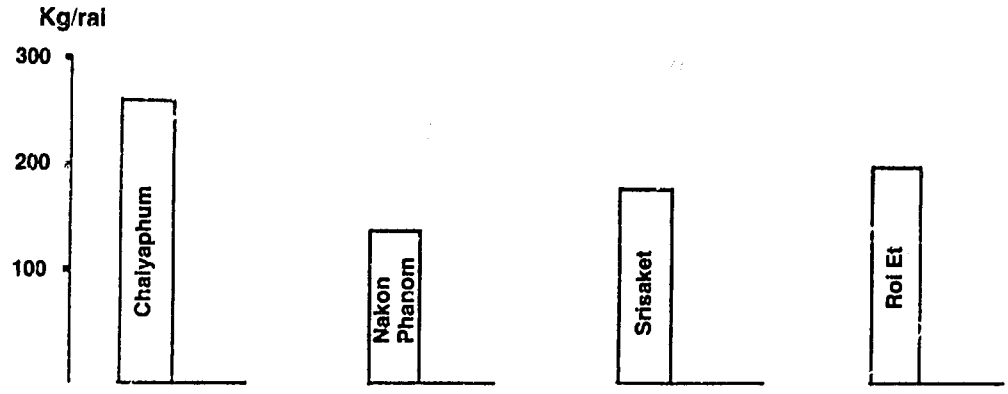


Figure 5. Mean Rice Yields-Farmer Estimates (kg/rai) for NERAD Principal Villages, 1983.

Farmers also have various strategies for dealing with the uncertainty of rainfall in the region. For rice these include: use of photosensitive rice varieties; small, bunded fields; rice-storage; and by following what can best be termed compensatory cropping strategies. A good example of the latter comes from Roi Et where farmers plant kenaf in the paddy before rice. In dry years the kenaf produces higher yields because waterlogging problems are reduced and the kenaf can be left in the field longer since rice transplanting is either not possible or is delayed by lack of rain. Thus, there is some compensation for reduced rice yields in dry years by higher cash earnings from kenaf.

Results

NERAD has been running cropping system trials for two years in farmers' fields in nine tambons in four changwats in Northeast Thailand. Two sets of trials have been conducted. First, cropping intensification trials have been conducted over the entire tambon following DOA-recommended practices for planting dates, fertilizer rates, etc. The second set of trials were conducted in only one principal village per tambon and were designed to solve current farmer problems identified during an interdisciplinary needs assessment conducted in each village. A summary of the results of last year's trials are presented in the Appendix.

At most, 100 trials, generally replicated over five farmers, were conducted with varying degrees of success. Available resources, however, were overextended, causing problems of inadequate data on which to base decisions for improving the systems. This made it difficult to prioritize the trials and to concentrate efforts on the technologies with the highest potential for benefiting farmers in each tambon.

A technical workshop was held to review the results of all the trials conducted and to classify the technologies into three categories:

1) Successful technologies which are considered suitable for expansion through extension demonstrations.

2) Promising technologies which still require further testing or modification by component technology research.

3) Technologies which under present or expected conditions are unlikely to significantly benefit farmers.

As a result of this triage process, technologies assigned to category 1 will be demonstrated in an extension phase by DOAE with technical support from DOA. Those trials classified as category 3 will be discontinued or passed back to the research stations but regularly reviewed to determine if technological advances or economic circumstances have changed sufficiently to warrant further testing. The project's cropping system trials program will concentrate on category 2 with an intensive series of on-farm trials including superimposed, component technology work to solve the remaining problems and develop the systems until they are ready for the extension phase. The overall cropping systems strategy will be implemented according to the system summarized in Figure 6.

Instead of reviewing the results of all the trials, some examples will be chosen to illustrate the triage process, to demonstrate the importance of understanding traditional cropping strategies and to assess the potential for cropping systems development in the Northeast. These examples are presented in Tables 1, 2 and 3.

A green manure trial was implemented in Srisaket to address the problems of low soil fertility and the high cost and associated risk of applying fertilizer to rice. Both the objectives of increasing rice yield and reducing fertilizer requirements were met by the trials. Although yield increases were only moderate, the farmers' response was extremely enthusiastic and the technology is already being rapidly adopted in the area. It is believed that the reason for this is that it satisfies the farmers' rice yield stabilization objective and does so in a low-cost, low-risk manner. A Cuban kenaf crop before rice as an improved compensatory system for fluctuating rice production is also considered ready for extension for similar reasons. At present prices, a net return of 747 Baht/rai from kenaf is equivalent to over 350 kg/rai rice, which is an acceptable yield level.

Yield and return from direct-sown rice and sesame before rice technologies were rather variable and well below potential. Still, they represent viable compensatory and income stabilization strategies with considerable potential for meeting these objectives in their respective areas. For this reason, they will receive high priority for further on-farm component technology trials to overcome the remaining problems. For direct-sown rice, research will include developing better plant spacing to facilitate weeding, herbicide trials and planting date trials. For sesame, the component technology work will be concentrated on planting date trials in an attempt to avoid waterlogging and drought.

Although net returns from a sweet corn crop before rice were acceptable, this trial was based on the erroneous assumption that farmers wish to increase cropping intensity on their paddy land.

Farmers in Nakon Phanom, however, have plenty of underutilized upland area which they prefer to use for cash cropping if it does not interfere with their subsistence rice production. The objectives of the mung bean before rice trial are considered to be valid and in line with farmers' objectives. Currently, however, the available mung bean varieties are not suitable for local conditions due to their preference for clay soils, sensitivity to waterlogging and their susceptibility to common pests and diseases. It is, therefore, felt that more on-station breeding work is necessary before further on-farm trials of this technology are undertaken.

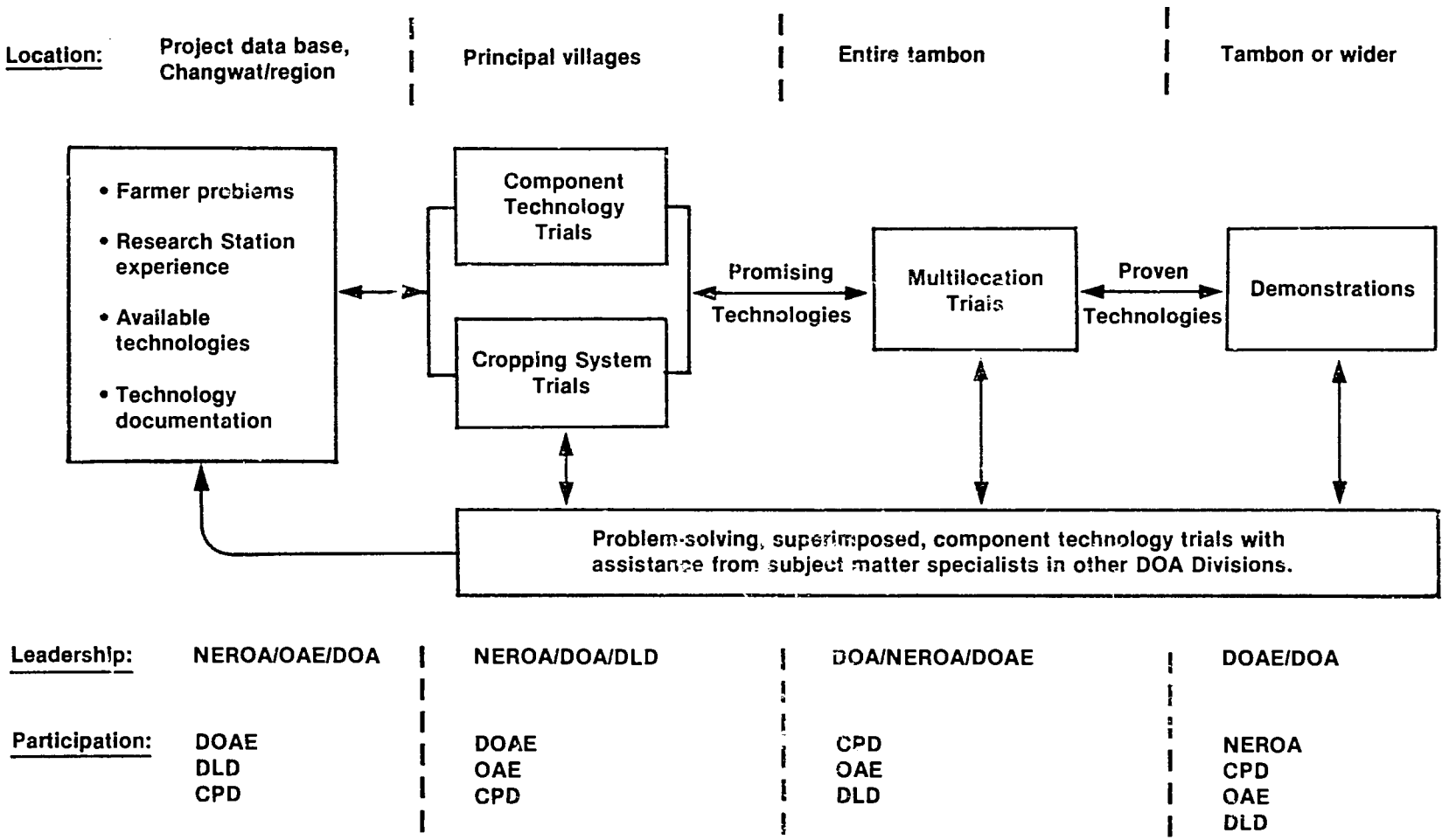


Figure 6. Implementation of NERAD Cropping System Trials.

Table 1. Examples of Successful Technologies Ready for Extension Through Multilocation Testing.

1. Cowpea (green manure) - Rice		**Srisaket**	
Farmer problems identified		1. Low soil fertility 2. High cost and risk of fertilizing rice 3. Prerice season underemployment	
Objectives of the trial		1. Increase rice yields 2. Reduce fertilizer requirements in rice	
Results (mean of 15 plots)	Cowpea-Rice (DM105)	15-15-15 + 16-20-0 at 20 kg/rai and ammonium sulphate at 10 kg/rai	YIELD = 543 kg/rai
	Fallow-Rice (DM105)	15-15-15 + 16-20-0 at 20 kg/rai and ammonium sulphate at 10 kg/rai	YIELD = 487 kg/rai
	Fallow-Rice (local)	44 kg various fertilizer (farmer check)	YIELD = 444 kg/rai
			- Yields are significantly different*
Conclusion: Improved Low-Input, Low-Risk "Stablization" Strategy			
2. Cuban Kenaf - Rice		**Chaiyaphum**	
Farmer problems identified		1. Unstable rice yields 2. Root rot disease build up on limited upland area where kenaf is continuously monocropped	
Objectives of the trial		1. Identify a prerice cash crop for the paddy land 2. Test a root rot-resistant kenaf variety	
Results (mean of 5 plots)		Cuban kenaf yield	= 280 kg/rai
		Net returns	= 747 Baht/rai
		Upland Thai kenaf (control)	= 207 kg/rai
		Rice after Cuban kenaf (4 plots = 0)	= 46 kg/rai
Conclusion: Improved "Compensatory" System			

Table 2. Examples of Promising Technologies That Require Further On-Farm Testing and Component Technology Research.

1. Direct-Sown Rice (Upper Paddy)	**Chaiyaphum**		
Farmer problems identified	1. Unstable subsistence rice production 2. Upper paddies planted only 1 year in 3		
Objectives of the trial	1. Produce rice in the upper paddies every year 2. Identify situations where direct-sown rice will give higher or more stable yields than transplanted rice		
Results (mean of 5 plots)	Direct-sown rice (RD6) yield (Rat + weed problems)	=	154 kg/rai
	Net returns	=	127 Baht/rai
	Transplanted rice (control) yield (Insufficient water for transplanting)	=	0 kg/rai
Conclusion: "Compensatory" Strategy for Dry Years			
2. Sesame - Rice	**Roi Et, Srisaket**		
Farmer problems identified	1. Limited market and unstable prices for present cash crops (watermelon and yard long bean)		
Objectives of the trial	1. Test the potential of a traditional technology successful elsewhere in a situation with similar agroecological conditions 2. Identify a viable prerice crop with high and stable prices		
Results (mean of 5 plots)	Sesame yield (waterlogging/drought)	=	90 kg/rai
	Net cash returns	=	747 Baht/rai
	Rice yield	=	unaffected by sesame
Conclusion: Promising Income Stablization Strategy			

Table 3. Examples of Technologies Unacceptable to Farmers to be Referred Back for Further Basic Research.

1. Sweet Corn - Rice	**Nakon Phanom**		
Farmer problems identified	1. Underutilization of paddy land		
Objectives of the trial	1. Increase cropping intensity in the paddy		
Results (mean of 13 plots)	Corn yield	=	2924 ears/rai
	Net returns	=	476 Baht/rai
	Rice yield	=	unaffected by sweet corn
Conclusion: Trial Objectives Do Not Fit Farmer's Strategy			
2. Mung Bean - Rice	**Roi Et**		
Farmer problems identified	1. Declining soil fertility 2. Limited markets and unstable prices for traditional cash crop (watermelon)		
Objectives of the trial	1. Improve soil condition by incorporation of legume crop residues 2. Stabilize returns from cash crops		
Results (mean of 5 plots)	Mung bean yield	=	44 kg/rai
	Net returns	=	88 Baht/rai
	Rice yield (after mung bean)	=	348 kg/rai
	Rice yield (after fallow) (not significantly different)	=	344 kg/rai
Conclusion: Stablization Objectives Not Achieved in Trials			

Major Soil/Water Management Issues

It would be appropriate to conclude with a summary of the major problems in soil, water and soil fertility management currently facing the cropping systems program within NERAD. Component technology work is already planned to address some of these issues. Suggestions and advice as to how to best design and implement on-farm trials to solve the following problems are welcomed from this workshop.

Upland Crops	- Adjustment of planting dates in accordance with local rainfall probabilities. - Selective erosion of organic matter and clay content (Mitsuchi, 1984). - Soil acidity management.
Prerice Crops	- Planting methods and soil management techniques to reduce the problems of waterlogging. - Adjustment of planting/harvesting dates in accordance with rainfall probabilities to avoid waterlogging and drought. - Management of soil acidity. - Green manure management for maximum benefit to the following rice crop.
Rice Crop	- Fertilizer types/rates/timing and placement to reduce risk under erratic rainfall conditions. - Decision guidelines based on rainfall amounts and dates for when to transplant and when to direct-sow rice in the upper paddies. - Rice crop residue management for maintenance of soil fertility.
Postrice Crops	- Soil moisture conservation. - Planting methods and other management practices to reduce crop turnaround time. - Fertilizer application in dry conditions.
Entire Cropping	- Assessing trade-offs between optimal system planting dates for component crops in a multiple cropping system. - Long-term assessment of soil fertility maintenance by cropping system rotations. - Maximizing the utilization of residual fertility from a previous crop.

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Soil, Water and Crop Management Practices for Rainfed Agricultural Systems in Northeast Thailand

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ABSTRACT. This paper discusses the principal problems and constraints in crop production at the farm level in the undulating lands of Northeast Thailand. There, farmers grow rice mainly for subsistence, and drought tolerant long-duration cassava and kenaf for cash. The rationale for farmers choosing such crops is given. The principal constraints to agricultural production on the undulating land, including poor utilization of upper paddy, are the shortage of water and low soil fertility on both paddy and upland fields. The recently terminated KKU-Ford Cropping Systems Project at Khon Kaen University attempted to improve the existing cropping systems by introducing several multiple cropping patterns to raise net income per unit area of land. Most of the cropping patterns tested gave poor and unstable yields. Some promising patterns, although agronomically successful, were not readily accepted by farmers because certain cropping practices interfere with other existing farm activities. Later on, well-established rainfed, multiple cropping systems were found to be practiced by some farmers in certain areas of the Northeast. These systems may provide some answers to the problems of underutilization of upper paddy land and poor soil fertility. Such findings also reflect how certain Northeast farmers utilize rainfall, soil moisture and fertilizers efficiently, and their integration with crop management practices that are both profitable and sustainable for rainfed agriculture.

Introduction

Although the Northeast is the largest region of Thailand, the population is among the poorest in the Kingdom since the principal source of income is based primarily on rainfed agriculture. Low and unstable agricultural productivity in the Northeast are attributed mainly to low soil fertility and erratic rainfall. Areas for agricultural production cannot be expanded further, and off-farm employment opportunities are limited. As population density increases, the policymakers and researchers are striving to increase the efficient utilization of agricultural land by upgrading soil fertility, developing water resources to alleviate drought problems, and more recently by multiple cropping (Patanothai, 1983).

Knowledge of how the Northeast farmers respond and adjust their cropping systems to drought stress and low soil fertility is lacking. Therefore, the purpose of this paper is to examine, particularly at the farm level, the problems and constraints to rainfed crop production in the Northeast. Ways to overcome such problems have been identified by the farmers themselves and by the researchers of the recently terminated KKU-Ford Cropping Systems Project at Khon Kaen University.

Crop Production in the Northeast

There are only four or five major crops that are grown in the Northeast. Rice (paddy) is the principal cultivated crop and is grown on 70 percent of agricultural land. Eighteen percent of the land is devoted to four upland crops including cassava (nine percent), corn (six percent), kenaf (two percent) and sugarcane (one percent). Fruit trees, vegetables and other field crops occupy only a small portion of the agricultural land. (Office of Agricultural Economics, 1983).

As a result, this discussion will center mainly on the problems and sustainability of rice and upland crop production as part of the cropping/farming systems of Northeast farmers.

Paddy Rice Production

The average regional yield per area of rice produced in the Northeast is always low compared to other regions of Thailand (Office of Agricultural Economics, 1983). Presumably, this is due to low soil fertility and erratic rainfall. In the past, there were recommendations to shift some of the areas that were traditionally planted to rice into upland crops, or even pasture for livestock. Such recommendations were largely ignored

since rice is the preferred crop and the staple food throughout the Northeast region. Moreover, the farmers are reluctant to change their paddy fields into cash crops because of unstable markets. At the village level, people also regard the level of rice production per household as the best indicator of a farmer's economic and social status. The preference of the Northeast farmers to grow rice continues to be strong as evidenced by the many upland fields previously under cassava production which are now planted to upland rice (Townsend and Baker, 1984). As a result, a careful assessment of rice production in the Northeast region has identified certain areas that appear to be stable from year to year in terms of the area planted to paddy and paddy yield per unit area (KKU-Ford Cropping Systems Project, 1982). These areas are along the Mekong River where rainfall is high and more evenly distributed. Rice production tends to be either unstable and/or low in the areas away from the Mekong River, particularly toward the mountain range in the west and southwest of the region (KKU-Ford Cropping Systems Project, 1982). In these areas, rainfall is lower and tends to be more erratic in both the annual amount and distribution during the rainy season.

Closer examination of the areas with rice production problems in the Northeast region shows that rice is frequently grown on the undulating land (Figure 1). Farmers on this type of land begin growing rice at the bottom of the depression and, subsequently, continue planting up the slope toward the upland. Rice production in the bottom or lower paddy is considerably more stable than rice grown in the upper paddy fields (Figure 1). At the upper paddy position, rice can be grown successfully only one to three years out of five because of insufficient water for transplanting. It follows then that two principal challenges to agriculture in the Northeast region are (1) how to increase stability of rice production on the upper paddy fields, or alternatively, how to manage this type of paddy land so as to stabilize or even increase the income per unit area, and (2) how to increase the overall rice yield per unit area by improving soil fertility.

Increasing the Utilization Efficiency of Upper Paddy Land

The Origin of Upper Paddy Land and its Current Use

Efforts to grow rice on the upper paddy position were prompted by the increasing population of the region. Nevertheless, crop failures occur frequently on upper paddy fields because of insufficient and erratic rainfall. Even if rice can be transplanted, yields per unit area are still low compared with those of lower paddy fields. Some farmers who have sufficiently large landholdings have had some degree of success on upper paddy land using short-duration rice varieties.

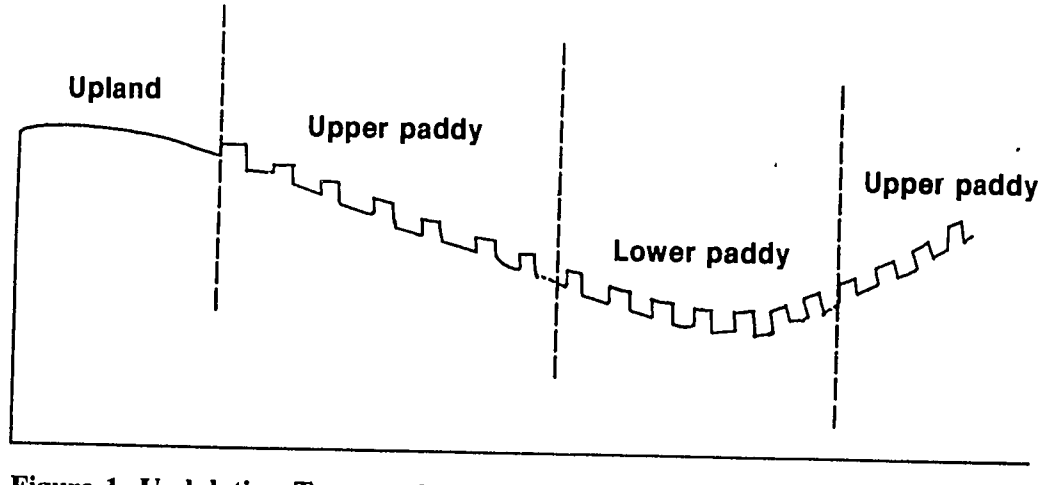

Figure 1. Undulating Topography of the Northeast Showing Upland, Upper Paddy and Lower Paddy Positions.

In many areas of the Northeast, drought is an event that occurs with expected certainty (KKU-Ford Cropping Systems Project, 1982). For example, in Khon Kaen, farmers who have comparatively large landholdings may not be too concerned about drought if it comes in alternate years with good rainfall. This is because the rice surplus obtained from the upper paddy fields in the good rainfall years will compensate for low production in the drought years.

To fully utilize the short period during which water collects in the upper paddy fields, short-duration rice varieties are used. These varieties are transplanted to upper paddy fields about one to two months later than those grown in the lower paddy fields, but harvested about 1/2 to 1-1/2 months earlier. Short-duration varieties often produce low yield due to the short vegetative growth period.

Research to Improve the Productivity of Upper Paddy Fields
Improvement of crop productivity on upper paddy fields was a critical issue addressed by the KKU-Ford Cropping Systems Project from 1976 to 1983. Several cropping patterns were tested (Figure 2), and results are available elsewhere (KKU-Ford Cropping Systems Project, 1982; Patanothai, 1983; Polthanee, 1983). Only a brief summary of results is presented here.

1) Growing short duration field crops before rice. An objective of this project was to utilize the previously vacant upper paddy fields prior to the delayed transplanting of short-duration rice. Short-duration field crops were planted in late April and May and harvested before rice seedlings were transplanted about mid-August to September. Several field crops were tested but only a few promising possibilities emerged, including mung bean and red cowpea. These two crops are short-duration legumes which can be harvested within 75 days, thereby allowing sufficient time for paddy fields to collect water for subsequent rice transplanting. This technology, though practical, was not readily accepted by the farmers. Planting of the two legumes required substantial production inputs and intensive management (e.g., weed and pest control) which tended to compete for labor that was committed to transplanting rice on the lower paddy fields during June and July. Furthermore, good mung bean production seemed to be location-specific, occurring mainly on slightly heavy soils, and there was no established market at that time for cowpea. Unlike cassava and kenaf, these two legumes were not sufficiently drought tolerant, causing the yields to vary considerably from year to year.

2) Growing field crops after rice. An attempt to establish field crops after rice was met with total failure due to lack of sufficient residual soil moisture to support growth. Techniques to conserve soil moisture were also not well-established at that time.

3) Double cropping of field crops on upper paddy fields. Studies on double cropping with two short-duration field crops were conducted as a possible option for replacing rice on upper paddy fields. However, experiments over a number of years produced variable results. Establishment of the second crop was often unsuccessful because of waterlogging during the heaviest rainfall period. The cooperating farmers were never very interested in double cropping as an alternative system, believing that the upper paddy fields should be utilized for rice production. Planting of the second crop was often delayed until September or later. Establishment and performance of late planted field crops depend on the occurrence of late rains which are also uncertain.

4) Direct seeding of rice. Some stabilization of rice yields against drought on the upper paddy fields can be achieved by direct seeding of rice in early June. This concept was also evaluated by the KKU-Ford Cropping Systems Project (1978). The results looked promising in terms of yield. However, the problems that were of greatest concern were the increased labor required for weeding, flooding of small rice seedlings, and pest control practices.

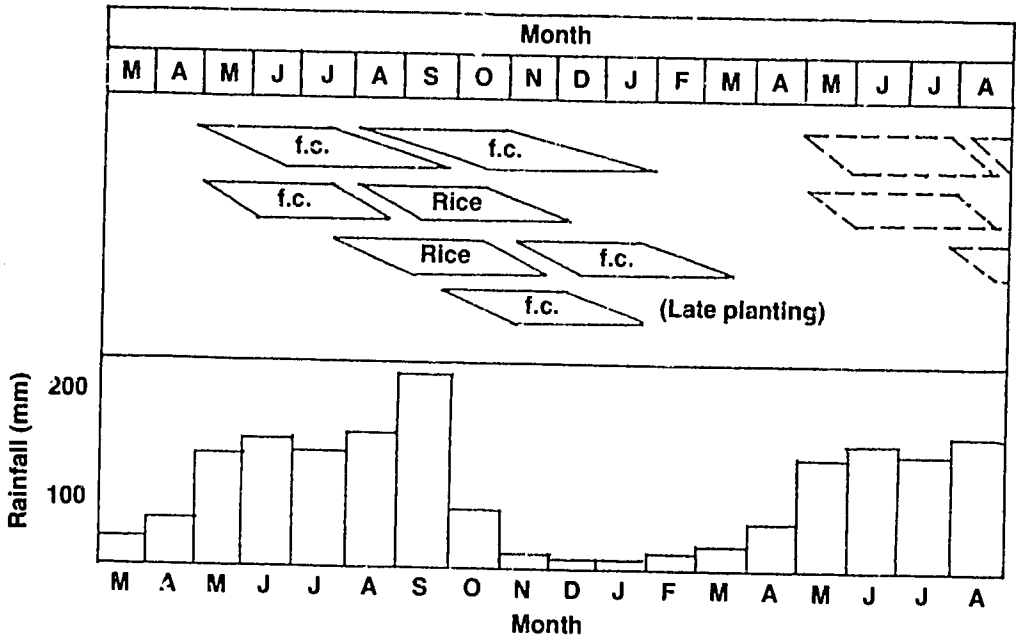

Figure 2. Calendar of the Improved Cropping Systems for the Upper Paddy Fields on Undulating Land in the Northeast as Proposed by the KKU-Ford Cropping Systems Project (f.c., field crop).

Because of the increased demand for rice to meet the needs of an increasing population, there should be a tendency for farmers to adopt direct seeding methods on the upper paddy fields. In low rainfall areas of Chaiyaphum, farmers in some villages have already started to use direct seeding by broadcasting rice seed and incorporating it by shallow plowing. This practice is followed when the rains come late, or when an earlier drought has destroyed the nursery bed. Although rice yield per unit area is rather low and can be unstable from year to year, the farmers are willing to take the risks (Jureerat Thomas, personal communication). In many areas of Khon Kaen Province, upland rice has been established for more than five years by some local farmers and it should be relatively easy to apply their methods and techniques to the upper paddy fields.

Indigenous Cropping Systems on the Upper Paddy Fields in the Northeast

The rice-based cropping systems evaluated by the KKU-Ford Cropping Systems Project were not entirely successful when implemented in certain areas of Khon Kaen Province. However, it was later learned that similar systems had been successfully established and utilized much earlier in some small areas of the Northeast. Examples of growing field crops before rice were found at a number of locations: sesame before rice (Changwat Buriram) and kenaf before rice (C. Chaiyaphum, C. Roi Et). Examples of field crops grown after rice on the upper paddy fields are: peanut and native cowpea (C. Surin), cassava (Amphoe Ban Phai, C. Khon Kaen), and rice-watermelon-kenaf (C. Roi Et). Some of these cropping patterns have been practiced for over 20 years (e.g., peanut after rice). Examples of some systems are shown in Figure 3.

Studies of existing cropping patterns have been undertaken by monitoring the farmers' cultural practices, assessing environmental changes (e.g., soil moisture status and water table fluctuations) and conducting farmer interviews (by KKU-Ford Cropping Systems Project/KKU-USAID Farming Systems Project). The results thus far have shown how the

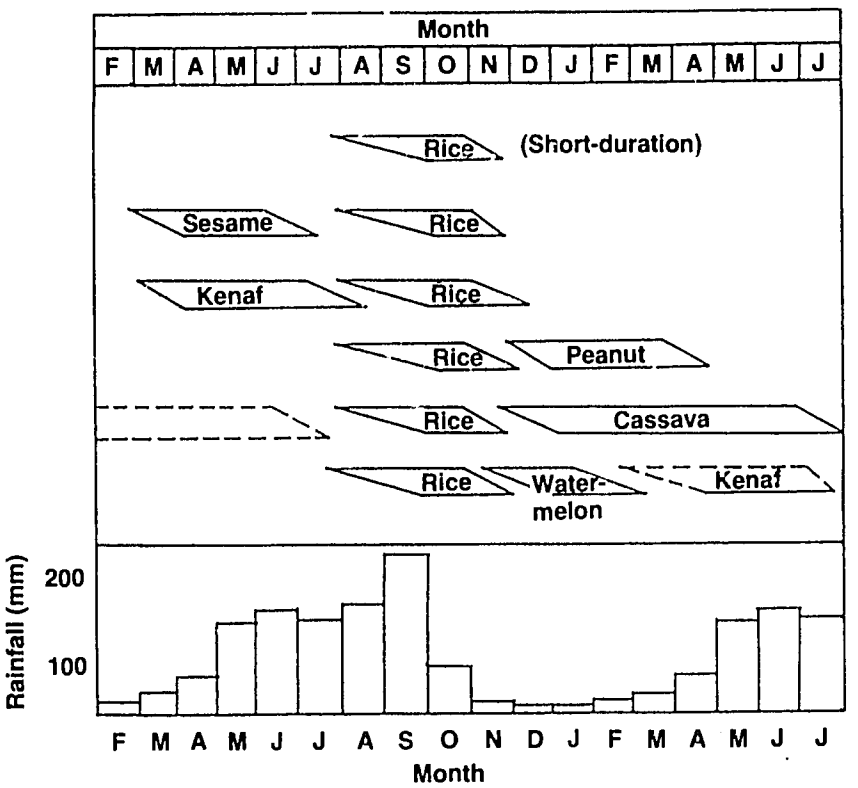

Figure 3. Alternative Cropping Systems for Upper Paddy Fields on Undulating Land in the Northeast.

farmers select a certain crop to plant under a specific set of environmental conditions and in accordance with certain modifications in cultural practices. It has been observed that land preparation and planting techniques can differ widely, depending on whether the field crops are grown before or after rice.

Where peanut is grown after rice, three to four tillage operations may be needed to ensure that the top soil is sufficiently finely tilled to conserve subsoil moisture. This practice is critical because there is an extremely low probability of any rainfall occurring during the first two months (December-January) of peanut growth. Thus, early growth of this crop will depend almost entirely on stored soil moisture. Peanut seed is also pregerminated to enhance early growth and then planted at about a five-inch depth when soil moisture is adequate for root growth (Polthanee, 1983). The success of this cropping system may also depend on choosing the right crop. For example, peanut has been observed to develop its entire fibrous root system along the tap root underneath the seed position (Limpinuntana, private communication). This is in contrast to many other field crops, particularly cereals, which tend to develop fibrous roots close to the soil surface even when they are deep-seeded (e.g., six to ten inches in corn) (Martin and Leonard, 1965). Rainfall may also modify crop performance. If off-season precipitation occurs before pegging (December-January), crop yields tend to be reduced. In contrast, early rains prior to the following rainy season (February-early March) tend to increase yields (Polthanee, 1983). The first type of rainfall often results in soil compaction which increases bulk density and impairs penetration of the young pegs into the soil. The second type of rainfall may serve to replenish the supply of stored soil moisture during the critical pod-filling stage.

Land preparation and planting techniques may be quite different when field crops are grown before rice. Kenaf and sesame are crops that can be grown successfully before rice. Both of these crops can survive extended periods of drought and resume normal growth when rainfall occurs. This type of crop is, therefore, most suited for growth during the light and sporadic rains which occur at the onset of the rainy season (February to April). For land preparation, plowing is done only once after the early rains have wetted the soil down to a depth of five to six inches. Seed is broadcast and the soil is immediately harrowed to cover the seed. It is essential that farmers finish land preparation and seeding within a short period to maximize germination and plant establishment before available soil moisture is depleted. Yield per unit area may be small but the total yield for one operation is high, thus, the available soil water must be efficiently used.

Careful monitoring of existing cropping systems suggests that good performance of certain crops, e.g., groundnut and sesame, may be location-specific and dependent upon the existence of shallow water tables. The utilization of capillary water from shallow water tables by crops may play an important role in supporting crop growth during the dry periods. On the other hand, performance of some crops such as kenaf may be less dependent on shallow water tables but more on adequate initial moisture to support early growth and establishment.

Improvement of Soil Fertility on Paddy Fields

Low fertility of paddy fields is the current problem of most concern to many farmers in the Northeast. This problem is particularly severe at sites where there is little or no adjacent forest land. In the past, reasonably high rice yields were obtained on the lowland paddy fields because of the accumulation of organic matter and debris from the nearby forest areas.

In view of the erratic rainfall patterns and inadequate levels of soil moisture, farmers are reluctant to apply chemical fertilizers on their paddy fields because of high risk due to drought and the high cost of fertilizers. The use of fertilizers in Northeast paddy fields is rather low, with an average of about 3-5 kg/rai of N-P-K fertilizer. Farmers will apply fertilizers by broadcasting, but very sparingly as a "medicine" on poor spots of paddy fields. However, both chemical fertilizers and animal manures are used intensively for the establishment of rice seedlings in nursery beds.

Most farmers prefer to put heavy rates of fertilizer on a few rai of high value cash crops grown after rice, e.g., watermelon (C. Roi Et), tobacco (C. Roi Et) and green corn (Ban Fang, C. Khon Kaen), and allow the following rice crop to be grown on the residual fertilizer from these cash crops. The farmers also rotate the plots where the cash crops are planted so that every paddy field can receive fertilizer every three to four years. Recently, it was observed that changing the rice variety from a traditional one such as San Pa Thon to an improved glutinous variety such as RD6 requires fertilizer input to achieve optimum yields. Farmers in villages such as Ban Hin Lard and C. Khon Kaen are now applying relatively heavy rates of fertilizer to this new variety.

For rice-based double cropping systems, we still do not know whether there is any effect of residues from field crops on subsequent rice yields. Where cassava is grown after paddy, some farmers claim that residues from unfertilized cassava can increase the yield of the following rice crop. Nevertheless, studies have not conclusively shown that there are benefits from cassava residues on subsequent rice yields (Watayanon, 1985).

Upland Crops

Zones of Upland Crops in the Northeast

The problems involving the production of crops on upland fields of the Northeast are generally less severe than for paddy rice. There are two principal zones for upland agriculture in the Northeast. The first is found at the foot of mountain ranges in the western, southwestern and southern parts of the region. The soils of this upland zone are rather heavy textured and very fertile since they originated from parent materials enriched in various mineral nutrients. Field crops that require more fertile soils are grown in this foothill zone, usually without the addition of fertilizers. Crops grown here are corn, sorghum, cotton, soybean, cassava and kenaf (KKU-Ford Cropping Systems Project, 1982). The chief constraints to crop production in the foothill zone are erratic rainfall, drought and unstable markets. The latter problem can be a most serious one for those farmers whose operations consist mainly of upland crops with little or no paddy land.

A second zone of upland crop production is the upper position of the topographic scheme shown in Figure 1, which is also referred to as a miniwatershed (KKU-Ford Cropping Systems Project, 1982). Farmers in this zone grow subsistence paddy in the depression areas and raise cash crops on the upland areas. These upland soils have been extensively leached and eroded and, consequently, are of low fertility, sandy texture, low water holding capacity, low organic matter, low pH and low cation exchange capacity (KKU-Ford Cropping Systems Project, 1982). Upland crops grown on these areas are mainly low-input and long-duration type such as cassava and kenaf.

Rationale for Growing Cassava and Kenaf on the Upland Areas

Farmers choose to grow the low-input, long-duration upland crops on the undulating, upland areas because they are basically rice farmers who have little available labor for other crops during the rainy season. Since precipitation at the onset of the rainy season is light and sporadic, the crops most suitable for these conditions are those which are drought tolerant, and also able to grow on low fertility sandy soils. Moreover, the long growing period of these two field crops allows the farmer to devote most of his time and labor to transplanting rice during the rainy season (June to September). Early establishment of cassava or kenaf at the onset of the rainy season also provides plenty of time for weeding. Upland crops grown during the rainy season, especially with the addition of fertilizer, require considerable hand labor for weed control and compete with rice transplanting for available labor. Early establishment of kenaf allows for leaf canopy closure prior to the period of midseason, high rainfall intensity, providing effective control of soil erosion. Also, growing cassava at the end of the rainy season (October) can further reduce both weeding activity and soil erosion.

Figure 4 shows how the farmers of undulating upland areas may allocate their time and labor on different types of land (Polthanee, 1983).

Problems of Upland Crop Production and How Farmers Resolve Them

The problem with cassava and kenaf planted on upland with undulating topography is mainly low productivity rather than yield instability. Low yield per unit area has been cited by many farmers who have grown cassava and kenaf on the same piece of land for several years. A few farmers have already started to fertilize cassava and kenaf. Once used, the fertilizer rate is still low (about 10 kg/rai of mixed N-P-K fertilizer). For both cassava and kenaf, chemical fertilizer is added at the time of weeding, mainly by broadcasting. In some villages, one spoonful of chemical fertilizer plus one handful of livestock manure are used to sidedress the cassava plant. Some farmers of Tambon Donchang, a subdistrict in C. Khon Kaen, grow upland rice in rotation with cassava. High yields of upland rice (300-500 kg/rai) have been obtained with the application of 20 to 30 kg/ha of a mixed N-P-K fertilizer. Farmers also reported increased yields of cassava

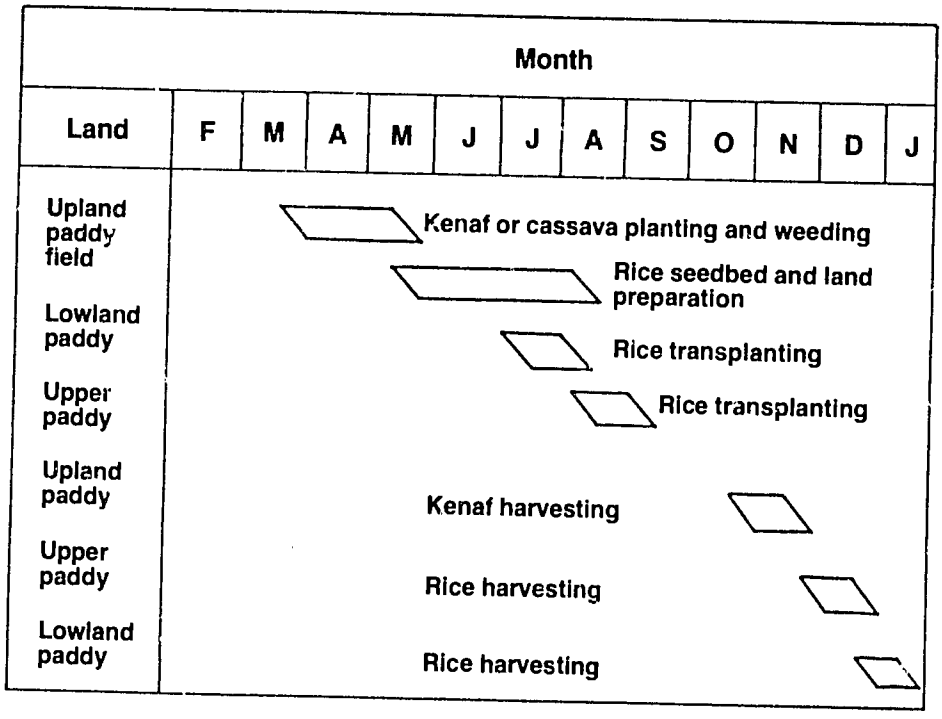

Figure 4. Seasonal Distribution of Labor for a Farm Household Cultivating on the Three Positions of Undulating Land (Polthanee, 1983).

when planted after upland rice that received heavy fertilization. Some farmers occasionally rotate cassava with peanut and have attributed increased cassava yields to the peanut plant residue.

Research on Improvement of Cropping Systems for Undulating Land

Improvement of cropping systems on the upland position of the undulating topography of Northeast Thailand was also a goal of the KKU-Ford Cropping Systems Project during 1976-1983. Types of cropping systems tested included intercropping of cassava with short-duration field crops, double cropping of two short-duration crops (to replace cassava and kenaf), and growing short-duration field crops after kenaf (Figure 5). Results of these studies can be obtained from a number of sources (KKU-Ford Cropping Systems Project, 1982; Polthanee, 1983; Patanothai, 1984).

For intercropping of cassava with short-duration crops, the most promising patterns were cassava and peanut, and cassava and red cowpea, as these patterns produced higher income than growing cassava alone in several trials. However, farmers were reluctant to adopt intercropping of certain crops because of the additional labor requirement. Weeding was the main constraint to intercropping of cassava since it takes three to four times longer than on cassava monocropping. This, of course, competes for labor normally devoted to rice transplanting. Traditionally, farmers accomplish weeding by running a buffalo plow along the cassava rows. Intercropping cassava with a legume prohibits the use of buffalo in weeding. The weeding then must be done with hand labor, i.e., with a hoe. Moreover, to obtain yield stability, both cassava and the intercropped legume must be planted rather late in the rainy season (late April-June), increasing the probability of insect problems.

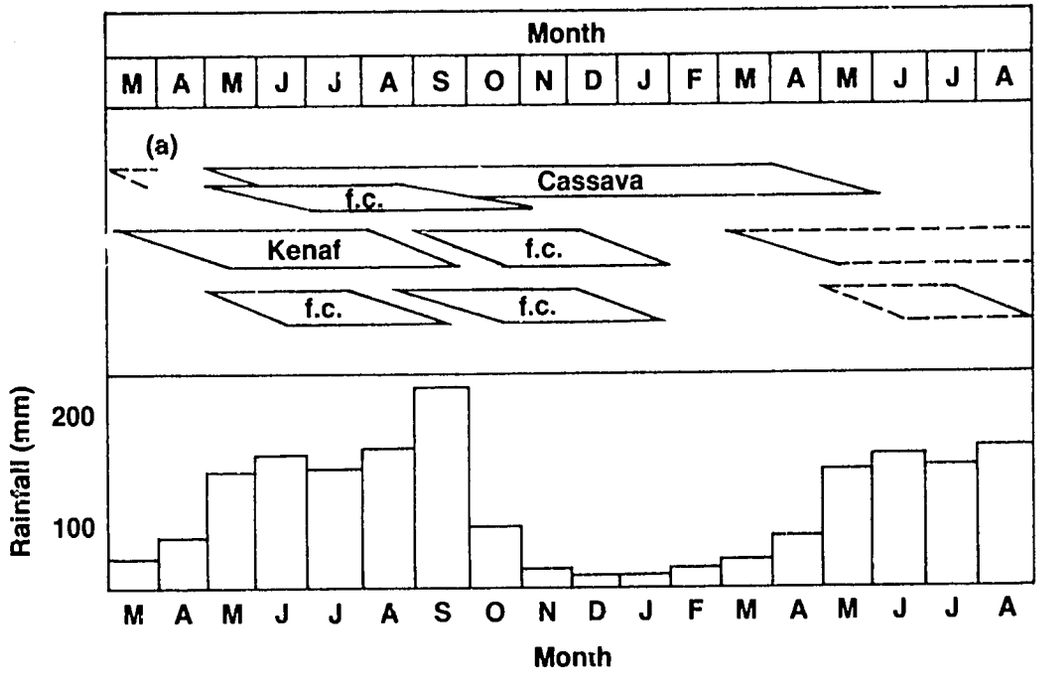

Figure 5. Calendar of the Improved Cropping Systems on the Upland of the Undulating Topography Proposed by KKU-Ford Cropping Systems Project (a, traditional planting date; f.c., short-duration field crop (2-1/2 to 4 months)).

Growing short-duration field crops after kenaf produced poor results as assessed by the Cropping Systems Project. The decrease in kenaf fiber yield due to early cutting could not be compensated by the net return from the subsequent field crops. Many second crops showed low and unstable yields because of insufficient soil moisture. However, this type of cropping system, e.g., kenaf-peanut (C. Surin), kenaf-watermelon (C. Nakon Phanom), is practiced by some farmers in certain areas of the Northeast.

The kenaf is cut at full maturity, then the second crop is grown successfully on the capillary soil water derived from the shallow water table below.

Growing two short-duration field crops to replace cassava and kenaf on the upland areas is not likely to be adopted by the farmers. Most crops tested required much higher cash inputs for fertilizers and pesticides, and more labor than cassava or kenaf. The double cropping systems also competed with rice transplanting for labor. Establishment of the second field crop was also difficult due to waterlogging from heavy rains. Risk of soil erosion was substantially increased after the soil had been plowed and harrowed for the second crop. The farmers themselves avoid planting crops on the upland during the rainy season, but if they do, the crops are planted in beds to avoid waterlogging and to prevent soil erosion (e.g., growing watermelon in September in Ban Sam Jan, C. Khon Kaen).

Conclusion

This paper has described the current cropping systems at the farm level in the Northeast, identified the principal agronomic and economic constraints to increased agricultural production with these systems, and suggested ways in which the systems can be improved. Noteworthy conclusions are as follows:

1) There are cropping systems in the Northeast that utilize rainfall and residual soil moisture very effectively and efficiently, e.g., sesame/ kenaf before rice at the onset of the rainy season, and peanut after rice during the dry season.

2) Farmers in the Northeast are willing to invest in high-input cropping systems (e.g., growing watermelon after rice) as long as the stability of the whole system is maintained, including available and stable markets.

3) Farmers in the Northeast do not seek to establish a high yield per unit area of any one particular crop (as those of us in research attempt to do), but they tend to assemble several crops together with other farm activities into a whole system and then assess the total net return from that system.

Therefore, a better understanding of how and why the farmers organize and manage their own farming systems and how the systems adjust to the natural and socioeconomic environments is urgently needed. Such understanding will help us, as scientists, to identify the type of both basic and applied research that is applicable and appropriate to the farmers' circumstances. It will also help extension workers to be more effective in the transfer of technology to the farmers.

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Soil and Water Management Research Experience in the Central Region

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ABSTRACT. Understanding the complex interaction of soil properties, plant growth and development, and atmospheric-environmental relationships is a basic prerequisite to the development of an improved crop production management program. Past soil and water management research efforts were aimed at collecting and analyzing relevant data and quantifying some of the soil-plant-water relationships for use in systems modeling. In the Central Highland region of Thailand, the goal is to utilize the modeling approach to evaluate and characterize those relationships that would best stabilize and improve the field crop production systems for soils of the Ultisols order.

This paper discusses some of the important considerations and constraints in the modeling approach and emphasizes the importance that modeling can play in future agrotechnology transfer schemes.

Introduction

A high percentage of soils in the Central Highlands corn belt belongs to the order of Ultisols. This classification implies that the soils are very old and inherently low in plant nutrients. Soil fertility is contained primarily in the organic matter or humus fraction and not in the kaolinitic clays which are generally the dominant mineral component of these soils. Trees exploit these soils by removing nutrients from deeper soil depths and recycling them near the soil surface in decomposing leaf litter. Forest canopies provide the necessary protection of topsoils against soil erosion and nutrient losses from intense tropical rains. Humus, in effect, helps topsoil hold water against dry spells and by absorbing runoff, it slows erosion. Thus, a satisfactory natural equilibrium for the semiarid tropics is sustained.

Indiscriminate deforestation has created such rapid ecological imbalance in the hydrologic cycle, energy balance and biotic environment that the region has become reputed for the hazards of drought, fire, flash floods and severe soil erosion. These adverse environmental conditions are also often conducive to insect and disease infestation, which can inflict widespread damage to crops. With proper management, the newly cleared forest areas can maintain a satisfactory subsistence level of production for a number of years. As long as farmers did not expect a high yield from these lands, they usually found that the natural fertility of the soil was sufficient. In fact, until the last decade, little attention was given to the problems of fertility and conservation of these lands and essentially all crops were cultivated without fertilizer The most damaging circumstances, however, have been attempts to "modernize" crop production. Modern technology and economic pressures have helped encourage a riskier way of farming, i.e., a shift away from mixed crop-livestock farming, crop rotations and soil conservation practices toward intensive row cropping and chemical weed control which render soils vulnerable to erosion and nutrient runoff. Topsoil left unprotected on a hill slope gradually gives up its organic matter to a thin sheet of moving water. Tropical rains are intense with a high energy load and can cause severe erosion to exposed soil, particularly when the soil is freshly plowed and has little or no residue to protect the surface from direct raindrop impact. As the slope erodes, runoff increases and less water infiltrates. Thus, in those areas where water storage in the soil profile is critical, there will be little available for future use and crop yields will be reduced because of moisture stress and drought. The thinner the topsoil layer, the greater the productivity loss for each additional increment that erodes. In shallow soils, or those areas where the water holding capacity of the topsoil has been reduced by continued overcultivation, crop productivity cannot be restored by only applying more fertilizer.

This is the situation which many farmers are currently facing. The hazards are particularly prominent in maize production on soils commonly referred to as Pak Chong and which belong to the family of very fine, clayey, kaolinitic, acid Oxic Paleustults.

Agronomic Results and Observations

Results from six years of experimentation show that a greater and more stable yield of maize can be achieved with zero-tillage compared to tilled Pak Chong soils (Table 1). In fact, untilled soil with killed-sod cover results in greater rainwater conservation, i.e., greater infiltration and a reduction in evaporative water loss (Tongyai *et al.*, 1981). Table 2 shows results from runoff plots in the adjacent area of Phra Phuttabat Station (Ueno *et al.*, 1983) where a 16 to 20 percent reduction in runoff occurred under cropped no-till plots compared with conventional tillage. Although these figures may be less than generally expected, they do demonstrate the fact that runoff can be greatly reduced. Even when soils are poorly managed, infiltration and the retention/storage of precipitation can be substantially increased with no-till compared to conventional tillage.

The agronomic solution to greater and more stable crop yields in the Central Highlands-Northeast Plateau regions, where short-term droughts of approximately 20 days are common, tends to be increasingly weighted toward conservation tillage practices. There are, however, many constraints associated with the practice of conservation tillage. The most important prerequisites for success are fertilizer application and a good weed control program.

Nitrogen fertilizer, particularly, is needed as a normal crop requirement and to offset the effect of microbiological immobilization of mineral nitrogen. During early maize growth the killed-sod cover, which has a wide C/N ratio, undergoes decomposition. This could lead to a temporary, but serious, nitrogen deficiency for crops. The recommended N-fertilizer level for tilled soil, however, appeared to be adequate in the zero-till experiments at Phra Phuttabat Station and Suwan Farm.

Table 1. Grain Yield of Maize Under Varying Tillage Practices and Fertilizer Applications from a 1979-1984 Long-Term Experiment on Pak Chong Soil at Phra Phuttabat Station, Lopburi, Thailand (Tongyai *et al.*, 1981).

Tillage Practice	Fertilizer			Grain Yield					
	N	P	K	1979	1980	1981	1982	1983	1984
				..... *kg ha*$^{-1}$					
Rough conventional	-	+	+	2140	2210	2800	1630	2890	1020
	+	+	+	3000	4280	3960	2500	3420	1880
Powdery	-	+	+	1980	1980	1960	1220	2410	130
Conventional	+	+	+	2590	2620	4910	2710	2220	430
Zero-till	-	+	+	1590	3210	1550	1190	3570	1390
	+	+	+	3080	5160	5380	3640	4010	3430
Seasonal rainfall (mm)				320	730	850	500	670	490

The method/rate of N-fertilizer application under this higher zero-till moisture regime needs to be investigated in more detail, particularly in relation to soil water movement characteristics. The greater leaching of NO3-N that has been observed in some zero-till experiments could be a great economic constraint to the use of this management practice in many areas.

The fertilizer requirement for crops was essentially the same for zero-till and conventional tillage at the Phra Phuttabat Station. Here, the downward movement of water is greatly impeded below a depth of 50 cm by subsoil characteristics. In 1979, low rainfall conditions, conventional tillage and the application of a high rate of fertilizer to maize resulted in noticeable salt injury, with only slight effects observed under zero-till. In an experiment at Suwan Farm, where the soil is deep and downward water movement is not noticeably restricted, greater leaching was observed under zero-till conditions. These conflicting results suggest a complex interaction between soil water movement and the behavior of N-fertilizer under different tillage systems. This should be investigated for all locations before zero-till systems are widely recommended. Since these soils are known to be deficient in phosphorous and the incidence of potassium deficiency is frequently observed in imbalanced fertilizer experiments, other fertilizer requirements should also be studied.

Table 2. Runoff as Percent of Total Annual Rainfall from a 1981-1982 Experiment on Pak Chong Soil at Phra Phuttabat Station, Lopburi, Thailand (Ueno *et al.*, 1983).

Tillage Management	Conditions		Runoff	
	Crop	Slope	1981	1982
		.....	%	.....
Conventional	-	1	38	41
		5	50	49
	+	1	26	31
		5	33	38
Cornstalk mulch	-	1	15	6
		5	21	16
	+	1	3	2
		5	11	6
Zero-till	-	1	21	27
		5	21	15
	+	1	9	6
		5	17	12
Annual rainfall (mm)			930	920

As mentioned earlier, it is of the utmost importance to have a good weed control program prior to planting because conservation tillage practices rely heavily on the use of herbicides. Too much vegetation in the field might require mowing or some other thinning method before applying a herbicide. Increasing the rate of herbicide application, or follow-up applications may also be necessary for effective weed control. On the other hand, insufficient vegetation would not provide the necessary protection of the soil surface which, in turn, would lower the effectiveness of the method. Therefore, weed taxonomy, growth and development characteristics, and methods to effectively control weeds should be studied thoroughly at every location where conservation tillage is likely to be adopted.

There is great concern regarding the use of paraquat, the herbicide that made conservation tillage possible. This bipyridyl herbicide is highly toxic to man and has no known antidote. If ingested orally, it causes damage to the lungs, kidneys and liver. If splashed into the eyes, it is a severe irritant. It is likewise a moderate skin irritant, but it does not appear to be significantly absorbed through intact skin (WHO, 1975 Data Sheet on Pesticides No. 4). Paraquat, however, is already widely used in this region. Thus, careful attention should be given to each specific area where the herbicide may be used, particularly taking into account the water supplies available for emergency situations and the need of users to take precautionary measures when working with it.

The greatest potential benefit of conservation tillage would be its long-term contribution to maintaining and improving soil productivity. For example, there is no waiting period necessary to perform tillage. Cornstalks can be easily knocked down to provide more effective soil cover which helps to conserve enough soil water at the end of the cropping season for growing another short-term legume crop such as cowpeas or mung bean. Residue left on the soil surface in this manner not only serves as mulch, which reduces evaporation and provides the necessary protection against direct raindrop impact, but it also decomposes slowly, thereby providing a valuable addition to soil organic matter. Residue from the relayed legume crop provides an additional measure of low C/N organic matter to the soil, which contributes to the improvement of soil productivity.

The experimental results indicated that only four out of six years received adequate rainfall at the end of the growing season to support a second crop. Nevertheless, the tilth and friability of the soil was noticeably improved after three to four years of a maize-cowpea rotation. A suitable cropping pattern, however, will depend primarily on the weather, more specifically the rainfall distribution/water balance, which would have to be analyzed for each specific location.

It is obvious from this brief discussion that many factors need to be investigated, and their effects integrated, before conservation tillage management practices can be properly and confidently recommended for any specific area. Using the trial-and-error approach would certainly be costly, not only in terms of the budget and manpower, but also in terms of the loss of valuable time.

The Modeling Approach

In modeling, the effects and/or interactions of various factors on plant growth and development are quantified and then assembled into an integrated model in an orderly manner. This type of model, when properly assembled physically and mathematically, can be used to simulate plant growth and development under various soil-water-plant nutrient conditions, management practices and environmental situations. Thus, the effects and interactions of these factors on crop yield, which is the most important criterion in crop production, can be determined and characterized.

Modeling of crop growth and development has been restricted to certain conditional relationships because of insufficient detailed information on soil-water-plant-atmosphere-environment relationships and, obviously, the voluminous data and computational capability are needed to run a simulation model. Advances in research, through the development of higher precision instrumentation for measuring the soil-plant-water-nutrient relationships, plus the availability of low-cost high-power computers, now makes it possible to utilize this powerful analytical tool more fully.

The CERES-WHEAT, CERES-MAIZE and SOYGRO models presently used in the U.S. demonstrate that modeling crop growth is possible. Their utilization for decision-making in production management, even for determining the most suitable insect spraying program, demonstrates their powerful capability for practical application.

In research, a model serves as a practical two-way analytical tool. Not only does it enable greater detailed and integrated analysis of the results of experiments, utilizing all available and essential data more fully, but it also aids in a better planned and organized data collecting system, minimizing the data sets to those that are most essential and sensitive for the research situation. At present, conservation tillage research is being studied under the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) program. This program is aimed at collecting their interrelationships and characteristics to fit the crop growth model, and, through computer simulations, determining their applicability and sensitivity to the system. After the relationships and the model have been refined, the essential minimum set of data for extension of prediction to other sites will be identified and collected. The overall objective is to achieve greater precision and reliability in agrotechnology transfer.

Although many relevant past research results are already available, they generally lack certain essential data to enable their direct use in this research scheme. They will, however, still be useful for verification purposes after the model is completed. In studying the IBSNAT minimum data set scheme and some of the mentioned models, it is obvious that many soil, plant and atmospheric parameters and relationships still need to be evaluated for their applicability under tropical conditions and conservation tillage situations. At least one experiment will have to be set up with detailed measurements and samplings of soil and plant characteristics to obtain the necessary basic parameters and relationships required for the model.

The experiment at Suwan Farm was set up to gather this basic soil-plant information in addition to the maize N-fertilizer requirements under conventional versus zero-tillage systems. Suwan Farm (the National Corn and Sorghum Research Center) was selected because it is located on Pak Chong soil and it is fairly well-equipped for collecting the minimum data set. During the study, however, many problems in the experimentation and data collection procedures became apparent. Five main problem areas are identified below.

The Need for a Highly Detailed Data Collection Program

The manual provided by the IBSNAT Program to participants was very thorough in detail on experimental design and minimum sets of soil-crop-weather data necessary for testing and validating simulation models. However, it did not elaborate on how these data are presently being utilized in the simulation models. To a researcher who lacks knowledge in some of the specific fields and who has little or no background in modeling, this manual will be misleading. He will collect only the minimum data set, thinking that it is adequate for simulation purposes. Actually, meaningful simulation is possible only when the basic soil, plant and atmospheric parameters and relationships have already been established. This calls for a much more detailed data collection program.

The Need for a Basic State-of-the-Art Manual

Since it is unlikely that every researcher will be knowledgeable in all of the fields integrated into the simulation model, i.e., micrometeorology, soil-plant-water relationships, and plant physiology and nutrition, it is absolutely necessary that information on standard and alternative procedures, and the state-of-the-art information in obtaining these basic parameters and relationships be made available to all participants. To produce such a manual, however, would be a major undertaking and would require cooperation from scientists with expertise in all the specific fields. This can probably be arranged only by an organization such as IBSNAT.

The Need for Instrumentation

Many key instruments for precision measurements in the field will not be available for many years under normal budgetary situations. This is an important problem for many developing countries and could be a major setback to this type of integrated research program. Among the most needed instruments are data loggers and sensors for acquisition of micrometeorological data, precision balances, ovens, portable area meters and neutron moisture meters with surface and depth probes.

The Need to Demonstrate the Importance of Modeling

Each key participant needs to have available a personal computer (PC) compatible in capacity and capability with those used by others in the network. This is essential not only for the data gathering and analysis/organization/communication/modeling work required by the program, but also for ease in demonstrating and convincing other researchers, administrators and colleagues of the importance of the modeling activities.

The Need to Establish Scientist-to-Scientist Linkages

There is a need to establish scientist-to-scientist linkages, especially between scientists with the same field of interest, in countries within the network so that a more personal research atmosphere can be achieved. This will promote a more effective exchange of information, closer cooperation among research scientists and a more productive effort overall.

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Soil and Water Constraints and Management in Rice-Based Cropping Systems of Songkhla Lake Basin

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ABSTRACT. Most of the rice producing areas of Southern Thailand are located on the eastern coast and are characterized by a short rainy season and a pronounced dry season. One such region is Songkhla Lake Basin. Rice production is dominated by a single wet season rice crop cultivated under rainfed conditions.

As large-scale irrigation projects are under study for Sathing Phra peninsula, this paper points out some features of the present soil and water constraints and management in rice-based cropping systems in the Sathing Phra area in order to evaluate the feasibility of such irrigation projects.

Regarding the rainfall pattern probabilities and soils properties, the difficulty of controlling the water level in paddies is the key constraint to soil and water management in the area.

During the rainy season, the sudden and high flooding forces farmers to grow dryseeded rice in such conditions that drought may occur both at the early stage of cultivation and at grain filling. The quality of land preparation is the major determinant of yields.

In contrast, during the prerainy season, upland crops like mung bean are generally dramatically damaged by temporary waterlogging of soils. The value of irrigation without a good drainage network is then highly questionable. Other relevant research programs are discussed.

Introduction

Southern Thailand is often erroneously classified as belonging to the wet monsoonal tropics. Closer analysis of rainfall data reveals that the eastern plain, with only three consecutive wet months (monthly rainfall > 200 mm) and a pronounced dry season (at least two months < 100 mm), is comparable to the major part of central and north Thailand (IRRI, 1974; Apakupakul, 1984).

In fact, most of the rice producing areas of Southern Thailand are located on this eastern plain such as along Songkhla Lake Basin (SLB) with almost 1.5 million rai (240,000 ha) of paddies (Figure 1). Rice production is dominated by a single wet season rice crop cultivated under rainfed conditions. Yields average 250 to 300 kg/rai (1.6 to 1.9 t/ha). According to SLB Project estimates (1985), the existing irrigation systems together may cover a total of 69,000 ha (29 percent of the total area), but this is mostly operative during the wet season rice cultivation. Only five percent is irrigated during the dry season for rice cultivation and probably less than three percent of the paddies are being used for field crops between rainy seasons.

As Southern Thailand is a net importer of rice from other parts of the Kingdom, the temptation is great for agricultural planners to propose irrigation projects in the belief that these will improve rice-based cropping systems. The recent construction of a 56 km canal (ARTHIT canal) from Ranot to Songkhla, together with the launching of a feasibility study of a salinity barrier on Songkhla Lake which could irrigate up to 200,000 rai (32,000 ha), illustrate this latter belief.

One should consider, however, whether irrigation is really the answer to improving the existing rice-based cropping systems of Songkhla Lake Basin. The aim of this paper is to point out some features of the present soil and water constraints and management in rice-based cropping systems of SLB in order to evaluate the potential usefulness of irrigation.

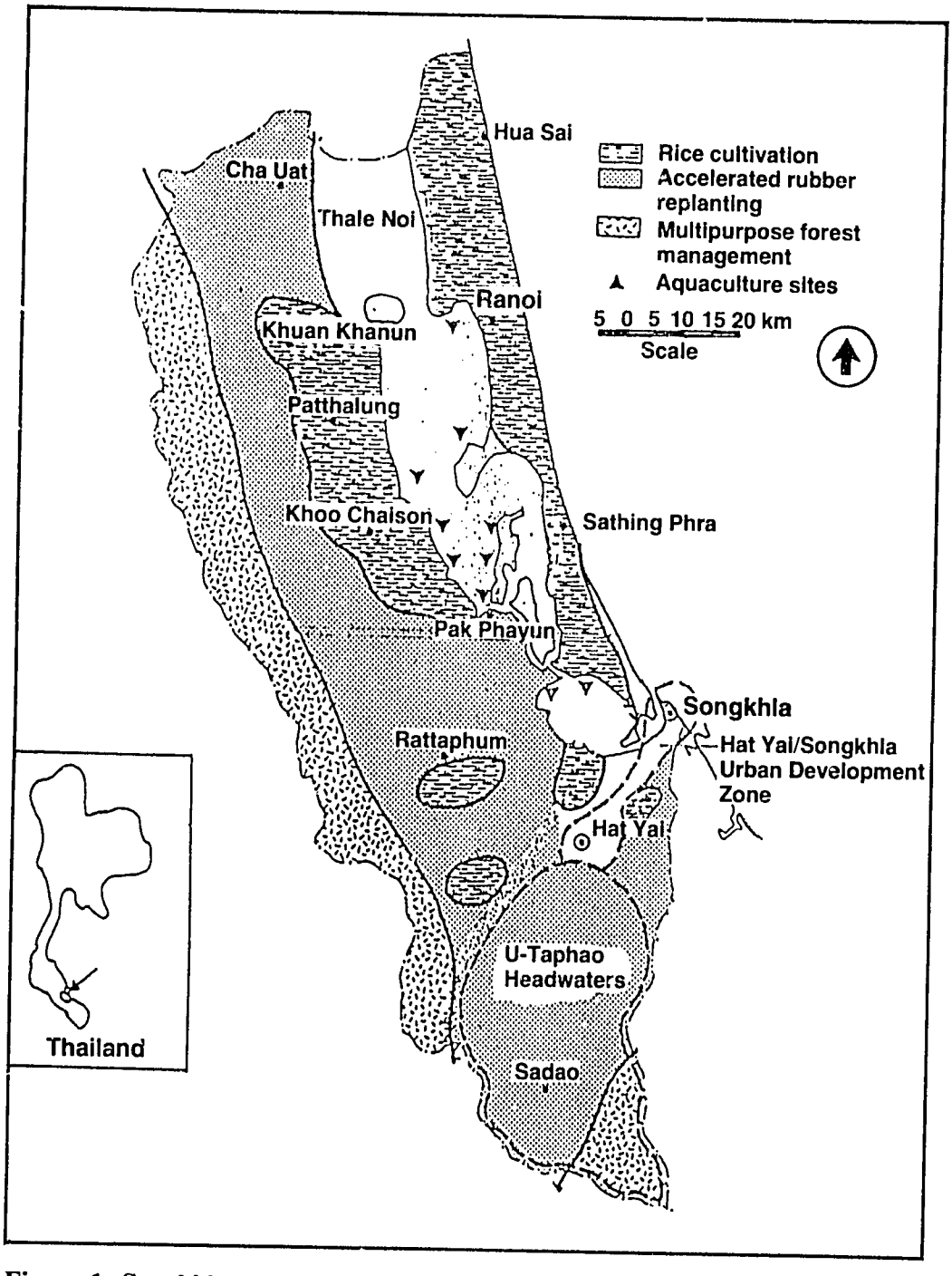


Figure 1. Songkhla Lake Basin Resources: Location of the Principal Rice Producing Areas.

This evaluation will focus on the peninsula area of Sathing Phra, primarily because it is the target area of these large-scale irrigation projects, and second because detailed analyses and research have been carried out in this area by the Thai-French Farming System Research Project since 1982 (Trebuil *et al.*, 1983; Trebuil, 1984; Crozat, 1985).

Rainfall Pattern and Soil Characteristics

Serious interannual variability characterizes the rainfall distribution of the area. The annual mean reaches 2100 mm and more than half of this amount falls from October to December (1300 mm). Figure 2 shows the lower (0.2 prob.), median (0.5 prob.) and upper limits (0.2 prob.) of the ten-day rainfall pattern in Sathing Phra peninsula, based on 28 years of recording.

According to Gomez (1983), by superimposing potential evapotranspiration (PET) and 1/2 PET (Penman formula) on rainfall patterns, three seasons may be defined but with variable boundaries.

1) A rainy season defined by rainfall (R) > PET starts in rainy years on September 10 (upper limit of rainfall) and in dry years on October 20 (lower limit of rainfall). It ends on December 20 during dry years and on January 10 during rainy years.

2) A poorly delineated dry season (R < 1/2 PET) starts in January and ends either on May 10 or continues until the onset of the rainy season. The probability of either condition is 0.5.

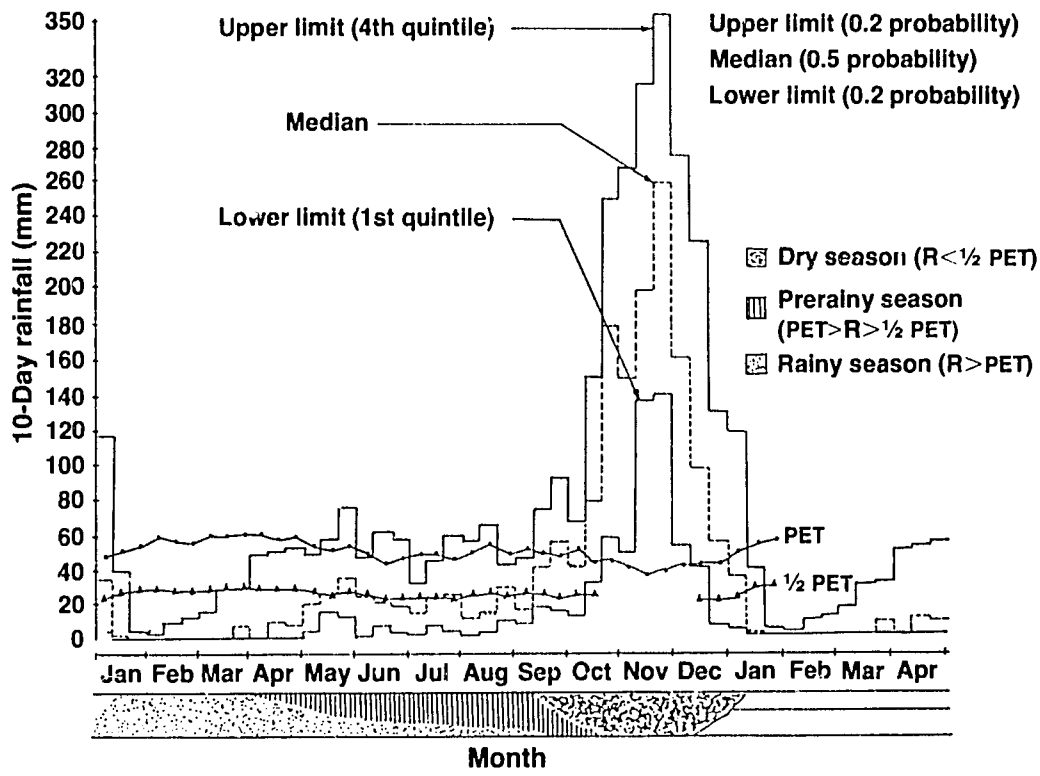


Figure 2. PET and 1/2 PET Estimated by the Penman Formula from Songkhla Meteorological Station's Data (1974-1982) Superimposed on the Upper Limit (Upper 0.2 Prob.), Median (0.5 Prob.), and Lower Limit (Lower 0.2 Prob.) of the Ten-Day Rainfall Pattern in Sathing Phra (1955-1983). The Range of Duration of the Different Seasons of the Year are Denoted.

3) In years in which there is an early end to the dry season (0.5 prob.), a prerainy season (PET > R > 1/2 PET) may be defined from May 10 to September 20. However, rainfall distribution appears erratic and dry periods (R < 1/2 PET) alternate with rainy periods (R > PET).

The land formation of the peninsula is quite recent (Quaternary) and still undergoing change (Sawata *et al.*, 1983; Trebuil *et al.*, 1983). It is dominated by sedimentation of clay and mud in the west (hydromorphic alluvial soils and low humic gley soils) and the addition of new sand bars formed by marine deposits in the east (Regosols). From the coast (east) to the lagoon (west) ten agroecological zones have been identified along the peninsula (Figure 3). From a rice-based cropping systems point of view, these zones represent three main agroecological units whose main features are summarized in Table 1.

Except for Unit I, which represents less than five percent of the cultivated area, rice-based cropping systems are situated on clay-textured soils with low fertility and poor to very poor drainage. The location of the peninsula, caught between the sea and the lagoon, increases this drainage problem.

Table 1. Main Features, and Agronomic Use and Problems of the Different Agroecological Units of Sathing Phra Area.

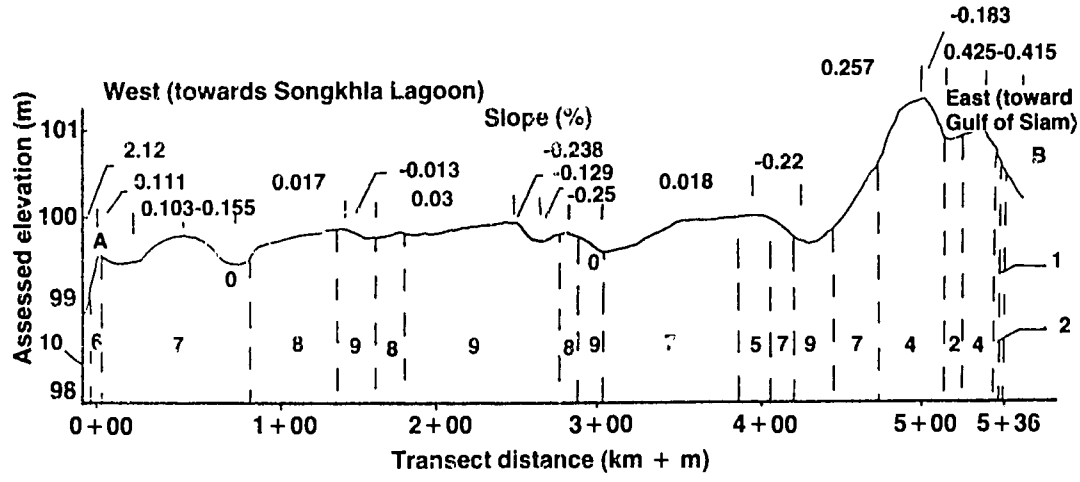
	Agroecological Units		
	I	**II**	**III**
	Village areas, ridges	**Paddies surrounded with sugar palm trees** *(Borassus flabellifor)* **planted on the bunds**	**Low paddies without sugar palm trees**
Main features of the unit	-Sandy soil -pH < 5.1, P, K very low -%C < 0.7% -Fast drainage	-Sandy clay soils in the upper parts (limit of UNIT I) to clay to heavy clay soils in the lower parts (limit of UNIT III -pH < 5.5, P very low, %C < 1% -Drainage: slow	-Clay to heavy clay soils -pH < 5.3, P very low % C < 1.2% -Drainage very slow -Early flooding
Agronomic use and problems	-Gardens + some rice fields -Low fertility -High weed infestation in paddies -Diseases -Drought	-Rice exclusively and sugar palm trees -Wide range of suitable technical itineraries for rice according to microtopograpy and farming systems -High weed infestation -Poor soil structure -Low fertility for rice -Drought during rice grain filling	-Rice exclusively -High diversity of technical itineraries determined by rainfall distribution of the year and the risk of fast flooding -Early land preparation which leads to poor soil structure

In terms of soil and water management, the inability to control the water level in the paddies is the key to understanding the existing cropping systems. Most of the farmers' management tactics are based on security techniques set up to avoid the consequences of sudden flooding (especially at the onset of the heavy rainfall) together with drought that may occur because no irrigation network exists.

These environmental constraints affect soil and water management by farmers during rice cultivation in the rainy season. They may also explain the quasi-inexistence of a second crop during the prerainy season.

Soil and Water Constraints During the Rainy Season

The irregular rainfall distribution and the inability to control the water level in paddies allow only one rice crop a year. The rice cultivation period ranges from mid-August to March with a peak harvesting time generally occurring in February.



Zones	Characteristics	
0	Drainage canal.	
1	Sand dunes on present existing coast.	
2	Uninhabitated coastal land.	
4	Type A village on sand ridge, with many gardens.	Agroecological
5	Type B village on narrow sand ridge, with few gardens.	Unit I
6	Type C village beside the lagoon.	
7	Sugar palm trees closely associated with rice.	Agroecological
8	Sugar palm trees loosely associated with rice.	Unit II
9	Rice field without sugar palm tree.	Agroecological Unit III
10	Grassland beside the lagoon.	

Figure 3. Topographical Profile and Distribution of Agroecological Zones Along an East-West Transect Line of Sathing Phra Peninsula.

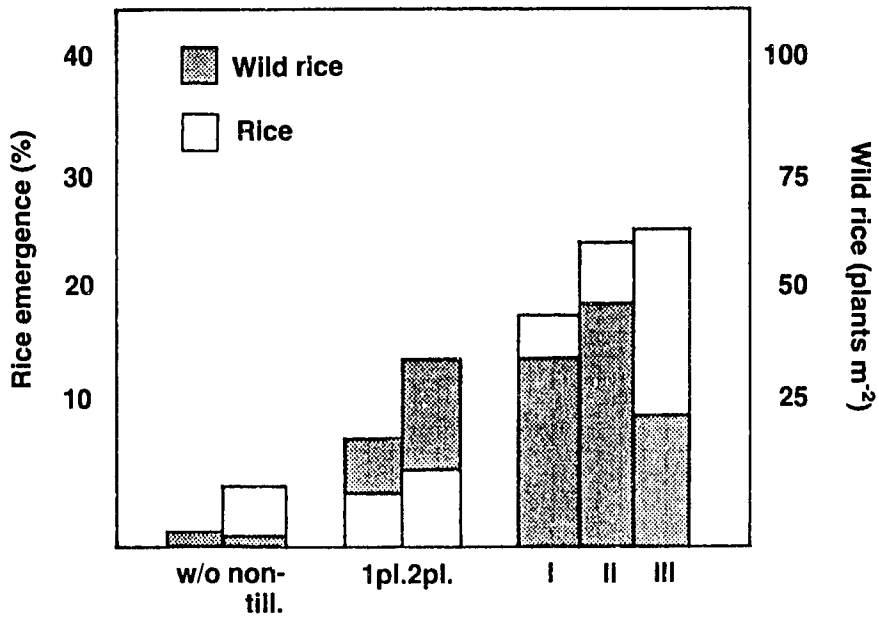
Replanting is seriously limited since water level conditions required for this technique last only a short time and then create too high a manpower demand over a short period. In 1982, only 15 percent of cultivated paddies were transplanted, principally in upper paddies of Unit II, because the onset of heavy rain was late and rapid (end of October). Thus, in order to plant all their rice fields, farmers broadcast dryseeded rice early, generally after a single plowing under dry conditions. To avoid a peak of work and the hazard of flooding, they also combine this technique with the use of a wide range of local varieties. These varieties are chosen according to the maximum water level (20 to 120 cm) and the duration of flooding that may be expected in the paddy.

Different varieties may even be found within the same field if the microtopography varies. Late-maturing varieties (180-200 days) adapted to high water levels are broadcast early in the lowlands of Unit III and in some of Unit II because flooding occurs early and persists. In contrast, early maturing varieties (150-160 days) are suitable for the upper parts of Unit II.

Under such water conditions, drought probability is high at the beginning of rice growth whatever the planting date and the agroecological unit (Table 2). Drought probability during grain filling is low in lower paddies of Units II and III but relatively high in upper paddies of Unit II (Table 2). One should consider that the use of a crop coefficient equal to 1 underestimates drought probability after the full tillering stage. On the other hand, a water level of more than 50 cm may occur during the second half of November with a probability of 0.60, and even earlier if daily variation of water level is considered. Careful land preparation is then a key to improving rice yield. The abundance of big-sized clods that generally characterize the seedbed leads to poor rice emergence and distribution and to high weed infestation, especially of wild rice (*O. perennis*) (Figure 4). As a consequence, weed control, which can be done only by hand, is very time-consuming (150 days/ha). The extent of hand-weeding directly affects the amount of fertilizer used by farmers and, consequently, the yield (Trebuil *et al.*, 1984). With no hand-weeding, farmers usually apply less than 20 kg/rai 16-20-0. A maximum yield of 420 kg/rai was recorded with complete hand-weeding and the use of 45 kg/rai 16-20-0.

Table 2. Probability of Drought in the Dryseeded Rice Cultivation in Agroecological Units of Sathing Phra Area.

Available Water in Different Paddies	Planting Date	Probability of Drought Before Tillering (soil moisture < field capacity) During the First Three Decades After Broadcasting	Probability of Drought (available water exhausted)	
			Formation and Filling	Maturation Harvesting
Upper paddies of Unit II (300 mm) early to medium maturing varieties (150-160 days)	11 Sept.	0.52	0.16	0.66
	21 Sept.	0.24	0.32	0.84
	1 Oct.	0.08	0.64	0.91
Lower paddies of Units II and III (500 mm) late maturing varieties (180-200 days)	1 Sept.	0.64	0.00	0.17
	11 Sept.	0.52	0.00	0.30
	21 Sept.	0.24	0.17	0.43



Land Preparation

w/o:	fallow; no rice cultivation
nontill.:	direct planting without plowing
1 pl.:	one shallow plowing (5-10 cm depth)
2 pl.:	one shallow plowing followed by a deeper plowing (10-15 cm depth)
I:	seedbeds characterized by large clods; 26% > 123 cm^2
II:	seedbeds characterized by medium clods; 6% > 123 cm^2
III:	seedbeds characterized by small clods; 3% > 123 cm^2

Figure 4. Percent Emergence of Dryseeded Rice and Wild Rice Infestation (*O. perennis*), According to Land Preparation.

Finally, the shallow and irregular plowing (3-10 cm depth), often characterized by the existence of a marked plow pan (no porosity) seriously limits the drought avoidance of rice during maturation.

Soil and Water Constraints During the Prerainy Season

During this season, a few farmers (< 3 percent) grow mung bean and cucumbers in Unit II as soon as the first rains of mid-April and May allow plowing. In fact, during this period it was demonstrated that the most serious yield constraints were the successive occurrence of waterlogging and dry periods (Crozat, 1985). With regard to the low permeability of the clay-textured soils of the area and the intensity of the rainfall, waterlogging occurs as soon as two consecutive daily rainfalls exceed 35 mm. Probabilities of such an event are given in Table 3.

In terms of probability, waterlogging may occur at least once during mung bean cultivation one year out of two, whatever the planting date. In 1984, of 22 fields where mung bean was cultivated, the yield of only five exceeded 100 kg/ha. In 24 percent of the cases, no harvest was possible because waterlogging led to complete plant population mortality.

Table 3. Probability of Having at Least One Waterlogging Event During the Prerainy Season (25 Years).

Decade	May	June	July	Aug
1	0.16	0.12	0	0.16
2	0.20	0.24	0.12	0.16
3	0.28	0.24	0.12	0.12
2-Month Period		May-June:0.64	June-July:0.52	July-Aug:0.48

In fields temporarily flooded, plant population was also reduced and yields were negatively correlated with waterlogging duration by its dramatic effects on pad production (Figure 5). A brief survey of farmers who had cultivated mung bean for four years showed that in three of those years, crops were seriously damaged by waterlogging, and in one year, limited by drought.

Conclusion

In terms of soil and water management throughout the Sathing Phra peninsula, drought and flooding cannot be separated. Noncontrol of flooding and drought is the key problem of rice-based cropping systems because of both extremely erratic rainfall patterns and the poor drainage ability of clay-textured soils. During the rainy season, sudden and high flooding, together with manpower constraints of farming systems, force farmers to grow mainly dryseeded rice. In such conditions, drought periods may occur both at the early stage of rice cultivation and at grain filling. The use of high yield varieties is also limited because of the large variation in water levels. Land preparation quality appears to be the

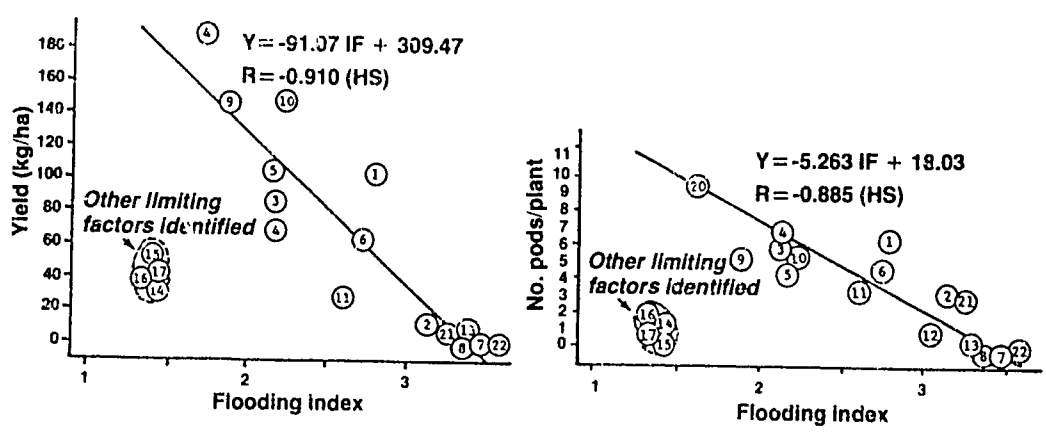


Figure 5. Relationships Between Flooding Index (Log (No. of Days of Flooding x Percent Area Flooded)) and Pod Production and Grain Yield of Mung Bean Crops in 22 Farmer-Managed Fields (Prerainy Season 1984).

key determinant for rice population and weed infestation, especially of wild rice *(O. perennis)*, and even for drought resistance. During the prerainy season, however, yields of upland crops like mung bean may be seriously damaged by temporary waterlogging. This risk exists at least one year in two.

Without an efficient drainage network, the value of irrigation is questionable and its practice risky. In addition, with the three farming system types identified in the area (Trebuil *et al.*, 1984; Trebuil, 1984), irrigation is probably accessible to not more than 30 percent of the households because of the economic constraints and socioeconomic strategies followed by each farming system type. During the interrice cultivation period, around 60 percent of the farmers obtained income from sugar palm, so the target population for double cropping is limited. One may wonder if the existing association of a rustic perennial crop like sugar palm (*Borassus flabellifer*) with rice is not an optimum adaptation to the environmental constraints of the area.

Since 1984 the Thai-French Farming System Research Project has undertaken research on sugar palm production improvement, as well as a cropping system research program. As part of this latter program, land preparation management for dryseeded rice and the introduction of legume green manures adapted to successive waterlogging and drought periods appear to be the most promising means of reducing rice-based cropping system constraints (Crozat, 1985). These constraints were clearly identified as poor rice implantation (low density, irregular spatial distribution, low drought resistance), weed competition and low soil fertility (low nitrogen) (Crozat and Chitapong, 1984).

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Soil, Water and Crop Management in Rainfed Agriculture: The Indian Experience

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ABSTRACT. At present drylands in India occupy 73.5 percent of the net cultivated area of 143.8 Mha and contribute 45 percent of cereal yield and 75 percent each in oil seeds and grain legumes. Inspite of peaks and troughs due to fluctuations in rainfall over the years, Indian agriculture is improving. Irrigation agriculture would not be a viable solution to increase food production in India.

The drylands of India are impoverished with low investment capacity; the holdings are small and scattered. The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) has evolved simple and easily implementable practices to increase the crop production in farmers' fields by at least 100 percent. These practices include timely seedbed preparation, ideal plant populations, timely weed control, use of high yielding varieties and hybrids, and use of moderate levels of fertilizers. Efforts have been made to identify alternate crop strategies to meet weather aberrations.

Runoff is inevitable and varies from 10 to 40 percent in sierozemic soils and Vertisols, respectively. On-farm management of rainwater through different land configurations provides additional production of only 15 percent, an amount which is not visible to the farmer; hence, the practice is not easily implemented. On the other hand, irrigation with runoff collection into dugout farm ponds increased cereal yield by 2 q/ha/cm. Pulses and grain legume yields were increased by only 1 q/ha/cm.

The cropping intensity in the drylands of India is low. However, improved intercropping systems in areas receiving more than 625 mm rainfall have been identified. Furthermore, with further increases in rainfall beyond 800 mm and with soils having 200 mm or more storage capacity, double cropping is possible. Both these systems provide the potential for increased production of the much needed grain legumes and oilseeds for the country.

Soil erosion is a serious problem. If the farmers become aware of the potential value of their drylands, they may be willing to participate in the program of soil conservation. To induce farmers to participate, simpler programs like key-line farming, the use of existing waterways and flexibility in the spacing of the graded/contour bunds may be useful.

To meet the country's increasing food needs, drylands with good agricultural potential should be identified and exploited to prevent a shortage of productive land for food grains.

Training of the farmers and distribution of agricultural inputs are important requirements for achieving higher productivity in drylands. Providing spot guidance would further enhance the yields.

Introduction

India is a nation of youth. Fecundity being high, the estimates on population have gone awry and instead of 935 million, we are likely to be 1.0 billion by 2000 A.D. Today, India produces about 150 Mt of food grains, but by 2000 A.D., about 240 Mt of food grains will be needed. At present, drylands occupy 73.5 percent of the net cultivated area of 143.8 Mha and contribute up to 45 percent in cereals and 75 percent each in oilseeds and grain legumes to the national food basket. Table 1 shows that most of the pulses, oilseeds and coarse millets are grown in drylands, and even rice is grown to the extent of 61.7 percent under rainfed conditions.

Table 1. Percent Area Under Dryland Crops (1978-79) in India.

Crop	Percent Area
Sorghum	95.5
Groundnut	94.6
Pulses	92.4
Chickpea	84.7
Maize	82.3
Cotton	78.2
Rapeseed/mustard	65.8
Rice	61.7
Barley	44.0
Wheat	35.0

When the production levels over years are considered (Table 2), the droughts of varying intensities are reflected in reduced production. Inspite of such troughs in production, certain important points have emerged out of the scenario. They are:

1) The peaks over progressive years were increasing as was total production.

2) Similarly, the troughs due to drought years also showed considerable improvement.

These points simply prove that Indian agricultural productivity is improving.

In order to increase production from 150 to 240 Mt by 2000 A.D., improvements in rainfed agriculture must be achieved. Irrigation was thought to be an easy solution to the problem of hunger. However, out of 15 Mha of canal irrigated area in India, at least 10 Mha are affected by waterlogging or salinization. The loss of land due to such a calamity is more serious in deep black soils. In addition, average yield of irrigated crops is only 1.4 t/ha whereas it could be 5.0 t/ha. Lands irrigated with groundwater give higher yields (1.7 t/ha) than those irrigated with surface water (canal irrigated lands) (1.1 t/ha). The areas using these sources of irrigation are about equal.

Another interesting point is the high cost of major river projects compared to minor irrigation works. Minor irrigation works cost about one-third of the large river projects on a unit area basis. From an analysis of all these aspects, three things have become clear in India:

Table 2. Peaks and Troughs in Food Grain Production in India.

Year	Food Grain Production	Peak Point	Trough Point
	.....	*Mt*	.....
1960-61	82.3		82.3
1961-62	82.4	82.4	
1962-63	80.3		80.3
1963-64	80.7		
1964-65	89.4	89.4	
1965-66	72.3		72.3
1966-67	74.2		
1967-68	95.1	95.1	
1968-69	94.0		94.0
1969-70	99.5		
1970-71	108.4	108.4	
1971-72	105.2		
1972-73	97.0		97.0
1973-74	104.7	104.7	
1974-75	99.8		99.8
1975-76	121.0	121.0	
1976-77	111.2		111.2
1977-78	126.4		
1978-79	131.4	131.4	
1979-80	109.6		109.6
1980-81	129.4		
1981-82	133.1	133.1	
1982-83	127.9		127.9
1983-84	151.6	151.6	

1) Drainage is a must in irrigation projects.

2) The minor irrigation projects are more remunerative than the major ones.

3) The yields are hopelessly low.

Under these circumstances, the first priority should be to use the presently available irrigation water more efficiently and to prevent waterlogging or salinization of the irrigated lands. The next priority should be to exploit the full yield potential of the drylands.

Scenario of Drylands

The drylands of India are more hungry than thirsty. They are mostly eroded with multiple slopes and their productivity is very low. The ability of farmers in these regions to invest in modern agricultural systems is poor. The holdings are small (2.00 ha) and scattered. The sources of energy are inadequate—cattle and human. Thus, it would be a monumental task to increase yields and stabilize them at higher levels in such regions.

Earlier Efforts in Improving Productivity in Drylands

Efforts were made in the mid-thirties to alleviate the problem of low productivity in these lands through establishment of five research centers in various parts of the country. At that time, the effort was primarily to improve the yields of the existing crops through deep plowing, application of farm yard manure, wider spacing and clean cultivation. But these methods increased the yield only 20 to 25 percent, a level which was not visible to the farmers when the productivity levels were low.

Subsequent to this, in the mid-fifties, an effort was made to manage the soil with the implementation of conservation programs and research in soil and water conservation. Eight research centers were established at that time but farmers were hesitant to implement new practices because expected yield increases were only 15 to 20 percent. In addition to the soil and water conservation programs, scientists conducted analyses of rainfall data and characterization of growing seasons. It was found out that some crops required a longer growing season in some areas than in others and, hence, were subjected to the effects of drought. For example, in the postmonsoon Deccan region, crop varieties of not more than 100 days duration could be grown. It was only in the mid-sixties that such genetic material became available through the Crop Improvement Projects of the Indian Council of Agricultural Research (ICAR). When high yielding crop varieties were made available, great enthusiasm was generated because of the obvious potential for increasing agricultural productivity in these dryland areas. To meet this challenge and opportunity, the Government of India sanctioned through ICAR the establishment of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in June 1970 as a collaborative project with the Canadian International Development Agency (Government of Canada). The Project consisted of 23 Cooperating Centers located in different agroclimatic regions with a Project Directorate at Hyderabad (see Figure 1).

Recent Efforts in Increasing Productivity in Drylands

AICRPDA is a multidisciplinary effort meant to increase the productivity and stability of cropping systems in the drylands of India. To achieve this goal the following three objectives were established:

1) To identify the best management practices for increasing the productivity of drylands by at least 100 percent in the farmers' fields;

2) To determine the means to minimize yield fluctuations caused by erratic weather patterns; and

3) To conserve and optimize the use of natural resources, e.g., land and water (rainfall), at the farm level.

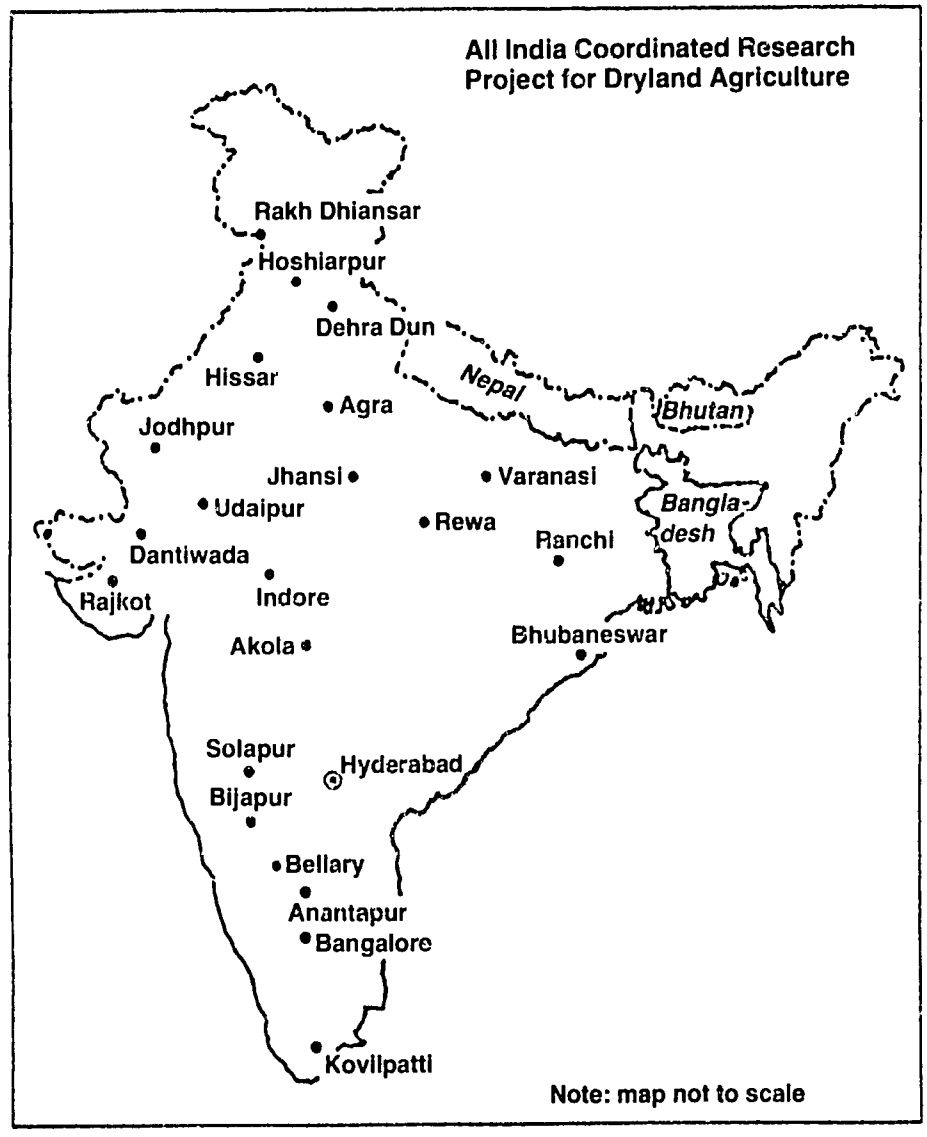

Figure 1. Location of Cooperating Centers.

There are two options which could increase and stabilize production:

1) Disregard entirely the existing systems of farming and convert dryland agriculture into high investment agriculture comparable to irrigation agriculture.

2) Recognize the constraints and bring about small but critical changes that could easily be implemented over large areas.

High energy systems utilizing costly external inputs in most cases would be unsuitable unless they were developed with strong infrastructural support. The use of on-farm, internal resources should be maximized wherever possible, and external inputs should be used as critical supplements but not as substitutes. The first concern would be how to organize the natural resources available at the farmer level along with his own internal resources to develop an efficient and profitable production system.

Low Monetary Inputs

The three basic components in rainfed farming are improved management, improved seed and use of moderate levels of fertilizers. Management primarily contributes low monetary inputs including tillage, sowing with improved seed, adequate plant populations, timely weeding, and avoidance of pests and diseases through cultural practices.

Off-Season Tillage

Off-season tillage prior to the monsoon season is shown as the first step in achieving the maximum benefit of other components of the low monetary systems except in areas where dust storms are possible (sierozemic soils of Northwest India). Off-season tillage helps in early seedbed preparation and also avoid pests and diseases. Since the plots would be more hygienic, weed populations would be relatively less.

Plant Population

Use of adequate plant stands is needed for obtaining increased yields in dryland crops. The old adage "sow thin for grain and thick for fodder" was true for the local varieties which were tall and selected for performance at an individual plant level. With the high yield varieties and hybrids (HYV/HYB) which are short-statured and selected for performance as a population, a higher plant density is needed.

The improved seed-cum-fertilizer drills developed by AICRPDA help to achieve this goal. The following drills are important:

S. No.	Name of the Ferti-Seed Drill	Place of Origin
1)	FESPO plow	Single-tyne seeder from Hyderabad
2)	Eenati Gorru	Three-tyne seeder from Anantapur
3)	Ragi ferti-cum-seed drill	Six-tyne seeder from Bangalore
4)	Ridger seeder	Single-tyne seeder from Hissar
5)	Two-bowl seeder	Single-tyne seeder from Solapur

These are all bullock-drawn seed-cum-fertilizer drills which are easily accessible to the farming community in the drylands of India.

Weed Control

In the case of weed management, the principle that prevention is better than the cure should be adopted. If not properly controlled, weeds can remove as much as 30 percent of available moisture and nutrients, leading to substantial yield decreases. While off-season tillage helps to minimize the weed problem in monsoon crops, it is also imperative to remember that for 100-day and 150-day duration crops the first three to five weeks are important for establishment and for effective weed control; otherwise, yields would decrease substantially.

Wide row planting and use of blade harrows for interrow weeding are effective weed control practices. These low monetary inputs have been thoroughly evaluated at several locations in India and results are presented in Tables 3 and 4.

In the Hyderabad area where the soils (Alfisols) are extremely deficient in phosphorus and low in nitrogen, mean response to low monetary inputs was 3 q/ha. Considering that the mean farm yield was only 4.7 q/ha, this response was dramatic. When the soil fertility was higher, as in Bellary Centre, the response to inputs was striking—6.5 q/ha with the farmers' variety compared to 16.5 q/ha with improved variety. In the Indore area (Vertisols with high rainfall) a large number of cultivated drylands gave an average of 5 to 6 q/ha of sorghum grain for a traditional variety and management practices and 10 to 12 q/ha for an improved variety and low monetary practices. It can be concluded that

Table 3. Contribution of Inputs to Grain Yield of Rainy Season Sorghum in Alfisols of Hyderabad.

Treatments	1976	1977	1978	1979	Mean
	..... $q\ ha^{-1}$				
Farmers' variety + farmers' practices	4.2	6.6	2.1	5.8	4.7
Farmers' variety + LMI† + fertilizer	12.9	13.5	6.5	11.5	11.1
HYV + LMI	5.1	12.3	4.4	8.8	7.7
HYV + LMI + fertilizer	16.2	26.1	14.1	22.9	19.8

† LMI (low monetary inputs) are year-round tillage, early sowing, optimum plant density and weed control.
‡ 40 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}.

Table 4. Contribution of Inputs to Yield of Postmonsoon Sorghum in Vertisols of Bellary in 1975.

Treatments	Yield	
	Grain	Straw
	..... $q\ ha^{-1}$	
Farmers' variety + farmers' practices	7.4	23.1
Farmers' variety + LMI†	13.9	69.1
Farmers' variety + LMI + fertilizer‡	16.5	73.5
HYV + farmers' practices	6.7	16.5
HYV + LMI	23.2	46.8
HYV + LMI + fertilizer	27.5	48.0

† LMI (low monetary inputs) are year-round tillage, early sowing, optimum plant density and weed control.
‡ 30 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}.

unless the soils are very poor in fertility, low monetary inputs can give significant yield increases. It is also clear that when low monetary inputs are combined with high-cost inputs such as fertilizer, the yield increases are even greater.

High-Cost Inputs

Essentially, the high-cost inputs include chemical fertilizers, pesticides, tractor power, runoff management and increased cropping intensity.

Fertilizer Use

Use of fertilizers can increase the yield of dryland crops. The relative responses of crops to N and P_2O_5 are given in Tables 5 and 6.

From the data, it is evident that under normal conditions the response of crops to fertilizers is greater in irrigated cropping systems. However, with the prevalence of small and marginal farmers in the drylands, at least two important principles have to be borne in mind, i.e., the law of diminishing returns (Figure 2) and the law of the minimum (Figure 3). Simply stated, each law suggests that we should operate in the linear region of the response curves in the drylands to maximize net returns and profitability. Balanced fertilizer use is important; however, it is often overemphasized under irrigated systems and particularly in the drylands. Fertilizers should be used in the dryland regions very selectively to minimize risk, taking advantage of available water, and to provide basic crop requirements on a short-term basis.

Increasing Fertilizer Use Efficiency

Broadcasting of fertilizer is inefficient. Fertilizers should be placed in and/or near plant rows to increase their efficiency. When placing fertilizer within the row, salt injury is possible. Not more than 10 kg/ha N should be placed together with the seed in confined furrows, while 20 kg/ha N can be placed with broad furrows. Placement of a part of the nitrogen and all the phosphorus along with and/or adjacent to the seed row with the bullock-drawn seed-cum-fertilizer drills would help in reducing energy requirements and ensuring healthy vigorous seedings.

Table 5. Response of Rainfed Crops to Applied Nitrogen.

Crop	Fertilizer Level	Average Response
	kg N ha^{-1}	*kg grain kg^{-1} N*
a) Monsoon crops		
Pear millet	40	19.2
Sorghum	40	26.7
Maize	40	15.5
Rice	40	20.3
b) Postmonsoon crops		
Sorghum	30	14.4
Barley	20	22.8
Wheat	25	31.0
Safflower	25	15.8
Mustard	20	13.6

Table 6. Relative Response of Crops to Phosphorus at 30 to 50 kg P_2O_5 ha^{-1}.

Crop	Average Response
	kg grain kg^{-1} P_2O_5 ha^{-1}
Sorghum	9.0
Pearl millet	7.2
Maize	12.2
Safflower	3.2
Mustard	5.7
Gram	10.9

Split application of nitrogen fertilizer in the dryland areas is recommended and practiced by farmers to obtain greater N use efficiency and to avoid partial N loss if aberrant weather should lead to yield reductions and crop failures.

The basic principle in many of the research programs in India has been to conserve and improve the quality of the land through the use of organic wastes and better cropping systems with the overall aim of maximizing the economic use of chemical fertilizers. In relatively high rainfall areas with a growing season of more than 30 weeks, legumes in cropping sequence, including intercropping, can provide upwards of 20 kg/ha N.

Pesticides

Early sowing usually provides vigorous seedlings which can more easily cope with pests, diseases and weeds. Most of the important pests on crops are weather-dependent, and by manipulating the sowing time and/or by selecting suitable varieties, it is possible to minimize their impact. For example, the ear-head bug is a problem on sorghum after the crop comes to the milky stage during late August, such as in Alfisols of the Hyderabad area. If the crop is sown early, in June, damage by this pest could be avoided. If sowing is delayed, then shifting from CSH-5 (110-day variety) to CSH-6 (100-day variety) would be helpful.

The problem of parasitic weeds like striga can be overcome by changed cropping patterns (shifting to pearl millet) or by using tolerant varieties.

While there might be instances when pesticides have to be used, they should be used carefully and only after proper diagnosis of the problem.

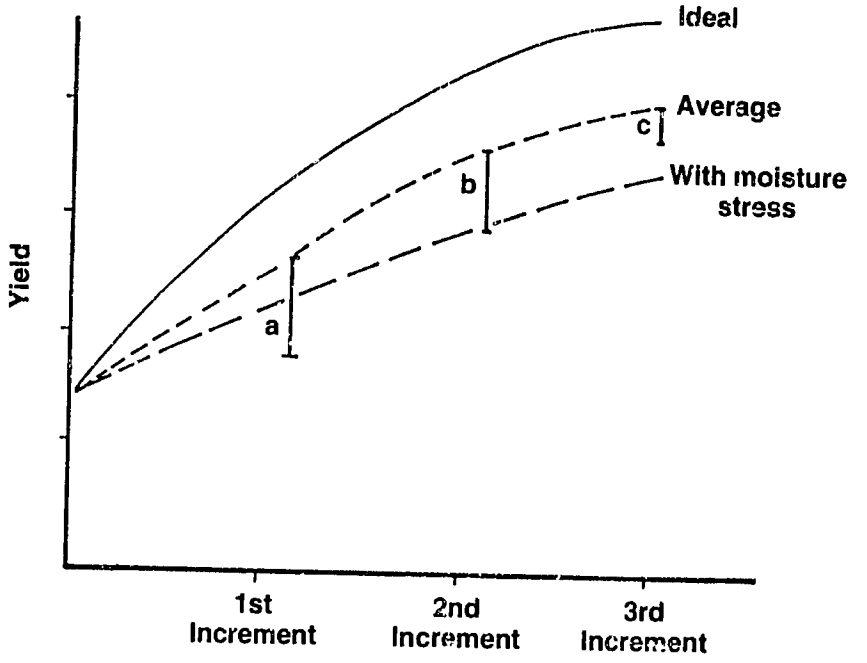

Figure 2. Typical Crop Yield Response Curves with Successive Increments of Inputs.

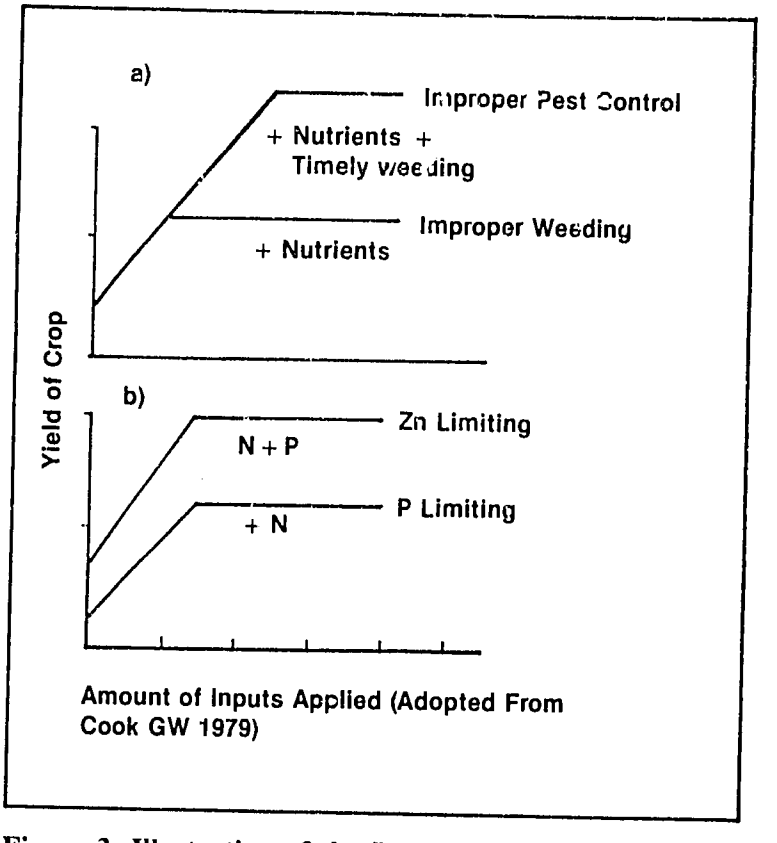

Figure 3. Illustration of the Law of the Minimum.

Use of Tractor Power

Most farmers in the dryland areas of India use bullocks as the primary source of power for preparing the land. However, where possible, the use of tractor power has been encouraged for two important reasons. First, primary tillage with tractor provides an extended period for sowing and also leads to improved land preparation over the traditional systems. Second, weed infestation is more easily and effectively controlled with tractor tillage. Thus, the Government of India has recently initiated some trial subsidy programs to provide tractors for primary tillage in certain regions. Tractorized seeding would also be very helpful for receding moisture situations in the postmonsoon and when deep plowing has to be done either for textural profiles in Alfisols or for weed infested Vertisols.

Runoff Management

Runoff. Moisture stress is one of the important constraints to crop production in the drylands of India. While storms of high intensity rains are common, the soil profile can hold only limited amounts of water due to soil textural and structural deficiencies, as well as water infiltration problems. Thus, frequent and excessive runoff is common.

The research information from different areas in India shows that runoff is generally highest in Vertisols and lowest in sierozemic soils. The average runoff is 100 to 200 mm (20 to 25 percent of total rainfall) from Alfisols and alluvial soils; 150 to 300 mm (30 to 40 percent of total rainfall) from Vertisols and 30 to 50 mm (10 percent of total) from sierozemic soils. Though this is the general trend of runoff behavior, the runoff at a particular time would depend upon the soil cover, the antecedent moisture in the soil and on the soil physical characteristics, particularly at the surface. Thus, the high runoff from the black soil regions is mainly due to low infiltration rates of the easily dispersing soils. Again, at the start of the monsoon season, the Alfisols are more prone to runoff than Vertisols because of more severe crusting.

Runoff harvesting. There are several possibilities for collection and recycling of runoff water for use by crops:

1) *In situ* water harvesting;
2) Collection of runoff in dugout ponds for recycling; and
3) Collection of runoff in percolation tanks, by gully plugging and check dams, for recharging groundwater.

***In situ* water harvesting.** Precipitation enters the soil through the process of infiltration. Land configuration becomes important in this process since it determines the detention time for the rainwater to enter the soil where it falls. Thus, *in situ* harvesting is the best way of storing rainwater for crops grown in drylands.

Over the last six to eight years, different land configurations were tested at selected research centers of the Project. The following results are relevant:

1) All land configurations tested gave increased yields of only 15 percent which provides little incentive for implementation at the farmer level.

2) The most suitable land configuration systems found for different zones are:

Rainfall Pattern	Soil Type	System Recommended
High	Vertisols Alfisols Alluviums	Bed and furrow Graded border strip Interplot water harvesting
Medium	Alfisols	Sowing on grade and ridging later
Low	Alfisols Sierozems	Dead furrow system Interrow water harvesting

Runoff collection in dugout ponds. Even though runoff occurs and its collection in dugout ponds is possible in most of the dryland areas, this may not be a viable economic proposition unless the water can be harvested and retained for a minimum of four to eight weeks. The pond waters are subject to loss through deep percolation in the soil profile and evaporation into the atmosphere. The percolation/seepage rates are mainly a characteristic of the soil. In sandy to sandy loam soils, the percolation rates are high (20 to 40 cm per week) and, therefore, without effective sealants, the water will not be available for more than three to four weeks. However, with the soil loss that accompanies the runoff, natural surface sealing takes place within five to six years. In clay or clay loam soils, water would be retained for longer periods, even without any artificial sealants, since the percolation rates are low (1 to 4 cm per week).

Artificial sealants have been investigated, some of the promising being: 1) asphalt, 2) soil-cement (4:1 or 8:1), 3) polyethylene films; and 4) brick with cement plastering. Even though the capital cost for lining with polyethylene and brick with cement is high, the sealant lasts a long time and little maintenance is needed. Therefore, in the long run, such sealants could be economically viable. Water losses from small ponds through evaporation are generally low as compared with percolation losses during the growing season. Weekly potential evapotranspiration does not exceed 25 mm in most areas; however, this loss can be minimized by reducing the surface area of the ponds.

Runoff recycling. The next crucial question is how to use the harvested water effectively, efficiently and profitably. Studies conducted in the Dryland Project clearly show that about one ton of additional cereal grains can be harvested by adding 5 ha cm of water. About 10 ha cm are needed to produce an additional ton of pulses and oilseeds. The economics further depends on the value of produce, and cash crops such as vegetables have a definite advantage in this regard.

Possible ways of utilizing the harvested water have been extensively studied. In most cases the harvested water can be profitably used for lifesaving irrigation during the crop growing season. This works as an insurance against a total crop loss, particularly when severe moisture stress or drought situations occur at critical stages of crop growth.

Alternatively, the harvested water can also be used to increase cropping intensity in areas where the establishment of a second crop becomes difficult due to early monsoon withdrawal.

Although runoff harvesting has been recognized as a means for providing stability to crop production in drylands, there are some constraints to this approach. First, the farm ponds are costly, especially if sealants are needed to reduce percolation losses; and, second are the location and size of water harvesting ponds. As long as the site is on government land, there is no problem. However, if a farmer's land is involved, then ownership and using water for more than one holding can pose certain problems.

Recharging groundwater. Another way of water harvesting is by providing percolation tanks, gully plugging and check dams in community lands to ensure increased groundwater recharge.

The dugout ponds, on the other hand, can be made on small individual holdings in most dryland areas. The size of the pond should depend on the amount of runoff and catchment area. For example, in Alfisols of the Hyderabad area which receive 750 mm of total rainfall, about 150 mm, or 20 percent of the total, is lost as runoff during four to five rainfall events. Therefore, pond size for a one-hectare catchment is around 250 m^3. Individually owned ponds are generally more costly (Rs. 2500 to 3000 per ha) to construct and maintain despite the advantage of harvested water. These small ponds can be profitably managed if the water is used for raising nurseries and for growing cash crops such as vegetables. A major handicap in the use of harvested water is the lack of low-cost lifting devices, i.e., pumps. However, the sharing of water needs to be critically evaluated. Lifting water from small ponds can be done through improved counterpoise. Sometimes, stored water can be manually lifted and applied to crops in the adjacent areas. Research is still needed for developing suitable portable types of water lifts that small farmers can afford.

Cropping Systems

In areas where annual rainfall ranges from 375 to 625 mm and soil moisture storage capacity is less than 10 cm, it is preferable to take a single monsoon crop. However, when the storage exceeds 20 cm (Vertisols), it is possible to take only a postmonsoon crop. When the rainfall is between 625 and 700 mm with a period of moisture surplus, intercropping is advocated for increasing and stabilizing crop production. In regions of higher rainfall and with soils having 20 cm of storage capacity and above, it is suggested that double cropping be seriously considered.

As cropping intensity is increased, the overall plant nutrient requirement is also increased, and it may then be necessary to increase the application of nutrients from external sources (i.e., chemical fertilizers).

Intercropping. Systems of intercropping are age-old practices and seek to optimize production by taking advantage of the higher rainfall years. In normal years, intercropping might also give additional or bonus yields. Some of the more profitable intercropping systems developed are given in Table 7.

Sequence cropping. Sequence or double cropping provides a scope for additional production of the much needed oilseeds and pulses. Some of the suitable sequences are given in Table 8.

For sequence cropping to be successful early planting of the monsoon crop for early harvest is important so that the second crop can be planted quickly in the postmonsoon season. This is feasible in areas where temperature transition is gradual and where crops do not have high thermal sensitivity. However, in North India postmonsoon crops are thermally sensitive, and sowing must be delayed to avoid high temperatures. This causes additional risk since moisture deficits are often associated with delayed sowing of the postmonsoon crop.

Table 7. Some Suitable Intercrops for Different Regions.

Region	System	Yield	
		Base Crop	Intercrop
		..... $q\ ha^{-1}$	
Bijapur	Pearl millet	14.1	
	Pearl millet + Pigeon pea	11.6	8.0
Ranchi	Maize	28.6	
	Maize + Pigeon pea	28.2	6.2
Akola	Sorghum	33.5	
	Sorghum + Mung bean	30.8	
Solapur	Pearl millet	18.0	
	Pearl millet + Pigeon pea	18.3	17.0
Hyderabad	Sorghum	34.4	
	Sorghum + Pearl millet	33.5	5.5
Rewa	Sorghum	25.4	
	Sorghum + Pigeon pea	22.8	4.7
Indore	Sorghum	32.7	
	Sorghum + Peanut	28.3	7.6

Weather Aberrations

There are at least four important aberrations in rainfall behavior:

1) The commencement of rains may either be very early or considerably delayed.
2) There may be prolonged droughts during the cropping season.
3) There may be spatial and/or temporal aberrations in rainfall.
4) The rains may terminate earlier than normal or continue for longer periods.

AICRPDA explored ways and means of stabilizing crop production in drylands by following contingency plans to deal with such aberrations. The main approaches are:

1) Choice of suitable crops.
2) Choice of suitable crop varieties.
3) Alternative crop strategies.
4) Midseason corrections.
5) Crop lifesaving measures.

Table 8. Suitable Crop Sequences for Different Regions.

Region	Crop System	Yield	
		First Crop	Second Crop
		..... $q\ ha^{-1}$	
Samba	Pearl millet-Wheat	21.5	24.0
	Fallow-Wheat	-	33.3
Dehra Dun	Maize-Wheat	38.5	31.8
	Rice-Wheat	43.1	29.9
	Fallow-Wheat	-	26.8
	Maize-Chickpea	30.3	16.2
Varanasi	Rice-Chickpea	30.2	25.4
	Fallow-Chickpea	-	35.7
Hoshiarpur	Maize-Wheat	27.3	27.2
	Fallow-Wheat	-	23.2
	Maize-Chickpea	27.3	15.3
	Fallow-Chickpea	-	17.0
Bangalore	Cowpea-Finger millet	8.6	27.6
	Ragi (alone)	26.9	-
Akola	Sorghum-Safflower	45.4	14.1
Anand	Cowpea-Tobacco	8.2	9.7
Bijapur	Mung bean-Safflower	7.5	10.6
Indore	Maize-Safflower	29.5	10.8
	Sorghum-Chickpea	32.1	13.9
	Maize-Chickpea	35.5	14.3

Choice of Suitable Crops

Often, certain crops are grown more for convenience or by convention. This is because a farmer's first priority is the production of food for his family and feed for his animals. However, the selection of crops that are compatible with a particular environment generally leads to increased and stabilized production. For example, the best environment for growing rice would be at least an average rainfall of 200 mm per month over a period of three months with breaks of not more than seven days in the monsoon period. The soils also need to be less permeable.

Choice of Suitable Crop Varieties

Replacement of the existing local varieties with new high yielding varieties or hybrids provides a basis for introducing improved crops for drylands. While these new selections may not outperform the traditional varieties in low rainfall years, they usually produce much higher yields during average or high rainfall years. Therefore, a farmer is well-advised to select hybrids and high yielding varieties for dryland cropping systems.

Alternative Crop Strategies

Sowing of crops depends on rain in the dryland areas. Often the rains may commence quite early or may be delayed considerably and the same crop cannot be sown over this entire period since yields may be reduced because of pests and diseases or a shorter growing season. Basic data on crop performance as affected by different sowing dates and locations was urgently needed by farmers to provide options and flexibility. Alternate crop strategies have now been developed to deal with weather aberrations in all of the 23 regions where Project centers are located. Examples of these are listed in Table 9.

Midseason Corrections

If moisture stress should occur after the crop is growing, there are certain options that could be employed such as thinning, ratooning or replanting when moisture conditions were again favorable. For example, thinning of sorghum by removing every third row was found to be advantageous to mitigate moisture stress in the Deccan black soils region under Rabi (postmonsoon) conditions. These results are shown in Table 10.

Training

An objective of the Dryland Project has been to develop methods and practices that are technologically viable and economically feasible for farmers with varied means and resources. The first concern is to improve the farming practices and then to determine the level at which production inputs could be made. Certainly, high-cost inputs could be made to achieve high potential yields. However, with the prevalence of small and marginal farmers and the possible risk in dryland crop production systems, it is more logical to focus on moderate inputs and yield levels.

Evaluation of Methods in Technology Transfer

The Farmers Training Center group of the Project undertook a study to evaluate the impact of different systems of technology transfer. The results are given in Table 11.

It is clear that the farmers would accept the technology when 1) there is spot guidance made available and 2) the inputs are supplied at cartable distances. However, training of the farmers becomes absolutely essential as technological advancements in dryland crop production are made through research. The innovative approach adopted by the Farmers Training Center is "Learning." The farmers are exposed to the improved practices with three training programs of two days during each preseason, midseason and postseason/harvest periods.

Resource Conservation

Dr. W.C. Lowdermilk once said, "The use of land is a down-to-earth index of a civilization, for land has been the silent partner in the rise and fall of civilization." Today, there is a growing realization that poor soil and water management is a serious constraint to achieving higher crop yields. Deforestation, overgrazing and increased cropping intensity on marginal lands, bunding without vegetative cover and other improper management practices are causing increased runoff, reduced groundwater recharge and

Table 9. Alternate Cropping to Deal with Weather Aberrations.

	Soil (Region)	Alternate Crop Strategy	
		Normal	Delayed
1.	Chota Nagpur (Ranchi)	1 Rice 2 Finger millet + pigeon pea 3 Groundnut	1 Transplanted finger millet 2 Maize + pigeon pea 3 Rainy season potato
2.	Deccan (Bellary)	1 Sorghum 2 Safflower	1 Sorghum (fodder) 2 Safflower 3 Chickpea
3.	Alluvial	1 Rice 2 Maize 3 Pearl millet 4 Blackgram 5 Greengram 6 Sesame To be followed by chickpea	1 Rice (short-duration) 2 Pearl millet 3 Blackgram 4 Greengram To be followed by chickpea
4.	Rainy season black soils (Rajkot)	1 Sorghum 2 Pearl millet 3 Groundnut 4 Cotton 5 Castor	1 Cotton 2 Castor 3 Sesame
5.	Rainy and post-rainy season black soils (Indore)	Sequence cropping: Maize or soybean to be followed by safflower or chickpea	Intercropping: Sorghum + pigeon pea; sorghum + soybean; safflower alone in early postrainy season if monsoon is further delayed
6.	Sierozem (Hissar)	1 Pearl millet 2 Greengram	1 Transplanted pearl millet 2 Greengram
7.	Submontane	Short-duration rice or maize (hybrid) to be followed by wheat or chickpea	Transplanted rice or Sathi maize followed by chickpea, mustard in September

severe soil erosion. All these lead to soil degradation, low yields, flooding of lowlands and sedimentation of small tanks and reservoirs. In India, the per capita land availability was 0.33 ha in 1951. It has decreased to 0.29 in 1971 and is expected to decrease to 0.18 ha by the year 2000.

Table 10. Effect of Thinning on Yield of Sorghum (Bellary).

Thinning System	Grain Yield			
	1974-75 (Subnormal)	1975-76 (Above Normal)	1977-78 (Subnormal)	1978-79 (Above Normal)
	..... $q\ ha^{-1}$			
Original population	15.5	24.2	5.4	24.9
Third row removed	21.1	20.2	9.2	23.3

Table 11. Evaluation of Methods in Technology Transfer.

System	Average Yield of Sorghum
	$q\ ha^{-1}$
Traditional	7.4
Training	12.7
Training + inputs at cartable distance	14.8
Training + inputs at cartable distance + spot guidance	28.8

Soil Erosion

Soil erosion is a serious problem in India. It leads to loss of topsoil, siltation of reservoirs and even disasters like landslides. During 1951 to 1983, an additional area of 24 Mha was brought under cultivation. However, most of this is marginal land where soil erosion is a serious problem. The area lost due to deforestation in the same period was 4.3 Mha. Studies have shown that at least 58.1 Mha of arable lands are subject to soil erosion with a loss of 5.0 t/ha per annum. Most of the money being spent for soil and water conservation programs in the country has essentially been devoted to building mechanical structures that minimize soil loss from cultivated lands and promote uniform water conservation for increased yields. However, the net benefit that accrued from this program was very low, mainly because the farmer was not considered a partner due to his limited resources. Efforts by AICRPDA have made it clear that the dryland areas of India are capable of producing 300 to 400 percent more food and fiber than is currently being done. Once the farmer becomes aware of this, it might be easier to involve him in conserving the natural resource base (i.e., soil, water, forests) for posterity. Certain simplified procedures like key-line farming, use of existing waterways and varied intervals between bunds, should be adopted to involve the farmer and to make him more aware of the principles of soil and water conservation.

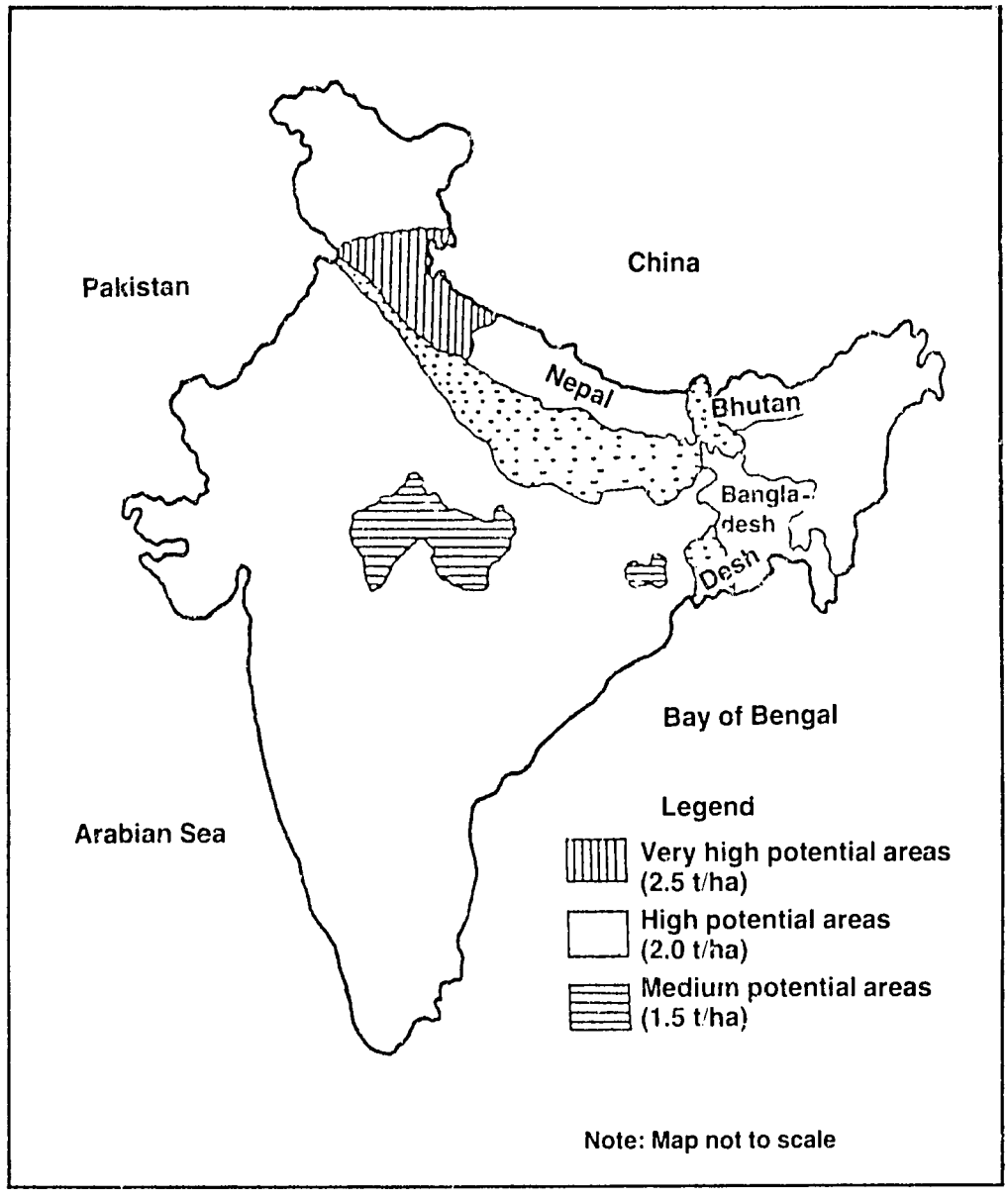

Figure 4. Potential Barani Wheat Areas.

The Future

To meet India's evergrowing need for food, drylands must be fully exploited. Efforts should be made to orient the production of different crops in their potential areas. Examples of such potential areas for wheat, groundnut, safflower and sorghum are given in Figures 4, 5 and 6. These are based on the potential and actual yields that have been obtained/reported in various experiments and reports.

However, there is an ecological crisis of production from the land due to the relative competition for different production objectives, especially food, fiber and fuel. Production objectives are based on economic imperatives. For example, in India about 0.8 Mha of medium to shallow black soils which were earlier devoted to sorghum have now been shifted to sunflower. Similarly, about 1.0 Mha medium to deep black soils have gone from

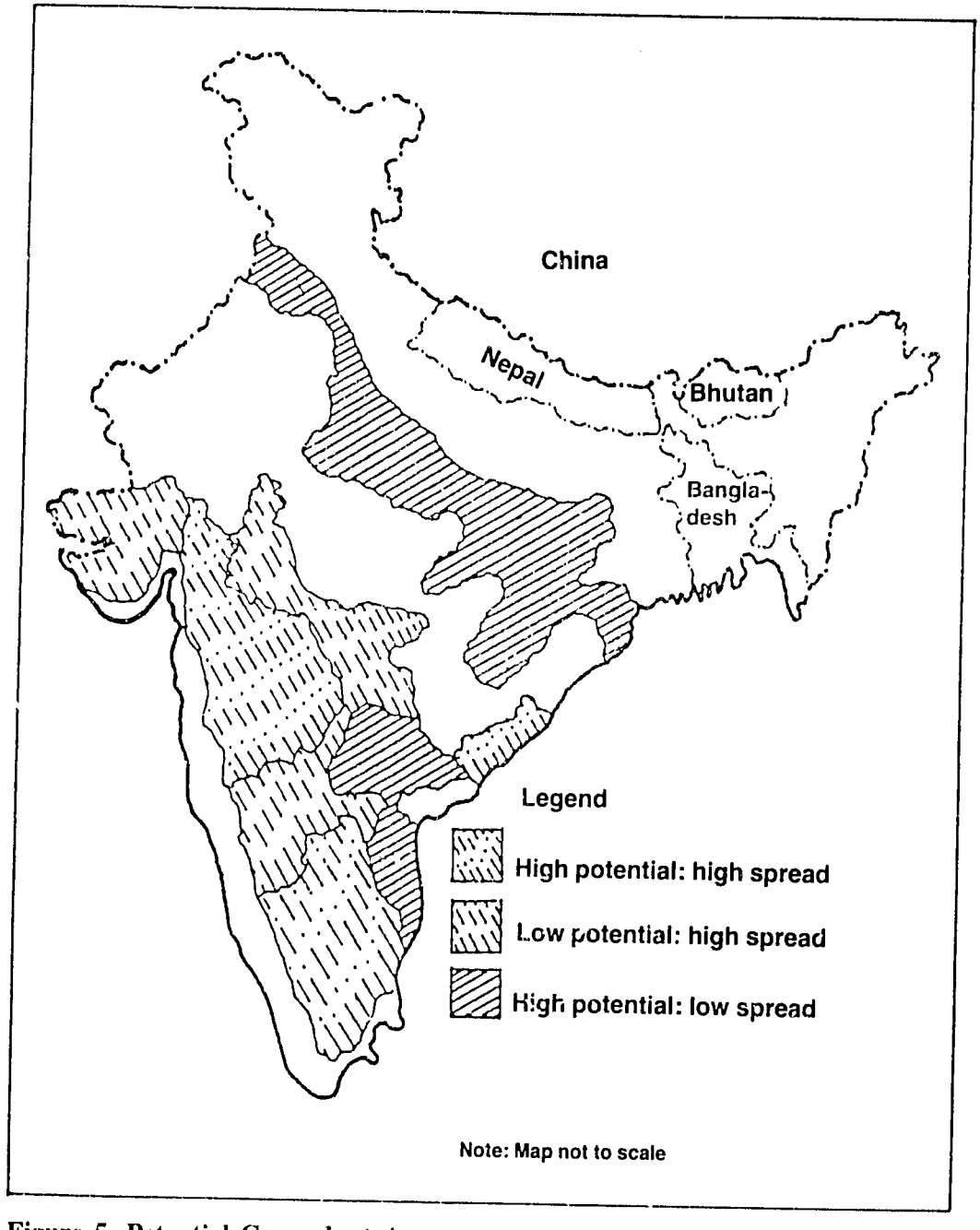

Figure 5. Potential Groundnut Areas.

sorghum production to soybeans. Pigeon pea is also replacing sorghum in many other areas. For that matter, even irrigated rice areas are now going toward cotton. Even good lands (Class I & II) are going to tree farming, particularly eucalyptus, in several states. All of these trends, some of which are just beginning, are based on economic considerations. However, there is concern that if the trend continues, there eventually could be a shortage of cropland for production of food grains. In the future, it may be necessary to consider subsidies to ensure a stable cropland base for food grain production.

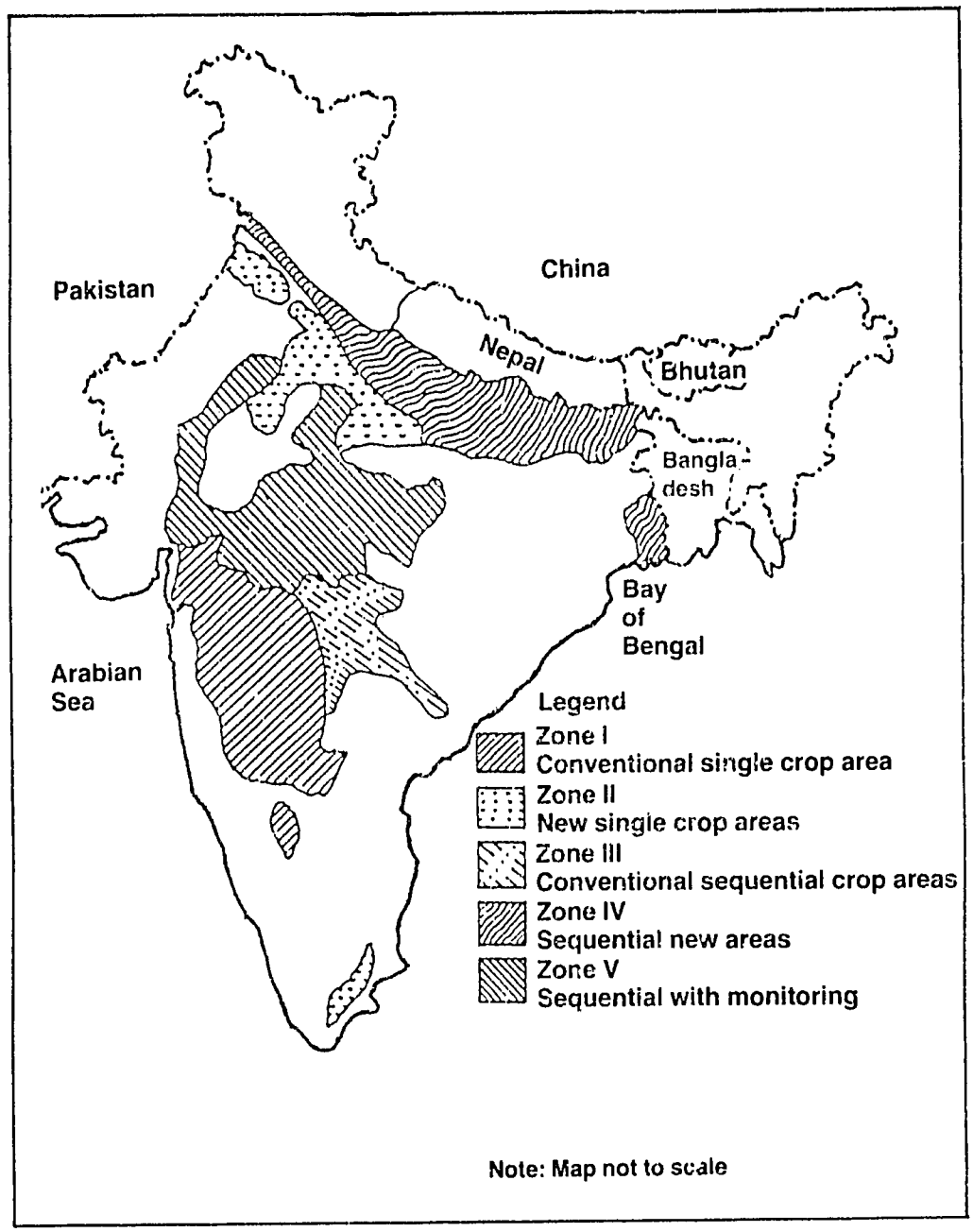

Figure 6. Potential Safflower Areas.

An Overview of Land and Water Conservation and Management Under Rainfed Agriculture in Sri Lanka

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ABSTRACT. Shifting cultivation (chena practice) was the traditional method of cultivation of unirrigated highlands that was practiced in the sparsely populated dry zone of Sri Lanka until recently. It has long been recognized, however, that this traditional practice must eventually be replaced with a less exploitive, more scientific and permanent type of agriculture if the basic food and fiber requirements of the country are to be realized. Consequently, field and laboratory studies were undertaken to investigate the possibility of setting up economically viable and stable unirrigated farms in the dry zone of Sri Lanka. Through long-term extensive studies, continuous progress has been made in incorporating the knowledge and experience gained from this research. The results are convincing that viable upland unirrigated small farm units can be operated successfully. However, the innovations made so far are basically related to land conservation measures at the macro level, and further studies are needed to develop effective practices at the micro (on-farm) level.

Introduction

Shifting cultivation, locally known as "chena" or "hena," was the slash and burn type of rainfed highland farming practice that was popular among Sri Lankan peasants until recently. Rainfed homestead, which is grown largely to perennials of horticultural and domestic interest, was the exception, especially where supplementary irrigation is used.

Emphasis on the need to substitute the rainfed chena system with a more stable and scientific system was, for the first time, officially made by the Director of Agriculture F.A. Stockdale in 1926. Stockdale's acquaintance with (a) the success of rainfed (highland) farming in some parts of India, where the rainfall was considered less favorable for dry farming than in Ceylon and (b) the success of experimental cotton plantings in several dry areas on the island convinced him that systematic highland-rainfed cultivation was equally feasible in Ceylon and India. Eventually, the ill effects of the chena practice became obvious and it was imperative to conduct investigations on replacing the chena system with a more acceptable system of cultivation. Difficulties related to the control of weeds, the system of land tenure, the liberal policy for clearing and cultivation of government-owned forest land, and the farmer's traditional practices were the main issues to be considered if a settled, permanent system was to replace shifting cultivation.

During the early years of this century, chena was largely practiced within the North Central Provinces of the island, probably because the thinly scattered village settlers who cultivated a small acreage of paddy under a village tank or pond could easily acquire a few acres of Crownland for their chena practice from the sparsely populated territory. Also, the chena practice was the traditional method of cultivation on unirrigated plots.

A Permanent Rainfed Agriculture to Replace Shifting Cultivation

The wide exposure of the North Central and Southern Provinces to the chena practice and the availability of state-owned forest lands within the territories for planned agriculture focused special attention on the possibility of establishing rainfed agricultural settlements in these regions. The extent of agricultural development in the wet, intermediate and dry zones of Sri Lanka (Figure 1) is shown in Table 1.

The availability of land for settled agriculture was determined after a land suitability evaluation. This required consideration of soil and water conservation measures because there was no previous experience with continual cropping of highlands (even on small parcels of land) for more than three to four years under rainfed conditions in the North

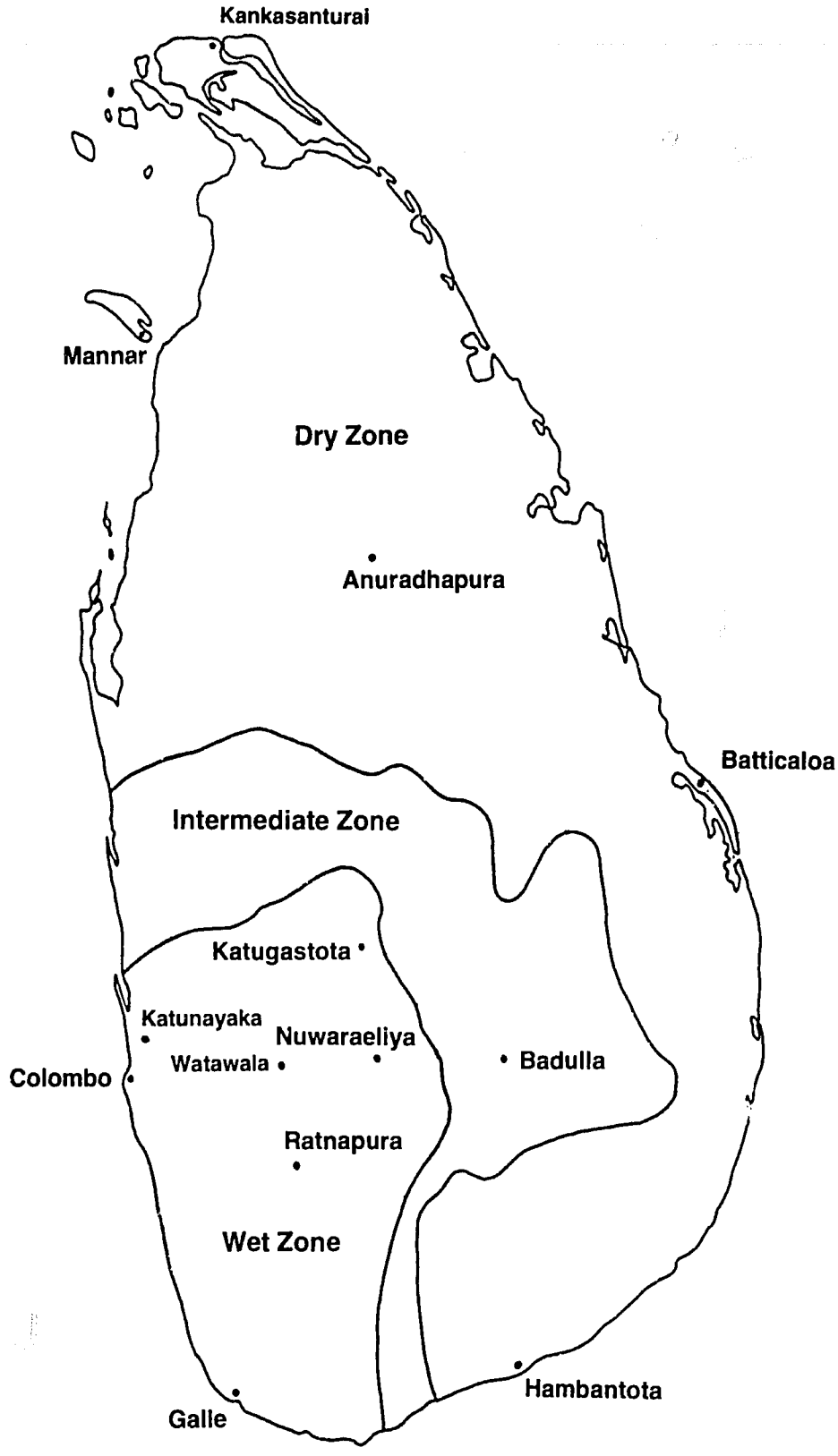


Figure 1. Broader Climatic Zones in Sri Lanka.

Table 1. Land Area, Population and Development by Zones in Sri Lanka (Sri Lanka Country Study on Rural Employment Promotion. Geneva, ILO 1975).

Climatic Zone	Acreage	Total Area	Developed Population	Developed Land†
	acre x 10^6	.....	%	.....
Wet	3.8	23.2	55	70
Intermediate	2.2	3.3	20	49
Dry Arid Zone	10.3	63.5	25	—
Total	16.3	100	100	

† Permanent cultivation.

Central and Southern Provinces. There was concern that physical and chemical properties of the soil on the newly cleared lands would deteriorate rapidly through accelerated soil erosion (Joachim and Kandiah, 1984).

The gently sloping lands and the lower total annual rainfall of the North Central and Southern Provinces are generally more conducive to settled annual crop production than the wetter areas with steeper slopes (see Tables 2 and 3). The annual runoff percentages shown in Table 2 would also tend to support the intuitive selection of lands for settled agriculture (Ailes, 1958). According to a broad climatic zone classification, these lands are included in the dry zone (Figure 1). Thus, for a long time, rainfed farming in Sri Lanka has been referred to as "dry farming."

To ensure the successful development of a stable agriculture, experimental data were needed on: 1) the size of rainfed farm that could be managed by a single family unit, 2) the potential income from a farm of manageable size, and 3) whether the fertility of the soil could be maintained over a long period of continual rainfed cultivation. Consequently, a preliminary field experiment was started in 1933 to collect the necessary data. The location of this experiment was Kurundankulama in the North Central Province, about 5 miles from the Provincial capital of Anuradhapura.

The annual rainfall at this location is between 55 and 60 inches, of which approximately 30 to 35 inches is received from mid-September to late December, and 10 to 15 inches from mid-March to the end of April. Soils at the site are representative of the major soil group found in the North Central and Southern Provinces, and are now classified as Reddish Brown Earths (Alfisols). The topography here is undulating.

The experimental rotational farming scheme, where each beneficiary farmer cultivated a ten-acre allotment, gave promising results (Jinendradasa, 1948). Tentative conclusions were: 1) settled agriculture could replace the chena practice in the North Central Province of Sri Lanka if proper mechanical measures for soil and water conservation and crop rotations are adopted, 2) the lower areas of the soil catena could not support a healthy highland crop if poorly drained conditions prevailed for relatively long periods during the

Table 2. Some Land and Climatic Features of Sri Lanka.

Climatic Zone	Annual Rainfall	Annual Effective Rainfall	Annual Runoff	Terrain
	..... *in*		%	
Wet Zone	100-200	>40	17-84	Rolling, hilly, mountainous
Humid Zone	75-100	0-40	47-67	Undulating, rolling, hilly
Dry Zone	50-75	0-40	25-47	Flat-undulating, rolling, hilly
Arid Zone	<50	<40	0-12	Flat-undulating

main rainy season, 3) land preparation and possibly some other agricultural practices would have to be done exclusively with machinery which would facilitate the complete cropping of the ten-acre allotment during the season, and 4) the construction of broad-based, graded bunds with a shallow drain on the upperside, spaced at 100- to 500-foot intervals, was the mechanical soil conservation measure then recommended, but subsequently replaced after further experimentation.

Soil Problems and Land Capability

The soil problems associated with continued cropping of the same unit of land for a relatively long period, using tillage primarily as a weed control practice, had to be further evaluated. The effect of the natural hydrologic cycle on different physiographic units of the landscape had to be considered prior to the formulation of crop rotation recommendations specific to land units. Also, crops acceptable to the new environment had to be identified. For those reasons the Dry Zone Research Institute (DZRI) was established in 1948 at Maha Illuppallama, about 20 miles south of Anuradhapura (Abeyratne, 1956).

Land capability classification needed for the North Central Province and for similar parts of the dry zone evolved within a short time after the establishment of the DZRI (Sirimanne, 1958). In addition, soil studies of direct relevance to unirrigated highland farming were undertaken. Three morphologically distinct drainage classes of special significance to upland crop performance were identified. A unique pattern of soil water release was detected where 80 to 85 percent of the total available moisture is released at one bar, a relatively low soil moisture potential. These observations were made with reference to rainfed highland farming during the early years after the establishment of the Institute (Panabokke, 1958).

The role of pasture in the overall development of the dry zone landscape was evident from research on the introduction of pasture as a rotation crop that was well-suited to the imperfectly drained lands (Fernando, 1958). Crops that were acceptable to the cropping sequences in the dry zone and of specific economic importance to its farmers were also

Table 3. Mean Annual Rainfall, Erosivity and Elevation for Selected Locations in Sri Lanka.

Location	Elevation	Mean Annual Rainfall	Percent Erosive Rain†	Mean Annual KE > 1‡
	m	*mm*	%	*ft tons x 10^2 acre^{-1}*
Dry Zone				
Hambantota	18	1000	43	172
Mannar	3	950	56	211
Kankasanturai	6	1100	55	242
Batticaloa	6	1500	65	378
Anuradhapura	91	1300	56	203
Wet Zone				
Katunayaka	6	2000	64	492
Colombo	6	2200	53	566
Galle	21	2300	62	561
Ratnapura	50	3200	56	706
Katugastota	457	2000	47	361
Badulla	677	1800	27	195
Watawala	994	4000	33	513
Nuwaraeliya	1880	1700	4	27

† Erosive rain includes all rainfall with intensities exceeding 1 in h^{-1} (25 mm h^{-1}).
‡ KE > 1 represents the kinetic energy for all storms defined as erosive (i.e., with intensity exceeding 1 in h^{-1}).

identified and introduced within a few years after the establishment of the Research Institute (see Abeyratne, 1956). Crop selections made at the DZRI such as M.I. varieties of chili and mung bean continue to be the varieties most acceptable to farmers throughout the dry zone.

The ideology which evolved through the years at Maha Illuppallama was tested on the Yoda Ela Dry Highland Farming Project. Highland farming as practiced here gave more emphasis to animal husbandry. The results from this Project were convincing that three- to five-acre allotments of highland/rainfed cultivated land in the dry zone could be economically viable units. However, the farmers involved in this program became rather unhappy because they lacked paddy land with irrigation facilities that were enjoyed by other farmers at the lower end of the catenary sequence. Consequently, most of these farmers eventually left the Project. However, those farmers which remained appear to be fully satisfied with the success they have made and continue with the same enthusiasm they had when the Project began.

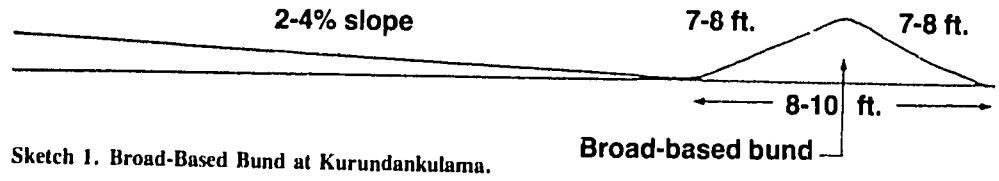
Soil and Water Conservation Research

The soil and water conservation methods employed both at the Maha Illuppallama Research Institute and at the Yoda Ela Dry Farming Project are graded bunds (narrow-based type) with a grade of approximately 1/250-1/500 (see sketches 1, 2 and 3 in Figure 2). The maximum spacing between bunds is 100 feet depending on the main slope of the land. The natural slope here is generally between three and five percent.

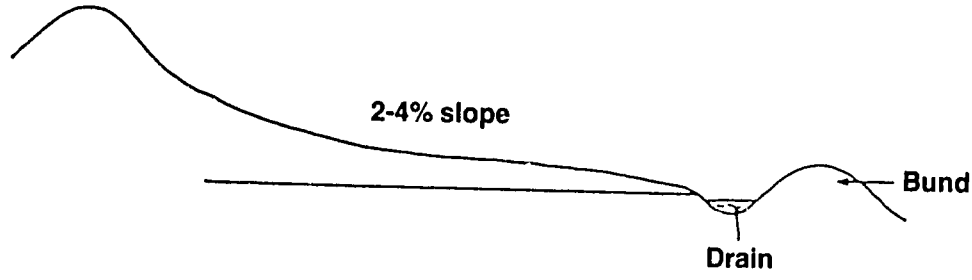
A modification of the Yoda Ela system was evaluated by another agricultural extension oriented project, i.e., the CIDA Dry Farming Project, where the Project beneficiaries owned a plot of paddy land under a minor tank, together with a settled block of rainfed highland. In addition, these farmers also had the privilege of cultivating a chena plot. The project sites were located in close proximity to the Dry Zone Research Institute which is now known as the Regional Research Center. This Project confirmed the feasibility of replacing the chena practice with the settled highlands rainfed farming system.

The CIDA Project Staff had also attempted to solve some problems related to farm power and tillage implements. Efforts were made to identify possible ways of reducing soil evaporation. Although positive effects of mulches have been observed at different locations with respect to the general performance of crops, the purely agronomic nature of the trials undertaken has not established whether the observed better growth is the result of reduced evaporation of water or temperature effects related to the mulching treatment.

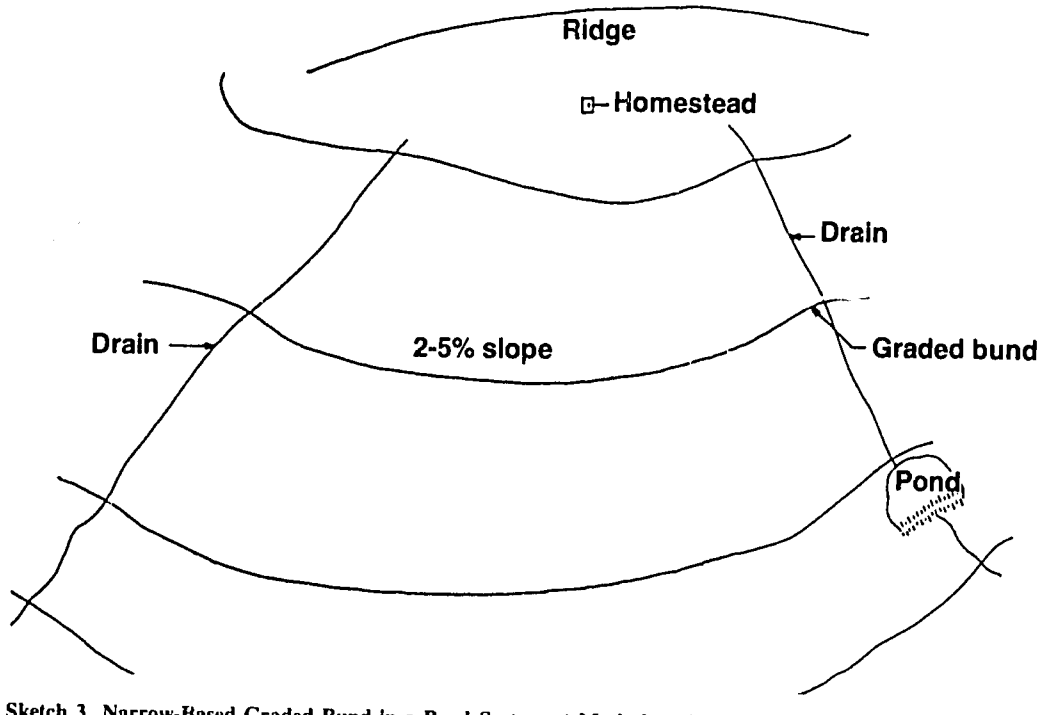
The Muthukandiya Dry Zone Project, a joint venture between Sri Lanka and the Australian Government, is a current ongoing project where the highland culture in a part of the six-acre block allotment has the facility of a small farm pond. The dimension of this pond is about 25 to 30 feet in diameter and about ten feet deep. It has a storage capacity of about 20,000 gallons. Runoff collected during the main rainy season is the source of water for the pond, which provides for the irrigation of crops grown nearby. The farm ponds are interconnected so that excess water from the pond at a higher elevation can be conducted to ponds situated at lower elevations along the waterway. This Project, which is located in the southeastern part of Sri Lanka, is apparently located in an environment distinctly different from that of the North Central Province environment. The experience thus gained indicated that this Project appears to be successful. However, further observations over a longer period are needed before this system is extended to similar adjacent areas.



Sketch 1. Broad-Based Bund at Kurundankulama.



Sketch 2. Narrow-Based Graded Bund at Yoda Ela and Anuradhapura.



Sketch 3. Narrow-Based Graded Bund in a Pond System at Muthukandiya.

Figure 2. Sketch Diagrams of the Various Mechanical Soil Conservation Measures Employed.

The other related project currently functioning in the North Central Province is the Anuradhapura Dry Zone Agriculture Development Project assisted by the Asian Development Bank. Here, the goal is to settle 4000 farm families, with each family receiving a one-acre paddy block under a village tank, and a three-acre parcel of unirrigated highland from a single block located within close proximity to the village. Mechanical soil conservation measures and the road network at each village settlement are developed as a centralized effort. The features used here consist of graded terraces with a grade of 1/250 and an interval of 50 to 100 feet depending on the slope. The maximum length of a single graded bund is usually not allowed to exceed 1000 feet.

It is now apparent that settled annual crop production in the dry zone could be a successful economic venture, especially if rapid soil degradation could be controlled by improved farming methods. Soil deterioration from arable farming may not be severely limiting (Table 4); however, the main problem is soil moisture conservation on agricultural lands. Statistically valid data is lacking on soil moisture cycle interaction with dry farming practices at the farm level.

Table 4. Changes in Soil Composition Under the Chena System of Cultivation.

	Adjoining Jungle	Jungle Before Clearing	After Burning	After 1st Crop	After 2nd Crop	After Five Years Recuperation
	..... %					
Site 1						
Moisture	4.29	4.55	4.36	3.38	2.15	3.18
Organic matter	5.45	4.52	4.40	3.91	3.63	3.99
Total replaceable bases (meq/100g soil)	20.98	20.26	25.64	20.24	20.42	19.00
Reaction pH	7.0	7.0	7.4	7.6	7.7	7.4
Site 2						
Moisture	1.96	2.08	2.06	1.57	1.13	1.97
Organic matter	2.64	2.38	2.28	2.13	1.94	2.72
Total replaceable bases (meq/100g soil)	11.43	12.37	11.13	10.19	10.29	11.21
Reaction pH	7.3	7.4	7.4	7.4	7.4	7.3

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Section III

Soil-Water Relationships

Methods of Characterizing Soil-Water Relationships

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ABSTRACT. The relationships between soils and the water they contain are highly complex and have a major influence on soil and crop management decisions and on crop yields. Therefore, a knowledge of soil water status is important for making decisions relative to crop production. In this report, various aspects of soil water status, along with techniques for determining the plant water extraction limits, determining field soil water contents, and recommendations for technology transfer and further research, are discussed.

Introduction

Relationships between soils and the water they contain are highly complex and have a major impact on crop management and production. Numerous articles have been published pertaining to soil-water relationships. Most, however, are outside the scope of this report. For this report, we emphasize the (1) importance of knowing the status of water in soils (amount, availability, distribution, movement, etc.), (2) techniques for determining or establishing soil water limits, (3) techniques for determining soil water contents under field conditions, and (4) recommendations regarding agrotechnology transfer and research that are needed to more efficiently use available water resources for crop production.

Soil Water Status

In this report, the soil water status refers to the amount, availability to plants, distribution with depth, distribution throughout the year, and movement of water in the soil profile. Information about these factors is required for effective management of rainfed and irrigated crops because these factors influence, among other things, what crops can be grown, when they can be grown, and what yields can be expected; crop response to fertilizers; and timing of cultural operations. As crop management intensity increases, as with the use of irrigation, fertilizers and improved cultivars, this knowledge becomes even more important for economical crop production. For example, applying too little water or fertilizer could result in limited yields; applying too much could result in losses of nutrients from the soil and, consequently, also result in limited yields and inefficient crop production.

The total amount of water that a soil can hold is influenced by such factors as its texture (sand, silt and clay content), organic matter content, bulk density (including soil structure), profile development, depth and coarse fragment content. Some water may drain freely from the soil; other water may be held at energy levels at which it cannot be extracted by plants. The upper limit of water available to plants is termed field capacity (FC) and the lower limit is termed the permanent wilting point (PWP). Water in the range between the limits is termed plant available water (PAW). The classical (historical) definition of PAW is largely inadequate from a theoretical viewpoint because FC does not exist due to continuous water movement (drainage) and PWP is both a plant and soil related property (Hardner, 1968). Nevertheless, PAW has been widely used and it does convey some practically important information for soil water management.

Water distribution with depth in a soil profile has a marked influence on its availability to plants. Crops extract PAW from throughout the zone into which roots penetrate. Shallow-rooted crops cannot extract water from deep in the soil when only a few roots penetrate to the deeper depths. Deep-rooting crops must have PAW in upper soil layers during early growth because roots do not grow into or through dry soil.

The distribution and amount of water in soil throughout the year is strongly influenced by distribution of precipitation. Soil water contents are highest immediately after precipitation, then decrease with time, initially due to drainage and, subsequently due to plant water use or evaporative loss.

The water retained in soils at matric potentials of -0.33 and -15 bars (-33 and -1500 kPa) is often used to represent FC and PWP, respectively. These values are useful laboratory approximations for establishing limits, but they are not precise and must be defined when used in a quantitative sense (Gardner, 1968). The lower limit (PWP) is generally applicable to all soils. The -0.33 bar value is generally applicable for the FC of fine-textured soils; for coarse-textured soils, a matric potential of -0.05 to -0.10 bar is often considered to be more appropriate.

The matric potentials indicate the energy by which water is retained in soils, but give no indication of the amount of water retained. The amount of water retained in soil is strongly influenced by its texture (sand, silt and clay content) as well as other soil factors such as coarse fragment content, organic matter content and bulk density. Soil salinity affects water availability by decreasing the osmotic potential in the soil water solution against which roots must work to extract water.

Soil Texture Effect on Water Retention

A generalized illustration of the relationship between soil texture and soil water holding capacity is given in Figure 1. The water is retained in relatively large soil pores for coarse-textured soils (sands) and small pores for fine-textured soils (clays). Large pores drain more freely than small pores. Consequently, the amount of water retained at PWP and at FC generally increases with increasing amounts of silt and clay (fine particles) in the soils. Soils having loam or light clay textures retain almost as much water as those with silt loam textures.

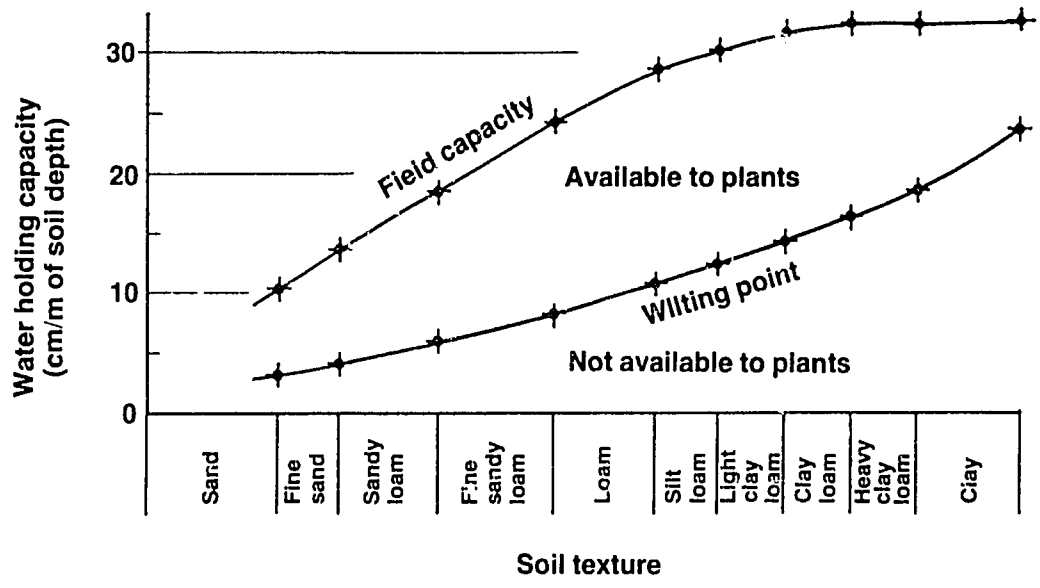

Figure 1. Typical Water Holding Capacities for Soils of Different Textures (From USDA, 1955).

Data in Table 1 illustrate the effect of soil texture on PAW retained at FC and on percent of PAW retained above and below a matric potential of -1 bar. These data clearly show that sandy soils retain less water than soils with higher clay content and retain most of their water at high matric potentials (>-1 bar), whereas clay soils retain most of their water at lower matric potentials (<-1 bar). This is further illustrated in Figure 2 by soil water characteristic curves, which show the relation between the water content and matric potential for several soils of different texture. The silty clay soil retained about 11.6 percent water between -0.33 and -15 bars matric potential. For the same range, the sandy loam and sandy soils retained about 13 and 4 percent water, respectively. Even by using -0.10 bar as FC for the sandy soil, it retained only eight percent water in the available range. Consequently, such sandy soil would retain only 8 cm of PAW to a 100 cm depth and would need to be replenished with water by precipitation or irrigation more frequently to avoid plant water stress than the loam and clay soils, which have greater storage capacities. Not only would more frequent replenishment be needed for the sandy soil, but the amount needed at each application would be less because of the limited storage capacity. Applications exceeding the storage capacity would result in percolation losses of water and leaching of nutrients, which could limit crop yields.

Organic Matter Effect on Water Retention

Increases in soil organic matter content generally result in increased water retention by soil with the increases being greater for coarse- than for fine-textured soils (Jamison, 1953). The benefits of increased organic matter in coarse-textured (sandy) soils result from diluting the inorganic material with the organic matter which has a greater water retention capacity. The benefits in fine-textured soils result mainly from improved soil structure, which reduces soil crusting and surface sealing, permits greater water infiltration and increases root proliferation throughout the soil profile, thus allowing plants to use soil water more effectively.

Table 1. Effect of Soil Texture on Plant Available Water (PAW) at Field Capacity (FC) and on the Percentage of PAW Retained at a Matric Potential of -1 Bar (Adapted from Black, 1957).

Soil Texture	PAW m^{-1} Soil at FC	PAW	
		Above -1 bar	Below -1 bar
	mm	..... %	
Coarse sand	37	95	5
Very fine sand	108	78	22
Very fine sandy loam	157	64	36
Silt loam	177	43	57
Silty clay	213	18	82
Clay	233	22	78

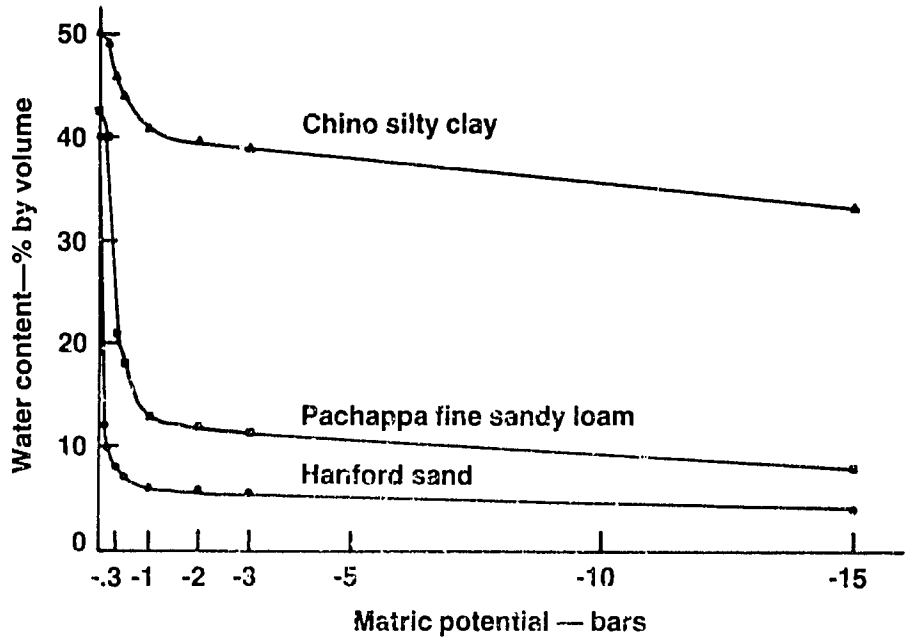

Figure 2. Water Retention Curves Showing the Relationship Between Water Content of Soil Cores as the Matric Potential Decreases From 0 to -15 Bars (Redrawn from Richards, 1955).

Although organic matter has a greater effect on sandy soils than on clay soils (Jamison 1953), Unger (1975) obtained significant (P = 0.001) relationships between water retention at FC and PWP, and organic matter content of soils that ranged in texture from sands to clays by using regression techniques. The results showed that PAW increased about 1.8 percentage units for each percentage unit increase in soil organic matter content when organic matter content, soil bulk density and soil clay content were used in the regression equations. Such an increase would be relatively small for fine-textured soils, but could have a major influence on water retention by coarse-textured soils. Increasing soil organic matter content is difficult. However, returning most or all residues from well-managed, high-residue crops should maintain or gradually increase the soil organic matter content (Allison, 1973) and, thereby, increase soil water retention. Possibly of greater importance would be the effect of organic matter on maintaining surface soil structure stability, thereby enhancing water infiltration and resulting in favorable conditions for plant establishment and growth.

Bulk Density Effect on Water Retention

The effect of soil bulk density (encompasses soil structure) on water retention is variable and is influenced by soil texture. Because water is retained in soil pores, bulk density affects water retention through its relationship to porosity and pore size. Increasing the density of fine-textured soils through compaction reduces their porosity and, consequently, their capacity to retain water. In contrast, coarse-textured soils have large pores that retain little water. By increasing the density of coarse-textured soils, total pore space is reduced, but the amount of fine pore space is increased, thus increasing the capacity of the soil to retain water. Compacted soils, however, may not be penetrated by roots and, thus, less total water may be available to plants.

Salinity Effect on Water Availability

Soil salinity refers to the presence of soluble salts in the soil. The effect of salts is manifested through the osmotic potential of soil water. The osmotic potential has little effect on water movement and the matric potential of the soil. Its major effect is on uptake of water by plant roots. To extract water from soils, plants must counteract the total soil water potential, which includes matric and osmotic potentials. Because these potentials are basically additive, plants can extract more water from soils having a high osmotic potential than from soils with a low osmotic potential. Consequently, if the osmotic potential of the soil solution is -3 bars and the matric potential is -3 bars, then plants would have the same difficulty extracting water from this solution as they would if the soil contained pure water (zero osmotic potential) at a matric potential of -6 bars (Russell, 1961). This implies that saline soils hold less PAW than similarly textured soils that are not saline.

Soil Water Movement

Water movement in soil includes the processes of infiltration, redistribution in the profile, drainage or percolation, uptake by plants, rise from a watertable and evaporation from the surface. In all cases, movement results from a water potential gradient with water moving from areas of high potential to areas of lower potential (higher potential) to soil at 1 bar potential (lower potential).

Water movement by the various processes has been widely discussed in the literature. Some of these processes occur simultaneously in a soil and the relationships are very complex. For this report, however, only brief comments are made about each process. A more detailed discussion can be found in Hillel (1982).

Infiltration

Infiltration is the process of water entry into a soil. It occurs when precipitation or irrigation provides free (liquid) water at the surface. The rate of water infiltration is controlled by soil conditions at the surface and within the profile. For rapid infiltration, the surface must permit rapid entry of water into the soil. This occurs when stable aggregates at the surface maintain open pores through which water can enter the soil. Unstable aggregates disperse when wetted or when raindrops impact, resulting in surface sealing and rapid declines in water infiltration rates. Crop residues on the surface intercept falling raindrops, thus reducing their energy, minimizing soil dispersion and, thereby, maintaining high infiltration rates.

Subsurface conditions that influence infiltration include soil texture, porosity (density), restricting layers and antecedent water content. Infiltration is also decreased as soil porosity decreases (density increases) because the number and size of water conducting pores decrease. Because coarse-textured soils have larger pores, infiltration is usually more rapid into them than into fine-textured soils. Infiltration may be greatly restricted by dense, impervious layers in the profile. Although infiltration may be rapid into a dry soil, infiltration in the same soil may be slow if it is wet because of a lower hydraulic gradient. For swelling clay soils, infiltration may become extremely low when the soil is wetted because of reduced hydraulic conductivity.

Redistribution

Although occurring simultaneously with infiltration, redistribution of water in the soil profile continues after infiltration ceases through drainage or percolation, uptake by plants, evaporation from the surface and rise from a watertable. Redistribution occurs in response to soil water potential gradients, and the water moves toward a state of equilibrium

throughout the soil-water system. For a natural soil system, however, equilibrium is never achieved because of continual additions or losses of water.

Drainage and Percolation

Drainage and percolation involve removal of free water from the soil profile. Drainage water moves in response to the force of gravity, mainly in large pores, and is that water held between saturation and FC. The water may move to a drainage system (ditches, canals, etc.) for discharge into streams or to an underground watertable. A watertable near the surface can supply water to plants if it is not too saline.

Uptake

Growing plants extend their roots into moist soil and extract water. Because of soil water potential gradients resulting from water extraction, water also moves from wetter soil to plant roots in drier soil. The movement is mainly by unsaturated flow. Under unsaturated conditions, large pores are filled mostly with air and small (capillary) pores are filled with water and some air. At high matric potentials (greater than about -0.1 bar), unsaturated flow is greater in coarse-textured (for example, sandy loam) soils than in finer-textured (clay) soils. At lower matric potentials, the trend is reversed (Brady, 1974). In addition to unsaturated flow in response to extraction by plants, soil water also moves in the vapor phase. Such movement probably is not great when the water content is within the optimum range for crop plants. However, it may be of importance in supplying water to drought-resistant desert plants that can exist at very low soil water levels (Brady, 1974).

Rise from Watertables

When underground watertables lie sufficiently close to the soil surface so that plant roots extend into or near to them, plants can obtain water from the underground sources. For roots growing into watertables, little water movement in the soil occurs. However, for roots near the watertable, water moves to the roots by unsaturated flow through capillary rise of water and as vapor flow. The height of rise is usually greater with fine-textured soils if sufficient time is allowed and the pores are not too small. For sandy soils, the adjustment is more rapid, but the height of rise is less because water does not rise as high in large pores as in the finer pores of fine-textured soils. The effects of soil textures and time on movement of water from a watertable as illustrated in Figure 3 (from Brady, 1974). These results suggest that sandy soils could provide water more readily to plants than loam and clay soils, provided that the watertable was a reliable source of water and the roots extended to near the watertable.

Evaporation

Soil water evaporation is the vapor movement of water from the soil to the atmosphere. It involves either water initially at the surface or soil water that moves to the surface by unsaturated flow or in the vapor phase. Many factors affect soil water evaporation, and research has been conducted to determine methods for controlling it. In general, evaporation can be decreased by reducing the energy for evaporation, reducing vapor transfer from soil to the air, or by reducing water flow (liquid or vapor) to the site of evaporation, which may be below the surface. Where water excesses cause problems, evaporation would be enhanced by increasing the above factors.

Establishment of Limits

Many techniques have been used to describe and define PAW, any of which may be useful depending upon the application desired. It is important to remember, no matter what technique is used to measure PAW, that the availability of water to plants is not a static characteristic of the soil, but is affected by many plant and environmental factors as well.

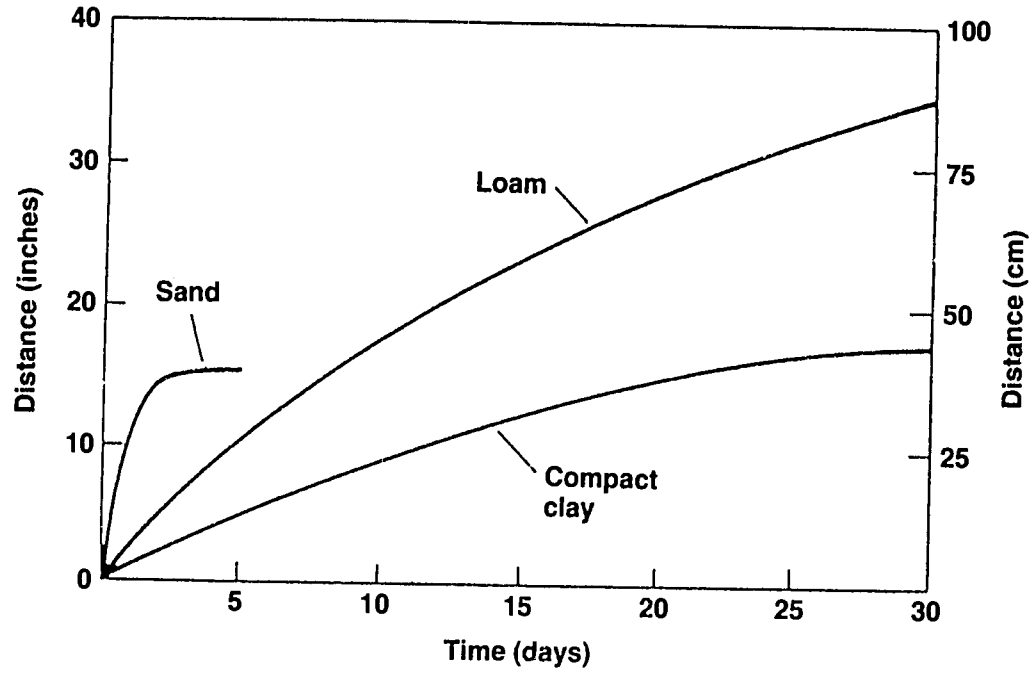

Figure 3. Upward Movement of Water from a Watertable Through Soils of Different Textures and Structures (From Brady, 1974).

Satisfactory utilization of soil water depends on root development and extension throughout the profile. If conditions are not favorable for root development during the vegetative period, then soil water will not be completely exploited during dry periods later in the season. The evaporative demand can at times exceed the ability of the soil to transmit water to the roots or the roots to absorb water, regardless of the amount of water in the soil. In this case, the water stress suffered by the crop would not be limited by soil water content, but be induced by atmospheric demand. For germination, emergence and establishment of the crop, availability of water in the upper layers of soil, rather than water content in the full root zone, is of concern. Tillage and residue management particularly affect soil water availability near the surface.

When sampling a soil profile for measurement of PAW, the depth of the root zone is defined and layers within the root zone are identified. Samples are then taken from each layer for determination of FC and PWP.

Laboratory Measurement of PAW

The most common definition of PAW is the difference between water held in the soil at -0.10 or -0.33 bar, FC, and at -15 bars, PWP. Usually, -0.33 bar is used, but sometimes -0.1 bar is used for coarse-textured soils. The FC measurement should be made on an undisturbed soil core since the soil structure affects the amount of water held at low tension. The measurement is made by mounting the core on a pressure plate assembly. The pressure in the chamber is raised to +0.1 or +0.33 bar. After drainage from the core has stopped, the water content of the soil core is determined by weighing.

The PWP is measured by placing the soil sample in a pressure apparatus having a ceramic pressure plate or a cellulose acetate membrane. The soil sample is often ground and sieved to improve contact between the sample and the membrane. The wilting point is limited by

the specific surface area of the sample, so destroying the soil structure does not affect the measurement. The pressure plate or membrane containing the samples is sealed inside a pressure chamber and pressure inside the chamber is raised to +15 bars. Water flows from the sample through the micropores of the plate or membrane, and the soil water content is determined after equilibrium is reached.

Field Measurement of PAW

Some researchers feel that the limits of -0.33 and -15 bars may not adequately describe water available for plant growth. The effects of soil structure on soil water holding capacity are disregarded, even though soil profile development increases the water holding capacity and water holding capacity from a profile is not uniform with depth. The soil will be dried to a higher tension near the surface and to a lower tension at greater depths. Ritchie (1981) proposed field measurements of the drained upper and lower limits to describe extractable water in a profile. In this technique, the soil is initially wetted with enough water to wet the entire root zone, covered for about two days, and then sampled to determine the amount of water held in the profile. The objective is to wait until drainage from the bottom of the root zone becomes very slow (0.1 cm/day or less).

The lower limit is determined by growing a crop on the soil and allowing it to deplete as much of the water as possible. The best data are obtained when the crop is grown to full size with minimal stress, which ensures that the root system develops throughout the soil until the plant dies or becomes dormant from water stress. Visible symptoms of water stress such as accelerated senescence are needed in order to determine the lower limit of water availability. Ritchie (1981) found that many crops have similar lower limits of extractable water. Differences among crops can be important on deep profiles where certain species or varieties might be more effective at extracting water from the lower portions of the profile. If conditions during the early growth stages of the crop inhibit root development (for example, frequently wetted surface, waterlogged soil, low evaporative demand), then the plant would not be able to extract water to the lower limit of the profile later in the season. The upper and lower limits of PAW, as measured by laboratory and field techniques, are shown in Figure 4. Ratliff *et al.* (1983) compared 401 observations of field and laboratory measurements of PAW and found that there can be serious discrepancies between the two methods. They suggested that the field-measured limits of soil water availability are more realistic than laboratory measurements in that they incorporate plant and climatic factors that affect soil water availability. However, the lower limit of available water is difficult to measure in the field in humid regions unless a rain-out shelter is available.

Estimates of PAW from Empirical Equations

Plant available or extractable water data are generally available at experimental sites, but often are not available for all agricultural soils of a region. Soil survey information that is generally available includes textural analysis (percent sand, silt and clay), bulk density, percent organic matter and identification of soil horizons. To obtain an estimate of PAW from available data, many researchers have developed regression equations relating soil survey data to upper and lower limits of available water. Unger (1975) developed regression equations to estimate the -0.33 and -15 bar volumetric water contents of soil pores using the percentage of clay or sand. He found little improvement in the correlation coefficients or standard errors when bulk density or percent organic matter was included in the regression equations. Gupta and Larson (1979), Rawls *et al.* (1981), and Rawls and Brakensiek (1982) used soil survey data (such as textural analysis, bulk density and organic matter) to estimate water retention over a range of tensions from -0.33 to -15 bars. Cassel *et al.* (1983) developed regression equations to estimate the field-measured upper and lower limits of water availability using soil texture analyses and cation exchange capacity data.

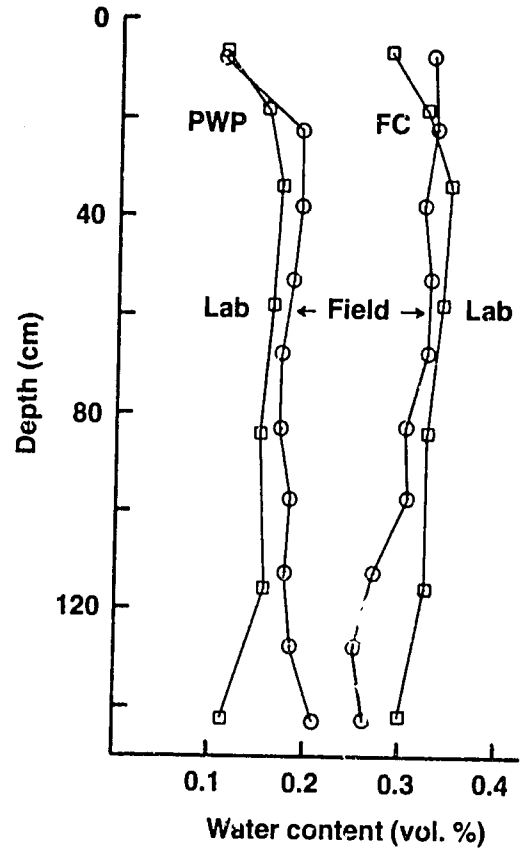

Figure 4. Water Retention in Pullman Clay Loam Soil at Field Capacity (FC) and Permanent Wilting Point (PWP) as Determined by Laboratory (-0.33 and -15 Bars Matric Potential) and Field Methods. Laboratory Data Obtained from Taylor *et al.* (1963) and Field Data from J.L. Steiner (Unpublished).

Field Measurement of Soil Water

A knowledge of the field soil water content is important for making sound soil and crop management decisions. Water content is determined by several methods. The more common are the gravimetric method, tensiometer, electrical conductivity, radioactivity and psychrometry.

Gravimetric

The classical method is the gravimetric method. Samples of field soil are obtained and the percent water determined by use of Appendix Eqs. [1] to [4], depending upon the particular need or application. To obtain total water in the profile, amounts for the various depths are summed. If PAW contained in the profile is desired, water retained in the profile at the PWP must be subtracted. Because sampling is usually done after the soil has drained to the FC limit, no corrections with regard to FC are usually required.

Tensiometers

Tensiometers measure the matric potential at which water is held in soil by use of a porous clay (ceramic) cup filled with water. Water in the cup is in contact with a vacuum gauge or a manometer (usually mercury). As soil dries, water moves from the cup to the

surrounding soil to maintain equilibrium, thus creating a vacuum (suction or tension) that is measured by the gauge or manometer. Tensiometers can also be used to determine matric potential gradients for monitoring the direction of water flow in the soil.

The effective range of tensiometers is from 0 to about -0.85 bar matric potential. Consequently, they are more suitable for use in coarse- textured (sandy) soils than in fine-textured soils because most PAW in sandy soils is held at potentials greater than -0.85 bar. Installation of tensiometers at several depths has been used to determine when to apply water to various field, orchard, nursery and turf grass crops (Donahue *et al.*, 1977).

Electrical Conductivity

The electrical conductivity (or resistance) of some porous materials such as gypsum, nylon and fiberglass is related to their water content. When blocks of these materials containing two electrodes mounted at a fixed distance apart are imbedded in the soil, the conductivity (resistance) measured changes in response to the water content of the soil. The system can be calibrated and subsequent resistance measurements can be used to determine soil water content from FC to PWP. The accuracy is higher near the PWP than at higher matric potentials.

Radioactivity

Methods of determining soil water content by radioactivity are neutron scattering and gamma ray attenuation.

Neutron scattering. The neutron scattering method is based on the capacity of hydrogen nuclei to scatter and slow neutrons emitted from a suitable radioactive source. Since most hydrogen in soil is associated with soil water, differences in count rates registered by neutron meters result primarily from differences in soil water content. The measurements are made in tubes installed vertically to the desired depth in the soil. Measurements can be made repeatedly at the same site without disturbing the soil after tube installation. Currently available neutron meters provide soil water contents directly on a percent volume basis. A unique characteristic of the neutron method is that the same calibration of the equipment may be adequate for different soils. However, the calibration should be checked in the particular soil, especially if soil water contents determined by several methods are to be compared.

Gamma ray attenuation. The gamma ray attenuation method is based on the principle that soil particles and soil water attenuate or reduce the energy of gamma rays passing through a soil column from a source to a detector. If soil bulk density is constant, then changes in equipment output (readings) from one sample to the next represent changes in soil water content. For soils whose bulk density changes with changes in water content, the single-source gamma ray attenuation method is not suitable. However, equipment using two sources (high and low energy) of gamma rays can simultaneously measure soil bulk density and water content (Corey, 1979). When used in the field, the source and detector are placed in separate holes, each at the depth at which bulk density and water content are to be determined. A single probe unit is also available for determining densities near the soil surface.

Psychrometry

A soil psychrometer is a device that measures the total soil water potential (matric + osmotic potential) in a soil. The osmotic potential would have to be measured independently if the matric potential is desired. Total soil water potential is the parameter relevant to plant growth. The soil water potential is related to the relative humidity of the

soil air. Determination of the soil water potential involves passing a current through a thermocouple encased in a porous cup to cool the junction below the dew point. This causes condensation of water on the thermocouple and subsequent evaporation of water into the cup atmosphere. By measuring the temperature of the thermocouple before cooling and during subsequent evaporation, the relative humidity can be determined. This, in turn, is related to the total soil water potential (Gardner, 1979). This method is not very reliable at high water potentials.

Other Methods

In addition to the methods discussed above, other methods of determining soil water content include (1) calculation of water content based on previous soil water content, precipitation, climatic conditions, etc.; (2) determining the depth of moist soil by pushing a probe into the soil; (3) feeling and squeezing the soil by hand; and (4) relating soil water contents to date and amount of precipitation. The last three methods give no numerical values for soil water content. However, some farmers and others have used these methods successfully to make management decisions.

In this section, various methods of determining soil water contents under field conditions were introduced with only limited information given about the different methods. More information concerning these methods is available in reports by Brady (1974), Corey (1979), Donahue *et al.* (1977), Gardner (1965, 1979) and others.

Agrotechnology Transfer and Research Needs

Methods of characterizing soil water relationships have been widely discussed in the literature. Many of the methods are readily adaptable for obtaining information about soil water to improve soil and crop management. The particular method used will depend on numerous circumstances including training of personnel, information needed and availability of funds and equipment. It is doubtful that method development will be required to improve soil and crop management.

For dryland crop management, knowledge about soil water conditions is particularly important at planting time. High levels of water available in the soil at planting time will often provide a base level of yield that could be expected, regardless of the rainfall later in the season. Knowledge of soil water content can be used to determine which crop to plant, whether to plant a long- or short-season variety of the crop selected, and whether supplemental fertilizer is likely to be sufficiently beneficial to justify the cost of application. Information about soil water content is also important in making decisions about tillage. Tillage immediately prior to planting may dry the profile excessively and impair germination and establishment of seedlings if rainfall is not received. Tillage when the surface soil water content is excessive is detrimental to soil structural properties and should be avoided. However, when excessive water may inhibit germination and establishment of seedings, tillage after the surface has begun drying may be desirable in some cases to speed drying of the soil profile.

Research that could possibly improve crop production involves the determination of the contribution of flow from watertables to crop growth. Information needed includes amount of water supplied, reliability of the watertable during the growing season and location of dependable watertables with respect to topography. Other research could involve the determination of which crops are best adapted to soils where the watertable recedes during the growing season, the effect of soil water and soil fertility interactions on yields, the potential for interseeding and multiple cropping, and the effect of surface treatments (land leveling or grading, contouring, terracing, crop residue management, etc.) on soil and water conservation.

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Appendix

Soil Water Content Calculations

Soil water contents of samples are usually found by determining sample wet weight, drying at 100° to 110°C, determining sample dry weight and calculating the percent water. For this method, with tare weights subtracted, percent water by weight (H_2O% by wt.) is determined by:

$$H_2O\% \text{ by wt.} = \frac{\text{sample wet wt.} - \text{sample dry wt.}}{\text{sample dry wt.}} \times 100 \qquad [1]$$

In practice, if standardized containers are used and the tare weight is obtained directly, Eq. [1] simplifies to:

$$H_2O\% \text{ by wt.} = [(\text{sample wet wt.})/(\text{sample dry wt.})-1] \times 100 \qquad [2]$$

In many cases, percent water by volume (H_2O% by vol.) is a more meaningful measure of soil water content than percent water by weight. Soil bulk density (BD) must be known to obtain percent by volume:

$$H_2O\% \text{ by vol.} = H_2O\% \text{ by wt.} \times \text{BD} \qquad [3]$$

For Eq. [3], BD is in g cm^{-3}. The terms cancel out when the right hand term is multiplied by the specific volume of water (cm^3 g^{-1}). A further step is to obtain the depth of water (depth H_2O) in a given depth of soil. This is obtained by:

$$\text{Depth } H_2O = H_2O\% \text{ by vol.} \times \text{depth of soil}/100 \qquad [4]$$

By using Eq. [4] the depth of water will be in the same unit as that used for soil depth.

After determining the water content by Eq. [4], the difference between the water content at FC and at PWP for each layer is summed to determine the amount of PAW in the total profile. This is obtained by:

$$\text{PAW} = \sum_{1}^{i} (\text{depth } H_2O_{FC} - \text{depth } H_2O_{PWP}), \qquad [5]$$

where i is the soil layer ranging from 1 for the surface layer to n for the bottom layer of the root zone.

Water Requirements and Water Use Efficiency of Crops

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ABSTRACT. Crop water requirements, i.e., water needed for unrestricted, optimum growth and yield, are generally reported as evapotranspiration (ET) in mm per day or mm per period. Water use efficiency (WUE), yield/ET, is generally expressed as kg/m^3. This report suggests methods for estimating ET and discusses the effects of various management practices on WUE. In most cases where water supply is fixed, any management factor that increases yield will increase WUE because ET is largely climate dependent and cannot be greatly influenced by management practices.

Introduction

Doorenbos and Pruitt (1977) defined crop water requirements as "the depth of water needed to meet the water loss through evapotranspiration (ET crop) of a disease-free crop, growing in large fields under nonrestricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment." Power (1983) defined water use efficiency (WUE) as the yield of plant product (grain, silage, tuber, or other plant product) produced per unit of water used. Mathematically, water use efficiency is expressed as:

$$WUE = Y/ET$$

where Y is the quantity of the crop (either total biomass or marketable product) produced on a given area in a given time period (usually a growing season) and ET is evapotranspiration from the same surface area during the same time interval. WUE can also be expressed in terms of transpiration (T) only, but in almost all field situations, ET, rather than T, is measured. Evapotranspiration includes water removed from the soil by evaporation and transpiration during the growing season, and excludes deep percolation and surface runoff.

Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979) have published extensive working papers on crop requirements and water use efficiency. These publications present methodologies to quantify yield response to water and to assess crop yields under both adequate and limited water supply. The authors take into account maximum and actual crop yields as influenced by water deficits using yield response functions to relate relative yield decreases and relative evapotranspiration deficits. Application of the method provides the user with 1) guidance in selection of crops; 2) assessment of crop yield under different water regimes; 3) criteria, in terms of crop production, for allocating limited water supplies; and 4) directives for field water management for optimum crop production and water efficiency.

Taylor *et al.* (1983) have edited a book that deals comprehensively with practically every aspect of water from the time it falls as rain, passes through the soil and plant, and emerges again into the atmosphere. It also includes detailed consideration of the many interactions of water with plant tops, roots, soil and soil organisms, especially as they affect crop yield. The book particularly focuses upon factors likely to be involved in research that affect water as a limiting resource.

The publications listed above provide both theoretical and practical information about crop water requirements and water use efficiency. They should be studied carefully to gain a thorough understanding of these subjects. No attempt will be made in this paper to discuss

these subjects in detail, but only to present some of the general concepts that will be useful during our discussions on "Cropping Systems and Soil Fertility Management for Increased Water Use Efficiency."

Crop Water Requirements

Crop water requirements, the depth of water needed for unrestricted, optimum growth and yield, are generally reported as evapotranspiration (ET) in mm per day or mm per period. Climate is one of the most important factors that governs the ET rate. It was clear very early that with well-watered plants, transpiration variation with climate caused changes in water use as the season progressed. Differences occurred among years and among locations, but "free water" evaporation and saturation deficit could be used to normalize the transpiration component. This was illustrated by Briggs and Shantz (1917); a summary of their findings is shown in Table 1. Tanner and Sinclair (1983) also reviewed these relationships in detail.

Since the level of ET has been shown to be related to the evaporative demand of the air, the evaporative demand can be expressed as the reference evapotranspiration (ET_0, sometimes called potential ET). When calculated, ET_0 predicts the effect of climate on the level of crop evapotranspiration. ET_0 is defined as the rate of evapotranspiration from an extensive surface of green grass that is between 8 and 15 cm tall, of uniform height, actively growing, completely shading the ground and not short of water. There are several methods of calculating ET_0 values and some of the more widely used procedures are described by Doorenbos and Kassam (1979). They also give approximate ET_0 values for different agroclimatic regions, shown in Table 2.

Table 1. Water Requirement of Alfalfa (*Medicago sativa*) at Different Stations in the Great Plains of the United States (Briggs and Shantz, 1917).

Location	Growth Period (1912)	Water Requirement†	Average Pan Evaporation	WR/ Evaporation
		g g⁻¹	*mm day⁻¹*	
Williston, North Dakota	29 July-24 Sept.	518 ± 12	4.04	128
Newell, South Dakota	9 Aug.-6 Sept.	630 ± 8	4.75	133
Akron, Colorado	26 July-6 Sept.	853 ± 13	5.74	146
Dalhart, Texas	26 July-31 Aug.	1005 ± 8	7.77	129

† WR is the water requirement which was obtained by dividing the grams of water transpired by the grams of dry matter produced.

Table 2. Reference Evapotranspiration (ET_0) for Different Agroclimatic Regions (Doorenbos and Kassam, 1979).

Regions	Mean Daily Temperature, °C		
	< 10 (cool)	20 (moderate)	> 30 (warm)
	..... *mm day*$^{-1}$		
Tropics			
Humid	3 - 4	4 - 5	5 - 6
Subhumid	3 - 5	5 - 6	7 - 8
Semiarid	4 - 5	6 - 7	8 - 9
Arid	4 - 5	7 - 8	9 - 10
Subtropics			
Summer rainfall:			
Humid	3 - 4	4 - 5	5 - 6
Subhumid	3 - 5	5 - 6	6 - 7
Semiarid	4 - 5	6 - 7	7 - 8
Arid	4 - 5	7 - 8	10 - 11
Winter rainfall:			
Humid - subhumid	2 - 3	4 - 5	5 - 6
Semiarid	3 - 4	5 - 6	7 - 8
Arid	3 - 4	6 - 7	10 - 11
Temperate			
Humid - subhumid	2 - 3	3 - 4	5 - 7
Semiarid - arid	3 - 4	5 - 6	8 - 9

Empirically determined crop coefficients (kc) are used to relate ET_0 to maximum crop ET when water supply meets the water requirements of the crop. The kc values vary with crop, development stage and somewhat with windspeed and humidity. For most crops, kc increases from a low value at the time of crop emergence to a maximum value as the crop reaches full development and then decreases as the crop matures. Evaporation from the soil is the dominant component of ET for most crops during early growth stages, and transpiration becomes dominant as a full crop canopy develops. However, for paddy rice, the kc is practically constant throughout the growing season because free water is available for evaporation. Crop coefficients for some crops grown in Northeast Thailand are given in Table 3. For a given climate, crop and development stage, the maximum

Table 3. Crop Coefficients (kc) for Some Selected Crops (Doorenbos and Kassam, 1979).

Crop	Initial	Crop Development	Mid-Season	Late Season	At Harvest	Total Growing Period
Maize	0.3-0.5	0.77-0.85	1.05-1.20	0.8-0.95	0.55-0.60	0.75-0.90
Rice	1.10-1.15	1.10-1.50	1.10-1.30	0.95-1.05	0.95-1.05	1.05-1.20
Watermelon	0.40-0.50	0.70-0.80	0.95-1.05	0.80-0.90	0.65-0.75	0.75-0.85
Sorghum	0.30-0.40	0.70-0.75	1.00-1.15	0.75-0.80	0.50-0.55	0.75-0.85
Groundnut	0.40-0.50	0.70-0.80	0.95-1.10	0.75-0.85	0.55-0.60	0.75-0.80
Bean (Green)	0.30-0.40	0.65-0.75	0.95-1.05	0.90-0.95	0.85-0.95	0.85-0.90
(Dry)	0.30-0.40	0.70-0.80	1.05-1.20	0.65-0.75	0.25-0.30	0.70-0.80
Sugarcane	0.40-0.50	0.70-1.00	1.00-1.30	0.75-0.80	0.50-0.60	0.85-1.05

evapotranspiration (ET_m) in mm per day of the period is $ET_m = kc \times ET_0$. The constant, kc, refers to conditions when water and other inputs are adequate for unrestricted growth and development. Under conditions where water becomes limited, ET_m cannot be maintained and actual evapotranspiration (ET_a) will be less. The ET_a will decrease as the available soil water is depleted. The particular crop grown and the texture of the soil are important factors that affect the rate of decline of ET_a rates under limited water conditions. Some crops such as most vegetables need relatively wet soils to maintain $ET_a = ET_m$, while others such as sorghum can deplete soil water much further before ET_a falls below ET_m. Soil water is more easily transmitted to and taken up by plant roots in sandy soils than in clay soils, but the total amount of available soil water is greater in clay soils. Doorenbos and Kassam (1979) have presented a method for estimating ET_a values under limited water conditions.

Yield-Evapotranspiration Relationships

When yields are transpiration-limited, strong correlations occur between cumulative seasonal dry matter and cumulative seasonal transpiration (De Wit, 1958; Arkley, 1963). De Wit (1958) showed that for dry, high-radiation:

$$Y/T = m/T_{max}$$

where Y = total dry matter per area, T = total transpiration per area during growth to harvest, and T_{max} = mean daily "free water evaporation" for the same period. The constant, m, is governed mainly by species and is largely independent of soil nutrition and water availability, unless the soil is seriously nutrition-limited or unless soil water is too high, causing a lack of aeration or leaching of nutrients. Since it is difficult to separate

transpiration from evaporation from the soil surface, the total ET is most often measured. Many studies have shown that transpiration and ET are closely correlated, and particularly so after a plant canopy has formed. A representation of dry matter yield as a function of ET is shown in Figure 1. The intercept along the ET axis presumably represents evaporation from the soil surface. For crops that have a relatively constant harvest index, the harvestable portion of the crop can be substituted in the relationship. As an example, data from the USDA Conservation and Production Research Laboratory, Bushland, Texas for grain sorghum are presented in Figure 2. There is a very good linear relationship between the yield of grain and ET. The relationship shows that 15.5 kg/ha of grain is produced for every millimeter (1.55 kg/m^3) of ET above the threshold value of 126 mm. The slope of the line for any given crop species will, as discussed above, be influenced by the climate of the area.

Sensitive Growth Periods

The linear relationship between yield and ET has been shown to hold for many crops (Doorenbos and Kassam, 1979). Therefore, reasonable yield estimates can be made from ET values. Water deficit of a given magnitude, expressed as a ratio of actual ET (ET_a) to maximum ET (ET_m), may occur continuously over the total growing period of a crop, or it may occur during only one or more of the individual growth periods. The growth periods are commonly referred to as 0 - establishment, 1 - vegetative, 2 - flowering, 3 - yield formation and 4 - ripening.

Doorenbos and Kassam (1979) have determined generalized relationships between the relative ET deficit and relative yield decrease. When the deficit occurs over the entire growing period, the decrease in yield is proportionately smaller than the increase in water deficit for crops such as groundnut, while it is proportionately greater for crops like maize (Figure 3).

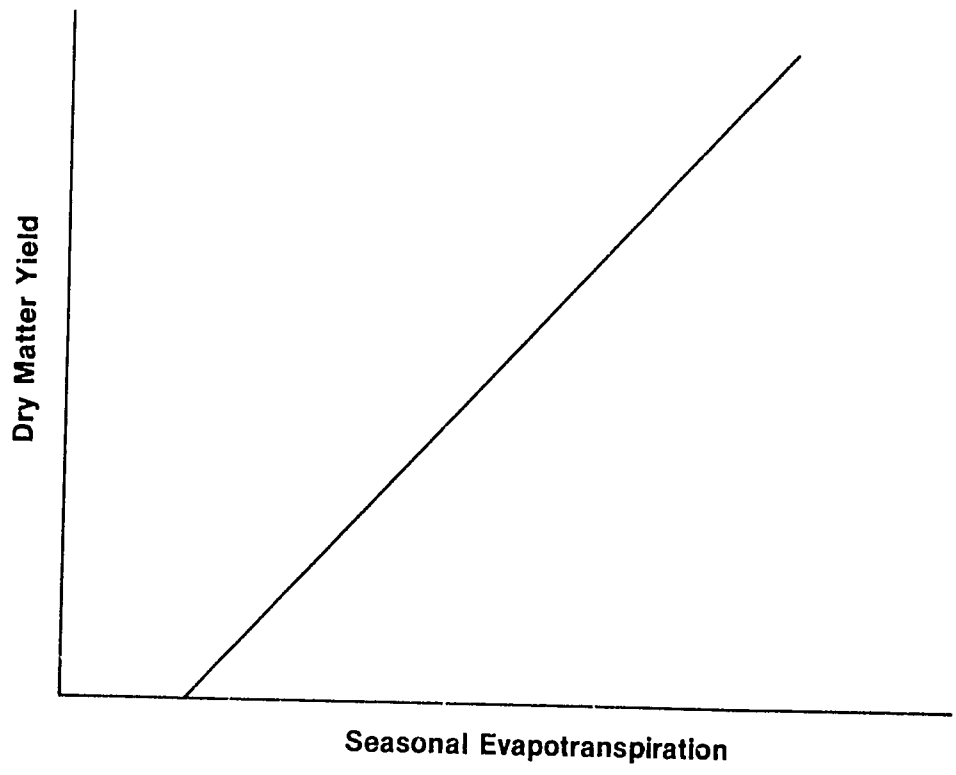

Figure 1. Representation of the Relationship Between Dry Matter Yield and Seasonal Evapotranspiration.

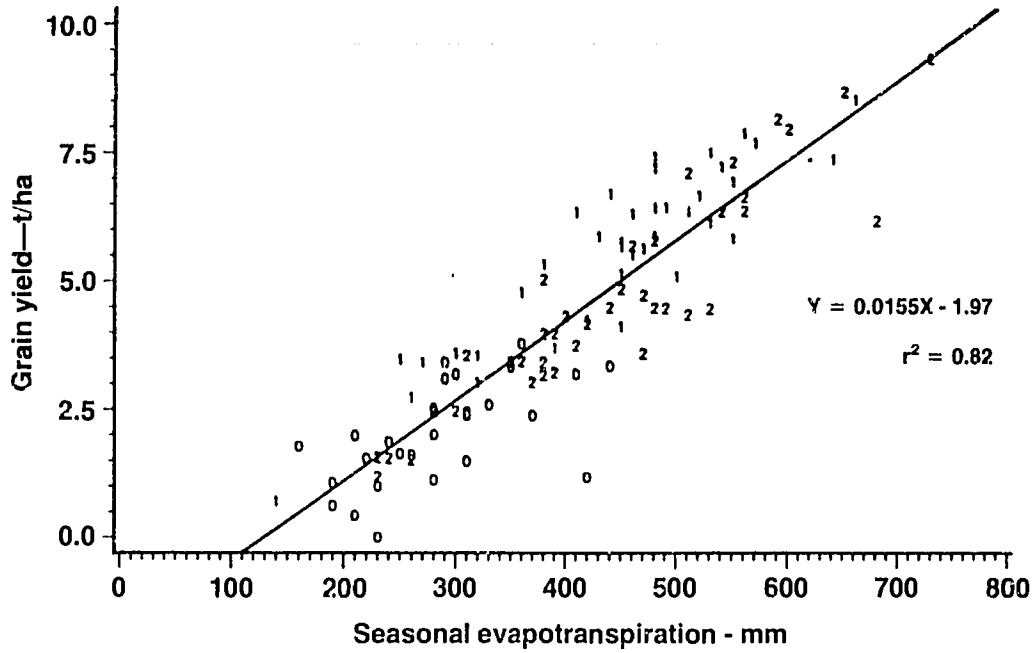

Figure 2. Relationship Between Yield of Grain Sorghum and Seasonal Evapotranspiration at the USDA Conservation and Production Research Laboratory, Bushland, Texas (0 - unpublished data, O.R. Jones; 1 - Musick and Dusek, 1971; 2 - Steward *et al.*, 1983).

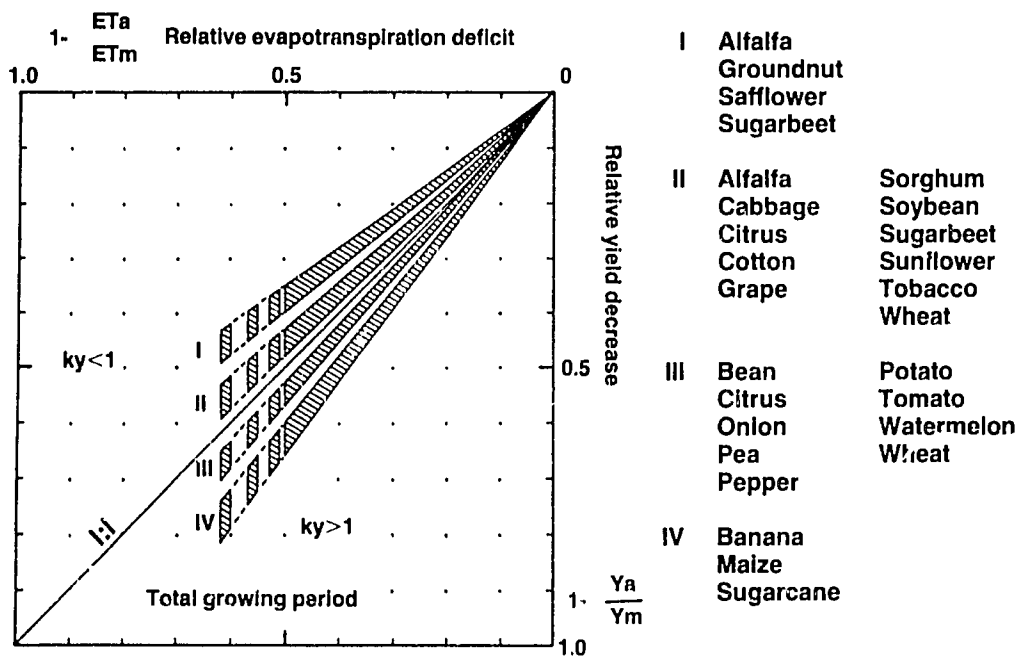

Figure 3. Generalized Relationships for Various Crops of the Effect of Increasing Evapotranspiration Deficit on Yield (Doorenbos and Kassam, 1979). ET_a is Actual Evapotranspiration, ET_m is Maximum Evapotranspiration, Ya is Actual Yield and Ym is Maximum Yield.

When ET deficits occur during individual growth periods, yield reductions can be markedly different. Decreases are relatively small when deficits occur during the vegetative or ripening periods, and relatively large when they occur during the flowering or yield formation periods (Figure 4). For some crops, the yield decreases can be extremely large. For example, Doorenbos and Kassam (1979) estimate that maize yield will be decreased by 45 percent with only a ten percent deficit in ET, if all of the deficit occurs during the flowering stage. Doorenbos and Kassam (1979) present information for 26 crops relative to their water requirements and the effect of ET deficits on yield decreases.

Water Use Efficiency

Water use efficiency (WUE), Y/ET, is generally expressed as kg/m^3. When Y is reported in t/ha and ET in mm, WUE in kg/m^3 can be obtained by 100·Y/ET. Since the relationship between Y and ET is linear, as previously shown in Figures 1 and 2, and the x axis (ET) is greater than zero, WUE increases as the yield increases. This is illustrated in Figure 5, which shows the data from Figure 2 plotted as a function of WUE against yield. The line drawn through the points was calculated from the regression line shown in Figure 2.

WUE was about 0.7 kg/m^3 at a yield level of 2 t/ha and about 1.1 kg/m^3 at a yield level of 5 t/ha. These values agree fairly closely with estimates by Doorenbos and Kassam (1979) who state that WUE ranges from 0.6 to 1.0 kg/m^3 when water requirements range from 450 to 650 mm for the growing season. Since WUE equals Y/ET, yields range from 2.7 to 6.5 t/ha.

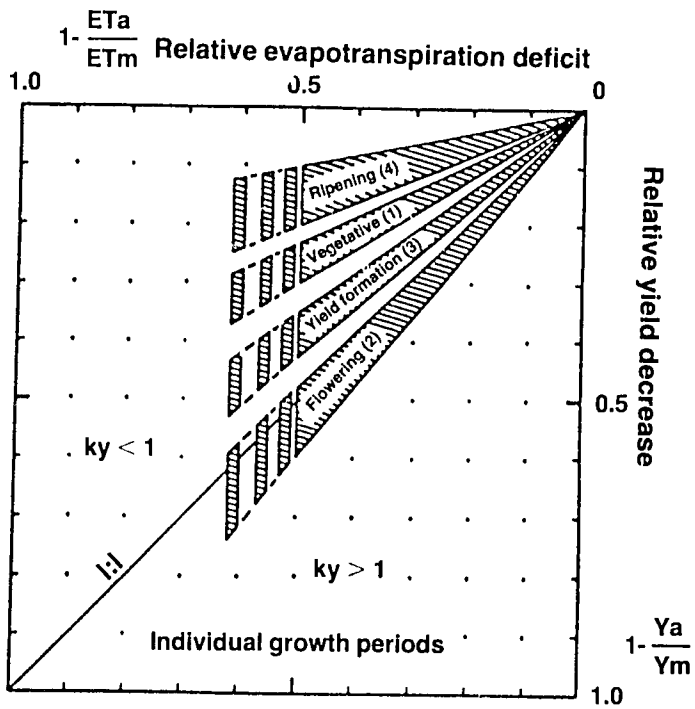

Figure 4. Generalized Relationships of the Effect of Increasing Evapotranspiration Deficit During Specific Growth Stages on the Crop Yield (Doorenbos and Kassam, 1979). ET_a is Actual Evapotranspiration, ET_m is Maximum Evapotranspiration, Ya is Actual Yield and Ym is Maximum Yield.

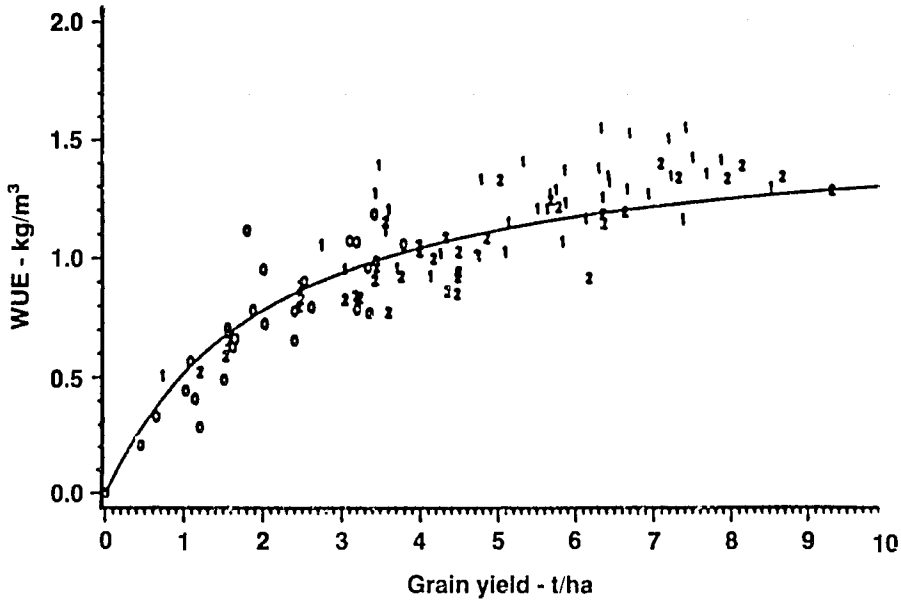

Figure 5. Relationship Between Water Use Efficiency (WUE) and Yield of Grain Sorghum at the USDA Conservation and Production Research Laboratory, Bushland, Texas
(Same data as presented in Figure 2).

Table 4 lists the range of water requirements and WUEs from some of the crops grown in Northeast Thailand. These values were obtained from Doorenbos and Kassam (1979) and the range of yields shown are calculated by WUE = Y/ET.

Soil fertility management is necessary for achieving high WUEs. Viets (1962) concluded that, in most cases when water supply is fixed, any management factor that increases yield will increase ET efficiency because ET will be little affected by the management. Many studies have shown that soil fertility can have marked effects on yield with little effect on ET. An example is the finding by Carlson *et al.* (1959) that irrigated maize biomass yields from a population of 34,600 plants per hectare were increased from 5,240 to 10,540 kg/ha primarily by nitrogen fertilizer, whereas ET varied only from 353 to 375 mm, respectively.

Crop Manipulation for Efficient Water Use

Crop manipulations involve variations in choice of species and cultivar, timing of events, plant density, fertility status, supplemental irrigation, pest control and other practices. The choices made are determined by many considerations, but economic factors are dominant in many cases. Nevertheless, strategies should be developed that combine our knowledge of the relationship between ET and crop production. Relatively few principles underlie farming practices that provide for the efficient use of water. A maximum proportion of the water should be expended in transpiration with minimum losses to evaporation, runoff and drainage. Basically, that involves rapid establishment and maintenance of a green plant canopy for as long as practical to minimize evaporation, maintaining soil conditions favorable for infiltration, and cropping with a rooting density sufficient to intercept drainage. Perhaps most important is a careful match between ET and water supply. Loomis (1983) has presented graphically some crop manipulation tactics to match ET to an available moisture supply of 500 mm (Figure 6). Reference evapotranspiration (ET_0) is shown as 4 mm/day during the cool season and 6 mm/day during the warm season. Actual

Table 4. Water Requirements and Water Utilization Efficiency Values for Some of the Crops Grown in Northeast Thailand.

Crop	Growing Period	Water Requirements	WUE	Yield
	days	*mm season^{-1}*	*kg m^{-3}*	*t ha^{-1}*
Maize	100-140+	500-800	0.8-1.6 (grain, 10-13% moisture)	4.0-12.8
Rice (paddy)	90-150	350-700	0.7-1.1 (grain, 15-20% moisture)	2.5-7.7
Watermelon	80-110	400-600	5.0-8.0 (fruit, 90% water)	20-48
Sorghum	100-140+	450-650	0.6-1.0 (grain, 12-15%)	2.7-6.5
Groundnut	90-140	500-700	0.6-0.8 (unshelled dry nut, 15%)	3.0-5.6
Bean (fresh)	60-90	300-500	1.2-2.0 (lush, 80-90%)	3.6-10.0
(dry)	90-120		0.3-0.6 (10%)	0.9-3.0
Sugarcane	270-365	1500-2500	cane: 5-8 (80%) sugar: 0.6-1.0	75-200 9-25

evapotranspiration (ET_a) is plotted against crop duration, and days of maximum evapotranspiration (ET_m) are given numerically. Figure 6a shows the performance of a standard annual crop during the warm season (ET = 6 mm/day). Full cover ET is extended in Figure 6b by an early maturing cultivar having a shortened juvenile period. A drought tolerant crop can be utilized in areas where periodic rains occur, as illustrated in Figure 6d. The most effective means for extending the length of the growing season is to limit ground cover so that the crop coefficient is less than 1, which means ET_a (kc × ET_0) is less than ET_0 (illustrated in Figure 6c) or to grow the crop during the cool seasons when ET_0 is only 4 mm/day (illustrated in Figure 6e). Low population of crop plants and wider spacing of rows are useful tactics for limiting ground cover and reducing ET_a.

Evapotranspiration and Precipitation Curves for Northeast Thailand

Reference evapotranspiration values for four locations in Northeast Thailand are shown in Figures 7 to 10. These are unpublished values calculated by George Hargreaves, Utah State University; and E.L. Skidmore, co-author of this paper. Calculations were made as follows:

$$ET_0 = 0.0075 \times RS \times T°F$$

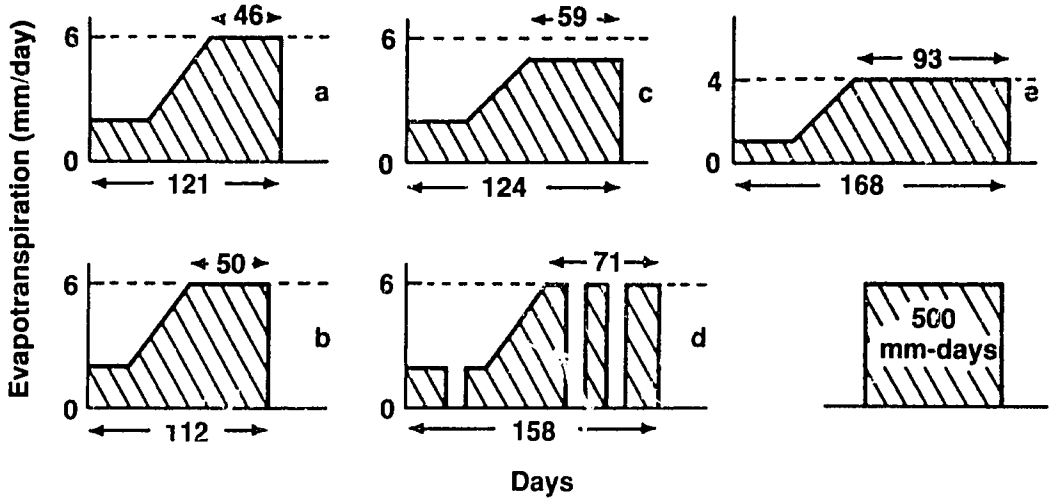

Figure 6. Generalized Examples of Various Ways That 500 mm of Seasonal Evapotranspiration Can be Utilized by Cropping (Loomis, 1983).

in which ET_0 and incident solar radiation (RS) are expressed in the same units of equivalent water evaporation, usually mm/day or mm/month, and T °F is mean temperature in degrees Fahrenheit. Incident solar radiation was determined by:

$$RS = 0.169 \times RA \times TD$$

in which RA is extraterrestrial radiation (Table 10, Doorenbos and Kassam, 1979) in mm/day, RS is solar radiation at the earth's surface in mm/day, 0.169 is a constant calibrated for Northeast Thailand, and TD is the temperature difference (mean maximum minus minimum temperature in degrees Celsius). RS can be measured directly in cal/cm^2/day or langleys (ly). RS, in mm of equivalent water evaporation, is equal to ly/58.5.

The 75 percent probability rainfall values are shown for the respective locations in Figures 7 to 10. These values are the rainfall amounts which have been exceeded in 75 percent of the years for each of the months. These data, along with some information regarding the available water holding capacity of the soil, are sufficient to allow some determination of crops that can be grown in the area and to project the yields that might be expected. In general, the locations represented in Figures 7 to 10 have sufficient to excess rainfall during the monsoon season, but any cropping beyond this period will be dependent on stored soil water or supplemental irrigation.

Matching Cropping System With Climate

In the final analysis, dryland cropping depends on matching a cropping system with the climate so that there is a good probability of producing a harvestable crop. Increased emphasis is being placed on probability levels as compared to average values. Average values, particularly in low rainfall regions, can be very misleading because a few very high, but rare, rainfall events can raise the average substantially. Probability levels can be set at any desired level and are a good way of assessing risks. Dancette and Hall (1979) have developed methods for improving management of water resources, using principles for soil and plant sciences. They prepared maps for the Sudanian and Sahelian zones of Africa showing maximum cycle lengths for millet that will result in crop water needs being satisfied to at least the 80 percent level, and for 80 years out of 100. The

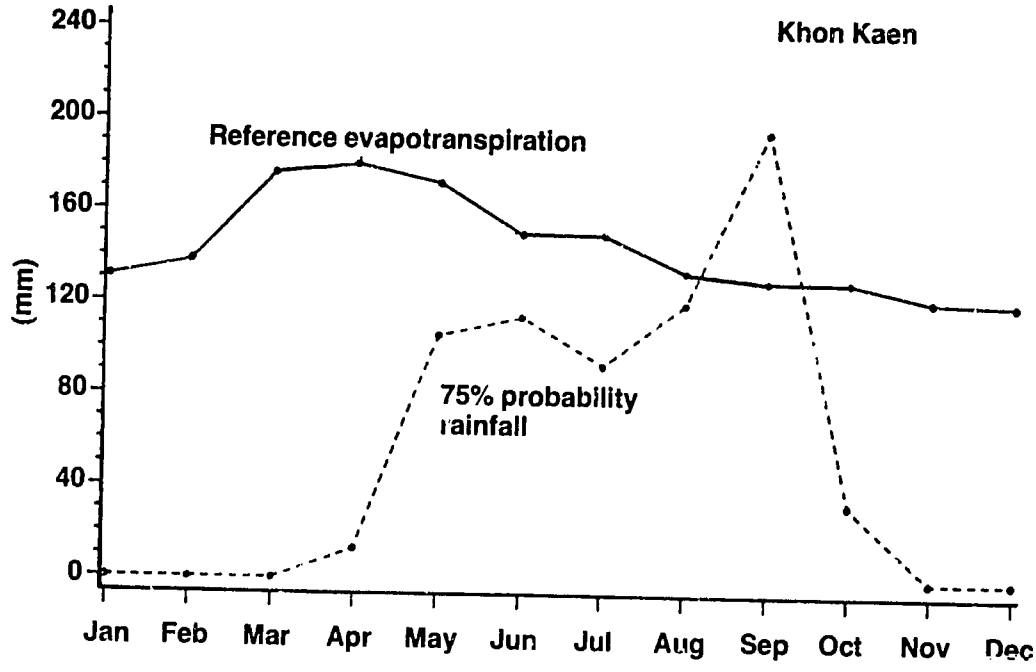

Figure 7. Monthly Estimated Evapotranspiration Values and Amounts of Precipitation Exceeded 75 Percent of the Time for Khon Kaen in Northeast Thailand.

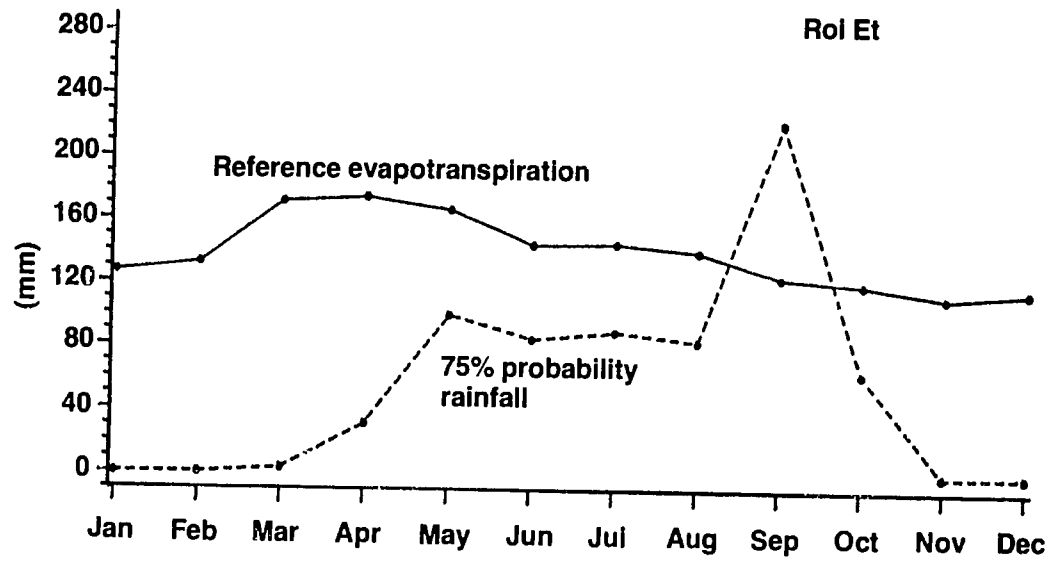

Figure 8. Monthly Estimated Evapotranspiration Values and Amounts of Precipitation Exceeded 75 Percent of the Time for Roi Et in Northeast Thailand.

information needed for such estimates are the rainfall, evaporative demand, crop coefficient of water use, rooting depth, water retention characteristics of the soil, and the availability of water in the soil.

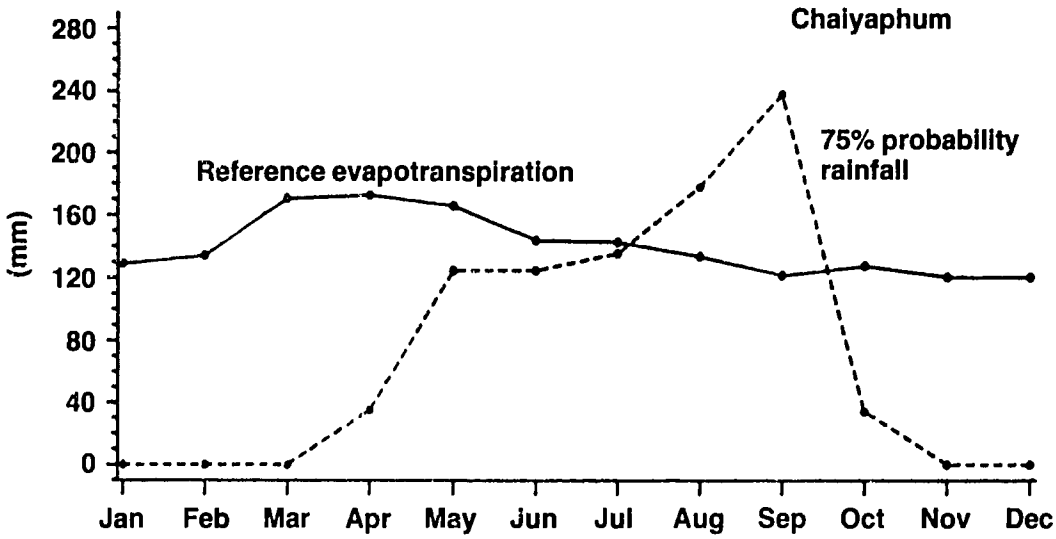

Figure 9. Monthly Estimated Evapotranspiration Values and Amounts of Precipitation Exceeded 75 Percent of the Time for Chaiyaphum in Northeast Thailand.

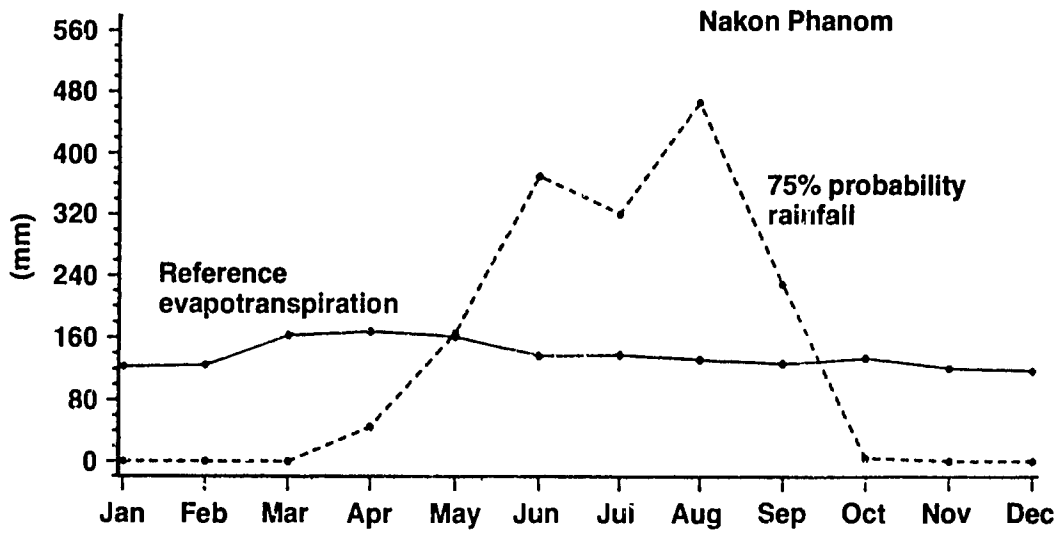

Figure 10. Monthly Estimated Evapotranspiration Values and Amounts of Precipitation Exceeded 75 Percent of the Time for Nakon Phanom in Northeast Thailand.

A rather simple approach to matching a cropping pattern to climate is shown for grain sorghum at Bushland, Texas in Figure 11. The solid line represents the weekly rainfall amounts that are exceeded in 50 percent of the years, and the dashed line represents the number of weekly heat units (degrees C above 0) exceeded in 50 percent of the years. The rectangular boxes represent crops of grain sorghum planted at four different times, and the numbers above the boxes are the 50 percent probability amounts of rainfall that occur during the periods. The four divisions within each period represent the emergence,

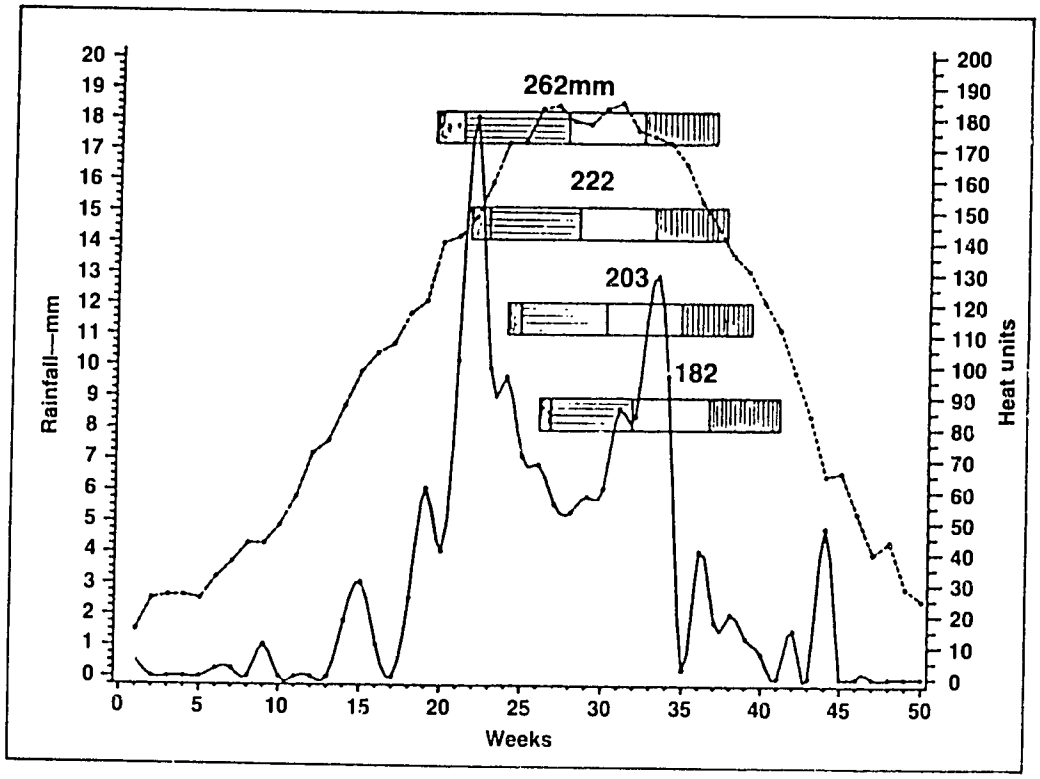

Figure 11. Weekly Precipitation and Heat Unit (Zero C Base) Values for Bushland, Texas that are Exceeded in 50 Percent of the Years (0 weeks begin on January 1). The Four Boxes Represent Grain Sorghum Seeded at Four Different Times, and the Values Above the Boxes are the Amounts of Rainfall Exceeded in 50 Percent of the Years During the Cropping Season.

vegetative, reproductive and grain filling stages of crop production. Although the same cultivar is pictured for each of the planting dates, the length of the growing season decreased from 121 days for the earliest planting to 104 days for the latest.

Grain sorghum is traditionally seeded in the area on about June 15 (represented by the third box from the top of Figure 11). The rainfall pattern readily shows the advantage of this seeding data because the rainfall preceding this time results in good soil water conditions for seeding. Also, there is a high probability of rainfall occurring during the reproductive growth period and of temperatures decreasing during the grain filling period. The disadvantage of this planting time, however, is that there is substantially less precipitation during the growing season than for an earlier seeding date. For example, seeding on May 10 (top box in Figure 11) results in a growing season with substantially more rain-fall. However, the reproductive portion of the crop season is now shifted to the hottest and driest portion of the growing season. An early seeding date may still be the most desirable, particularly if the soil profile is fully recharged; a later seeding would not conserve much of the rainfall that normally occurs during week 22. Early seeding may be enhanced by increasing row spacing and decreasing plant populations to maintain ET_a less than ET_m (as discussed in Figure 6c) so that the soil water reserves will not be totally depleted before the reproductive phase of the growth cycle is reached.

The above discussion is simply an example of how cropping systems and climatic data bases can be matched. In some cases, crop growth models such as the grain sorghum model of Arkin *et al.* (1978) can be used to estimate crop yields under various climatic conditions. Eventually, however, field data are required to validate these models and to obtain the data necessary to extend the models to specific environments.

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Recommended Water Conservation Practices for Northeast Thailand

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ABSTRACT. The traditional water conservation practices of farm families living in remote areas far away from water sources are described. The recommended Small-Scale Water Resources Development Projects for these areas are presented and discussed.

Introduction

Northeast Thailand is the most underdeveloped and also the poorest region of Thailand. It is also recognized by many Thais as its most arid region. The fact, however, is that its annual average rainfall is much the same in magnitude as that in other parts of the country. Average annual rainfall is approximately 1800 to 2500 mm on the eastern side of the mountain range, down to 1100 mm on the western side.

Most of the rainfall occurs from May to October, 85 to 90 percent of the total annual averages. The Mun and the Chi are the two major rivers; they flow eastward and discharge into the Mekong River. Deforestation of the upstream watershed has increased mainly for cassava production due to the population explosion of the past two decades.

According to the survey of the Office of Accelerated Rural Development (1969-1976), there are 2.6 million people in 4,567 villages lacking water for their domestic uses.

Traditionally, the people in remote villages far away from water sources have been using the following water conservation practices:

1) Dug ponds, which are usually located at village centers where they may be recharged from the watertable.
2) Fai Na (diversion dikes), i.e., construction of 1 to 2 m embankments closing the gaps between high grounds, with spillways to divert required water into paddy fields.
3) Fai Nong, i.e., construction of small bunds around natural ponds and swamps.
4) Cultivating rice in low areas to receive runoff from a watershed three to four times the size of paddy areas.
5) Shallow wells.

For planning purposes, the Asian Institute of Technology (1978) divided the Northeast into three zones. In Zone I and Zone II there are possibilities of large-scale water resource projects and pumping from reliable rivers. But 80 percent of farm families are living in Zone III where these possibilities do not exist. Their basic water requirements can only be satisfied through the development of small water resource projects or water conservation.

The Royal Thai Government recognized these people's difficulties and in 1977 initiated Small-Scale Water Resources Development Projects. Since then, 16 governmental agencies have engaged in construction of the basic infrastructures, namely, small reservoirs, diversion weirs, farm ponds, swamp excavation, pumps, distribution canals, groundwater development and water conservation in natural waterways. The conceptual framework of this small reservoir/farm ponds system is depicted in Figure 1.

However, in many cases villages will continue to rely on rainfed agriculture and cannot expect the benefits of fully irrigated agriculture.

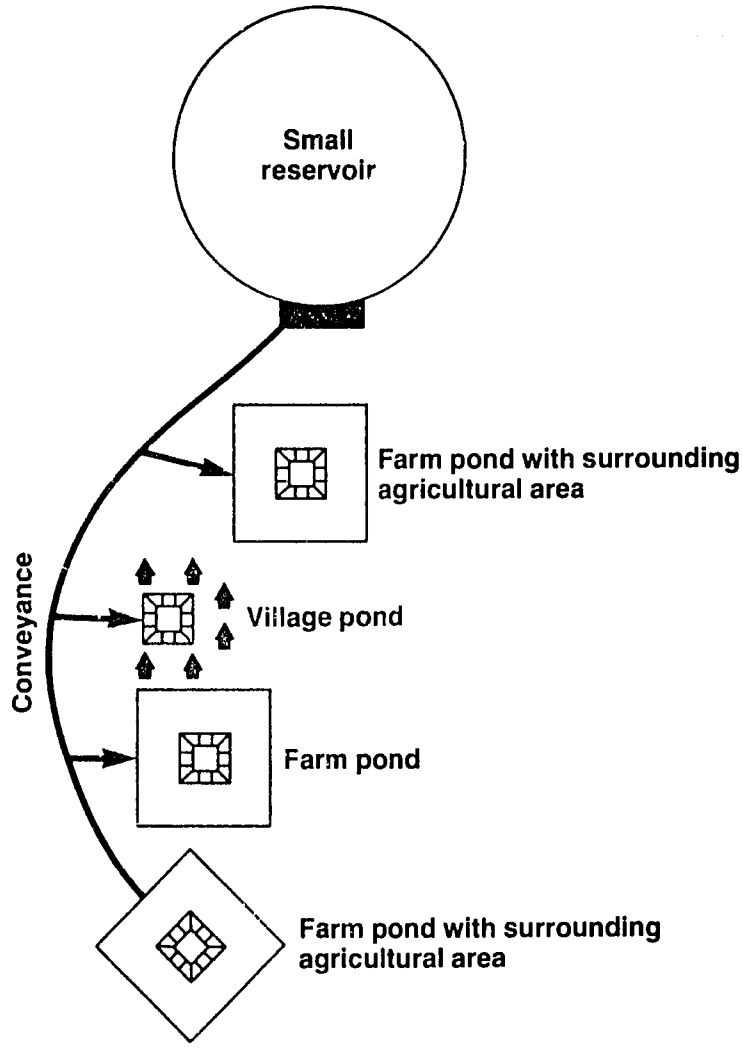

Figure 1. Small Reservoir/Farm Ponds System.

Objectives of Small Water Resources Development

The objectives of the program are to conserve water to satisfy basic water requirements and to improve the economic condition of the rural village population. The water requirements are, in order of priority:

1) domestic uses, especially in the dry season,
2) cattle raising,
3) fishery,
4) agricultural purposes such as vegetable cultivation, rice nurseries etc., and
5) other minor uses such as retting kenaf.

Water Requirement

In planning small water resources to meet the objectives, Table 1 may be used for estimation of the water requirement.

Table 1. Approximate Water Requirement.

Average Quantity Required for	Liter day^{-1}
Each member of family	30-60
Each cattle	50
Each hog	20
Six chickens	1
Each rai of vegetable	7,000
Each rai of wet season rice	600-800 m^3 $season^{-1}$

Extension of Benefits

Many small reservoirs are able to conserve much less water than the annual inflow from upstream watersheds. In many cases, storage capacity cannot be enlarged due to topographical constraints, upstream land uses and land ownerships. Extension of the benefits from these small reservoirs may be possible through the construction of a series of farm ponds downstream. Farm ponds may be privately owned or communal. Timely regulation of the various water conservation facilities will extend the scope of water uses. In the same way, the diverted outflow from weirs may be conserved for drought periods.

Water Use

At present, more than 1700 small-scale irrigation projects have been constructed by the Royal Irrigation Department. Farmers obtain the benefits stipulated in the objectives but water use has not reached its full potential. It is necessary for village communities to develop organizations receptive to technological transfer so that other techniques for water conservation may be implemented, e.g., improvement of irrigation efficiencies and irrigation systems.

Conclusion

Since 1977, the government has concentrated on water conservation, creating a large amount of basic infrastructures for collection and regulation of water for the basic requirements of the rural population.

Many of these water conservation facilities have a greater potential than the basic water requirements of the villages. A program for maximizing water use should receive serious consideration.

Current On-Farm Water Conservation Practices for Agricultural Soils in Northeast Thailand

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ABSTRACT. Soil erosion became a serious problem in Thailand approximately 25 to 30 years ago. The rapid increase in population, together with diversification of crops for industries and export, has resulted in much of the forest being cleared for cultivation. Much of this new land is very susceptible to erosion because of topography, soil and rainfall characteristics. The extent of damage by erosion, however, depends on the type of land use and its management. It is estimated that 17.2 Mha, or 33 percent of the country's area, has been moderately to severely eroded. Suspended sediment deposition from all watersheds is estimated to be 27 million tons annually Erosion has also affected the natural environments and has caused severe sedimentation and pollution of streams and reservoirs.

Introduction

Water conservation can be divided into two phases: 1) conservation of soil moisture and 2) conservation of water for irrigation and other uses.

In the first phase, the construction of field terraces conserves some soil moisture. Furthermore, the use of cover crops, green manure, farmyard manure, composts, mulches and some waste materials such as rice hulls and sawdust all help to retain soil moisture. Among the latter, the use of compost has been widespread during the last few years. This has been one of the government's projects for assisting the rural poverty areas.

The second phase of water conservation, i.e., for irrigation and other uses, has been very well accepted by government agencies and people in the rural areas. In addition to the large dams which are operated by the Royal Irrigation Department and the Energy Generating Authority of Thailand, smaller dams and reservoirs are now constructed and maintained by numerous agencies including the Department of Land Development. The lack of water is, therefore, not critical at the moment.

The Soil and Water Conservation and Management Division of the Department of Land Development has been involved in soil and water conservation programs since 1963 by providing technical services as needed by farmers and conducting research and demonstrations at Land Development Stations. It has also provided training and short courses in soil and water conservation for extension workers and farmers.

General Information on the Northeast

Northeast Thailand is designated as the Northeast Plateau or Korat Plateau. It covers an area of 170,000 km^2 or 17 Mha and lies between 14° and 19°N latitude, and between 101° and 106°E longitude. The Northeast Plateau is bounded on the north and east by the Mekong River which forms the boundary between Thailand and Laos, on the west by the hills of the Phetchabun Mountain Range and in the south by the Dangrek Escarpment which forms the boundary with Cambodia. The elevation of the plateau ranges from over 250 m above sea level in the north and the west to about 100 m above sea level in the vicinity of Ubon Province.

Rainfall Distribution

In the west and south of the Northeast region of Thailand, the average annual rainfall is about 1300 mm. Total annual days of rainfall range from 107 to 132. In the northern and the eastern part of the region, the average annual rainfall ranges from 1400 to 1800 mm, and the days of rainfall range from 120 to 125 days. In some provinces such as Nong Khai and Nakon Phanom, the days of rainfall usually exceed 130 days.

Soil Problems

Most of the soils in the Northeast are sandy, low in fertility, highly erodible, tend to crust and compact, have low moisture holding capacity and are very low in organic matter content.

Activities

The Department of Land Development has established Stations for Land Development in many provinces, especially in Northeast Thailand, and have developed projects and programs for helping farmers in this region. Examples of these are the following:

1) The project on water resource development was conducted during 1977-1981, the period of the 4th National Development Plan. The Department of Land Development constructed some 495 reservoirs scattered throughout the Northeast, with a total water capacity of about 18 million m^3.
2) The project on soil and water conservation practices.
3) The project on making compost to improve soil productivity and to conserve soil moisture through increased retention and storage of water.
4) The project on wood lots for reforestation and water conservation.
5) The project on improving saline soils.
6) On-farm trials and research are underway for these principal projects.

Soil-Moisture Relationships in Agricultural Soils of Northeast Thailand

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ABSTRACT. The objective of this study was to determine soil moisture characteristics in Northeast Thailand. Results were obtained from a five-year study on upland soil and a one-year study at four locations with different topographic positions. The interpretation of LANDSAT imagery was utilized to delineate the zones where there was potential to develop cropping systems in the dry season under rainfed conditions. The results of this study can be summarized as follows:

For upland soils, crops planted early in the rainy season (April or May) are likely to suffer from moisture stress. July appeared to be a better planting time since sufficient moisture was generally available for at least the next four months.

Soil moisture data obtained from upland paddy fields indicated that the water accumulated in excess of the saturation percentage for only a short period. Rice could not survive readily under such conditions. However, sufficient water was usually found on the lowland paddy fields. Field crops are recommended for the upland and upland paddy fields since the moisture conditions were generally above the permanent wilting percentage for a relatively long period.

The moisture patterns of surface soils can be monitored by LANDSAT imagery. The dry, moist and saturated zones were easily delineated with high accuracy. However, the soil moisture patterns under a dense vegetation canopy could not be determined satisfactorily. With LANDSAT imagery, soil moisture conditions can be determined over a large area. Moreover, the information on soil moisture conditions could further be investigated by using multidate imageries.

Introduction

A basic requirement for the growth of all plants is that the soil moisture should be above the permanent wilting point (-15 bars) within some part of the rooting zone. Various crop plants differ in their requirements, including the total amount of water needed, the length of time over which it is needed and the ability to withstand periods of drought. For most crops, the rate of growth responds more or less linearly to an increase in available moisture up to a certain limit. Plants will die if they are allowed to remain beyond a certain period in soil that has exceeded the wilting point. Thus, crops respond in a distinctive manner to moisture availability and the requirements differ from crop to crop.

Moisture availability to plants is determined by a combination of the physical environment and human activities. The physical environment is comprised mainly of climate, soil, topography, vegetative cover and groundwater. Human activities can be defined as the impact of man acting upon the land surface, e.g., the construction of paddy bunds and terraces which, in turn, affect water conservation and storage. Figure 1 shows the components that affect the availability of water under rainfed conditions. Moreover, the interaction between these components must be considered.

The main landscape features in Northeast Thailand are the river terraces, the flood plains and the surface elevations ranging from 100 to 300 m (Moormann *et al.*, 1964; Scholten and Siriphant, 1983). The landscape is extensively populated (Boulbet, 1982) and consists of gently undulating terrain with varying densities of trees. The lowland and lower part of the upland are planted to rice fields, whereas the uplands have been developed for the production of field crops. Table 1 illustrates the landscape features and some characteristics associated with them. The most extensive soils in the Northeast are coarse-textured with low water holding capacity. In general, the rainwater will run off the upland

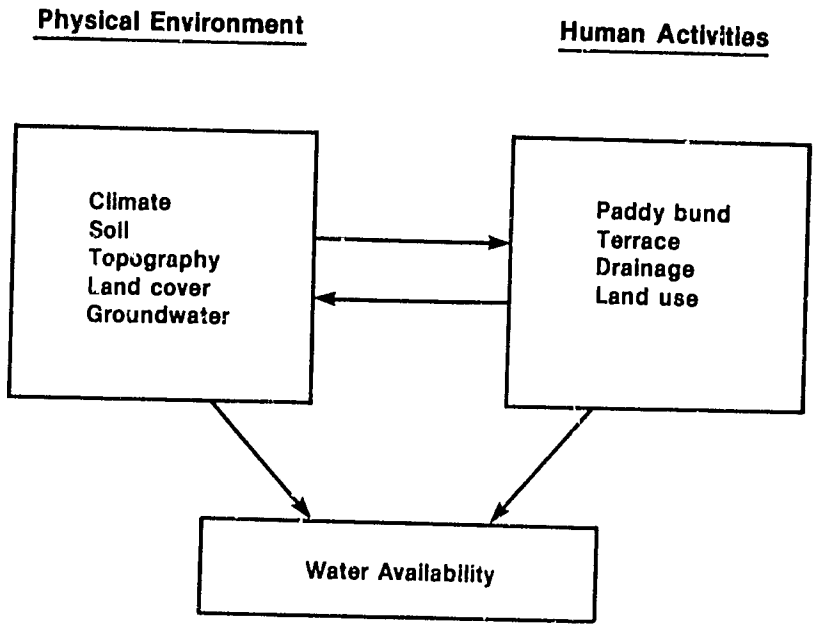

Figure 1. The Physical Environment and Human Activities Affecting Water Availability in Soils.

and inundate the surface of the lowland paddies. In most cases, the paddy bund terraces will prevent excessive runoff and increase the water available for rice production. Thus, the parameters that most directly affect water availability for crop production on the existing landscapes in the Northeast are topography, soil type and land management. The distribution of water in and on soil is the most important consideration in determining the crops to be grown, planting dates and cropping sequence.

Table 1. Some Characteristics of Landscape Features in the Northeast.

Field Type	Upland	Upland Paddy Field	Lowland Paddy Field
Drainage	Well-drained	Moderately drained	Poorly drained
Land Use/ Land Cover	Field crops with sparse trees	Rice	Rice
Soil	Fine-loamy, mixed, isohyperthermic Typic Paleustults	Paleustults/ Paleaquults	Fine-loamy, mixed, isohyperthermic Aeric Paleaquults
Agronomic Constraint	Low fertility, water deficit	Low fertility, water deficit	Low fertility

Materials and Methods

Moisture Content Distribution in Yasothon Soil Under Rainfed Conditions

This study was conducted from 1976 to 1980 at the Khon Kaen University (KKU) Farm. Soil samples were collected periodically from June 1976 until the end of 1980. They were taken twice a week from three fields at four depths, 0-10, 10-25, 25-45 and 45-60 cm, and the moisture contents were determined gravimetrically.

The soil type at the KKU Farm is mainly of the Yasothon series (fine-loamy, oxidic, isohyperthermic Typic Paleustults) which was formed on a high terrace position.

Effect of Topographic Position on Moisture Accumulation in and on the Soils

In developing viable cropping systems for rainfed agriculture in the Northeast, we found that the moisture status of soils varied according to specific topographic position and landscape. These relationships were investigated. In 1979 four locations differing in landscape pattern as well as soil type were selected. The location, topographic position (i.e., field type) and soil descriptions are shown in Table 2 (USDA, 1975).

Table 2. Description of Locations Studied.

Location	Village	Field Type †	Soil
1	Ban Donhun	UP	Fine-loamy, mixed, isohyperthermic Aquic Paleustult
		LP	Fine-loamy, mixed, isohyperthermic Aeric Paleaquult
2	Ban Muong	U	Loamy, siliceous Arenic Paleustults
		UP	Loamy, siliceous Aquic Paleustults
3	Ban Pasan	U	Isohyperthermic Ustoxic Quartzipsamment
		UP	Sand, siliceous, isohyperthermic Aquic Dystropept
4	Ban Koksri	UP	Loamy-skeletal over clayey, mixed Aquic Plinthustuns
		LP	Loamy-skeletal over clayey Typic Plinthaquult

† U, upland; UP, upland paddy field; LP, lowland paddy field.

Soil samples were taken from the different topographic positions twice weekly, at depths of 0 to 20 and 20 to 35 cm; soil moisture was determined gravimetrically. Whenever the soil water exceeded saturation, the depth of water on the soil surface was measured. The bulk density of soils was determined using a core method.

Mapping of Soil Moisture Conditions Using LANDSAT Imagery

LANDSAT imagery has proven to be useful in characterizing soil moisture conditions (Bruneau and Kiliand, 1983). The basic principle is that different objects on the earth's surface have different reflectance characteristics. These characteristics can be measured by means of remote sensing techniques with a multispectral scanner and a computer compatible tape. Enhancement of the image data improves the interpretability of an image by increasing the apparent contrast between the features in the study area. LANDSAT imagery with enhancement was employed to determine the soil moisture conditions in the Mun River Basin. Enhancement of the image data was performed as described by Mongkolsawat (1984). Moist, dry and saturated soils were outlined.

Results and Discussion

Moisture Content Distribution in Yasothon Soil Under Rainfed Conditions

Soil moisture distribution and the content of available water at various depths are shown in Figures 2 to 6 for the years 1976 to 1980, respectively. The results obtained reveal that during the period from January to March, there was very little rain and the available water approached zero. The rains usually began in late March or April, depending on the year, and the soil moisture content increased accordingly. From May to October, rainfall was rather evenly distributed in some years and moisture was sufficient for crop growth throughout this period. In most years, rainfall was unevenly distributed during the first half of the rainy season, and there were usually some lag periods in which the soil moisture dropped to a critical level, particularly in the plow layer. At greater depths, there appeared to be sufficient available water to sustain crop growth. When rainfall did not occur, soil moisture was limiting for crop growth at one, two, three and four weeks after the last rainfall for the 0-10 cm, 10-25 cm, 25-45 cm, and 45-60 cm soil depths, respectively.

Sufficient moisture was normally available during the second half of the rainy season, ending in late September or early October. After this time soil moisture content declined sharply. The topsoil or plow layer dried faster than the deeper zones. The period during which sufficient moisture remained in the soil to sustain satisfactory crop growth varied from year to year, depending on the end of the rainfall period. In some years residual soil moisture was depleted by mid-October, but remained considerably longer in other years (Mongkolsawat and Katawetin, 1980).

These results indicated that crops planted very early in the season (April or May) are likely to suffer from drought stress during the first half of the rainy season. Crops planted during this period should be those of a deep-rooted type to ensure drought tolerance. July appeared to be a more acceptable planting time since sufficient moisture was generally available for the next four months. In this particular soil the period of available moisture was usually six months (May to October). Double cropping is not generally feasible unless additional water can be retained and stored in the soil, possibly through special management and conservation techniques.

Effect of Topographic Position on Moisture Accumulation in and on the Soils

The accumulation of water in and on soils at different topographic positions at four locations from 1979 to 1980 is shown in Figures 7 to 10. In this year the total annual precipitation was about 1100 mm. The study was conducted on two different field types:

1) Upland paddy field (UP) + lowland paddy field (LP)
2) Upland (U) + upland paddy field.

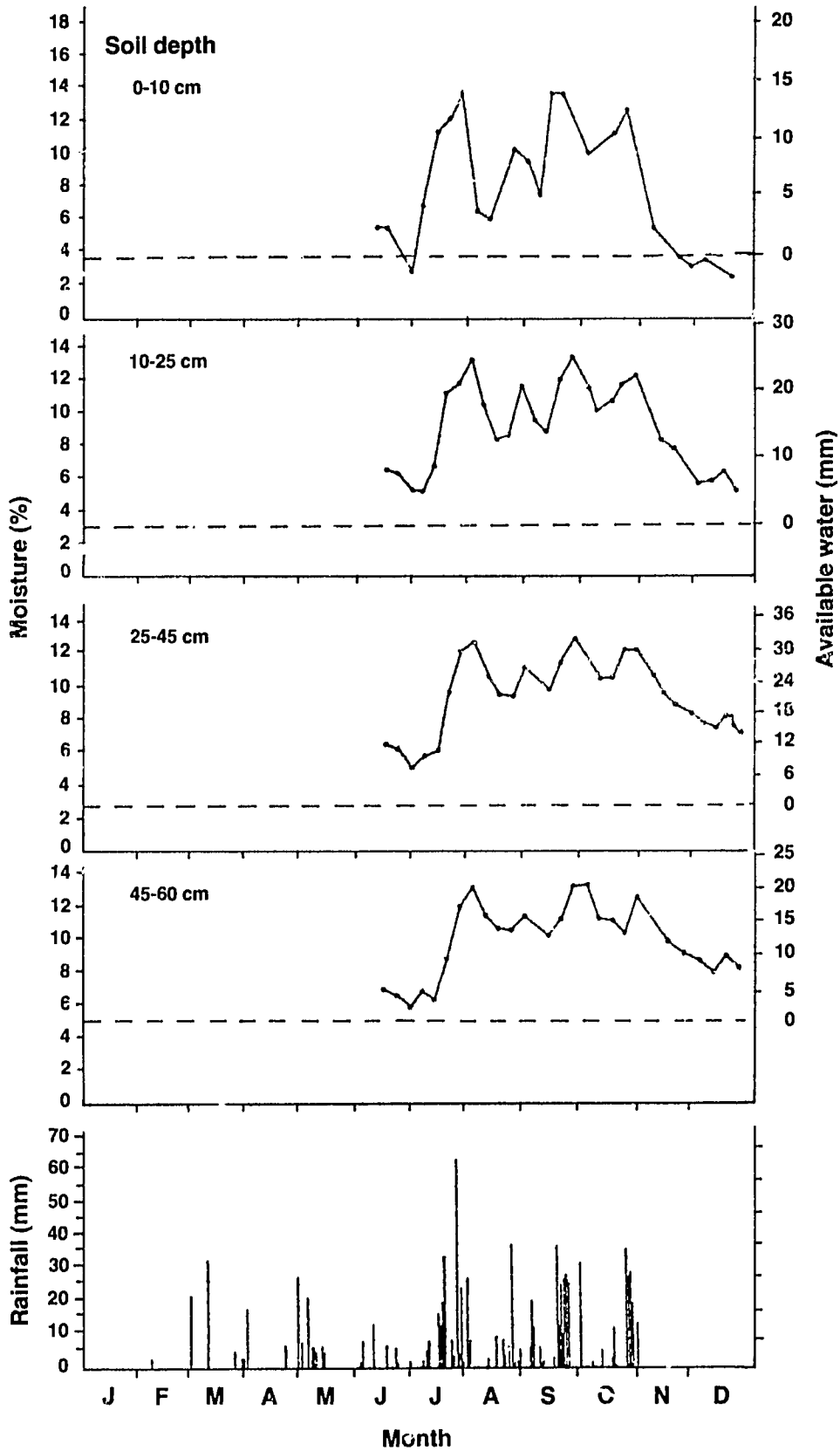

Figure 2. Soil Moisture at Increasing Soil Depths and Rainfall Distribution at the Khon Kaen University Farm in 1976.

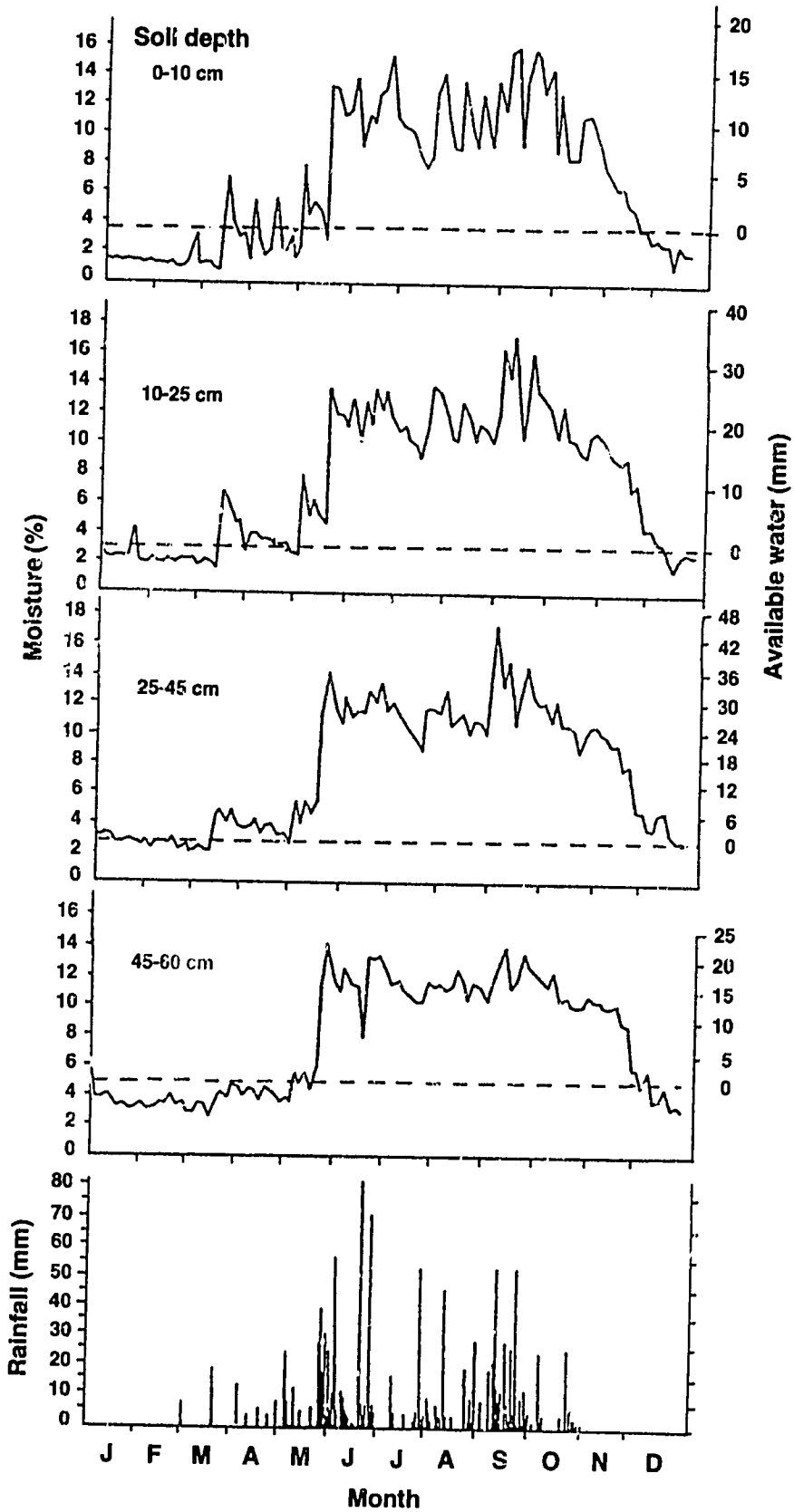

Figure 3. Soil Moisture at Increasing Soil Depths and Rainfall Distribution at the Khon Kaen University Farm in 1977.

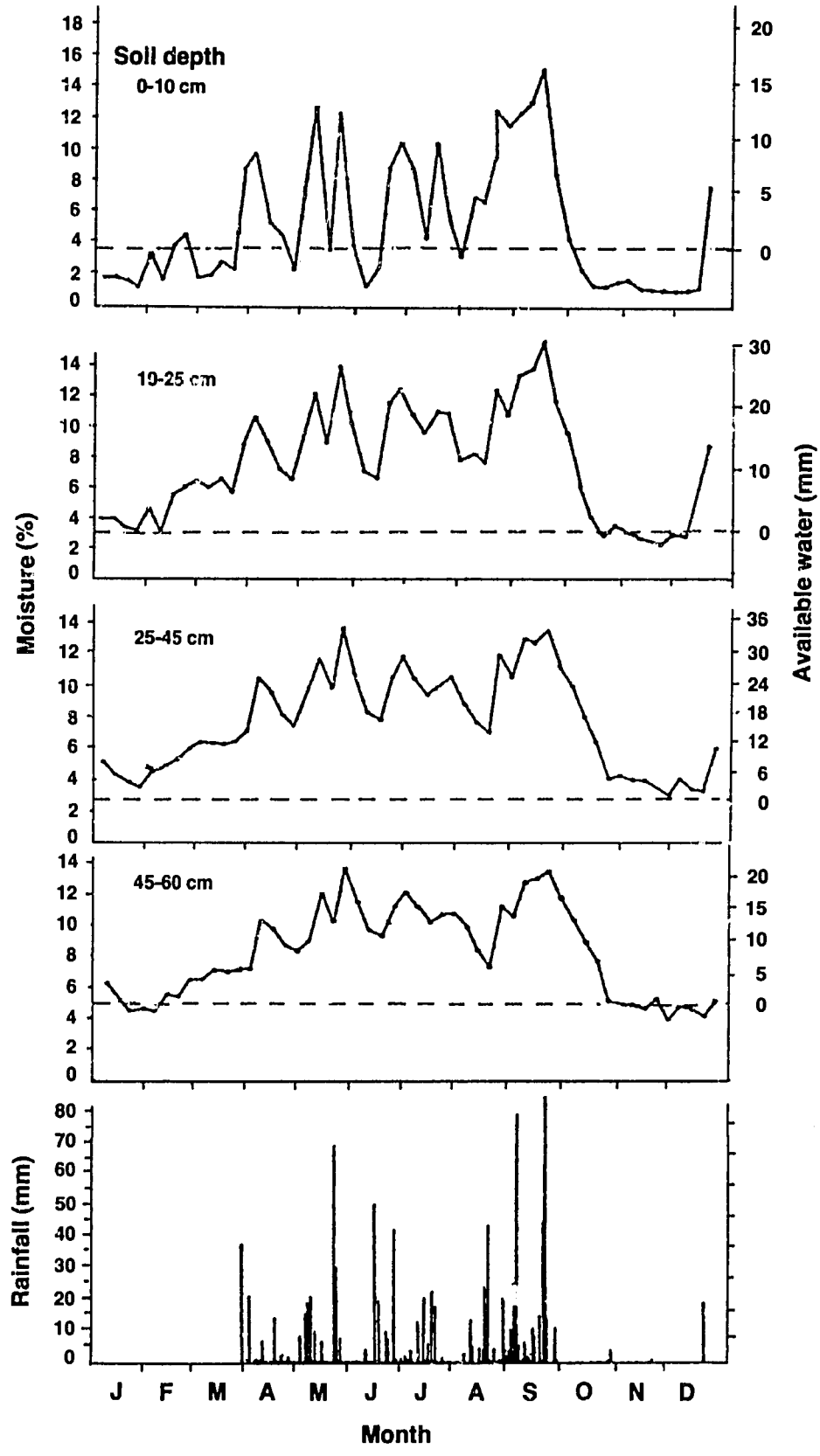

Figure 4. Soil Moisture at Increasing Soil Depths and Rainfall Distribution at the Khon Kaen University Farm in 1978.

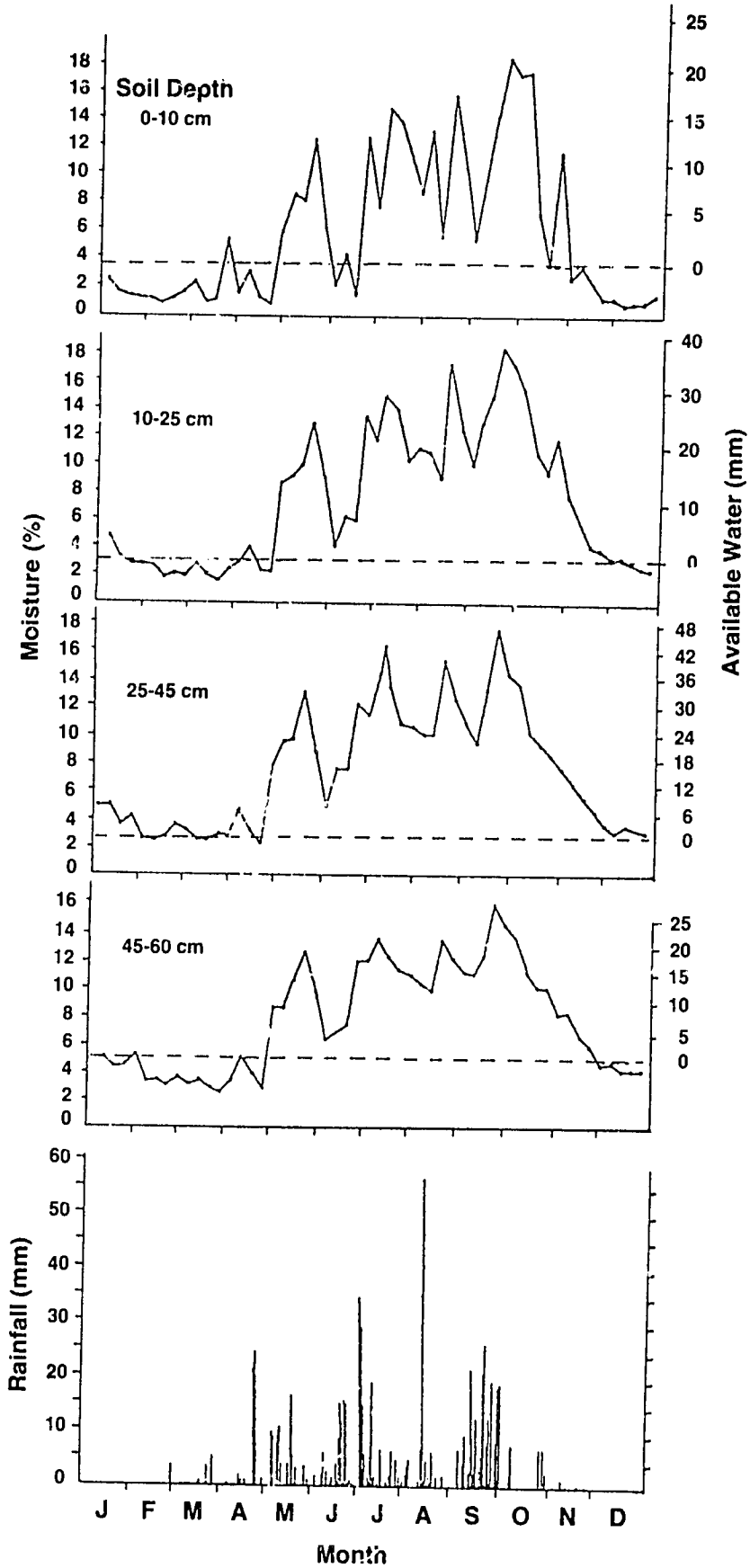

Figure 5. Soil Moisture at Increasing Soil Depths and Rainfall Distribution at the Khon Kaen University Farm in 1979.

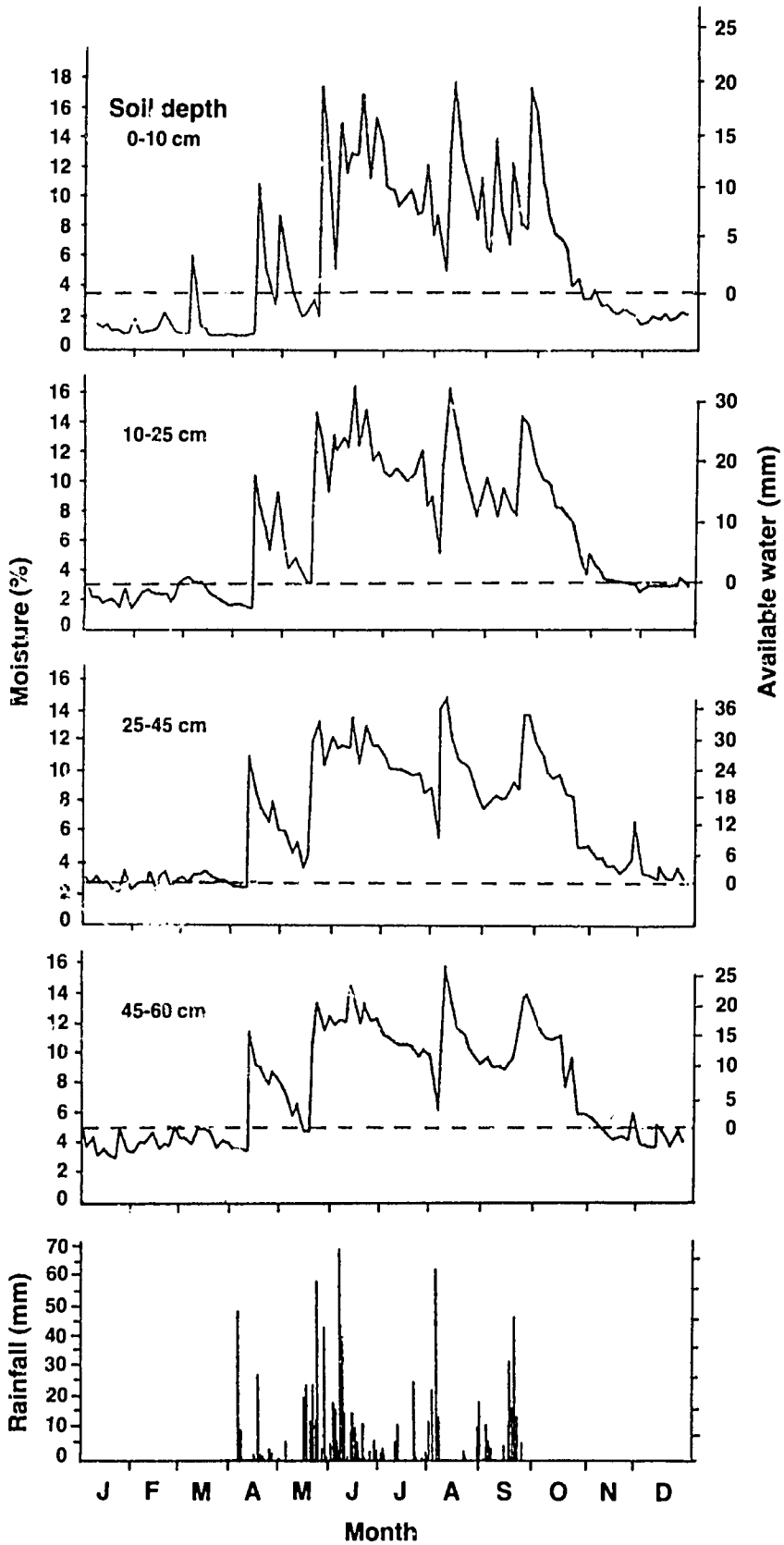

Figure 6. Soil Moisture at Increasing Soil Depths and Rainfall Distribution at the Khon Kaen University Farm in 1980.

Location 1 (UP + LP)

From early June to late October, water accumulated over saturated soil in the lowland paddy field (Figure 7). Prior to June, soil water content was below the saturation percentage. This indicates that the utilization of short-season crops in the early spring months would have a high probability of success. From early June to the end of October, only rice could be grown under this saturated condition. The available moisture content of the soil after October was sufficiently high to sustain field crops.

The soil moisture data for the upland paddy field indicated that soils were flooded for only a short period and, thus, rice could not be grown successfully. Traditionally, farmers grow rice on upland paddy fields. However, rice can be grown successfully at this position only during years of high rainfall.

Location 2 (U + UP)

The results of this experiment are shown in Figure 8. The moisture content of upland soil was substantially above the permanent wilting point in mid-March and was depleted by the end of October. The water content of the upland paddy field was higher than that of the upland soil and dropped gradually to the wilting point by the end of December. Flooding of paddy fields occurred during a very short period. Thus, attempts to grow rice on the upland paddy field are unlikely to be successful. Field crops can be grown successfully on the upland paddy field; however, the crop may suffer periodically from the effects of flooding. An effective drainage system is essential if upland field crops are to be grown.

Location 3 (U + UP)

The distribution pattern of the soil moisture content at this location (Figure 9) is similar to that of location 2. Soil flooding occurred for only a few days. Thus, rice would not have done well on the upland paddy field for the year 1979.

Location 4 (U + LP)

The soil moisture content of the upland paddy and lowland paddy fields in 1979 to 1980 is shown in Figure 10. From June to early October, water tended to accumulate above the saturation level although drought periods did occur for three to four weeks. The times during which the soil was saturated, below the wilting point and above the wilting point were 5, 2-1/2 and 4-1/2 months, respectively.

Mapping of Soil Moisture Conditions Using LANDSAT Data

Results of this study indicated that the soil moisture level could be clearly delineated between dry, moist and saturated conditions using LANDSAT imagery. It is generally believed that the moisture content of the soil surface is highly correlated with the underlying horizons. The soil moisture status could not be accurately assessed under a dense vegetation canopy. Where the vegetation canopy was less dense, the reflectance of the field was still influenced by the spectral characteristics of the soil moisture content. Thus, LANDSAT data provided measurements of soil moisture conditions and a characterization of other features of the soil surface as well. In the present study, we were interested in the residual soil moisture patterns after rice harvest. The establishment of a soil moisture map was done with LANDSAT imagery which allowed the opportunity to scan and study large areas. The map shown in Figure 11 represents the moisture conditions of the soil surface detected by a multispectral scanner. From the ground truth survey we found that the saturated zones corresponded to depressions, whereas the dry zones occurred at higher elevations. Obviously, the moisture conditions apparent in the

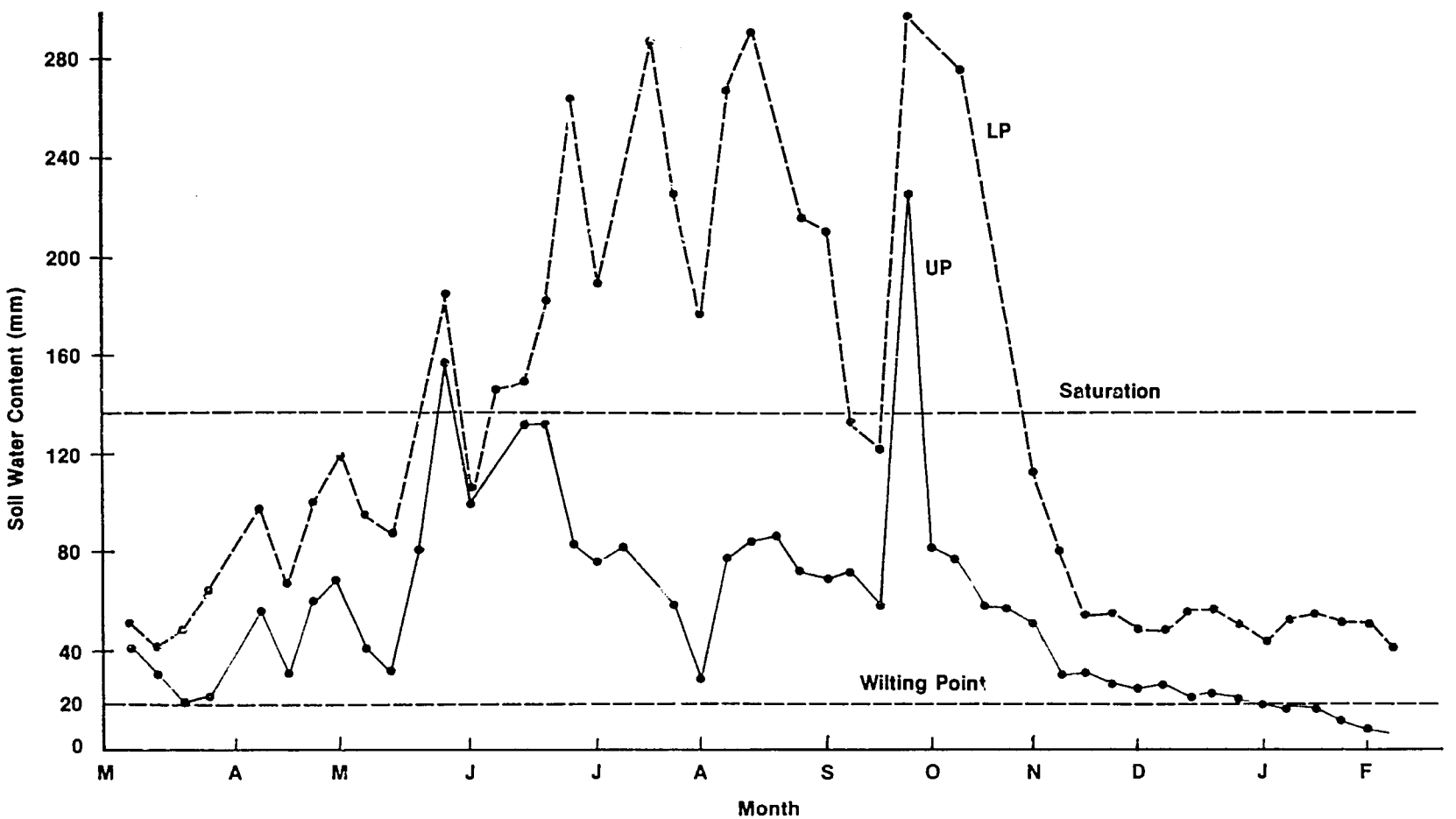

Figure 7. Water Content of Soil to a Depth of 35 cm for Upland Paddy and Lowland Paddy from 1979 to 1980 at Ban Donhun.

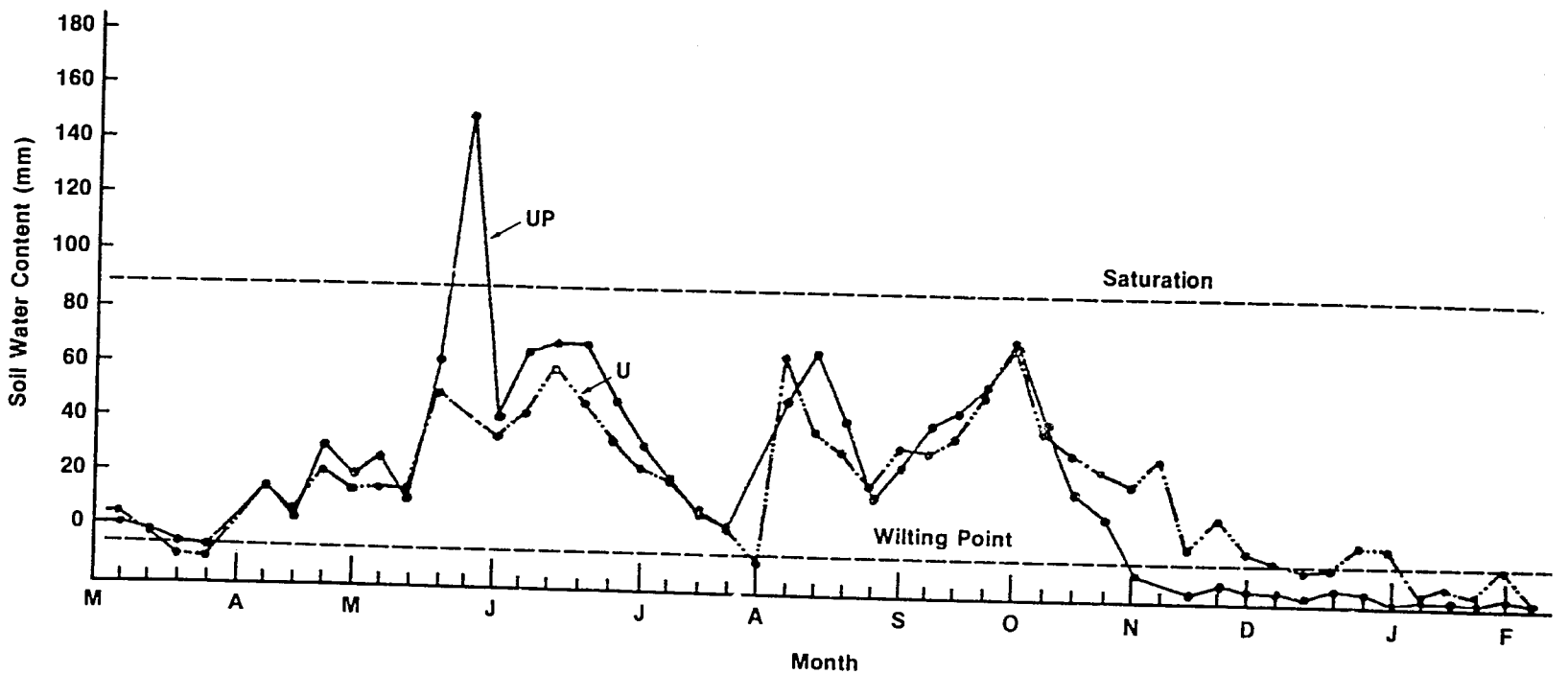

Figure 8. Water Content of Soil to a Depth of 35 cm for Upland Paddy and Upland from 1979 to 1980 at Ban Dasan.

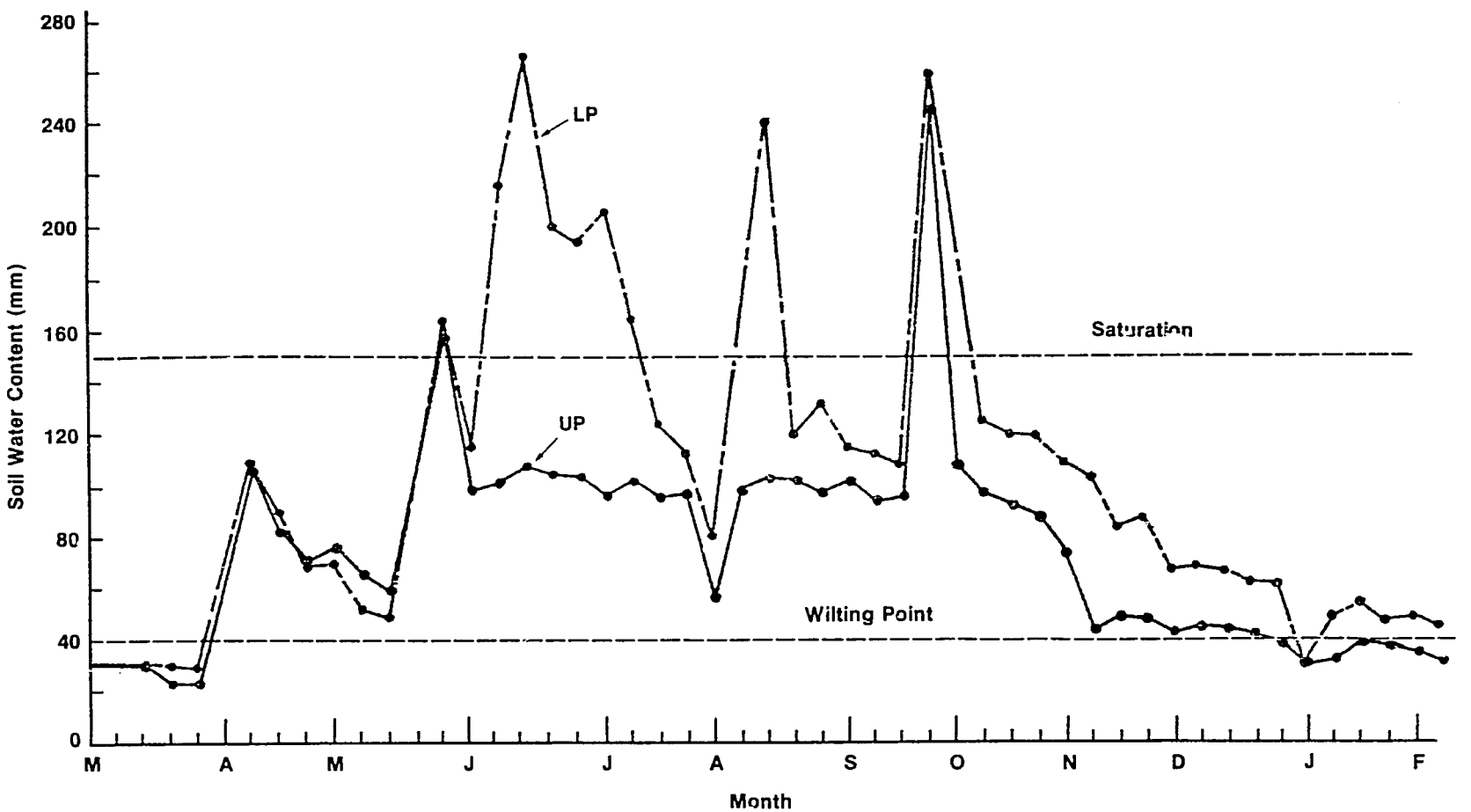

Figure 9. Water Content of Soil to a Depth of 35 cm for Upland Paddy and Lowland Paddy from 1979 to 1980 at Ban Koksri.

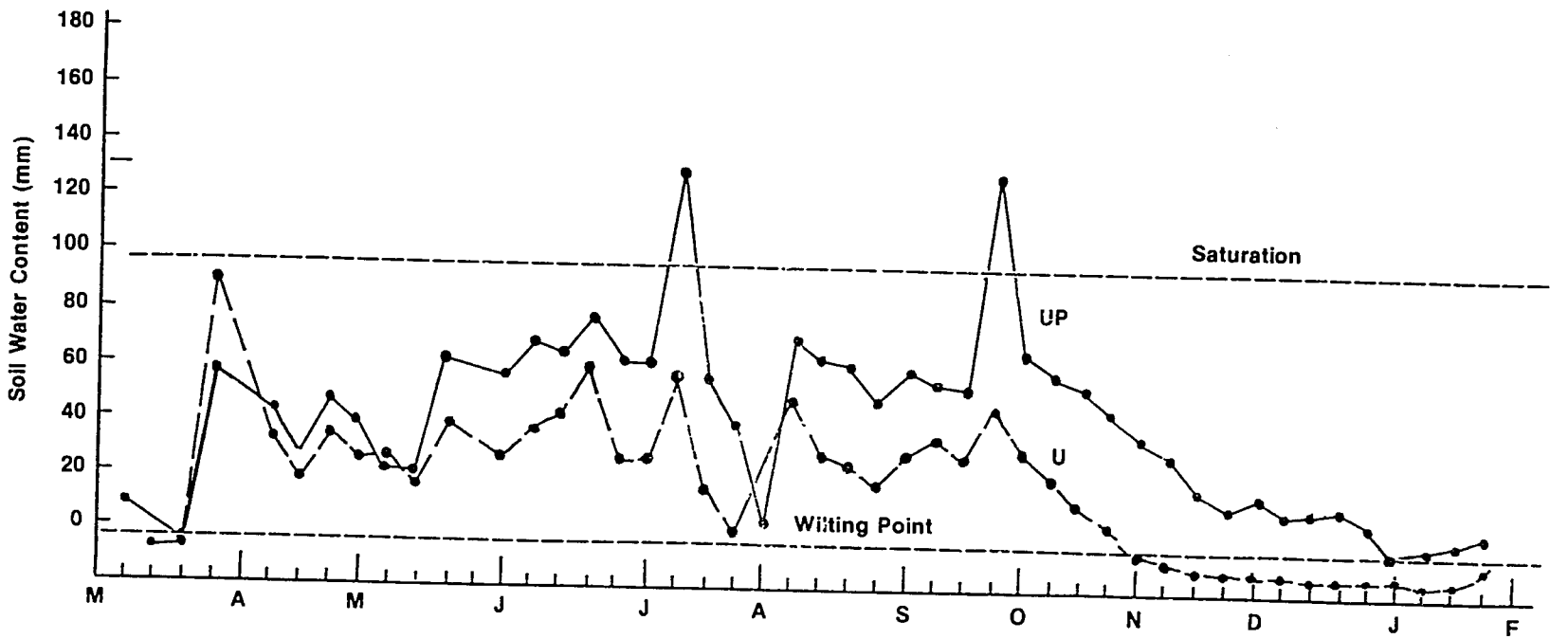

Figure 10. Water Content of Soil to a Depth of 35 cm for Upland Paddy and Upland from 1979 to 1980 at Ban Muong.

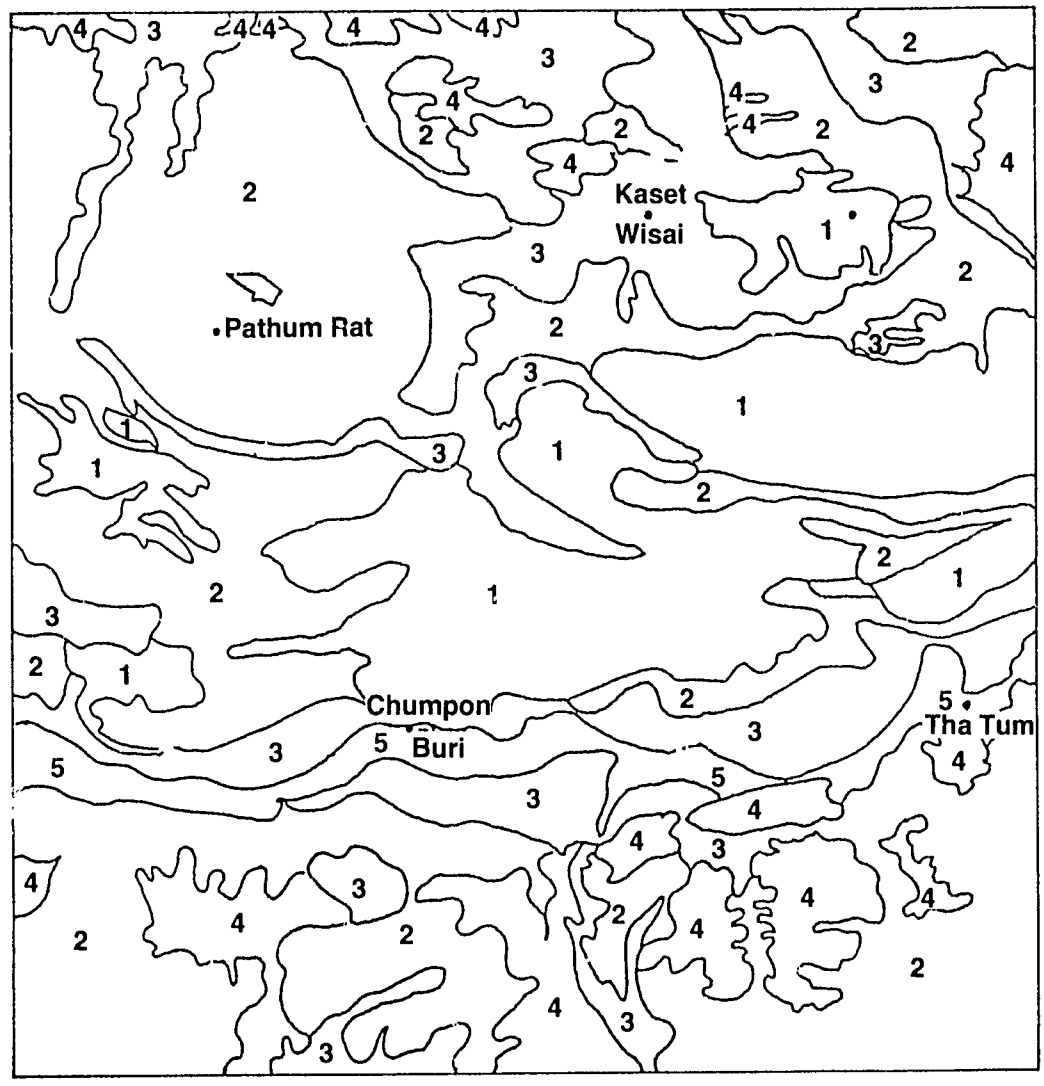

Figure 11. Soil Moisture Condition Delineated From LANDSAT Imagery, January 17, 1976. (1) Saturated, (2) Moist, (3) Dry, (4) Woodland, and (5) Riverine Shrub.

imagery were a result of a combination of several components, e.g., topography, soil and land management. The map developed from LANDSAT data gave reliable information on the zones where there is potential for growing a second crop during the dry season.

Conclusion

It is generally believed that rainfall in Northeast Thailand is so erratic that no meaningful relationship can be established between the amount of rainfall, soil moisture patterns and the growth and yield of crops. Nevertheless, an analysis of the soil moisture data, with particular emphasis on consecutive drought days, suggests that the beginning of the second half of the rainy season (July) is the most suitable time to establish an upland crop. During the first half of the rainy season the pattern of soil moisture distribution was highly variable and soil water conservation techniques such as mulching, conservation tillage, residue management and erosion control practices are needed to use the land resources effectively and efficiently.

The similarity in the soil moisture distribution patterns at two locations revealed that only the lowland paddy field was suitable for rice growing. The period during which the water accumulated over soil saturation was not adequate to successfully grow rice on the upland paddy field. With appropriate land management practices, the upland paddy field should be widely adapted for field crop production. Nevertheless, further investigations on soil moisture distribution at different topographic positions will be needed.

The use of LANDSAT imagery taken in January (the transitional period between wet and dry seasons) gave additional information on soil moisture conditions. Further investigations with multidate imagery (before and after January) should be undertaken to gain a better understanding of the dynamic nature of water in the zones studied. Moreover, the existing LANDSAT data from past years with low, medium and high amounts of rainfall should be analyzed to identify patterns of water distribution throughout the region.

Acknowledgement

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Hydraulic Properties of Major Northeast Soils

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ABSTRACT. Hydraulic properties of 12 major soil series in Northeast Thailand were studied to characterize soils for improved soil and water management. Included in the study were six upland soils: Korat, Nam Phong, Pak Chong, Satuk, Warin and Yasothon; and six lowland soils: Kula Ronghai, Phimai, Roi Et, Renu, Ubon and Udon. Measurements of the root zone were made at soil depths of 0 to 10, 10 to 30 and 30 to 60 cm. For soil water characteristics, the functions are in the form of $Se = (hd/h)^{\lambda}$ *where Se is effective saturation, hd and h are air-entry and matric potentials and* λ *is the pore-size distribution index. Values of* λ *range from 0.06 to 0.61 and correlate with the texture index (TI). A high TI corresponds to a lower value of* λ*, indicating a gradual change in soil water content with respect to matric potential.*

Measurements of the saturated hydraulic conductivity (Ksat) of soils showed a wide range of values varying from 0.07 to 240 mm/h. The average Ksat over a 0 to 60 cm depth was 8.2 mm/h for upland soils and 1.48 mm/h for lowland soils. Except for the Pak Chong series, all soils had low values of Ksat. The low Ksat value at lower depths serves as a barrier that retards loss of water from the root zone. Unsaturated hydraulic conductivities (K) were measured only for the Korat and Roi Et soil series. The functions are expressed as $K = ah^{\eta}$ *where a and* η *are constants. The coefficients change over five orders of magnitude from saturation to -10 atm of water potential. Although the conductivity is low and changes rapidly when the water content drops from saturation, sufficient water remains in the root zone for appreciable water uptake by roots. It is proposed that the upper water potential limit for plant available water of Northeast soils is -0.05 atm and the lower limit is -15 atm; the plant available water capacity for the root zone was 17.8 percent by volume for upland soils and 24.4 percent for lowland soils. The coarse-textured soils of the Northeast have, in fact, a high water holding capacity and a relatively low water conductivity.*

Introduction

This study on the hydraulic properties of Northeast soils is part of a four-year project designed to assess the characteristics of about 50 soil series found in Thailand. Included are 24 upland and 23 lowland soils from the Mae Klong Basin, Northeast and Southern regions and three forest soils from Chiang Mai province.

This paper reports the basic hydraulic properties of 12 major soils in the Northeast, particularly the saturated hydraulic conductivities (Akatanukul, 1981; Akatanukul and Treloges, 1982; Akatanukul and Sripongpankul, 1983) and the plant available water characteristics of these soils. Measurements were made on the soil-root zones from 0 to 60 cm. Such information is absolutely essential to the development of successful soil and water management practices that would provide for the implementation of effective and efficient crop production systems.

Materials and Methods

Twelve soil series were included in the study: Korat (Kt), Nam Phong (Ng), Pak Chong (Pc), Satuk (Suk), Warin (Wn) and Yasothon (Yt) which are upland soils, and Kula Ronghai (Ki), Phimai (Pm), Roi Et (Re), Renu (Rn), Ubon (Ub) and Udon (Ud and Ud, clay) which are lowland soils.

Both undisturbed and disturbed samples were taken at three depths 0 to 10, 10 to 30 and 30 to 60 cm. Undisturbed samples were used to measure bulk density, saturated hydraulic conductivities and the soil water characteristics from soil water potentials of 0 to -0.33 atm. Both constant and falling head methods were employed to measure saturated

hydraulic conductivities. Disturbed samples were used for measurements of particle density, texture and water characteristics in the range of soil water potentials from -1 to -15 atm. Unsaturated hydraulic conductivity functions were determined on the Korat and Roi Et series following the procedure of Bruce and Klute (1956). All measurements of basic hydraulic properties were made by the standard soil analysis methods as described by Black (1965).

Soil Water Characteristics

The water potential function is best expressed in the Brooks and Corey equation (1964):

$$Se = (\theta - \theta r)/(\theta s - \theta r) = (hd/h)^{\lambda}, \quad [1]$$

where Se is effective saturation; θ is water content at matric potential h; θr is residual water content, of which air-dry water content is used in this study; θs is saturation water content; hd and λ are constants. According to Brooks and Corey, hd is air-entry potential and λ is the pore-size distribution index. The dimension of θ is percent volume; hd and h are given in atm.

Texture Index

Particle-size distribution is represented by texture index (TI) as described by Sillanpaa (1982):

$$TI = 0.1\ (\%\ sand) + 0.3\ (\%\ silt) + 1.0\ (\%\ clay). \quad [2]$$

The size range is 2.0 to 0.02 mm for sand separates, 0.02 to 0.002 mm for silt and < 0.002 mm for clay separates.

Hydraulic Conductivity

The unsaturated hydraulic conductivity (K) is a function of matrix potential (h) and is expressed:

$$K(h) = ah^{-\eta}, \quad [3]$$

where K is in cm/s and h is in atm. Both a and η are constants.

The average K for the whole profile is obtained by using the thickness of each soil layer as a weighting factor (Hillel, 1980).

$$L/K = \ell_1/K_1 + \ell_2/K_2 + \ell_3/K_3. \quad [4]$$

where ℓ is the thickness of each soil layer from which unsaturated hydraulic conductivity, K_i, is determined. L is the total soil depth.

$$L = \ell_1 + \ell_2 + \ell_3. \quad [5]$$

Results and Discussion

Basic properties, i.e., density, porosity and saturation water content, of all the soils are summarized in Table 1.

A very low bulk density, 1 g/cm^3, is typical of the top layer of the Pak Chong (Pc) soil series which has a high organic matter content. The second layer (10 to 30 cm) has a higher bulk density resulting in lower porosity. If the structure is stable, the saturated water content should be the same as the porosity. In this study, upland soils showed an

Table 1. Summary of Soil Density, Porosity and Water Content at Saturation (θs) of Major Northeast Soils.

	Bulk Density		Particle Density		Porosity		θs	
Depth	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.
	..... $g\ cm^{-3}$				..... % vol			
Upland Soils								
0-10 cm	1.00-0.54	1.37	1.86-2.74	2.40	37-47	43	20-54	38
10-30 cm	1.03-1.56	1.41	2.03-2.61	2.24	34-51	40	32-48	38
30-60 cm	1.15-1.52	1.35	1.89-2.41	2.21	36-43	39	33-49	39
Lowland Soils								
0-10 cm	1.28-1.64	1.46	1.96-2.53	2.37	24-46	38	38-53	45
10-30 cm	1.53-1.77	1.64	2.25-2.47	2.36	25-37	31	33-52	42
30-60 cm	1.45-1.69	1.57	2.07-2.78	2.46	21-48	35	35-51	44

unstable soil structure, i.e., upon wetting, pore size was reduced and volume decreased. In contrast, the lowland soils showed a slight increase in their volume with wetting, indicating the presence of a certain amount of swelling clay.

In Table 2, the parameters hd and λ of the soil water characteristic curves (Equation [1]) and TI (Equation [2]) are shown. The majority of the soils have low TI values indicating a low percentage of clay separates. One exception is the Pak Chong series which has a very high clay content. The pore-size distribution index is generally high with the exception of the Pak Chong series. The higher λ values mean that the soils have a narrower pore-size range. It also indicates that at a specified matric potential, soils with higher λ values will release greater amounts of water per unit change in matric potential. The low value of air-entry potential, hd, confirms the presence of large pores in most of these soils. Apparently, Northeast soils consist mainly of large-size pores. This is clearly shown in the calculation of the pore-size distribution as percent of total porosity (Table 3). In contrast to Northeast soils, most of the soils of the Mae Klong Basin have TI values which exceed 50, indicating a predominance of small-size pores (Treloges, 1983).

Figures 1 and 2 are characteristic curves for two representative Northeast soils—Korat and Roi Et. The shape of the curves and the close correspondence between the measured and calculated values are evident. These two figures clearly show that water drains from these soils easily when the water potential drops from zero (saturation) to -0.05 atm. Thus, the hazard of waterlogging in these soils is unlikely. In dry soils, the water content at a water potential of -15 atm is two to five percent by volume. As dry as the soil may seem, its water is still available to plants. This contrasts with the heavy-textured soils of the Mae Klong Basin, where water is retained mostly in <0.2 mm size pores. Even though these soils appear to be moist, soil water at a potential of -15 atm is not available to plants.

Table 2. Texture Index (TI), Pore-Size Distribution Index (λ) and Air Displacement Potential (hd) Values of the Soil Water Characteristic Functions.

Upland Soils					Lowland Soils				
Soil	Depth	TI	λ	hd	Soil	Depth	TI	λ	hd
	cm			*atm*		*cm*			*atm*
Kt	0-10	15.6	0.45	-0.011	Ki	0-10	19.7	0.41	-0.044
	10-30	16.7	0.47	-0.021		10-30	16.2	0.45	-0.036
	30-60	22.9	0.32	-0.014		30-60	37.1	0.24	-0.072
Ng	0-10	12.3	0.44	-0.016	Pm	0-10	28.8	0.31	-0.016
	10-30	13.9	0.39	-0.006		10-30	32.5	0.30	-0.038
	30-60	12.8	0.46	-0.007		30-60	46.2	0.13	-0.007
Pc	0-10	53.8	0.091	0	Re	0-10	19.6	0.42	-0.022
	10-30	81.3	0.063	0		10-30	21.0	0.32	-0.014
	30-60	94.4	0.088	-0.001		30-60	21.0	0.42	-0.015
Suk	0-10	19.1	0.28	-0.010	Rn	0-10	17.3	0.48	-0.008
	10-30	20.7	0.35	-0.011		10-30	15.5	0.61	-0.043
	30-60	24.4	0.27	-0.002		30-60	21.1	0.34	-0.011
Wn	0-10	29.9	0.28	-0.028	Ub	0-10	10.3	1.07	-0.033
	10-30	44.3	0.17	-0.014		10-30	20.5	0.36	-0.035
	30-60	48.7	0.15	-0.008		30-60	13.9	0.65	-0.014
Yt	0-10	22.6	0.43	-0.019	Ud	0-10	15.5	0.50	-0.040
	10-30	31.0	0.24	-0.007		10-30	15.7	0.52	-0.050
	30-60	30.1	0.28	-0.009		30-60	18.7	0.47	-0.031
					Ud, clay	0-10	34.4	0.23	-0.006
						10-30	41.5	0.14	-0.002
						30-60	43.8	0.09	-0.001

An exponential relationship exists between λ and TI (Figure 3). There is greater dispersion at both ends of TI. This relationship shows soil water characteristic behavior which is not readily evident from textural information.

Table 3. Pore-Size Distribution as Percentage of Total Porosity.

Soil	Depth	Pore Size		
		>3.0 mm	3.0-0.2 mm	<0.2 mm
	cm	.....	%	.....
Upland	0-10	42	39	19
	10-30	42	34	24
	30-60	43	30	27
Lowland	0-10	43	44	13
	10-30	31	51	18
	30-60	34	42	24
Mae Klong	0-10	13	42	45
	10-30	22	31	47
	30-60	17	35	48

Table 4 shows the values of saturated hydraulic conductivity for three soil depths. The mean for the 0 to 60 cm profile was calculated according to Equation [4] using the thickness of each soil layer as a weighting factor. The mean for all soils at a single depth was calculated as a logarithmic average (Table 5). The lowest Ksat is the limiting rate for the 0 to 60 cm profile. Upland soils have a much higher conductivity than lowland soils (Table 5). For the latter, the surface layer has the highest Ksat. The smaller Ksat at lower soil depths decreases the overall Ksat values of the root zone significantly. Consequently, lowland soils can be used for paddy production because they maintain standing water on the surface with negligible loss by deep drainage. Table 6 summarizes Ksat values for the 0 to 60 cm profile for upland and lowland soils of the Northeast and also shows the comparable values for the Mae Klong soil series. The Mae Klong lowland soils have properties that markedly limit the loss of water from the profile, their Ksat values being three times less than that of the major Northeast soils. There appears to be no relationship between Ksat values and other basic parameters such as porosity, bulk density, TI or λ.

Unsaturated hydraulic conductivity functions were obtained for the Korat and Roi Et soil series as shown in Figures 4 and 5. K and h fit the exponential function $K = ah^{-\eta}$, where both a and η are constants (Equation [3]). Values for the two constants are shown in Table 7. Though the data are insufficient to correlate at present, they suggest that λ is negatively and linearly correlated with η. Thus, there is a gradual change in K as a function of the matric potential. The values of K(h) obtained for the Korat and Roi Et soils show that the conductivity changes over five orders of magnitude as the water potential drops from 0 to -10 atm (Figures 4 and 5).

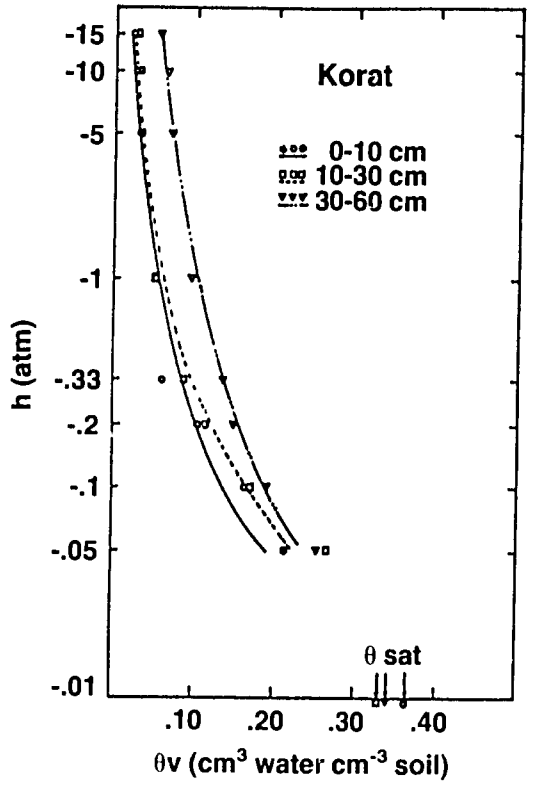

Figure 1. Soil Water Characteristic Curves for Three Soil Depths of Korat Soil Series. Symbols are Measured Values. Lines are Obtained from Equation [1].

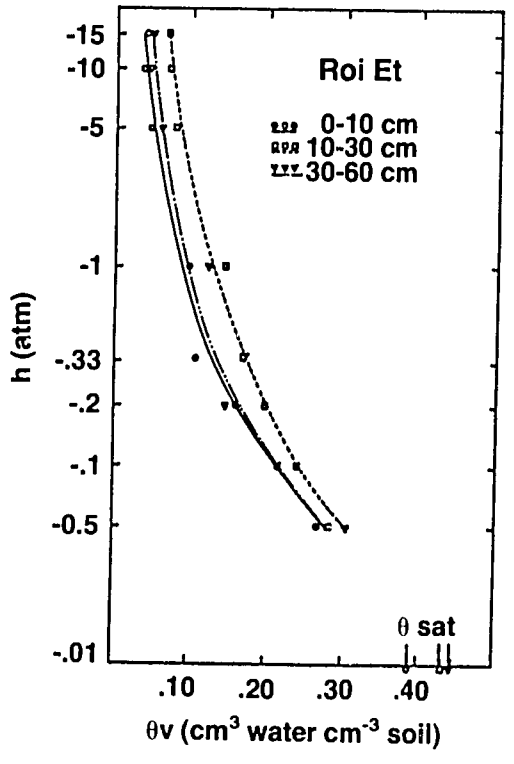

Figure 2. Soil Water Characteristic Curves for Three Soil Depths of Roi Et Soil Series. Symbols are Measured Values. Lines are Obtained from Equation [1].

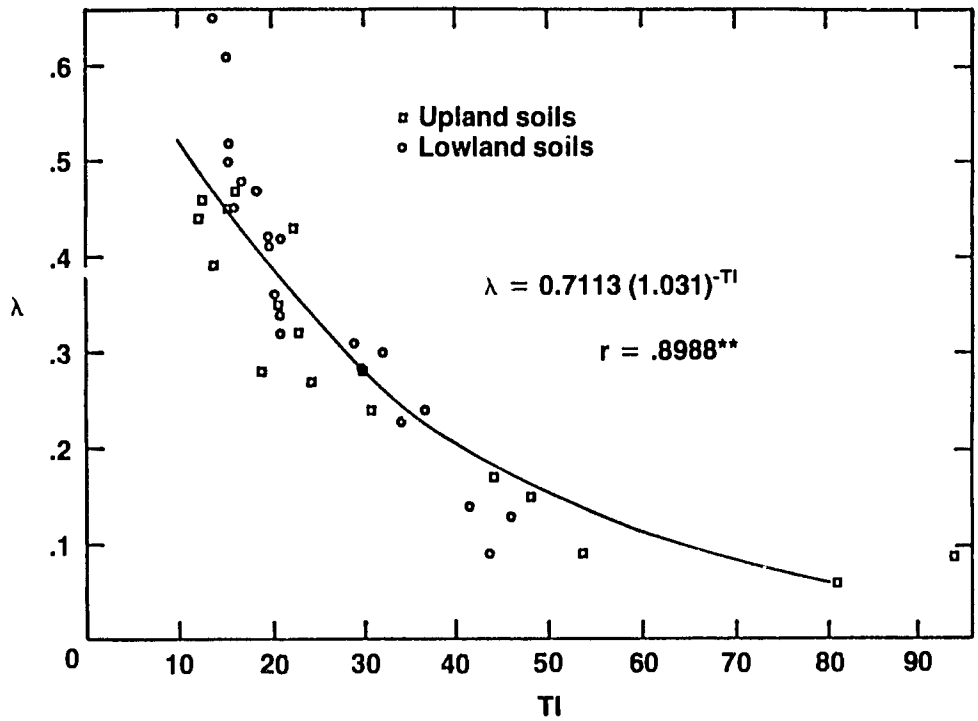

Figure 3. Relationship Between Texture Index (TI) and Pore-Size Distribution Index (λ) of Upland and Lowland Soils.

Linear scale plots of K as a function of h for the Korat and Roi Et soils show how sharply the conductivity changes as the matric potential drops below saturation (Figure 6). Assuming a uniform profile with a water potential of -0.05 atm, the movement of water due to gravity alone is roughly equal to the conductivity. In this case, the distance that water moves by deep drainage is about 5 cm/day. At this rate we believe that most of the applied water would remain in the 0 to 60 cm profile, allowing substantial water uptake by plants to occur. We propose that the easily available water at a water potential of -0.05 atm be used as the upper limit for plant available water in the major Northeast soils.

Direct measurements in the field of the field capacity of Northeast soils have not been made. However, our field measurements of the Kamphaeng Saen soil series indicate that two days after heavy rains, tensiometer readings at a 30 cm depth rarely exceed a water potential of -0.01 atm. Therefore, we feel that for tropical soils like ours, a more realistic upper limit of plant available water is at water potentials between -0.05 and -0.33 atm.

Using the soil water content at a water potential of -0.05 atm as the upper limit and soil water content at a water potential of -15 atm as the lower limit, Table 8 shows that for upland soil, the plant available water capacity (PAWC) is 17 to 19 percent by volume. PAWC for lowland soils ranges from 22 to 27 percent for the three layers. The available water in the 0 to 60 cm root zone is 107 and 146 mm for upland and lowland soils, respectively. With a more conservative soil water potential of -0.1 atm used as the upper limit, the PAWC of most soils would still exceed ten percent by volume. Consequently, our study showed that the plant available water capacity of most Northeast soils is quite high. The use of a soil water potential of -0.33 atm for the upper limit seems to underestimate the water holding capacity of these soils.

Table 4. Saturation Hydraulic Conductivity (Ksat) Values of Major Northeast Soils.

	Soil Depth (cm)			Average	
	0-10	10-30	30-60		
	..... *mm h-1*				*mm day-1*
Upland Soils					
Kt	11.5	7.0	7.0	7.5	180
Ng	19.6	9.7	1.0	1.8	44
Pc	131	240	2.3	4.5	109
Suk	10.8	6.1	7.7	7.4	178
Wn	5.4	1.5	24.1	3.6	86
Yt	7.1	7.1	22.5	10.8	259
Lowland Soils					
Ki	2.5	1.6	8.0	3.0	72
Pm	1.2	0.9	0.1	0.1	3
Re	8.0	0.5	4.8	1.3	31
Rn	8.3	6.3	6.9	6.9	166
Ub	4.1	0.7	10.4	1.8	43
Ud	6.6	2.7	0.3	0.6	13
Ud, clay	4.4	0.9	0.1	0.2	4

The volumetric water content (θv) at a water potential of -15 atm correlates well with the texture index (Figure 7). The relationship is in the form of:

$$\theta v = a + b \log(TI) \qquad [6]$$

with values of the constants a and b shown in Table 9. Although the water content at a soil water potential of -0.05 atm has a relationship similar to the water content at a potential of -15 atm, its correlation coefficient is much lower and the data are more scattered. This is logical since at a water potential of -15 atm the surface area, which relates to texture, plays a dominant role, whereas at a water potential of -0.05 atm, water fills most of the pores and structure becomes an important factor.

Table 5. Range and Mean Values of Saturated Hydraulic Conductivity (Ksat) for Successive Depth Increments of Upland and Lowland Soils.

Soil Type	Depth	Range	Mean
	cm	..... *mm* h^{-1}	.....
Upland	0-10	5.4-131	15.1
	10-30	1.5-240	10.2
	30-60	1.0-24.0	6.38
Mean	0-60		8.18
Lowland	0-10	1.0-8.3	4.20
	10-30	0.5-6.2	1.34
	30-60	0.07-10.4	1.29
Mean	0-60		1.48

Table 6. Mean Values of Saturated Hydraulic Conductivity (Ksat) for the 0 to 60 cm Root Zone of Major Northeast Soils and Mae Klong Soils.

Soil	Upland	Lowland
	.... *mm* h^{-1}	
Northeast	8.2	1.5
Mae Klong	4.4	0.4

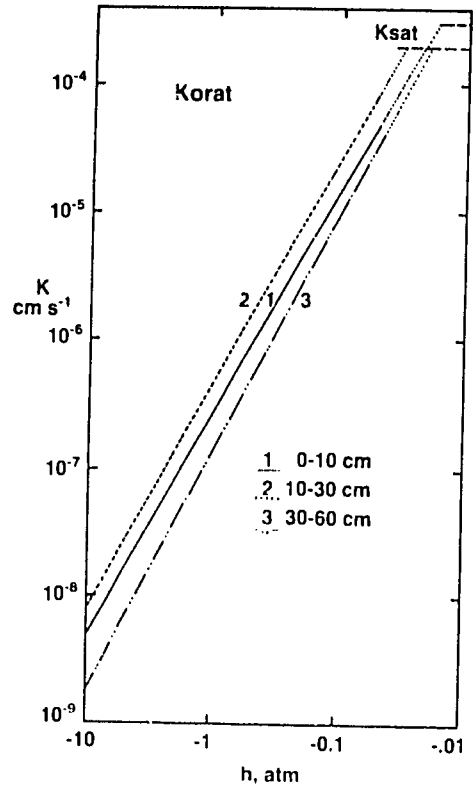

Figure 4. Unsaturated Hydraulic Conductivity (K) as a Function of Matric Potential (h) for the Korat Soil Series.

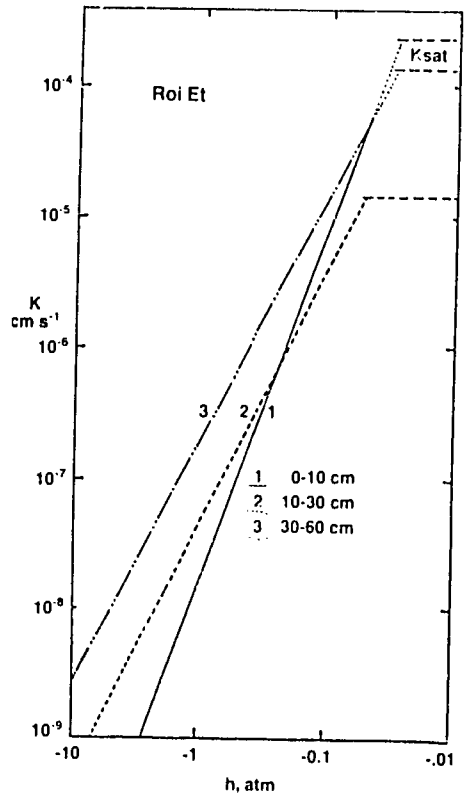

Figure 5. Unsaturated Hydraulic Conductivity (K) as a Function of Matric Potential (h) for the Roi Et Soil Series.

Table 7. Parameters for Hydraulic Conductivity Functions of the Korat and Roi Et Soils.

Depth	a	η
Korat		
0-10 cm	2.669×10^{-7}	1.749
10-30 cm	4.654×10^{-7}	1.755
30-60 cm	1.340×10^{-7}	1.872
Roi Et		
0-10 cm	1.465×10^{-8}	2.761
10-30 cm	4.380×10^{-8}	1.970
30-60 cm	1.929×10^{-7}	1.884

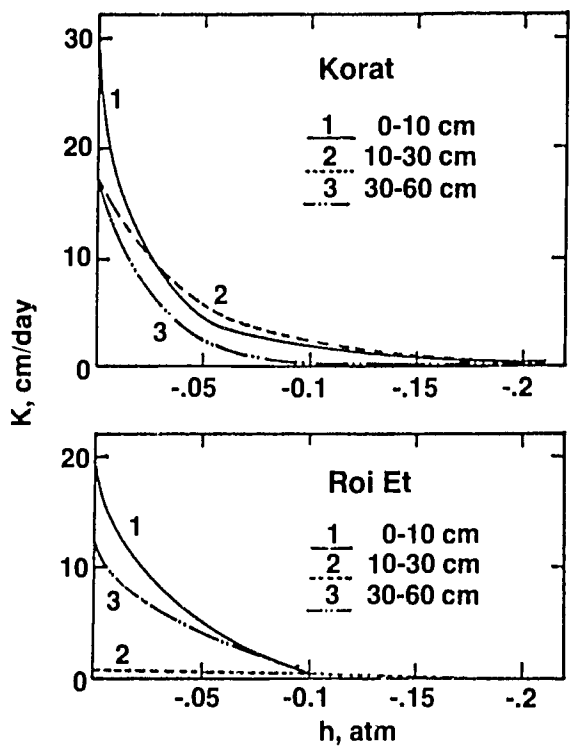

Figure 6. Unsaturated Hydraulic Conductivity (K) as a Function of Matric Potential (h) for the Korat and Roi Et Soil Series, Plotted on a Linear Scale.

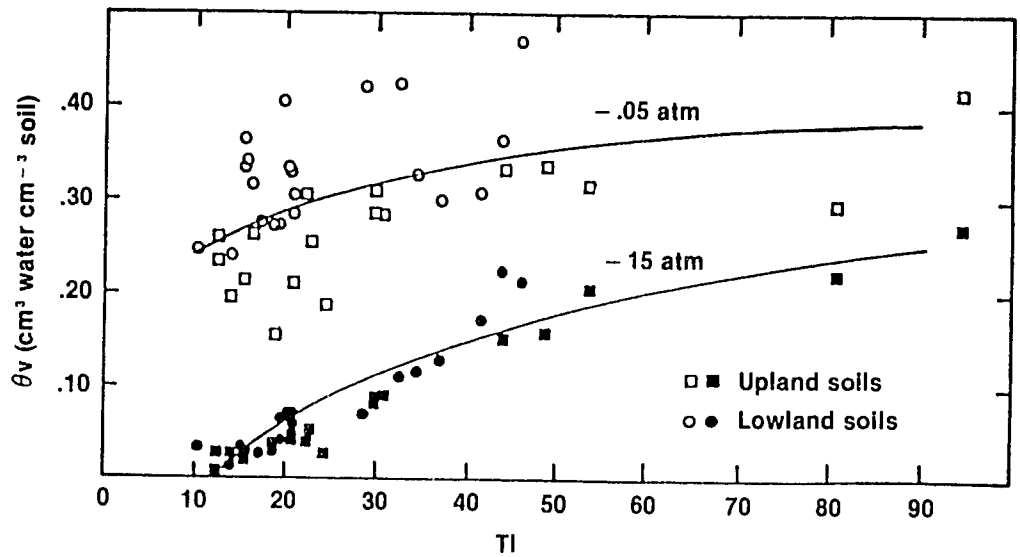

Figure 7. The Relationship Between the Volumetric Water Content (θv) and Texture Index (TI) of Upland and Lowland Soils.

Table 8. Volumetric Soil Water Content at the Upper and Lower Limits of Availability and Available Water Content for Three Depths and the Total 0 to 60 cm Root Zone of Upland and Lowland Soils.

Soils	Depth	h, atm -.05	h, atm -15	Available Water Content	
	cm	.....	*% vol.*	.....	*mm*
Upland	0-10	26.0	7.2	18.8	19
	10-30	26.4	9.3	17.0	34
	30-60	28.6	10.6	18.0	54
Total	0-60				107
Lowland	0-10	33.1	5.6	27.5	28
	10-30	33.4	7.4	26.0	52
	30-60	32.6	10.4	22.2	67
Total	0-60				146

Table 9. Parameters for the Logarithmic Relationship Between Texture Index (TI) and Volumetric Soil Water Content (θv) and Correlation Coefficient (r) at Soil Water Potentials of -.05 and -15 atm.

h	a	b	r
atm			
-.05	.0949	0.149	0.488**
-.15	-.0323	0.293	0.939**

** Significant at $P \leqslant 0.01$.

Conclusions

The examination of hydraulic conductivity functions led us to conclude that even though the major Northeast soils are of coarse texture, there is always an underlying layer within the root zone, 0 to 60 cm, that reduces water movement, retaining water in the profile for plant uptake. We propose that the soil water content at a water potential of -0.05 atm be used as the upper limit for the plant available water capacity. The problem of poor aeration is unlikely at this value. Moreover, at a volumetric water content of five percent, the soil water potential is still less than -15 atm, and some water is available to plants. Based on the hydraulic properties of major Northeast soils determined in this study, we conclude that the plant available water capacity of these soils is actually quite high. It would appear that with improved management techniques many of the problems previously attributed to poor soil-water relationships can be greatly minimized, allowing these soils to attain a substantially higher level of crop productivity in the future.

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Hydromorphological Survey and Mapping of the NERAD Project for Tambon Kwang Chon, Phu Khieo District, Chaiyaphum Province of Thailand

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ABSTRACT. This survey and mapping project provides basic data for a small water resources development project which was judged to be appropriate in the area. Surveying procedures included studying geomorphologic and other relevant hydrologic aspects of the area. The mapping units were based on geomorphology and relative permeability. Six main units were distinguished: the cuesta with high permeability soil, the escarpment, the mass wasting surface with high permeability, the wash surface with medium to high permeability, the denudational surface with low permeability and an unidentified alluvial plain with low permeability. These units were further subdivided according to relief and form. The surface lithology, which was mostly unconsolidated material of various textures underlain by lateritic and/or rock gravel, rock gravel, rotten and fresh bedrock, was indicated on the map as the different screens. Suitable locations for excavating shallow wells were rated by means of permeability, topography and existing data, and were also indicated with the descriptions of the subunits in the legend.

Introduction

The purpose of this survey and mapping project was to provide basic data concerning the hydromorphological properties of surface deposits in the Northeast Rainfed Agricultural Development Project (NERAD) area. The study site was in Northeast Thailand, the driest region of the country. With relatively low and erratic rainfall, crops in the region often suffer losses due to drought. To solve this problem, measures to confine rainwater, as well as the introduction of shallow subsurface water for use, especially for areas with low ground and surface water potential, were recommended.

In order to implement such measures, small reservoirs, farm ponds and shallow wells will have to be constructed or excavated. To determine the best locations for these resources, knowledge of the hydromorphological aspects of the area is essential.

Based on the assumption that the hydrological aspects of any given area are related to geomorphology (Meijerink, 1974), the mapping units of this survey, hydromorphological units, were based on geomorphic units. Identification and/or classification of these geomorphic features was done by means of aerial photointerpretation and ground survey. Further subdivision of the geomorphic units was done according to the relief and form of the land. The relative permeability, rated as hydraulic conductivity, and the suitability of the land for excavating shallow wells, were also described. Surface lithology (to a depth of 3 m below the surface) was screened as a background in the map. Locations for farm ponds as well as reservoirs were recommended in the report.

This survey and mapping project was the first attempt at applying geomorphology in Thailand. Although it is not complete, it has proved to be relevant to the NERAD Project's goals. More relevant data and/or pertinent interpretations and conclusions might be gained if some experimental studies, both in the field and laboratory, were conducted and physical hydrological data obtained.

Brief Description of the Area

The survey area is situated in the Northeast region of Thailand about 60 km north of Chaiyaphum Province (Figure 1). Its shape is rectangular, approximately 7.5 km in width and 17.5 km in length; the total area is about 130 km^2. The west side of the area is bordered by a 600 m escarpment which is a front slope cuesta. The other sides are not bounded by distinct topography and/or landmarks (Figure 2). The western escarpment slopes gently down to the east from an altitude of 300 m. At an elevation of 220 m, the

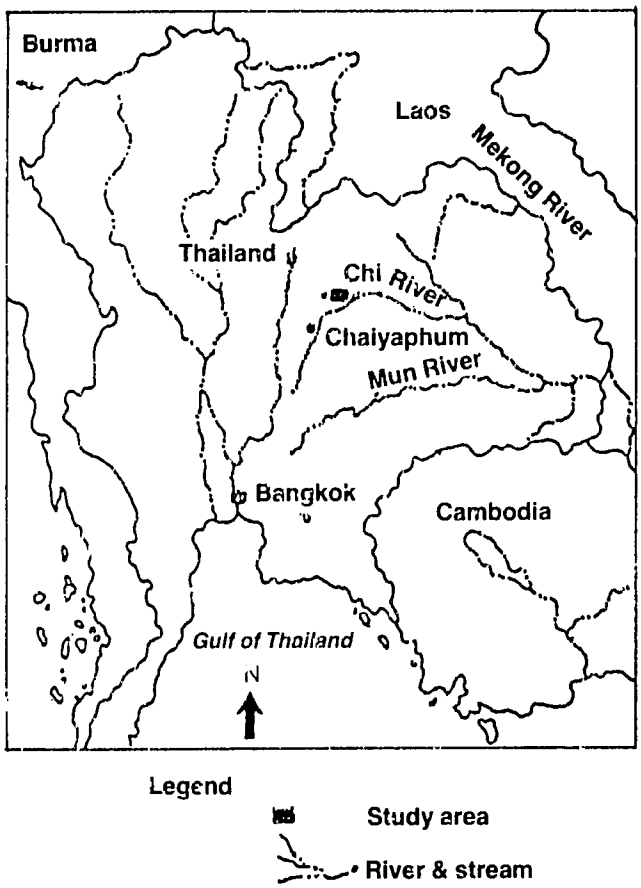
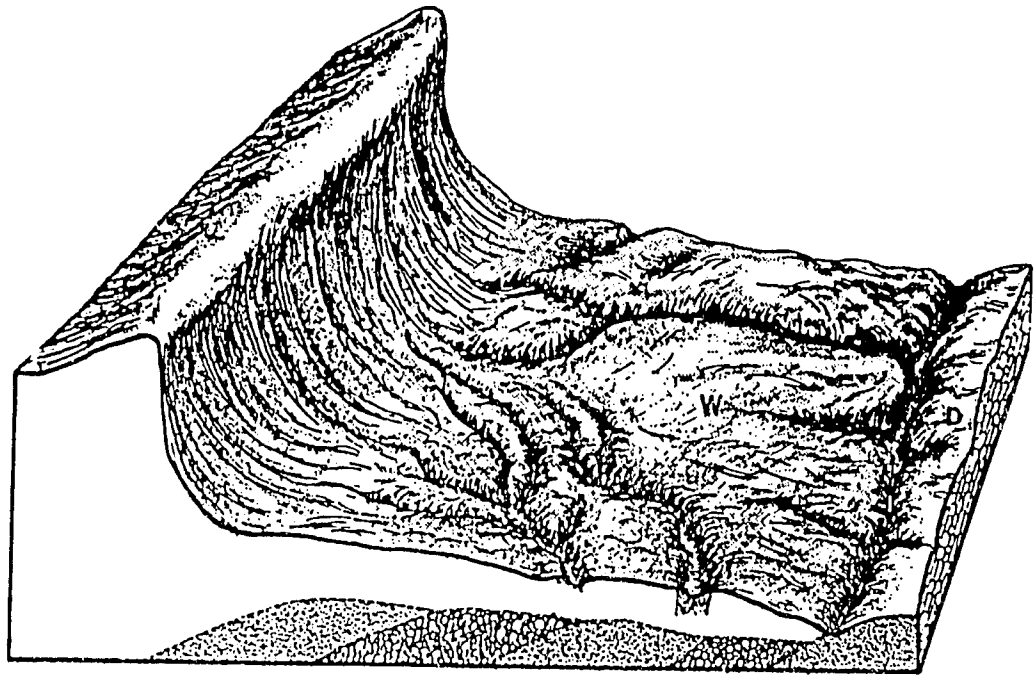


Figure 1. Location Map of the Area.

surface is dissected by narrow channels which flow in a north-south direction and parallel the boundary of the area. The plain also contains a number of small streams which originate in the escarpment and flow from west to east. To the east of these channels, the surface rises gradually from 220 to 240 m at the boundary of the area. It is noteworthy that the west side of the interrupting channel is sandy and the east side is clayey.

Geology

Structurally, the area is situated at the outer rim of an anticlinal valley, adjacent to the escarpment of a synclinal cuesta ridge (Figure 3). The bedrock forming the synclinal cuesta ridge is Lower-Middle Jurassic sedimentary rock, the Phra Wihan Formation. The valley consists of eroded anticlinal beds of Lower Jurassic sedimentary rock, the Phu Kradung Formation. The Phra Wihan Formation, forming the cuesta, consists of white, pink sandstone with some reddish brown gray shale and conglomerate. The Phu Kradung Formation consists mainly of brown or purplish red shale; brown, gray siltstone; and sandstone with some lime-nodule conglomerate. Borings which usually contacted the bedrock at relatively shallow depths indicated that most of the underlying bedrock is either shale or sandstone. The underlying bedrock of the western portion of the valley is an interbedding of shale and sandstone; the surface deposit is sandy and about 2 to 4 m deep. The surface of the eastern valley is usually covered by a laterite duricrust with shale present at a depth of 1 to 2 m.



Schematic Block Diagram of the Area

W = Wash surface
D = Denudational surface

boundary of bedrock with uncertain extent

fine-grain clastic

coarse-grain clastic

Figure 2. Schematic Block Diagram of the Area.

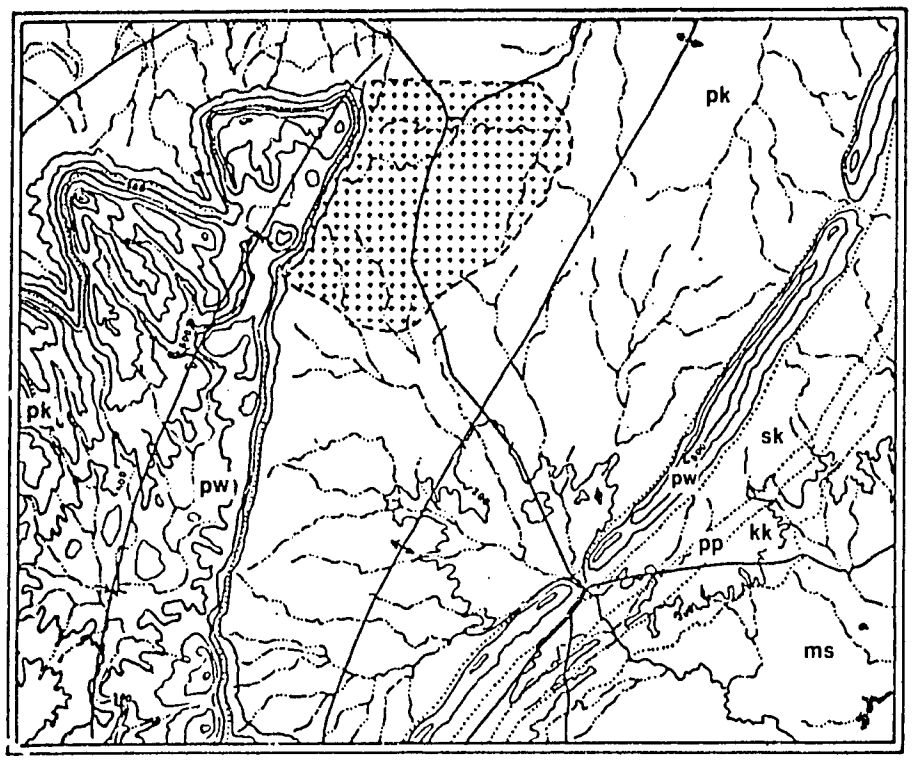
In areas where most of the covering soil is sandy, the surface stratigraphy consists of sandy or loamy material; laterite or gravel beds, loose or cemented; pallid or mottled clay horizon; rotten rock; and fresh bedrock. The material from the mottled clay zone downward should be sandy or clayey depending on the kind of underlying bedrock. It is sandy if the underlying bedrock is sandstone, and clayey if the underlying bedrock is shale. On the average, the sandy or loamy horizon is 1.5 to 2 m deep and the laterite or gravel horizon, mottled clay horizon and rotten rock horizon together are 1 to 3 m deep.

In the eastern portion of the valley, in an area where the majority of the covering soil is clayey, the surface stratigraphy consists of a thin loamy or clayey covering soil, hard laterite crust, mottled clay horizon, rotten rock and fresh bedrock, which is mostly shale. The depth from the surface to the bedrock averages 2 m.

In some places bedrock is exposed at the surface. The sandy covering material is believed to be wash material from the escarpment and the clayey one is believed to be residual and/or local alternative material.

Geomorphology

The main geomorphic features in the area are the mass wasting surface, the wash surface, the denudational surface and the alluvial plain. These major landforms were subdivided in accordance with relief, morphology and processes. This will be described in detail later.



Legend

	Uncomformity	Formation	Group	Age
ms	Mudstone; shale; siltstone; fine-grained sandstone; reddish brown, red, brick red, with rock salt and evaporite at the lower part.	Maka Sarakham	Korat	Lower Tertiary
kk	Sandstone; siltstone; shale; lime-noduled conglomerate; reddish brown, gray, grayish white, brown, with gypsum at the upper part.	Khok Kruat		Upper Cretaceous
pp	Sandstone; white, pale orange, pebbly. pebbles of quartz, chert, red siltstone and some igneous rock, up to 5 cm in diameter, sandstone; white, cross-bedded with shale and conglomerate beds.	Phu Phan		Lower Middle Jurassic
sk	Sandstone; reddish brown, white, micaceous, siltstone, grayish brown, reddish brown, shale, purplish brown, brick red, micaceous, lime-noduled conglomerate.	Sao Khua		Middle Upper Jurassic
pw	Sandstone; white, pink, orthoquartzitic, cross-bedded, massive, pebbly layering on the upper bed, with some reddish brown, gray shale and conglomerate.	Phra Wihan		Lower Middle Jurassic
pk	Shale; brown, reddish brown, purplish red, micaceous, siltstone; sandstone; brown, gray micaceous small-scale cross-bedded with some lime-noduled conglomerate.	Phu Kradung		Lower Jurassic

Symbols

- Boundary
- Anticline, with plunging direction
- Syncline, with plunging direction
- Surveying area
- River and Stream
- Lake or pond
- Contour line
- Road

Figure 3. Geological Map of the Area.

The most conspicuous landform in the area is the boulder to gravel rock surface that occurs on the eastern slope of the escarpment. This rock debris, occurring both on the surface and in the soil, is believed to be the remnant of a rapid mass wasting deposit, i.e., a slumping or sliding of colluvial material on the escarpment. Subsequent geomorphic processes have shaped it until at present, it is a gently sloping surface.

The most extensive landform in the area is the wash surface. In general, it gently declines from the mass wasting surface remnant to the dissected channel near the eastern boundary of the area (Figure 2). This plain is dissected by a number of streams and their tributaries, forming an undulating to nearly flat terrain. The southern portion is more dissected than the rest of the area. Along the streams and tributaries which originate from the escarpment and flow in an east-west or northwest-southeast direction, a narrow to wide alluvial plain is formed.

In general, the plain at the eastern portion of the area is an undulating surface. Its covering regolith is believed to have been formed *in situ* or through local alternation and it has been mapped as a denudational surface. Some dissected channels that can be distinguished as an alluvial plain have been observed on its surface. The channel with a narrow flood plain, the dividing line between the wash surface or slope and the denudational surface (Figure 2), is believed to be the boundary of different beds along the strike direction.

In the eastern portion of the study area, the covering soil material is influenced by wash processes and fluvial actions which have occurred in the past and present (Flenley, 1979; Hastings and Liengsakul, 1983). The presence of abundant laterite crusts or gravel in the covering soil profile indicates that the region as a whole experienced a drier era and/or pronounced wet and dry eras in the past. To form crusts, laterite must be exposed to the air for oxidation processes to occur (Goudie, 1973; McFarlane, 1976), so the laterite must have been close to the surface. These lateritic surfaces were subsequently blanketed by the younger transported material which washed down from the escarpment and/or other adjacent highlands when the climate changed to its present wetter condition.

Climate of the Area

Most of the rainfall in the area occurs during the southwest monsoon season from May until October with periods of drought in June and August (Table 1). The maximum rainfall is in September and/or October and the driest months of the year are December and January. Evapotranspiration is high from February until August. Temperature and relative humidity do not vary much over months; the yearly average temperature is 27 °C and the yearly average relative humidity is 66 percent.

Land Use Vegetation

The greater part of this region is cultivated. The upland or relatively high land is used for growing crops such as jute, corn and cassava. Where water is available, vegetable and cash crops are planted. In the lowlands along the streams, most of the land is in paddy. During the dry season the fields in this region are not cultivated. It is mostly covered by *Imperata* grass.

Existing Surface and Groundwater Status

There are six main streams in the area; from north to south, they are Huai Yai, Huai Ma Tai, Huai Sok Narong, Huai Hoi, Huai Ngu Luam and Huai Yang Yai (Figures 1 and 2). Tributaries of Huai Yai, Huai Sok Narong, Huai Hoi, Huai Ngu Luam and Huai Yang Yai originate from the escarpment, while the Huai Ma Tai and a number of dissected channels originate from the upland in the middle and eastern portions of the area. The general pattern of these streams is dendritic, except for the tributaries on the escarpment which are subparallel. All the tributaries and streams in the area are intermittent. They have continuous flow only in the rainy season, from June or July to November or

Table 1. General Climatic Information for the Study Area. Data Were Collected from Three Stations Within the Region Over 25 Years (1958-1982). Evapotranspiration was Calculated by Hargreaves' Formula (Hargreaves, 1981).

Month	Rainfall		Evapotranspiration	Temperature			Relative Humidity
	Average	No. of Rainy Days		Mean	Max	Min	
	mm		*mm*	..... °*C*			%
Jan	3	1	127	24	30	17	55
Feb	13	2	133	27	32	20	54
Mar	38	3	171	29	35	24	55
Apr	67	5	175	30	36	24	60
May	152	10	167	30	34	24	70
Jun	122	9	145	29	33	24	73
Jul	118	10	146	28	32	24	75
Aug	129	11	141	28	32	24	77
Sep	276	15	125	27	31	24	80
Oct	117	6	121	27	31	23	72
Nov	19	1	113	26	30	20	63
Dec	6	0	117	24	30	18	58
Year (annual)	1060	73	1681	-	-	-	-
Year (average)	-	-	-	27	32	22	66

December. In the early dry season, however, some waterlocking bodies, including a few reservoirs, can be observed along the streams. These become completely dry from March to May or June. The only water resources for people during this period are shallow wells of which there are only a few that provide permanent yield through ephemeral seepage. The wells were excavated in old and recent dry stream channels at the rim of the upland and on the alluvial plain. The depth of shallow wells in the area is 2 to 4 m. The two southern streams, Huai Ngu Luam and Huai Yang Yai, have many tributaries, both on the escarpment and plain. Thus, this area is very dissected and abundant narrow flood plains are formed. Many suitable sites for shallow wells are present and drought problems for people there are comparatively minor. At the head of Huai Ngu Luam where many tributaries from the escarpment join, a sizeable reservoir was constructed. In the future, drought problems for this area might be solved.

The groundwater level, except in the flood plain, is 30 to 45 m deep (Table 2). From a comparison of the discharge and the drawdown, the wells seem sufficient only for domestic use. The discharge rate is slow, too. Based on this data, the use of groundwater for agricultural purposes seems impossible. The low discharge rate, as well as the low availability of groundwater, might be, among other factors, due to the properties of the aquifer, which is an anticlinal valley with fine-grain clastic bedrock. The only measures that can be economically applied to solve the drought problems in the area are to confine surface water or induce near-surface water for use. Construction of a large reservoir that can provide water for the area requires a substantial investment. In addition, a large reservoir supplies water to locales having certain characteristics, and not to the whole area. The most suitable measures for the present socioeconomic situation and physical conditions of the area are to construct farm ponds for confining rain water or to intensively excavate shallow wells to induce near-surface water for use. Most of the area has a clayey impermeable layer at a depth of about 2 to 3 m. The depth where the near-surface water is available is the depth at which the clayey layer is present. Therefore, the construction of farm ponds, as well as the excavation shallow wells, should work well in this area. Survey and mapping of hydromorphological properties in the area are needed to determine the most suitable locations for shallow wells and farm ponds.

Survey and Mapping Procedures

Hydromorphological properties involve geomorphology, lithology, permeability/infiltration of the covering soil and land use or vegetation. The survey procedures thus start with an aerial photogeomorphological interpretation of the area. Since land use and vegetation vary with the landform, field work emphasized the investigation of lithology, the determination of hydraulic conductivity and studying the reliability of the interpreted geomorphological unit. Because they have been classified and described according to relevant hydrological factors, the mapping units are termed morphohydrological units. The main mapping units are the geomorphological units which have been classified in accordance with the genesis of landforms. Further subdivisions were based on relief and form. In addition to geomorphological aspects, relative permeability of the soil 1 to 1.5 m from the surface, estimated from its hydraulic conductivity, and the degree of its suitability for excavation of shallow wells were included in the description of the mapping unit. The degree of suitability was evaluated from observations in the field and deductions from aerial photographs. Surface lithology, relevant geomorphic processes and form were also indicated in the map as different screens and symbols. In rating the suitability of the terrain for shallow wells, the availability of the water, the capability of confining water and topography or physiographic position were taken into consideration. Among these factors, the most weight was given to availability of the water. The relative permeabilities, estimated from the hydraulic conductivity, are shown in Table 3.

Table 2. Deep Well Records of the Study Area. These Records Have Been Taken From the Department of Mineral Resource Well Logs.

Location	Well Number	Yield	Static Water Level	Depth Drilled	Draw-Down	Aquifer Rock Type
		U.S. gpm	..... *ft*			
Ban Kut Chanuan	D 432	52.4	10	60	10.1	Shale
		30.6	12		28.4	
Ban Nong Bua Phak Kwian	N 321	13.0	16	120	49.0	Shale
Ban Nong Po Daeng	N 322	26.0	22	160	43.0	Shale
Ban Non Thong	D 409	13.7	22	100	65.2	Shale
Ban Kwang Chon	D 431	19.81	8.3	80	49.8	Shale
Ban Don Champa	D 433	29.3	21.8	100	42.6	Shale
Ban Nong Kung Mai	D 408	15.7	21	120	66.1	-
Ban Nong Khan	N 385	12.0	29	120	31.0	Clay
Ban That	N 316	22.0	33	140	52.0	Clay

Results and Discussion

The Hydromorphological Unit

Six main hydromorphological units were recognized in the area. They are the gently sloping cuesta top, the escarpment, the mass wasting surface, the wash surface, the denudational surface and the unidentified alluvial plain. Details of each are described in Table 3.

1. The Gently Sloping Cuesta Top

The gently westward-sloping cuesta top at the extreme western portion of the area forms two levels. This is probably due to minor local displacement or variable resistance (composition) of the bedrock. Consequently, the cuesta top has been subdivided into higher and lower cuesta. The elevation difference between these two levels is 90 m. The higher level occupies the northernmost portion and includes about one-third of the cuesta. The surfaces of these two different subdivisions are slightly dissected and characterized by

Table 3. Actual Hydraulic Conductivity and Relative Permeability Classes of the Hydromorphological Units of the Area at Soil Depths of 30 and 60 cm.

Hydromorphological Unit		Actual Hydraulic Conductivity†		Relative Permeability‡	
Main Unit	Subunit	30 cm	60 cm	30 cm	60 cm
		..... cm h^{-1}			
Unidentified alluvial plain		1.90	0.11	moderately slow	very slow
Nearly flat wash surface	Nearly flat in general	11.1	2.35	moderately high	moderate
	Dissected channel or depression	1.66	0.45	moderately slow	slow
Undulating wash surface	Undulating in general	19.3	3.38	high	moderate
	Dissected channel or depression	6.20	1.90	moderate	moderately slow
Denudational surface	Undulating in general	0.20	0.06	moderately slow	very slow
	Dissected channel or depression	0.05	0.09	very slow	very slow
Mass wasting surface	Undulating in general	9.10	8.20	moderately high	moderately high
	Dissected channel	4.30	0.25	moderate	slow
Cuesta Top		13.3	-	high	

† Actual hydraulic conductivity is an average value.
‡ Relative permeability classes adapted from Table 31-1 (American Society of Agronomy, 1965).

nearly flat, gently sloping terrain dotted by a few outcrops. The westward-sloping direction is controlled by the bedrock structure. Few streams were observed and most flow west. Therefore, these subdivisions cannot be counted as the catchment of the surveyed area. The covering soil is loamy with sandy texture and high permeability. This shallow soil is derived from *in situ* weathering material of sandstone, which is normally present at shallow depths. The vegetation is mostly grass, especially *Imperata* grass, dotted with large secondary trees.

2. The Escarpment

It is the front slope escarpment of the cuesta where most of the streams in the area originate. This has been subdivided into two units: the bedrock scarp and colluvial scarp. The bedrock scarp occupies the higher elevations and is steeper (greater than 60 percent slope). Alignment of bedrock and the rock surface can be observed clearly both in aerial photographs and in the field from the bedrock scarp. Most of the bedrock is an alternating sequence of sandstone and shale or siltstone. The colluvial scarp is more gently sloping. It exists where the bedrock is obscured by colluvial material. The bedrock alignment, therefore, cannot be observed from aerial photographs of the colluvial scarp. It is strongly dissected; gullies and channels are abundant on its surface. On its footslope many slope and rock fans can be observed, both in the field and in aerial photographs. The covering soil is shallow and composed of sandy or loamy material and boulders and/or rock gravel. It is covered by moderately dense secondary forest. Erosion features other than gullies are rarely observed. Due to the dip direction (westerly) of the bedrock, springs are not observed even in the bedrock scarp. These two subunits are the catchment of the survey area.

3. The Mass Wasting Surface

The mass wasting surface is the undulating terrain adjacent to the escarpment. On its surface, rocks from big boulders to gravel are present. The surface is believed to be formed by mass wasting, i.e., either sliding or slumping. To some extent, this surface has been shaped by subsequent wash processes and dissected by a number of streams until its relief became undulating with a slope of three to six percent.

The mass wasting surface has been divided into two subunits: the undulating surface in general and the dissected channel. On the undulating surface, as mentioned previously, abundant rock from boulders to gravel are present. These kinds of rocks are also present in the covering soils which are sandy or loamy in texture until they reach the rotten and/or fresh bedrock. The underlying bedrock is not necessarily the same type of rock as the boulders or gravel present on the surface and in the profile. The permeability of the covering soil is moderate to high. Excavation of shallow wells on this surface is not advised because of the presence of abundant boulders and the unavailability of near-surface water.

On the dissected channel, the covering soil material is of a finer texture and fewer boulders are present. Permeability is slow. As the lowest position of landscape in the unit, it is moderately suited for shallow wells. This is confirmed by the existence of some shallow wells in this unit.

4. The Wash Surface

The wash surface is the most extensive unit in the area. It is the gently sloping surface descending eastward from the mass wasting surface to nearly the end of the eastern boundary. Geologically, it is believed to be the erosional bedrock surface blanketed by subsequent wash materials from the escarpment. Most of its covering soil material is sandy or loamy, and is underlain by a laterite or rock gravel layer, mottled clay or pallid zone, rotten bedrock and fresh bedrock. Where the topography is more pronounced, the underlying gravel is laterite and the bedrock is shale. The texture of the mottled clay or pallid zone usually conforms with the type of bedrock, e.g., if the bedrock is sandstone, the texture of that zone is sandy clay or sandy clay loam. In general, the permeability of the covering soil is rapid to moderate. Due to the presence of an impermeable layer, i.e., the mottled clay or pallid zone, drainage in some places is moderate to poor. This unit is divided into two subunits according to relief: the undulating terrain and the nearly flat terrain.

5. The Undulating Denudational Surface

This unit occupies the easternmost portion of the area. It is believed to be the source of the local fine-grain clastic bedrock. In general, it is undulating terrain with shallow covering soil material (not more than 1 m) and has been dissected to some extent. It has been divided into two subunits: the undulating surface in general and the dissected channel or depression in-between.

5.1 The Undulating Surface in General

Within the subunit, two distinct forms were observed with respect to underlying strata. One is present as a moderately deep to deep clay covering soil material (not more than 1 m) underlain by soft powdery and/or gravelly lime, rotten and fresh fine-grained clastic bedrock. The other is characterized by a relatively shallow loam or clay loam covering soil material (not more than 50 cm deep) underlain by a laterite crust or a gravel layer, mottled clay or pallid zone, and rotten and fresh fine-grain clastic bedrock. These two different forms were differentiated in the map by screening. According to soil texture and stratigraphic variation, permeability is slow to medium over slow. The soil texture, the presence of an impermeable layer (either laterite crust or bedrock) at relatively shallow depths, local relief and topography indicate that subsurface water should be available during a certain period in the rainy season. However, water can completely dry or drain out of the area by means of evapotranspiration and/or lateral seepage in a relatively short period. Therefore, the excavation of shallow wells is not recommended for this subunit. With two to five percent slope, this subunit is used for various kinds of upland crops, e.g., corn, fiber crops and sugarcane (where soil is underlain by a lime layer), and secondary dipterocarp forest (where the soil is shallow and underlain by laterite crust).

5.2 The Dissected Channel and/or the Depression In-Between

Like the other subunits with similar nomenclature, this is the recent and former drainage channel of the terrain. It has more or less the same texture as the previous subunit, but the covering soil is thicker. The permeability of this covering soil is low and drainable conditions are relatively poor. This subunit is not suited for shallow wells. It is usually used for paddy fields.

6. Unidentified Alluvial Plain

Along the major streams and tributaries, low-lying flat surfaces were observed. These surfaces are believed to have formed by sedimentation and erosion processes induced by the water in the streams. The texture of sediments in these flat surfaces varies from loamy to clayey depending upon the source of the sediment, the properties of the basement (in cases of formation by erosional process) and the texture of the covering soil of the adjacent highland from which the sediment washes. The soil in this unit is quite deep (more than 4 m) and heavy.

As an alluvial deposit, the soil profile shows some stratification. Its textural variations from 0 to 1.5 m have been shown in the map as different screens. The soil in this unit has a relatively heavy texture, sandy clay loam to heavy clay, permeability is slow and drainage conditions are poor.

From field observations made in June, groundwater is present at shallow depths, 2 to 3 m from the surface. Groundwater is usually present at the depth where the textural contrasting layer to the overlying soil is found, that is, if the overlying soil is of a loamy texture, groundwater will be found at a depth where the clayey layer is present. In the dry season, abundant shallow wells have been excavated in this unit, both for domestic

consumption and for irrigation of vegetable plots. This unit is the most suitable place for shallow wells. At present, most of this unit is used for transplanted rice.

Suggestions and Recommendations in Construction and Excavation of Farm Ponds and Reservoirs

In excavating the farm pond, two things are important: the location and size. Topographically, the farm pond should be located where there is sufficient catchment area for both seepage and surface water, i.e., in lowland areas. Along the dissected channel of the mass wasting surface and the alluvial plain are such places. In the alluvial plain, the excavation of shallow wells is easier and more effective, so farm ponds are not recommended. Moreover, large farm ponds could be troublesome to paddy field practices during the rainy season. Thus, only along the dissected channel is the excavation of a farm pond recommended. For irrigation purposes, the most suitable location is the area near the highest elevation of the dissected channel. From this position, water can be supplied to low-lying areas in the channel and to the adjacent highland through simple irrigation practices. The lower part of the channel can also serve as a spillway to release water from heavy rainfall when the pond is already full.

The size of the farm pond; irrigated area; nature, properties and environmental context of the site; kind and growing period of crops; farm management and practices; and climatic data of the area must be considered together. These factors have to be investigated.

As mentioned earlier, a sizable reservoir has been constructed at the head of Huai Ngu Luam stream where many tributaries from the escarpment join. Constructing a reservoir is a high-cost investment and the present socioeconomic situation precludes this. However, as the demand for available water increases, reservoir construction will become a higher priority. There are two other locations that are suited for reservoirs. They are at the head of Huai Sok Narong and Huai Hoi streams. Many tributaries from the escarpment join there and a large amount of water is believed to be available as the area is alluvial plain.

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Farmers' Attitudes Toward Soil and Water Conservation Practices: Barriers to Acceptance and Cost-Sharing Incentives

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ABSTRACT. Soil erosion became a serious problem in Thailand 25 to 30 years ago. Soil and water conservation has encountered several obstacles and found some success, especially in small holdings. Soil conservation practices are accepted and adopted by the farmers when they fit into their present farming systems. At this time, the increased importance of soil conservation in Thailand has prompted a number of researchers to establish the feasibility of applying the cost-sharing system here. In a survey in Nakon Ratchasima Province, the 306 farmers interviewed expressed their willingness to cooperate with government agencies and operate soil and water conservation measures on a cost-sharing basis. The overall figures obtained from the interview indicate that 78.4 percent of farmers are able to pay up to 25 percent of the cost of installing conservation measures on their lands; 20.9 percent may pay up to 50 percent; and negligible numbers, i.e., 0.4 percent and 0.3 percent can pay up to 75 percent and 100 percent, respectively. The survey shows that the chances of implementing cost-sharing in Thailand, particularly in the Nakon Ratchasima area, is very high. The authors, therefore, wish to ask the authorities of the Department of Land Development, Department of Agricultural Extension and other agencies concerned to seriously consider this as a viable approach to soil and water conservation programs to preserve our rich land heritage and feed our future generations and other hungry people.

Introduction

Soil erosion is Thailand's most serious natural resource problem. Soil, the foundation of agriculture, is being lost at an alarming rate. A Department of Land Development 1980 publication entitled "Soil Erosion in Thailand" points out that about 17 Mha of land widely distributed throughout the country have rates of soil erosion ranging from a medium to high degree of severity, particularly in upland soil areas with slopes greater than five percent. The severity of soil erosion increases in the highland areas of the North, Northeast and Central Highlands of the country where shifting cultivation and cultivation without proper conservation measures are widely practiced. Soil erosion in Thailand will be more serious in the future because the demand for cultivated land is steadily increasing.

The Department of Land Development has been involved in the soil and water conservation program since 1963 by providing technical services as needed by farmers, conducting research and demonstrations at land development stations and by providing training in soil and water conservation for extension workers and farmers. To date, most of the land development projects have been carried out as free services to farmers without any financial obligation from them. This has resulted in limited areas of operation and noncooperation by the farmers, thereby causing failure of the conservation measures applied to the fields. Because of the need for stronger incentives, we began to investigate whether soil and water conservation could be implemented on a cost-sharing basis, blending the American experience with Thailand's social and economic conditions.

Magnitude of Soil Loss

Soil erosion became a serious problem in Thailand approximately 25 to 30 years ago. The rapid increase in population together with diversification of crops for industries and export have resulted in much of the forest being cleared. Much of this new land is very susceptible to erosion because of topography, soil and rainfall characteristics. The extent of damage by erosion, however, depends on the types of land use and level of management. It is estimated that 17.2 Mha or 33 percent of the country has been moderately to severely eroded (Table 1). Suspended sediment from all watersheds is estimated to be 27 million tons annually. Erosion has also affected environments and has caused severe sedimentation in streams and reservoirs (Sombatpanit *et al.*, 1984).

Soil and Water Conservation in the Past

Before 1963 soil and water conservation activities were divided among several departments of the Ministry of Agriculture and Cooperatives. These departments carried out soil and water conservation projects on a small scale and mainly emphasized research work. In 1963 the Thai Government decided that soil and water conservation and management projects should be consolidated and expanded in the country. The Department of Land Development was thus established in 1963 under the Ministry of National Development. In 1973 the Department was transferred to the Ministry of Agriculture and Cooperatives. The main functions of the Department are:

1) Conducting soil and land classification and evaluation,

2) Establishment of land policies and land use planning,

3) Conservation and development of land and water resources, and

4) Reclamation of land in order to bring degraded and problem lands into production.

During the early stages, some financial assistance was given by USAID for soil and water conservation. The most common conservation practice at that time was the construction of field terraces, both level and graded. Later on, bench terraces and hillside ditches were constructed on high slopes. The construction of farm ponds started in 1970, but not until 1975 did it become a popular feature of rural development programs.

Table 1. Areas Affected With Soil Erosion in Thailand (Soil Erosion in Thailand, Department of Land Development, Ministry of Agriculture and Cooperatives, December 1980).

Degree of Soil Erosion	Area	Percent	Land Use Situation
	Mha		
Very low	19.0	36.0	Forest, rubber tree, fruit tree, paddy field
Low	14.4	28.1	Forest, fruit tree, paddy field
Moderate	4.2	8.1	New rubber, new fruit tree, upland crops, forest/upland crops
High	6.8	13.3	Upland crop, forest/upland crops, slash and burn practice
Severe	6.3	12.2	Upland crops, forest/upland crops, slash and burn practice
Others	0.7	0.2	Water resources, rivers, shrimp farm, mangrove swamp, beach, etc.
Total	51.40	100.00	

There are now several thousand farm ponds throughout the country and more will be constructed in the near future. The practices mentioned so far are now major components of land development projects in several locations in the country. On a country basis, soil conservation is practiced primarily in the North, and less in the Northeast and the Southeast.

Farmers' Attitudes Toward Soil and Water Conservation Practices

We conducted a survey to determine who the farmer consults if he has a soil problem. We found that most farmers were not able to solve soil conservation problems by themselves even though they knew the cause. More than half of the farmers asked were more willing to consult the Land Development Officers than other individuals (Table 2).

The survey shows farmers know the right place to go for help if they have trouble. However, the services provided in these villages are minimal because of budget and manpower constraints. We attempted to assess the farmers' familiarity with soil conservation by asking them several questions. The data in Table 3 show that most farmers knew the terms "soil conservation," "soil erosion," "soil improvement," and "how to make good soil." They understood the concepts but lacked knowledge of soil conservation methods and practices. There are many ways to conserve soil according to

Table 2. Percent Distribution of the Person Farmers Will Ask for Help if They Have a Soil Problem.

Whom do you think to ask for help if you have a soil problem?		%
1.	Friend	0.9
2.	Headman	14.9
3.	Kaset Tambon	6.3
4.	General Civil Servant	1.3
5.	LDC Worker	58.5
6	Kaset Tambon and LDC Worker	5.0
7.	Headman and LDC Worker	5.0
8.	Kaset Amphoe	1.8
9.	Other	2.7
10.	Don't Know	3.6
	Total	100.0 (222)

Table 3. Percent Distribution of "Wording" in Soil Conservation.

Do You Know	%
1. Water and soil conservation	100.0 (222)
Yes	81.1
No	18.9
2. Soil erosion	100.0 (222)
Yes	80.2
No	19.8
3. Soil improvement	100.0 (222)
Yes	86.0
No	14.0
4. How to make good soil?	100.0 (222)
Yes	85.4
No	14.6

the location, ecology and agricultural "know-how," i.e., socioeconomic experience. For example, we found that all kenaf is sold to market and farmers do not use it as green manure. Conservation is very abstract to them. Consequently, the Department of Land Development has used cost-sharing incentives to encourage and transfer this technology to farmers since 1960, but it is only one element of their total program.

Where Cost-Sharing has been Done in Thailand

As mentioned before, many social and economic development projects, including the land development ones, have given much aid to the cooperating farmers, making them feel the structures created on their land belonged to the government and not to them. As a result, most of the field terraces built in the past were neglected and frequently were plowed down by hired tractors. Many of the cooperating farmers feel that if any of the structures deteriorate, the government's personnel will restore them. They rarely repair damage by themselves.

To date there have been quite a number of conservation programs that can be categorized as cost-sharing. They are:

1) Acid Sulphate Soil Improvement Project. The farmers who till 900,000 ha of acid sulphate soils in the Central Plain can receive free marl from the government's marl pit 100 km away. They must pay for transport which currently costs 100 B/t.

2) In many provinces farmers tilling sloping lands can ask the land development stations in their vicinity to help them construct field terraces to reduce erosion. In this program the government's personnel come to the farmer's fields with the station's farm equipment to construct terraces using fuel bought by the landowner. The same program applies to the construction of farm ponds.

There are also projects administrated by other government agencies which are similar in nature. One project worth mentioning is the electricity utilizing promotion program of the Provincial Electricity Authority (PEA). In theory, the PEA should establish main electrical lines to all villages in the country, but in practice this is not possible. Hence, the PEA proposed to each village that if it would contribute at least 30 percent of the cost of main lines, the Authority would give that village a higher priority than those villages that did not contribute. After completion, the villagers felt proud that they bore a part of the cost of the undertaking. This kind of cost-sharing is considered an effective tool in accelerating the electrification of the rural areas of Thailand.

Survey of Farmers' Opinion Towards Cost-Sharing

In order to establish whether farmers in Thailand are prepared to accept cost-sharing programs in soil and water conservation, a survey was conducted in the Province of Nakon Ratchasima in August 1984 (Palasuwan *et al.*, 1984). Altogether, 306 farmers from the districts of Pak Chong, Sikew and Soongern were interviewed. Essential results are summarized in the two tables below. Table 4 shows that among the constraints that prevented farmers from implementing soil conservation practices on their lands, lack of know-how and lack of funds accounted for 43.5 and 42.7 percent, respectively; other constraints were minor. This finding reflects the need for both soil conservation education and funding from the public authorities (Upayokin *et al.*, 1983).

The survey also revealed that most farmers (78.4 percent) are willing to pay 25 percent of soil conservation costs, while 20.9 percent are willing to pay up to 50 percent (Table 5). The numbers of farmers willing to pay up to 75 percent and 100 percent of soil

Table 4. The Reasons Why Farmers Do Not Implement Soil Conservation Measures on Their Lands in Nakon Ratchasima Province.

No.	Nature of Reasons	%
1.	Lack of know-how	43.5
2.	Lack of funds	42.7
3.	Fear of difficulties in land preparation	4.8
4.	Fear of losing part of cultivable land	3.4
5.	Do not believe the measures can help	2.7
6.	Do not know how much the damage would be	1.3
7.	Fear of increased investment	1.0
8.	Do not think they are necessary	0.6
	Total	100.0

Table 5. Percent of Farmers Willing to Pay Varying Portions of Soil Conservation Costs, Nakon Ratchasima Province.

Soil and Water Conservation Measures	Percent of Farmers Willing to Pay the Following Portions of the Cost				
	25%	50%	75%	100%	Total
	.....	.....	%	.....	.....
1. Field terrace	79.6	19.1	0.6	0.7	100
2. Hillside ditches	89.1	10.6	0.3	-	100
3. Farm roads	67.1	32.6	-	0.3	100
4. Waterway	68.3	31.0	-	0.7	100
5. Farm ponds	84.7	14.3	0.7	0.3	100
6. Covercrop seeds	84.0	15.0	0.7	0.3	100
7. Greenmanure crop seeds	83.0	16.0	0.7	0.3	100
8. Fast-growing plant materials	64.3	35.1	0.3	0.3	100
9. Grass seeds or cuttings	85.0	14.3	0.7	-	100
Average	78.4	20.9	0.4	0.3	100

conservation costs are negligible. A closer examination of those farmers who are willing to pay up to 50 percent of the cost of conservation measures is enlightening.

In this case, the conservation measures could be divided into two categories, i.e, those for which more than 30 percent of farmers were willing to pay 50 percent of costs, and those for which less than 20 percent of farmers would pay 50 percent. It can be assumed that for farm roads, waterways and fast-growing plant materials, the farmers already realize their usefulness. But how about farm ponds which are very much needed now? The figure of 14.3 percent could be explained as follows: although farm ponds are very much needed, they are rather expensive to build and on many occasions farmers could have them constructed free of charge through existing government programs.

The figures in Table 5 show that most soil conservation measures are essential, not only for the farms, but also for the communities and well-being of people far into the future. The findings also conform well with cost-sharing figures for the United States--American farmers pay 20 to 50 percent of the cost of soil conservation.

These results are very encouraging. However, the authors would suggest that the authorities concerned (DLD, DOAE, etc.) determine whether the farmers who were interviewed have any more or fewer problems after our mobile units have implemented conservation measures in their fields. If they can receive the aid under the agreed terms, it means people in that area are well-informed and are ready to cooperate with the authorities to preserve the soil and water resources of the country. The success in the Nakon Ratchasima area will serve as a model for other land development projects to assure a real success and not an apparent one. The success of soil conservation in this country will further assure that Thailand will retain its role as one of the main producers of food for a hungry world for a long time to come.

Conclusions

From the results of the survey conducted in Nakon Ratchasima Province, it can be concluded that cost-sharing programs which contributed so much to the continued success of the soil conservation movement in the U.S. can be used as an important tool in promoting effective soil conservation measures to preserve the agricultural lands of this country. The authors suggest that the authorities concerned use this tactic in combination with other procedures for present land development projects and in the future.

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The Sukhothai Ground Water Development Project

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ABSTRACT. This paper assesses the changes in cropping patterns and the economic status of farmers after the establishment of a supplemental groundwater irrigation project at Sukhothai. The soil, water and crop management practices and constraints to agricultural production under supplemental irrigation are discussed. Finally, some alternatives for research and development of improved management practices are suggested.

Primary emphasis is directed toward the improvement of irrigation water use efficiency through increasing the rate of water distribution and, in turn, decreasing water losses from the soil root zone. The limits of supplemental irrigation in crop production are well recognized. The utilization of residual soil moisture and the selection of soybean varieties having a lower water requirement and which can compete effectively with weeds for residual moisture and nutrients are also discussed.

Introduction

The importance of irrigation projects in providing a reliable source of water for crops has long been recognized in agricultural development in Thailand. Despite the relatively high annual precipitation, a considerable portion of the agricultural land in Thailand is subject to moisture stress and drought because of erratic rainfall, excessive runoff and light-textured soils which have low plant available water capacities.

Although a large portion of the rainfall is not initially available to crops because of rapid percolation through the soil profile, the stored underground water can be brought back to the soil surface through tube wells. The Sukhothai region is known to have a large reservoir of underground water because of a high recharge rate from the Yom and Nan Rivers that flow through the area. Since Sukhothai soils are among the more productive agricultural soils in the country, utilization of this groundwater for irrigation to increase crop productivity was given a high priority. By the end of 1981, the Sukhothai Project consisted of some 100 tube wells provided with electrically operated pumps that were serving 30,000 rais of cultivated land. The implementation of this project has had a considerable impact on the entire area. Even though the farmers were initially inexperienced in irrigated agricultural practices, their net income doubled after two years of operation. Nevertheless, the soil, water and crop management practices employed here are poor, resulting in very low irrigation efficiency. Low irrigation efficiency has been a major constraint to increased agricultural productivity.

The purpose of this paper is to provide information on changes that have occurred in the Project area, the acceptance of new management practices by farmers, constraints to increased production efficiency, and some selected research and development activities that may significantly improve the production efficiency of the Project area.

Project Summary

Some selected statistics for the Sukhothai Ground Water Project are presented in Table 1. This discussion is limited to the activities of Zone 2 of the Project which have been in operation since 1982. It is interesting that this is one of the few, if not the only, irrigation projects, that have an underground water distribution system through a pipeline network. Conveyance loss is expected to be significantly less than for a conventional open-ditch system. Capacity of water supply varies from well to well. Records have been made at individual wells each day for operation and maintenance purposes as well as for collection of water fees.

Table 1. Basic Information for the Sukhothai Ground Water Project.

Zone 2 irrigable land	35,000 rai
Number of tube wells	100
Total farm families	966
Average family members	5
Well depth	120 m
Electric power with average pumping rate of	200 m^3 h^{-1}
Water cost †	0.12-0.13 Baht m^{-3}

† Water is distributed through underground pipelines with at least one riser outlet at each field. Each outlet is equipped with a rectangular weir.

The various operations that are practiced among farmers on irrigated lands of the Project are summarized in Table 2. Cropping patterns in 1982, the first year of the Project, started with the supplemental application of water to legume crops that had been grown under residual soil moisture following rice cultivation. In 1983, soybean and mung bean began to dominate the cropping patterns, especially at the beginning of the year.

Table 2. Information on Farmers' Practices and Operations on the Sukhothai Ground Water Project.

Crop patterns	Rice - grain legumes Soybean (Mung bean) - Rice - Rice Soybean (Mung bean) - Rice
Soil	Plow and dry for 15-20 days
Water management	No effective supply, drain ditch, flooded basin Large amount of water is applied at each irrigation, intervals are too long
Crop management	Broadcast with very high seed rate Practice no weed control S.J.4 variety
Pest management	Neither fertilizer nor Rhizobium is applied
Pest management	Improper use of insecticide

After the field crops had been harvested, two consecutive crops of rice utilized a good portion of the cultivated land for the remainder of the year. The excessive utilization of irrigation water in 1983 led to an agreement among the farmers that limited rice cultivation to one season, followed by a four-month rest period from August 15 to December 15 when no water was pumped.

The flooded basin has been the only irrigation method employed in the area from the beginning of the Project. Large amounts of irrigation water are applied to the fields, especially at the first irrigation because of the slow rate of water distribution through the fields. Soybean seeds (preferably S.J.4) are broadcast at a rather high rate of 25 to 30 kg/rai to minimize the growth and infestation of weeds. Neither fertilizer nor Rhizobium inoculum is utilized in growing the legume crops. There is a generally improper use of insecticides in the Project area.

Changes due to the Project

Regardless of the farmer's previous inexperience in irrigated agriculture, 1440 rais of land were irrigated in the dry season of 1982, the first year of Project implementation (Table 3). The irrigated area more than doubled in 1983 and increased to 5560 rais in 1984. Soybean yield per rai during the first year of irrigation (1982) was the same as in 1981. In 1983, however, the average soybean yield was the highest recorded during the study. In 1984, a considerable amount of the upland area was graded and converted into irrigated land. This may have caused some unfavorable conditions that resulted in a moderate decrease in soybean yields from 237 to 212 kg/rai.

Table 3. Soybean Cultivation on the Sukhothai Ground Water Project During the Dry Season of 1980 to 1984 (Rainy Season Average, 4330 rai).

	Year			
	1980/81	**1982**	**1983**	**1984**
Cultivated area (rai)	-	1436	3782	5557
Yield (kg rai^{-1})	152	151	237	212

The total annual cultivated area of the Project gradually increased in 1982 and 1983 to 31,500 rais and 47,800 rais, respectively (Table 4). The overutilization of water by growing two crops of rice in 1983 forced a change in cropping patterns and the total cultivated area decreased to 43,200 rais. This, in turn, caused the cropping intensity of the Project area to increase from 73 percent in 1980/81 to 101 percent and 154 percent in 1982 and 1983, respectively. There was a small decrease in cropping intensity in 1984 to 139 percent which was attributed to further changes in cropping patterns.

The changes in income of the Project area are documented in Table 5. There was an overall increase in income after the start of irrigation, with the exception of 1982 when large investment inputs were made. Assuming a Project cost of 15 million Baht per year, and without taking operation and maintenance costs into account, the Project cost will be paid off within 25 to 30 years.

Table 4. Changes in Annual Land Use on the Sukhothai Ground Water Development Project.

	Year			
	1980/81	1982	1983	1984
Cultivated area (rai)	22,500	31,500	47,800	43,200
Cropping intensity (%)	73	101	154	139

Table 5. Economic Status of the Sukhothai Ground Water Development Project.

	Year			
	1980/81	1982	1983	1984
Gross income (million Baht)	41	53	187	79
Net income (million Baht)	15	13	38	31
Expenditure (million Baht)	26	40	49	48
Gross family income (Baht)	42,484	55,331	90,321	82,122
Net family income (Baht)	15,145	13,437	39,182	32,153

Selected Research and Management Activities

Conventional tillage practices on the Project have often led to very high water consumption. Data collected (Table 6) by the Royal Irrigation Department (RID) demonstrated the relationship between water consumed during the first irrigation and the turnaround from various wells representing upland and lowland conditions. The average consumption of water on upland soils is 26.5 cm, while that for lowland paddy soils is 16.9 cm. Well No. 17 consumed 34.4 cm of water mainly because of large cracks in the dry, heavy soil. It is interesting to note that efficiencies of first irrigations were quite low, especially those of upland soils. Dry plowed soils absorb considerably more water compared with no-tillage soils (Table 7). The amount of water absorbed increases with increasing field size. One can conclude that the greater the roughness of the soil, and the longer the time allowed for the soil to absorb water, the higher the amount of water consumed.

Table 6. First Irrigation Data for Some Selected Tube Well Activities, 1985.

Site	Well No.	Irrigated Area	Flow Rate	Water Consumption	Irrigation Efficiency	Turn around Period
		rai	$m^3\ h^{-1}$	*cm*	%	*days*
Upland	22	96	216	27.9	24	7.5
	67	68	198	22.1	14	9.5
	76	37	209	29.6	11	7.1
Average		67	208	26.5	16.3	8.0
Lowland	17	19	234	34.4	-	6.1
	19	273	234	16.9	25	12.4
	23	152	216	21.3	33	9.8
	55	280	216	14.0	28	15.0
	88	285	216	15.3	29	13.7
	97	290	252	17.1	36	12.3
Average		256	267	16.9	32.2	12.6

Reduced tillage systems have generally resulted in a high density of weeds. Effective weed control in irrigated soybean fields has resulted in markedly increased yields as shown in Table 8. When weeds were controlled by two hoeings, soybean yields were more than double those of the control plots.

Nevertheless, hoeing weeds is a costly labor-consuming practice, and the farmers tend to prefer other means of controlling weeds. For example, a common practice is to broadcast soybean seed at higher than normal rates to increase plant density. This results in more effective competition with weeds for water and nutrients and an early canopy effect for shading young weeds. Seeding at a rate of 25 to 30 kg/rai provides a plant density of about 100 plants/m at germination rates of 70 to 80 percent. The effect of various planting densities of S.J.4 and O.C.B. soybean varieties on weed growth 30 days after germination is shown in Table 9. At a density of 116 plants/m^2, S.J.4 reduces weed growth to less than half of weed growth at a density of 43 plants/m^2. Effective weed control was obtained with O.C.B. at a density of only 52 plants/m^2. At a density of 98 plants/m^2, the field was almost weed-free. There has been speculation that such high population densities might cause a decrease in yield. Experiments conducted in Chinat and Chiang Mai Provinces (Table 10) demonstrated that this was not the case. A population density of 96 plants/m^2 did not cause adverse effects on soybean yield.

Table 7. Effects of Cultivation Techniques and Size of Irrigated Fields on Water Distribution.

Irrigation No.	Plot Size								
	400 m^2			800 m^2			1600 m^2		
	Till	No-Till	Ave.	Till	No-Till	Ave.	Till	No-Till	Ave.
	.....				*cm*				.....
1	10	6	8.0	17	8	12.5	19	10	14.5
2	6	7	6.5	7	6	6.5	8	8	8.0
3	12	8	10.0	10	9	9.5	13	5	9.0
4	9	8	8.5	13	6	9.5	16	9	12.5
5	10	9	9.5	15	8	11.5	11	9	10.0
6	9	8	8.5	11	6	8.5	8	9	8.5
Total	56	44	50.0	73	43	58.0	75	50	62.5
Average	9.3	7.3	8.3	12.2	7.2	9.7	12.5	8.3	10.4
Yield (kg rai^{-1})	281	262	272	264	242	253	272	266	269

Sources of Information

- Sukhothai Ground Water Project, Royal Irrigation Department
- Project Economic Evaluation Team
- District Agriculture Extension, DOAE
- Srinakorn Cooperative Land Settlement
- Srisamrong Experiment Station
- DOA Research Annual Report
- Soil and Water Management Pilot Project, DOA
- The Farmers

Conclusions

Despite the large cost of the Project, irrigation efficiency under farmers' conditions is quite low. However, there is great potential for increasing irrigation efficiency through simple changes in soil and/or water and crop management. Planting crops as early as possible would allow the utilization of residual soil moisture from the previous rainy season crop and also enhance the opportunity for establishing a second field crop before rice cultivation in the next rainy season. Conservation tillage facilitates the rapid movement and distribution of irrigation water through the field, minimizing the amount of water lost by deep percolation through the soil root zone. Moreover, smaller fields require less time for water to contact the soil and excessive use of water is avoided. New soybean varieties having high growth rates and early maturation can compete effectively with weeds, but they also require less water and allow more time and space for the second crop. Improved soil and water management can increase a farmer's income significantly by increasing the productivity of his irrigable land and his returns from a second field crop.

Table 8. Effect of Weed Control on Soybean Yield.

	1972		1973		Average
	Mae Jo	Kalasin	Phra Phuttabat	Maha Sarakham	
	.....	.....	*kg rai*$^{-1}$	.....	.....
Control	237	149	81	10	139
Hoe twice	490	452	203	156	326

Table 9. Effect of Densities of Two Soybean Varieties on Weed Growth 30 Days after Germination.

Soybean Variety	Density	Soybean Height	Ten Plants	Weeds
	plants m^{-2}	*cm*	*g cm*$^{-1}$	*g*
S.J.4	43	22.9	2.5	147.0
	79	36.0	1.1	154.7
	116	37.0	1.9	64.2
Average	79.3	31.9	1.8	121.9
O.C.B.	52	34.8	3.5	66.4
	98	36.3	2.6	8.8
Average	75	35.5	3.0	37.6

Table 10. Effect of Plant Population on Soybean Yield.

Province	Plants m^{-2}			
	16	32	64	96
	.....	*kg rai*$^{-1}$	.....	
Chinat (2 yrs. ave.)	126	211	276	303
Chiang Mai (4 yrs. ave.)	304	336	353	333
Average	215	273	314	316

Section IV
Soil and Water Management

Conservation Production Systems for Dryland Agriculture in the United States

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ABSTRACT. Much progress has been made in developing dryland conservation production systems that reduce erosion and increase water use efficiency of crop production in the United States. These technologies can be utilized on many kinds of soils in climatic regions ranging from semiarid to humid. Reduced tillage with emphasis on surface crop residue maintenance offers the best alternative to keep erosion within tolerable limits and maintain crop yields. Some researchable problems remain to adapt reduced tillage or no-tillage to situations such as poorly drained clay soils and regions with persistent perennial weed problems. These researchable problems include:

1) Fertilizer placement techniques: equipment, timing and amounts with reduced tillage or no-tillage systems with varying levels of surface crop residue.

2) Seeding equipment that can accurately place seed under crop residue mulches to improve stand establishment.

3) Improved economical weed control technology with conservation tillage including new herbicide formulations for persistent weeds, application methods and equipment.

Many runoff water management schemes have been researched. Furrow diking and conservation bench terraces conserve water for crop production in semiarid regions. Graded furrows and wide beds conduct excess storm runoff water from fields without excessive erosion in subhumid and humid regions. The potential of storing runoff water in small impoundments for later supplemental irrigation of crops during critical growth stages has also been evaluated in a number of regions.

Simulation models that are site-specific for prevailing soils, climate, crops and economic conditions are now needed to assist in management strategies from the farm level to the international level. Thus, the model(s) developed should be flexible enough to simulate management strategies employed by both large-scale and small-scale producers in temperate and tropical agricultural systems. They should be capable of predicting the long-term consequences of alternative agricultural systems under a wide array of environmental conditions. The model(s) would aid in optimizing on-site farm management decisions as well as contribute to a data base to improve policy decisions for the benefit of agriculture in both developed and less developed countries.

Dryland Crop Production Region

The major dry farming regions in North America lie west of the 96° meridian. Cannell and Dregne (1983) have described the climate, natural vegetation and soils of these regions (Figures 1, 2, 3 and 4). The western Corn Belt has climate and soil characteristics, and conservation production systems similar to the eastern Great Plains.

Conservation Production Systems

Terraces

Water conservation is essential to sustainable agricultural production in the subhumid and semiarid regions. Terracing is the major structural practice used to control runoff, particularly in the Southern Great Plains. In humid regions, it is used primarily for erosion control. Terraces, in general, are of the broad base type with some modifications. In humid regions, they have graded channels in order to move runoff water from fields to grassed waterways without erosion. In semiarid areas, terraces are level with ends usually closed to hold all the runoff on the field for crop use.

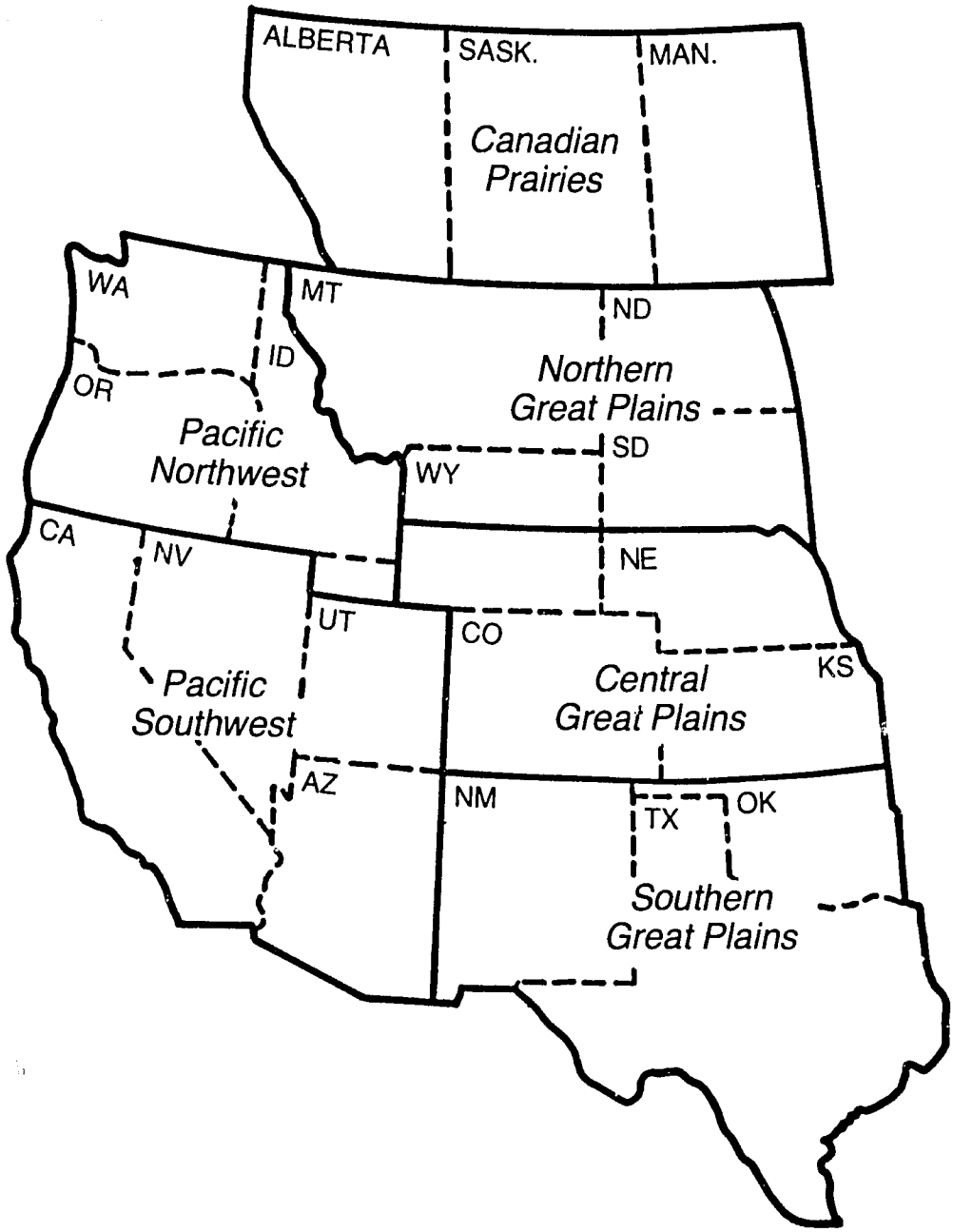

Figure 1. Dryland Agriculture Regions, USA and Canada (Cannell and Dregne, 1983).

There are a number of terrace systems that have been developed for special purposes. One of the most popular is the parallel terrace system designed to increase average row length and reduce or eliminate point rows. Large, modern farm equipment now used in the United States is not suited to narrow terrace intervals or point rows. Requirements for parallel terrace systems include relatively flat, uniform slopes and less erodible soils. The cost may be prohibitive if gully shaping or leveling is required to build parallel terraces.

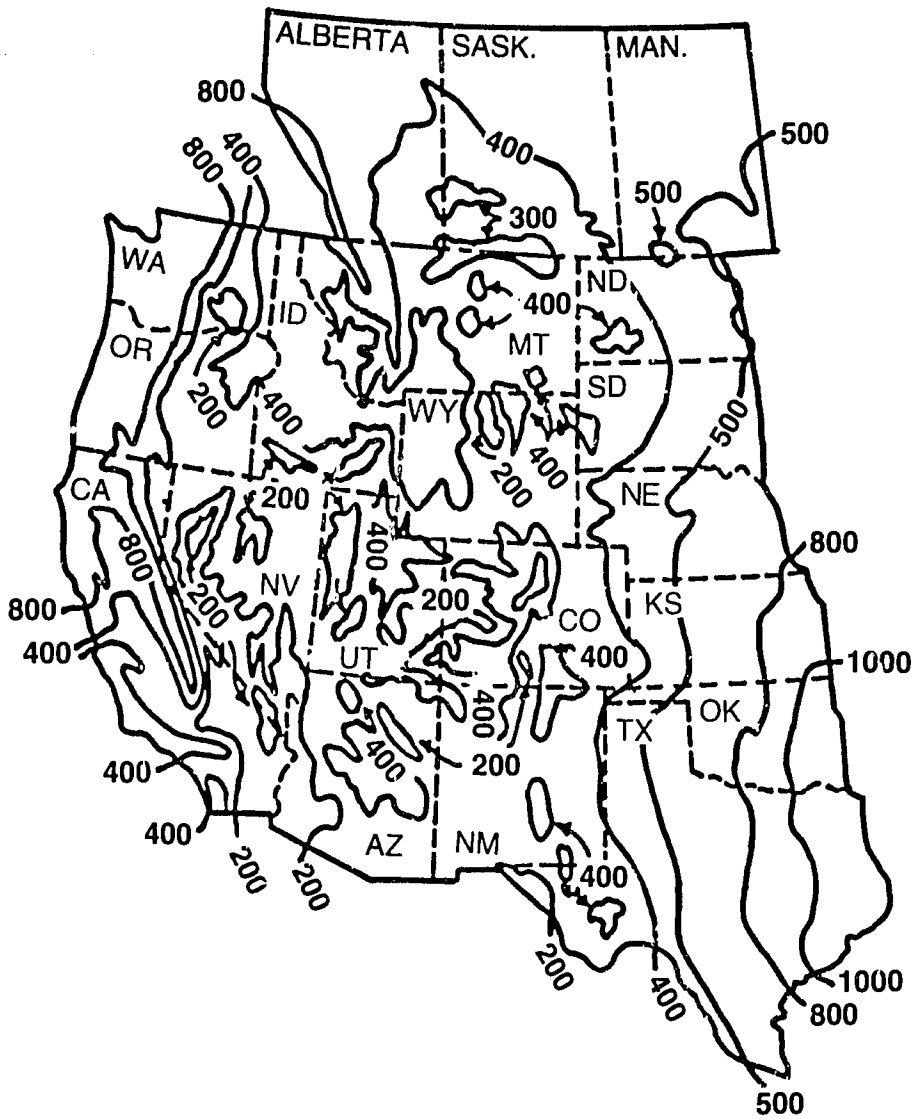

Figure 2. Isohyets for the Western USA and Prairie Provinces of Canada. Precipitation Given in mm (Cannell and Dregne, 1983).

Another specialized terrace system designed to enhance crop water use efficiency in semiarid areas is the bench terrace (sometimes called conservation bench) system (Aingg and Hauser, 1959). This system consists of a level bench with or without a contributing watershed. It has been evaluated at numerous sites throughout the Great Plains with generally positive results except on soils with low water holding capacity (Armbrust and Welch, 1966; Haas and Willis, 1968; Hauser and Cox, 1962; Michelson, 1968). The cost-effectiveness of the system is dependent on earthmoving costs and crop yield increases. Jones and Hauser (1975) showed that total production was highest on level benches without a contributing watershed, but the probability of poor yields was greater due to low water storage in dry years (Figure 5). Jones (1981) reduced construction costs by reducing the width of the conservation benches. Conservation bench systems are not practical in humid regions because the potential crop growing season does not offset the construction costs. In addition, some mechanism for drainage of the benches would be required during heavy precipitation periods.

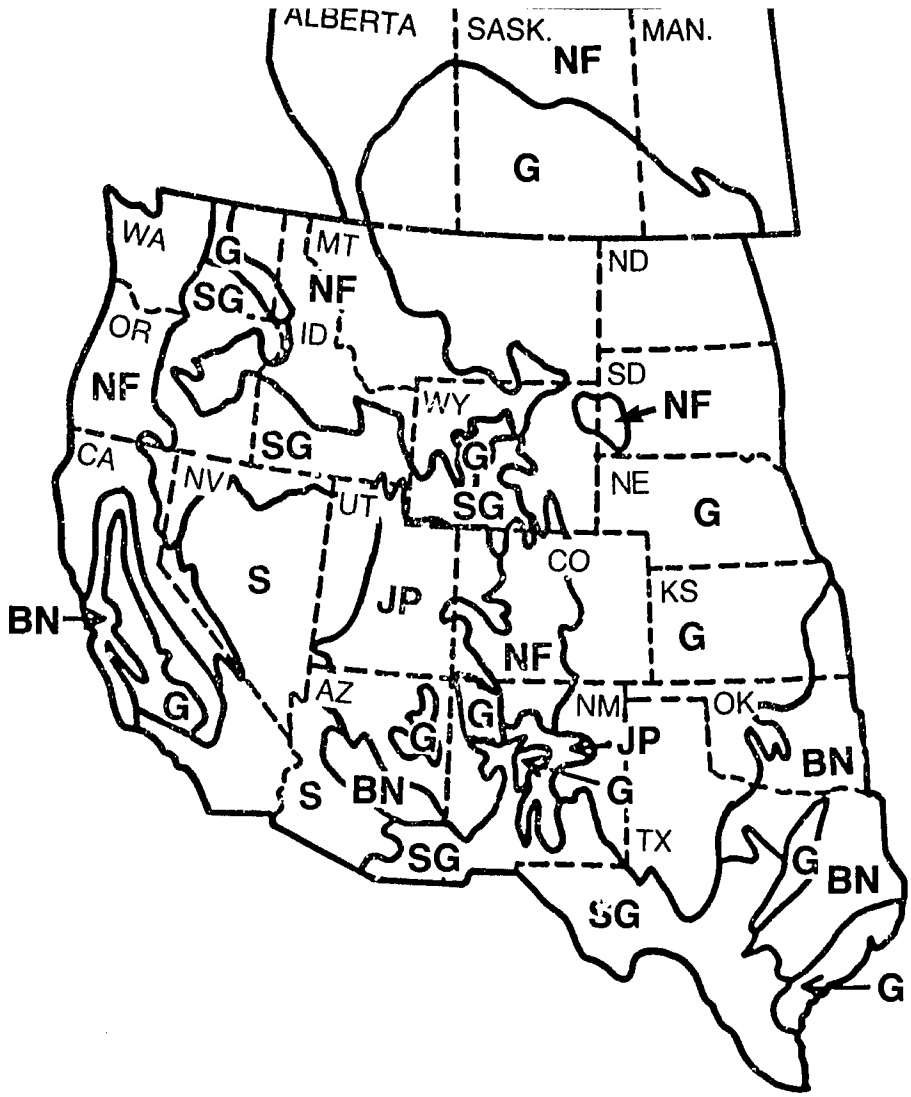

Figure 3. Natural Vegetation of the Western USA and Prairie Provinces of Canada. G, Grassland; SG, Shrub-Grassland; S, Shrub; JP, Juniper-Pinyon Woodland; BN, Broadleaf-Needleleaf Forest; NF, Needleleaf Forest (Cannell and Dregne, 1983).

Tillage

The tillage implements used for primary tillage vary with crop types, crop sequence, soil erodibility, crop residue amounts and desired disposition of crop residues. The implements include the moldboard plow, chisel plow with or without sweeps, tandem and one-way disk plows, and lister (double moldboard) plow. In the humid and subhumid regions, the tillage sequence for row crops (cotton, grain, sorghum and maize) has been early fall listing or bedding (double moldboard) and relisting in late winter or early spring with planting accomplished with a bedder planter. In recent times the chisel plow or tandem disk has largely replaced the lister plow for primary tillage and seedbed preparation, probably at the expense of increased erosion. Producers now use unit planters with double-disk openers on flat seedbeds in preference to the lister planter. Secondary tillage for weed

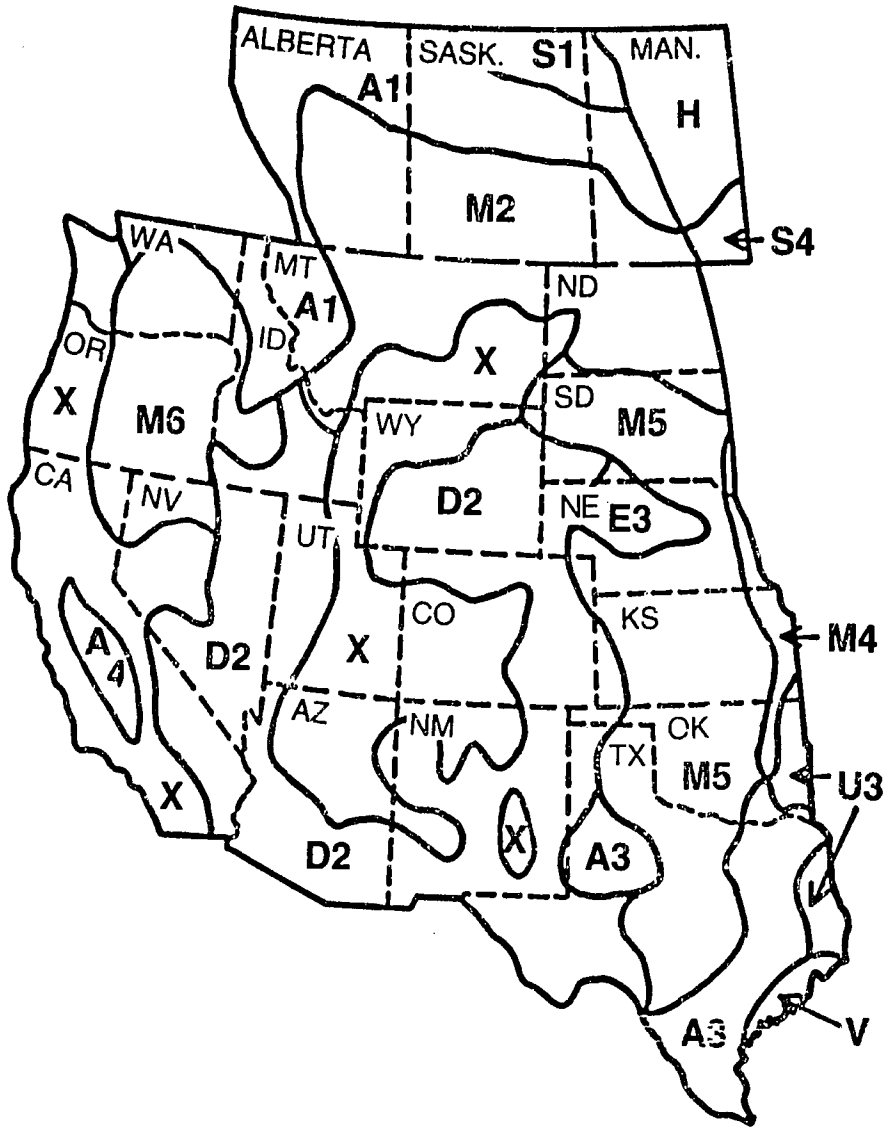

Figure 4. Suborders of Soils in the Western USA and Prairie Provinces of Canada. A1, Boralfs; A3, Ustalfs; D2, Argids; E3, Psamments; H, Histosols; M2, Borolls; M4, Udolls; M5, Ustolls; M6, Xerolls; S1, Spodosols (varied); S4, Orthods; U3, Udults; V, Vertisols; X, Mountain Soils (Cannell and Dregne, 1983).

control is done with conventional sweep cultivators. The primary tillage sequence for winter small grains (cereals) in the humid and subhumid regions historically was summer moldboarding followed by early fall disking for seedbed preparation. Chisel plows with sweeps have largely replaced the moldboard plow. Cereals are planted in the fall with a conventional single disk opener drill with drill rows spaced about 15 to 25 cm apart.

In the semiarid region the lister plow is used for fall plowing of row crops (cotton and grain sorghum). The beds formed by the lister plow may be undercut with a blade (knifing) or rod weeder if weeds are a problem prior to planting. Row crops are planted by splitting the beds and planting in the furrow to enhance seed contact with moist soil.

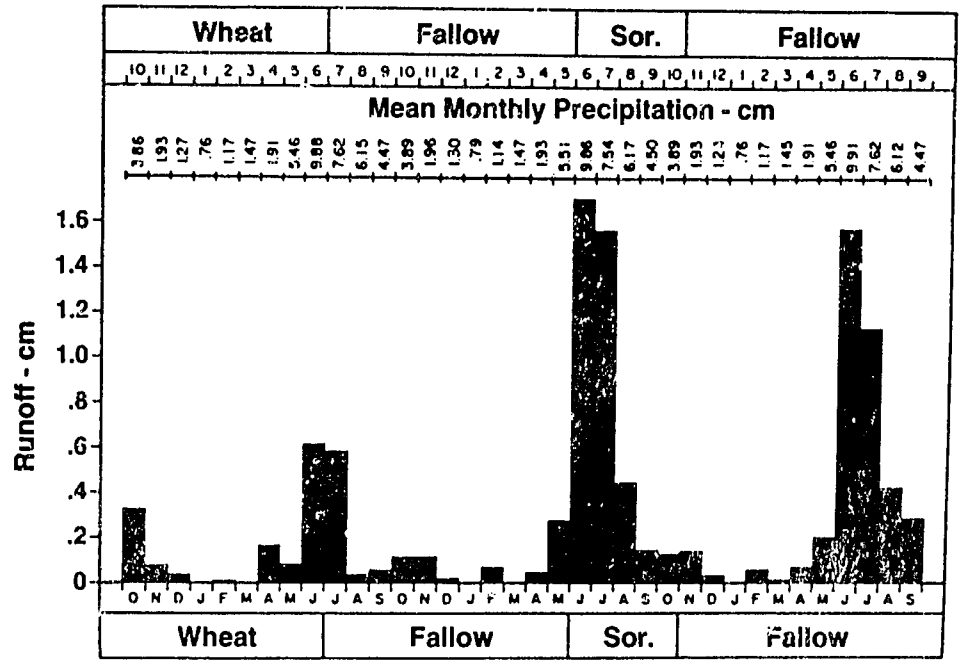

Figure 5. Fourteen-Year (1959-1972) Mean Monthly Precipitation and Runoff for a Field Cropped in a Three-Year Wheat-Sorghum-Fallow Sequence (Jones and Hauser, 1975).

Chisel plows and tandem or offset-disk plows have replaced the one-way disk plow for primary tillage for cereal grains in the semiarid Southern Great Plains. Drills with various kinds of openers including shovels, hoes and disks are used for seeding cereal grains at drill spacings of 18 to 35 cm.

Stubble mulch tillage is a practice designed to leave stubble or crop residues in place on the soil surface before and during the preparation of a seedbed. The practice conserves soil water and reduces wind erosion in semiarid regions that are primarily cropped to wheat and grain sorghum. Implements designed to leave all or part of the crop residue on the surface range from chisel plows to wide V-blade sweeps (50 to 200 cm). The sweeps undercut the stubble at a depth of 10 to 15 cm. Following the first sweep operation, additional tillage operations for weed control are done with sweep plows, field cultivators, or rod weeders. Both small grains and grain sorghum can be planted with disk opener drills. A coulter may be needed in front of the disks to cut residues.

Stubble mulch tillage is effective in conserving water and increasing crop production in the semiarid Southern Great Plains (Table 1) (Johnson and Davis, 1972). The practice of stubble mulch tillage is used more in the Central Great Plains than in either the Northern or Southern Great Plains (Black, 1973; Johnson *et al.*, 1983).

Fallow

The practice of fallow for water conservation in United States dryland agriculture is almost as old as dryland agriculture itself. Early farmers turned to fallow to increase water storage because of limited and erratic precipitation. Alternate crop- (usually wheat) fallow is used in much of the semiarid regions particularly in the Northern and Central Great

Table 1. Effect of Cropping System and Tillage Method for Winter Wheat on Soil Water Content at Planting, Water Storage Efficiency and Grain Yield (Johnson and Davis, 1972).

Cropping System and Tillage Method	Available Soil Water at Planting†	Water Storage Efficiency‡	Grain Yield
	cm	%	*kg ha⁻¹*
Continuous wheat			
One-way	9.1	20	585
Stubble mulch	10.3	22	685
Wheat-fallow			
One-way	12.8	10	927
Stubble mulch	15.4	15	1060
Delayed stubble mulch	14.4	13	1040

† Average for 1942 to 1969, determined to a 1.8 m depth.
‡ Average for 1958 to 1969.

Plains. A three-year sequence of winter crop (wheat)-summer crop (grain sorghum)-fallow is used more in the Southern Great Plains to take advantage of storm runoff (Figure 5). Fallow is used less frequently in subhumid regions. Water storage efficiency of fallow in different crop- fallow sequences is related to the time interval between crops and is generally low, but crop yield is improved (Table 2) (Unger, 1972). Willis (1982) has summarized the effect of fallow on spring and winter wheat yields throughout USA dryland agricultural regions (Table 3). Water use efficiency is higher in the cooler Northern Great Plains than in the Southern Great Plains.

Mulches

The use of mulches to conserve water and to reduce soil erosion is an age-old practice. Many materials such as stones, gravel, plastic film, asphalt emulsions, paper and plant residues have been used as mulches. Porous mulches may reduce raindrop impact, thereby increasing water infiltration. They may also reduce soil water evaporation by cooling the soil by insulation, reflecting solar energy and decreasing wind speed near the soil surface (Figure 6) (Willis, 1982). Artificial mulches are now seldom used in the United States because application is so labor-intensive. There is some use of plastic mulches for high-value crops where application can be automated. Crop residues are the only practical source of mulching material with large-scale mechanized agriculture in the United States.

Water storage efficiency with crop residue mulches in the semiarid Great Plains is low because of the limited amounts of residue produced under dryland farming (Unger, 1983; Wiese *et al.*, 1967). Unger (1978) discussed the effect of increasing rates of wheat straw mulch on water storage efficiency and grain sorghum yield on a clay loam soil in the Southern Great Plains (Table 4). Water storage efficiency and grain yield increased with increased mulch rates. Greb (1983) reported net soil water gain at four Great Plains locations at the end of the fallow period with increasing rates of straw mulch (Table 5). Storage efficiency is usually lower in the southern part of the region. Adams (1966) showed that, under subhumid conditions, straw mulches decreased soil water evaporation,

Table 2. Effect of Cropping Systems for Winter Wheat and Grain Sorghum on Soil Water Content at Planting, Water Storage Efficiency and Grain Yield (Unger, 1972).

Cropping System	Available Soil Water at Planting†	Water Storage Efficiency	Grain Yield
	cm	%	*kg ha⁻¹*
Continuous wheat	5.8	14.8	700
Wheat-fallow	9.3	8.3	970
Wheat-sorghum-fallow			
Wheat	8.6	13.9	850
Grain sorghum	9.4	14.0	1740
Continuous sorghum	7.6	20.1	1270

† Determined to a 1.2 m depth.

storm runoff and erosion, and increased crop yield on a clay soil in the subhumid part of the Southern Great Plains. Similar results have been reported under humid conditions in many parts of the world (Jacks *et al.*, 1955).

Row Spacing

In the semiarid portions of the United States dryland region, yields of grain sorghum are higher with a 1 m spacing between rows compared to narrower spacings (Bond *et al.*, 1964; Brown and Shrader, 1959; Greb, 1962). The increased yields are attributed to increased competition between plants within the row which reduced forage production but increased grain yield and water use efficiency for grain production. The wider rows provide stored soil water for crop use as the growing season progresses. Grain sorghum responds favorably to narrow-row spacing in subhumid parts of the Southern Great Plains. Adams *et al.* (1976, 1978) found that grain sorghum in 50 cm rows establishes a more complete canopy earlier than sorghum with conventional (1 m) row spacing. The improved plant canopy intercepted 12 percent more radiant energy and resulted in increases in grain yield averaging 20 percent (Table 6). The earlier and more complete ground cover also reduced runoff and erosion (Table 7). These results have led to the development of wide-bed narrow row systems which capitalize on the potential of crop yield increases and provide needed surface drainage for storm runoff when rainfall exceeds infiltration rate (Figure 7) (Arkin *et al.*, 1978; Morrison and Gerik, 1983).

Cotton is a major crop in the semiarid and subhumid parts of the Southern Great Plains. The crop is usually planted in 1 m rows but in areas with annual rainfall in excess of about 60 cm, yield increases with narrower row spacings (25 to 50 cm) can be obtained. As pointed out by Jones and Johnson (1983), in areas with less than 56 cm annual rainfall most dryland cotton is planted in skip-row systems even though yields are usually somewhat higher when every crop row is planted (Table 8). Common systems are: (1) two rows planted and two rows skipped; (2) two rows planted and one row skipped; and (3) four rows planted and two rows skipped. Since cotton lint yields are not significantly reduced, skip-row planting systems offer opportunities to control wind erosion by planting high-residue crops in the skipped row (Burnett, 1968; Fryrear, 1976).

Table 3. Average Values of Annual Precipitation, Grain Yields of Nonfertilized Spring or Winter Wheat, and Water Use Efficiency for Annually Cropped and Alternate Wheat-Fallow Over Five Selected Semiarid Regions in the Western USA (Willis, 1982).

Region	Years of Crop Record	Type of Wheat	Annual Precipitation†	Yield		Water Use Efficiency	
				Fallow	Annual	Fallow	Annual
			mm	....*kg ha*$^{-1}$....		*kg ha*$^{-1}$ *mm*$^{-1}$	
Northern Great Plains	359	Spring	394	1430	962	1.81	2.44
Central Great Plains	165	Winter	462	1630	653	1.76	1.41
Northwest	76	Winter	368	2400	---	3.26	---
	60	Winter	421	---	1010	---	2.40
Northwest	70	Spring	349	1960	895	2.81	2.56
Southern Great Plains	28	Winter	500	1010	646	1.01	1.29
Southwest	4	Spring (fall planted)	417	2380	767	2.85	1.84

† Harvest to harvest for annually cropped wheat.
‡ Water use efficiency is the weight of marketable grain per unit area divided by the total precipitation from harvest to harvest. Thus, precipitation for two years is used for wheat-fallow, and precipitation for one year is used for annual wheat. This definition does not imply that all water received is transpired.

Wheat and other small grains are not sensitive to row (drill) spacing because of their tillering ability. However, in the drier parts of the dryland agriculture region, wide drill spacings are used. The range in drill spacing from the subhumid to the semiarid region is 10 to 35 cm with averages of 18 cm and 25 cm in the subhumid and semiarid areas, respectively.

Weed Control

Weeds compete aggressively with crop plants for stored soil water. Therefore, weed control is the single most important water conservation practice for dryland agriculture. The vigorous root systems of weeds are often more extensive than the root systems of planted crops (Davis *et al.*, 1965; Davis et al., 1967) and may use soil water at rates of 0.5 cm/day (Wicks and Smika, 1973). Dry matter production of 1000 kg/ha by weeds uses 8 to 10 cm/ha of water (Greb, 1974). Timeliness of weed control affects water storage and crop yield. Delaying weed control until 17 or 24 days after weed emergence decreased soil water storage and yield of grain sorghum and wheat (Table 9) (Lavake and Wiese, 1979).

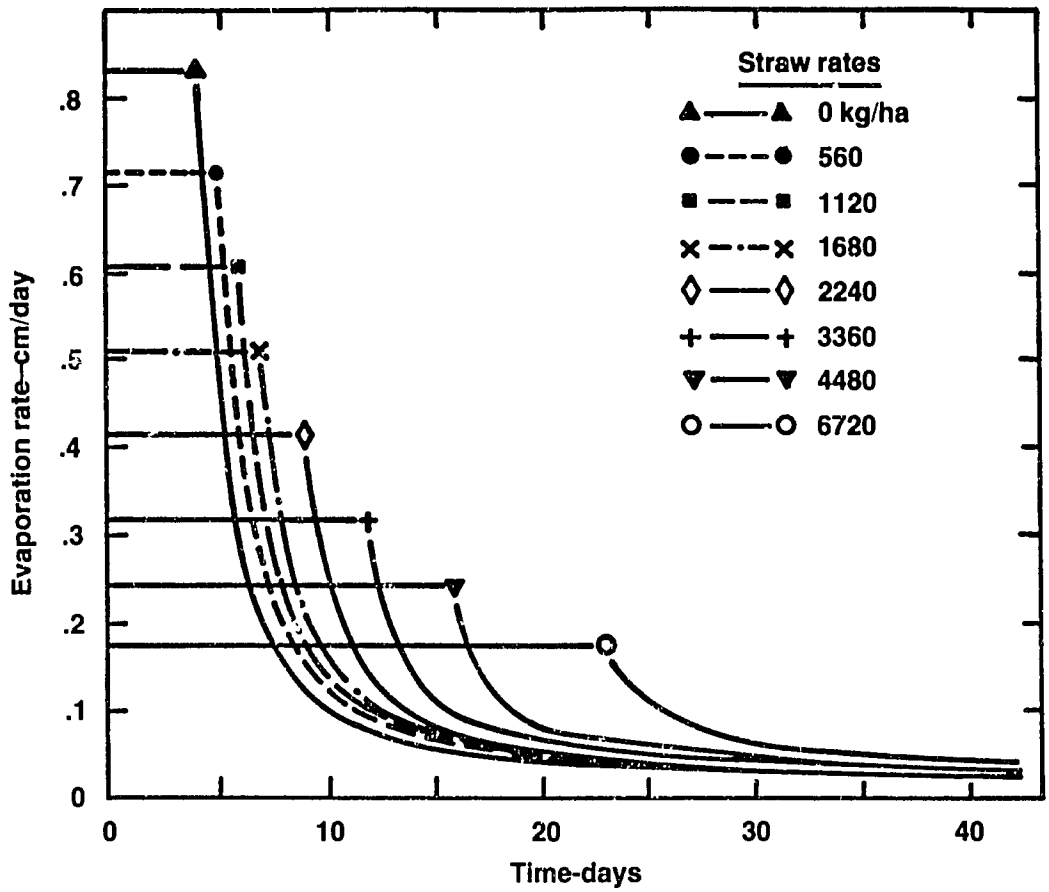

Figure 6. Soil Water Evaporation Rate with Time as Affected by Rates of Surface Residue (Band and Willis, 1969).

In recent years, herbicides have replaced tillage to a considerable degree for weed control in both continuous cropping and crop-fallow systems. The practice of chemical fallow has resulted in doubling of soil water storage compared with conventional bare fallow (Greb, 1983). However, chemical fallow did not increase soil water storage in the Pacific Northwest dryland region (Ramig *et al.*, 1983).

Soil Fertility

Nearly all USA dryland agriculture regions were in shortgrass or tallgrass prairie when first put into cultivation. Thus, there was a reserve of soil organic matter to supply nitrogen to wheat and sorghum, the principal crops for many years. This reserve supply of nitrogen was used fairly quickly because few legumes were grown and fallow was systematically included in crop rotations. Tillage for weed control during the fallow period accelerated the decomposition of soil organic matter. As a result, nitrogen is now applied to maximize crop yields in the dryland agriculture regions. Haas and Evans (1957) reported a decline in soil organic matter with cropping throughout the Great Plains. This decline was more rapid in the southern region than in the northern region because of higher temperatures. Fallow and row crop farming in the Southern Great Plains accelerated organic matter decline.

Table 4. Straw Mulch Effects on Water Storage Efficiency and Grain Sorghum Yield (Unger, 1978).

Mulch Rate	Water Storage Efficiency†	Grain Yield
t ha⁻¹	%	*kg ha⁻¹*
0	22.6c‡	1780c
1	31.1b	2410b
2	31.4b	2600b
4	36.5b	2980b
8	43.7a	3680a
12	46.2a	3990a

† Water storage determined to a 1.8 m depth. Precipitation averaged 318 mm.
‡ Column values followed by the same letter are not significantly different at the 5% probability level (Duncan's Multiple Range Test).

Table 5. Net Soil Water Gain at the End of Fallow as Influenced by Straw Mulch Rates at Four Great Plains Locations (Greb, 1983).

Location	Years Reported	Straw Mulch Rate (t ha⁻¹)			
		0	2.2	4.4	6.6
		.....	*cm*	.....	
Bushland, Texas	3	7.1	9.9	9.9	10.7
Akron, Colorado	6	13.4	15.0	16.5	18.5
North Platte, Nebraska	7	16.5	19.3	21.6	23.4
Sidney, Montana	4	5.3	6.9	9.4	10.2
Average		10.7	12.7	14.5	15.7
Gain by mulching			2.0	3.8	5.0

Table 6. Effect of Row Spacing on Grain Sorghum Yields on Houston Black Clay Soil at Temple, Tex., 1972-74 (Adams *et al.*, 1976).

Year	Row Spacing (cm)	
	50	100
	..... *kg ha*$^{-1}$	
1972	3890 (25%)†	3120
1973	3890 (20%)	3200
1974	5050 (18%)	4280

† The values in parentheses are the percent increase in grain yield over grain sorghum with 100 cm conventional row spacing.

Soils in dryland regions vary greatly in phosphorous and potassium. In the Northern Great Plains, the soils are generally low in P and high in K (Bauer *et al.*, 1966). Soils in the Southern Great Plains are very low to medium in P and medium to high in K. Erosion in the Pacific Northwest has resulted in both P and K deficiencies. In all regions crop response to added fertilizer is intimately associated with the quantity of water available to the crop. When the supply of water from either stored soil water or from rainfall is adequate, positive crop yield responses to N and/or P are obtained (see Table 10). Similar responses to N and/or P by various crops are reported from other regions (Brengle and Greb, 1963; Kissel *et al.*, 1975; Young, 1962).

Furrow Diking

Furrow diking, also called basin listing and furrow blocking, was introduced to the Southern Great Plains in the 1930s. It was used primarily during the fallow period after wheat. The practice did not become popular because of problems associated with seedbed preparation, weed control, planting and low yield response. Reintroduced in the 1970s by Clark and Hudspeth (1976) with improved equipment and chemical weed control technology, the practice has received enthusiastic acceptance for cotton and grain sorghum production in the semiarid Southern Great Plains (Figure 8). Jones and Johnson (1983) report that 0.405 Mha were furrow-diked in 1980. Furrow dikes are installed at planting time or soon after. This coincides with the time when there is the greatest probability of runoff occurrence.

Table 7. Effect of Row Spacing of Grain Sorghum on Runoff and Soil Loss from Houston Black Clay Soil in 1973 (Adams *et al.*, 1978).

Date	Days After Emergence	Rainfall	Runoff		Soil Loss	
			Row Spacing			
			50 cm	100 cm	50 cm	100 cm
		..... *cm*			.... *t ha*$^{-1}$....	
Before full development of plant canopy (ground cover)						
10 Mar.	-9	2.5	0.1	0.1	0.1	T†
24 Mar.	5	4.2	0.5	0.4	0.6	0.4
2 Apr.	14	1.5	0.3	0.3	0.3	0.4
15 Apr.	27	1.4	T‡	T‡	T†	T†
5-6 May	47-48	6.5	0.9	0.7	1.4*	0.8
Total		16.1	1.8	1.5	2.4	1.6
After development of plant canopy (ground cover)						
1-3 June	74-67	7.2	0.6	2.8*	1.8	5.0*
5 June	78	2.9	0.9	1.4*	1.0	1.8
15 July	118	3.0	0.1	0.5	T†	T†
Total		13.1	1.6	4.7	2.8	6.8
Annual Total		29.2	3.4	6.2	5.2	8.4

† T, trace; 0.05 t ha^{-1} soil loss.
‡ T, trace; 0.01 cm runoff.
* Difference between means for each date significant at 5% probability level according to t-test of paired means.

Cotton lint yield increases of 15 percent due to furrow diking were reported by Bilbro and Hudspeth (1977) and grain sorghum yield increases of 16 percent were reported by Clark and Jones (1981). Furrow diking should be useful to improve row crop production in regions where the soil profile is below field capacity at planting time and there is a high probability of rainfall exceeding infiltration capacity during the crop growing season.

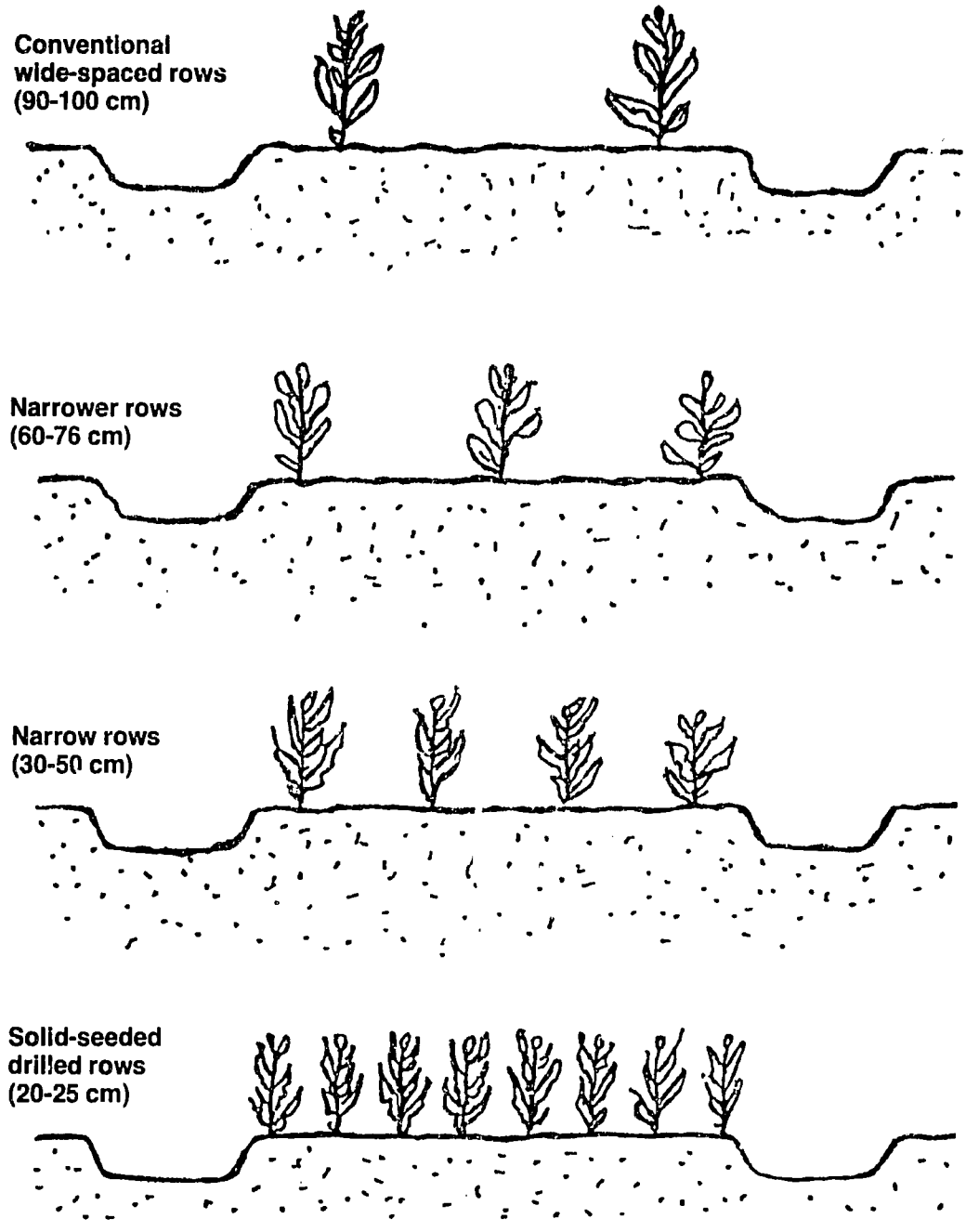

Figure 7. Wide-Bed Narrow-Row Spacing Configurations (Morrison and Gerik, 1983).

Vegetative Barriers

Field windbreak planting of trees and shrubs has long been used in the more humid parts of the Great Plains for wind erosion control and snow management (Frank and George, 1975). More recently, tall grass and other crop barriers have been introduced to achieve both wind erosion control and water conservation by snow trapping and wind reduction (Black and Siddoway, 1971; Greb, 1983; Radke, 1976). Snowmelt storage efficiency averaged 65 percent with tall grass barriers spaced 10 m apart under Central Great Plains conditions (Greb, 1978).

Table 8. Average Cotton Lint Yield for Total Area, Including Skip-Row. Cotton was Seeded in Rows 1 m Apart (Jones and Johnson, 1983).

Cropping System	Chillicothe, Tex. (Mulkey, 1968) 1965-1967	Lubbock, Tex. (Newman, 1967) 1963-1965	Big Sprint, Tex. (Burnett & Welch, 1966) 1958-1962	Spur, Tex. (Marion) 1930-1943
	..... *kg ha⁻¹*			
All rows planted	268	196	289	299
Skip-row				
1 in-1 out	---	---	292	281
2 in-1 out	291	165	284	285
2 in-2 out	280	178	261	---
4 in-4 out	291	---	226	---

Table 9. Effect of Tillage Frequency and Timing During 11-Month Fallow on Average Number of Tillage Operations, Soil Water and Grain Yields in a Wheat-Sorghum-Fallow System (Lavake and Wiese, 1979).

Tillage Treatment	For Wheat Crop			For Sorghum Crop		
	Tillage Operations	Soil Water at Planting†	Grain Yield	Tillage Operations	Soil Water at Planting	Grain Yield
		cm	*kg ha⁻¹*		*cm*	*kg ha⁻¹*
Every 2 weeks	10.3	11.8a‡	567ab	10.6	9.0a	2410ab
Days after weed emergence						
4	5.3	11.4a	629a	6.1	9.0a	2600a
10	4.3	10.7ab	583ab	5.1	8.9a	2530a
17	3.6	9.7b	564ab	4.0	8.4a	2100bc
24	2.7	9.1b	500b	4.0	7.9a	1900c

† Plant available water determined to a 1.2 m depth.
‡ Values within a column followed by the same letter are not significantly different at the 5% probability level (Duncan's Multiple Range Test).

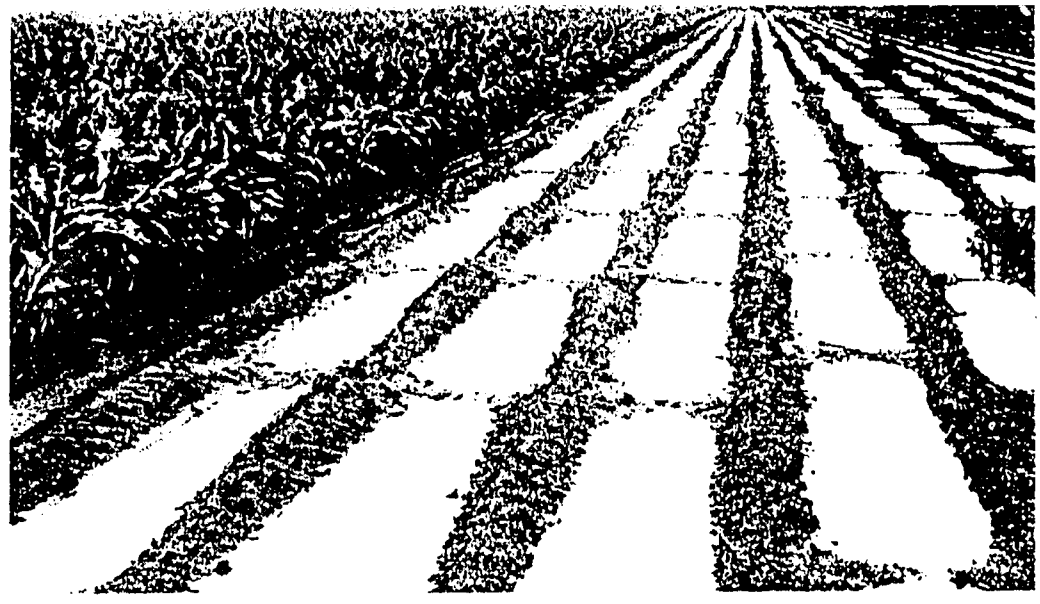

Figure 8. Runoff Conservation with Furrow Dams (Jones and Johnson, 1983).

Crop Rotations

Cropping systems that employ different crops enhance control of insects, weeds, diseases and erosion. In dryland agriculture, fallow is frequently included as part of the cropping sequence because of the role it can play in stabilizing crop production and in weed control. Crops useful for crop rotations in semiarid and subhumid dryland agriculture are limited in number compared to humid regions. Wheat is the principal crop grown in the dryland regions of North America (Table 11) (Smika, 1983). Winter (rather than spring) wheat predominates in all regions except the Northern Great Plains and Canada. The predominant sequence in semiarid regions is wheat-fallow with wheat-sorghum-fallow being important in areas where sorghum can be grown.

Multiple Cropping

This practice is not used in semiarid dryland regions and only on occasion in the subhumid regions of the United States. However, it is becoming increasingly important in irrigated areas and in humid regions in order to maximize resources. In addition to obtaining maximum total crop yields with the available water, multiple cropping can contribute to improved soil erosion control. In Mississippi, Hairston *et al.* (1984) compared monocrop and double crop production systems for runoff and erosion, crop yield and net returns (Table 12). Even though double crop soybean yields were lower, net returns from double cropping were much higher than in monocrop systems because of the added income from the wheat in the double crop system. The double crop system also reduced runoff and erosion significantly.

Table 10. Effect of Amount of Stored Soil Water and Growing Season Rainfall on Spring Wheat Yields and Yield Responses to P Fertilizer in Fallowed Soils of a "Very Low" P Test Level in North Dakota (Snider *et al.*, 1968).

Stored Water†	Rainfall‡	Number of Trials	Yield of Check	Yield Response to Added P (kg P ha^{-1})§			
				7	22	17	22
	cm		..... *kg ha^{-1}*				
Less than 5	Less than 15	1	280	50	70	110	140
	15 to 20	2	1140	280	280	290	300
	More than 20	2	1130	350	470	340	380
		5	960	260	330	270	300
5 to 10	Less than 15	5	1270	120	190	210	210
	15 to 20	3	1940	390	400	420	400
	More than 20	3	1860	540	790	840	840
		11	1610	310	410	440	440
More than 10	Less than 15	5	1610	340	430	500	550
	15 to 20	8	2220	440	550	620	660
	More than 20	4	2110	560	790	830	810
		17	1940	440	570	630	670

† To 120 cm depth or dry zone above 120 cm.
‡ From seeding to 5 days before harvest. Less than 15 cm is below average rainfall during the spring wheat growing season, 15 to 20 cm from slightly below to average; more than 20 cm from average to above average.
§ Phosphorus (0-46-0) was applied by drill with the seed.

Research and Technological Development Needs

Much progress has been made in developing dryland conservation production systems that reduce erosion and increase water use efficiency of crop production in the United States. These technologies can be utilized on many kinds of soils in climatic regions ranging from semiarid to humid. Reduced tillage with emphasis on surface crop residue maintenance offers the best alternative to keep erosion within tolerable limits and maintain crop yields. Some researchable problems remain, such as how to adapt reduced tillage or no-tillage to poorly drained clay soils and regions with persistent perennial weed problems. These researchable problems include:

1) Fertilizer placement techniques, equipment, timing and amounts to be used with reduced tillage or no-tillage systems with varying levels of surface crop residue.

2) Seeding equipment that can accurately place seed under crop residue mulches to improve stand establishment.

3) Improved economical weed control technology with conservation tillage, including new herbicide formulations for persistent weeds, and application methods and equipment.

Research on runoff water management schemes fully demonstrates the value of systems such as furrow diking and conservation bench terraces in conserving water for crop production in semiarid regions. It has also been shown that graded furrows and wide beds conduct excess storm runoff water from fields without excessive erosion in subhumid and humid regions. The potential of storing runoff water in small impoundments for later supplemental irrigation of crops during critical growth stages has also been evaluated in a number of regions.

Table 11. Hectares of Fallow and Major Crops Produced on Dryland in Each Geographic Area, 1977 Statistics (Smika, 1983).

Geographical Area	Total Fallow	Crop								
		Wheat	Corn	Rye	Barley	Oat	Sorghum	Cotton	Special Crops†	Oilseed‡
	ha x 10^3									
Southern Great Plains	1640	5860	—	—	—	—	2240	2920	—	0.2
Central Great Plains	5080	7960	120	76	217	190	2580	—	65	—
Northern Great Plains	5680	7610	1480	—	2010	2070	137	—	—	506
Canadian Prairie Provinces	7080	10100	730	242	4650	2130	—	—	—	1420
Pacific Northwest	1730	2390	—	—	686	122	—	—	71	—
Pacific Southwest	280	437	—	—	494	165	—	—	—	—
Total for All Areas	21500	34400	2330	318	8050	4680	4960	2920	1140	1930

† The special crop in the Central Great Plains is millet, in the Pacific Northwest pea.
‡ Oilseed crops in the Southern Great Plains are sunflower and guar, in the Northern Great Plains safflower and flax, and in the Canadian Provinces rapeseed and mustard.

Table 12. Soybean Yields, Runoff, Soil Loss and Net Returns Above Total Direct and Fixed Costs for Five Tillage Systems in the Mississippi Blackland Prairie (Adapted from Hairston *et al.*, 1984).

Tillage System	Soybean Yield 2-Year Average	Annual Runoff	Annual Soil Loss	Net Returns 2-Year Average
	kg ha⁻¹	*cm*	*t ha⁻¹*	*$ ha⁻¹*
Monocrop				
Fall chisel + spring chisel, prepare seedbed, plant, cultivate (CON+)	1810a†	21.0	12.3	105.18
Spring chisel only, prepare seedbed, plant, cultivate (CON)	1780a	19.4	7.80	131.75
Stubble-plant with no seedbed prepared, cultivate (MIN)	1340b	14.6	6.72	51.28
Stubble-plant with no seedbed prepared, no cultivation (ZERO)	1250b	21.1	6.53	59.48
Double crop				
Overseed or stubble-plant wheat, burn straw, no-till plant soybeans, cultivate (DUO)	(2980)‡ 1040c	11.5	2.48	315.02

† Means in a column followed by the same letter are not significantly different at P = 0.05, Duncan's New Multiple Range Test.

‡ Values in parentheses are double crop wheat yields (at 13.5% moisture).

Simulation models that are site-specific for prevailing soils, climate, crops and economic conditions are now needed to assist in management strategies from the farm level to the international level. Thus the model(s) developed should be flexible enough to simulate management strategies employed by both large-scale and small-scale producers in both temperate and tropical agricultural systems. They should be capable of predicting the long-term consequences of alternative agricultural systems under a wide array of environmental conditions. The model(s) would aid in optimizing on-site farm management decisions as well as in contributing to a data base to improve policy decisions for the benefit of agriculture in both developed and less developed countries.

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Strategies for Increasing Soil Productivity in Developing Countries

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ABSTRACT. The Green Revolution which had such an impact in Southeast and South Central Asia several decades ago demonstrated that high yields of improved cereal varieties, particularly wheat and rice, could be obtained with large inputs of chemical fertilizers, pesticides and irrigation. As a result, organic recycling practices which farmers had always depended on to supply plant nutrients and to maintain soil productivity, were largely replaced with chemical fertilizers. The lack of regular inputs of animal manures and crop residues to agricultural soils has, in many cases, led to serious soil erosion, a decline in soil productivity and reduced crop yields. This paper presents some perspectives and strategies for enhancing the use and benefits of organic wastes and residues in developing countries.

Introduction

Most developing countries have traditionally utilized various kinds of organic materials such as animal manures, crop residues, green manures and composts to maintain or improve the productivity, tilth and fertility of their agricultural soils. However, with the advent of the Green Revolution several decades ago, organic recycling practices were largely replaced with chemical fertilizers applied to high-yielding cereal grains that responded best to a high level of fertility and adequate moisture, including irrigation. Soil cultivation was also intensified to improve weed control and seedbed conditions. Consequently, the importance of organic matter in crop production received less emphasis, and its proper use in soil management was neglected or even forgotten. As a result of this, along with failure to implement effective soil conservation practices, the agricultural soils in many developing countries have seriously degraded and declined in productivity because of excessive soil erosion, plant nutrient losses from uncontrolled runoff, and a decrease in stable soil organic matter levels.

Proper management of agricultural and municipal organic wastes on land can protect agricultural soils from wind and water erosion, and prevent nutrient losses through runoff and leaching. Efficient and effective use of these materials as soil conditioners also provides one of the best means we have for maintaining and restoring soil productivity. The beneficial effects of organic wastes on soil physical properties are widely known as indicated by increased water infiltration, water holding capacity, water content, aeration, permeability, soil aggregation and rooting depth, and by decreased soil crusting, bulk density, nutrient runoff and erosion (USDA, 1957).

This paper presents some new perspectives and strategies for efficient and effective use of organic wastes to reduce soil erosion and improve soil productivity and tilth, with emphasis on developing countries.

Surveys of Organic Materials

Most of the developing countries lack reliable information on the types, amounts and availability of different organic wastes that might be used to improve the productivity of their agricultural soils. Such information is essential as a first step for successful planning and implementation of organic recycling programs. One such survey that could serve as a model is a recent report to the U.S. Congress on "the practicability, desirability, and feasibility of collecting, transporting, and placing organic wastes on land to improve soil tilth and fertility" (USDA, 1978). This information was urgently needed because of the steadily increasing costs of energy, fertilizers and pesticides to United States farmers and the problems of soil deterioration and erosion associated with intensive farming systems.

The report contains detailed information on the availability of seven major organic waste materials for use in improving soil tilth and fertility: animal manures, crop residues, sewage sludge, food processing wastes, industrial organic wastes, logging and wood manufacturing wastes, and municipal refuse. Information is reported on the quantity currently generated, present usage, potential value as fertilizers, competitive uses, and problems and constraints affecting their use.

Reintroduction of Organic Fertilizers

Organic fertilizers, including animal manures, crop residues, green manures and composts, were traditionally and preferentially used in developing countries until the 1960s, when chemical fertilizers began to gain in popularity. Chemical fertilizers became easily available and, compared to organic fertilizers, were less bulky and thus easier to transport, handle and store. They were also relatively inexpensive and produced more striking results than organic fertilizers, particularly during the era of the Green Revolution when crop varieties that responded best to heavy application of chemical fertilizers were introduced. Thus, when the world energy crisis began in the early 1970s, chemical fertilizers had virtually replaced organic sources of crop nutrients in developing countries (FAO, 1975). Because of steadily rising energy costs, especially in developing countries, chemical fertilizers have become more expensive and organic fertilizers have now started to regain their lost popularity.

A significant consequence of these events, as Hauck (1978) points out, is that "in many countries that have recently been increasingly dependent upon mineral fertilizers, the technical knowledge of organic waste utilization has been lost. It is thus necessary to reintroduce the established techniques, to improve them, and to develop new practices conforming to modern technology."

The shift away from organic recycling practices also served to emphasize the value of, and need for, organic amendments for the short- and long-term improvement of cultivated soils and maintenance of soil productivity. Without regular additions of adequate amounts of organic materials to soils, there is increased leaching, erosion and gradual deterioration of their physical properties. Moreover, as the soil degrades, there is a concomitant decrease in the crop use efficiency of chemical fertilizers, especially nitrogen.

Environmental pollution by organic wastes has also become an international concern. Thus, proper processing and recycling of organic wastes as resources for agriculture can greatly reduce environmental pollution. Additional benefits include improved public health, conservation of resources and better appearance of both urban and rural communities.

Reintroduction of Best Management Practices

Many farmers in developing countries have shifted toward intensive row cropping for short-term economic gain, and have thus neglected soil and water conservation practices. This has extensively damaged cropland and markedly increased soil erosion, sedimentation, nutrient runoff and enrichment of surface waters. With increasing public concern for environmental pollution and agriculture's contribution to it, there is an urgent need to reintroduce those soil and crop management practices that have been cited as the best management practices for controlling soil erosion and water pollution from croplands (USDA/EPA, 1975; 1976). These include the use of sod-based rotations, contouring, conservation tillage, cover crops, grassed waterways, and possibly others such as divided slope farming. Research and extension programs in both developed and developing countries should demonstrate the cost-benefit relationships of conservation practices. Aspects of multiple cropping systems such as double cropping, sequential cropping and intercropping may also help to control wind and water erosion and effectively recycle nutrients from crop residues (ASA, 1976).

The relationship of soil productivity to soil degradative processes and soil reclamation and conservation practices is summarized in Figure 1. As soil degradative processes proceed and intensify, there is a concomitant decrease in soil productivity. On the other hand, soil conservation and reclamation practices tend to increase soil productivity. In most agricultural soils, both events, i.e., soil degradation and soil reclamation, are occurring simultaneously. The level or status of productivity of an agricultural soil at any point in time is the result or interaction of the degradative processes and conservation/reclamation practices shown in Figure 1. For the most part, the "processes" and "practices" offset one another and the soil productivity status depends on the intensity or severity of degradation and the effectiveness of conservation and reclamation practices.

Composting to Enhance the Usefulness and Acceptability of Organic Wastes

One way to resolve some of the problems associated with various organic wastes, such as odors, human pathogens, and storage and handling constraints, is composting. Composts provide a more stable form of organic matter than the waste or residue material from which they were made. Thus, composts, more than the original raw materials, can greatly improve the physical properties of degraded agricultural soils. Composting is an ancient practice whereby farmers convert organic wastes into resources that provide nutrients to crops and enhance the tilth, fertility and productivity of soils. Through composting, organic wastes are decomposed, nutrients are made available to plants, pathogens are destroyed, and malodors are abated. The historical aspects of composting have been thoroughly discussed in reviews by Gotaas (1956) and Golueke (1972).

Recently, the U.S. Department of Agriculture at Beltsville, Maryland developed the highly successful Beltsville Aerated Rapid Composting (BARC) Method for composting sewage sludges, animal municipal refuse and pit latrine wastes (Wilson *et al.*, 1980). This method has been widely adopted by both large and small municipalities throughout the United States for composting sewage sludge and solid waste. Several developing countries have also adopted this technology. The method is simple and relatively inexpensive yet effective, and allows considerable tradeoff between labor and capital.

Special Management Practices for Proper Utilization of Organic Wastes and Residues

Special management practices may be needed if we are to obtain the full value of organic wastes as soil amendments and as sources of plant nutrients. For example, the value of organic materials as fertilizers is increased if nutrient release through decomposition and mineralization coincides with the crop's nutrient requirement curve. The nutrient release pattern of organic materials can be controlled to some extent by proper timing of application, pretreatment methods such as composting, and by the method of application. For example, certain organic materials may decompose more slowly if left on the soil surface or concentrated in the soil than if thoroughly mixed in the tillage layer (Parr and Papendick, 1978).

There are many problems involved in handling and applying organic wastes to land because their physical characteristics are so variable. Such wastes are almost always bulky, and can range from liquid on one extreme to dry solid material on the other. Existing application technologies are often ineffective and fail to achieve the desired level of erosion control or increased crop production. Methods of application must be simple, inexpensive, energy efficient and effective for nutrient recycling and erosion control.

An example of a particularly effective soil erosion control measure for sloping lands is vertical mulching, a subsoiling operation that incorporates organic materials such as crop residues into a vertical channel 30 to 40 cm deep and some 10 to 12 cm wide at the soil surface (Parr, 1959). The operation is usually conducted on the contour, with spacing ranging from 5 to 10 m. Several rather simple tractor-driven machines have been designed for the vertical mulching procedure.

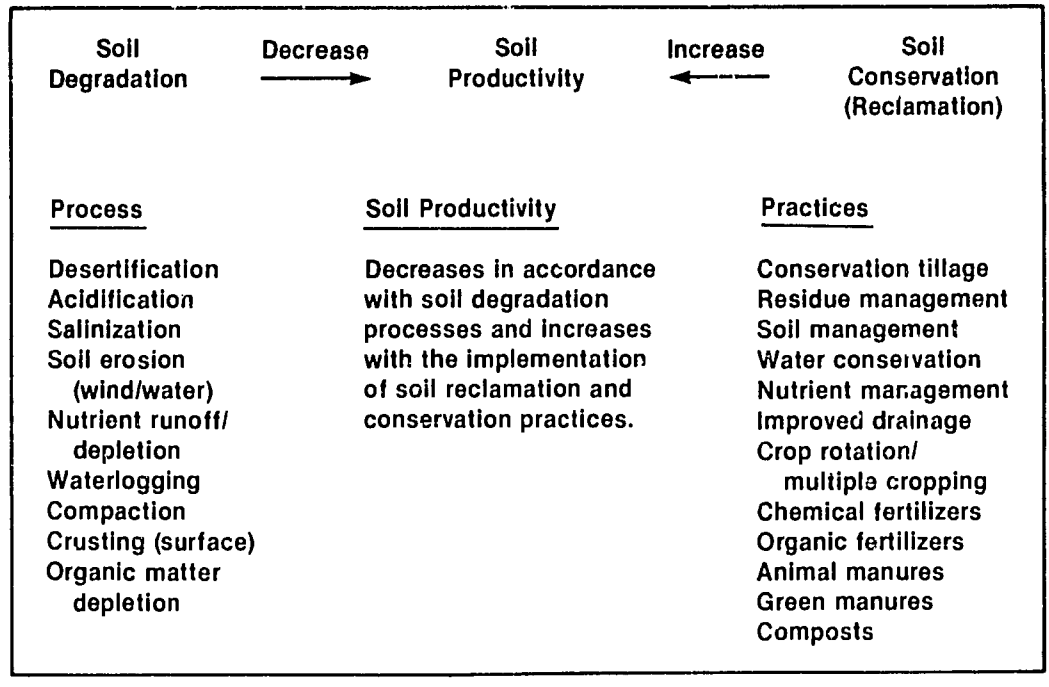

Figure 1. Relationship of Soil Productivity to Soil Degradation Processes and Soil Reclamation and Conservation Practices.

Research Needs

In addition to traditional organic materials such as animal manures and crop residues, developing countries are increasing their land application of municipal wastes (e.g., sewage sludges and effluents, and garbage) and industrial wastes (e.g., food processing and acceptable industrial organic wastes). Research is needed to determine how these wastes differ in their ability to improve the tilth, fertility and productivity of soils.

Information is limited on the substitutability of one particular organic waste for another in soil improvement. Criteria should be developed by which the relative effectiveness of different organic wastes can be compared. For example, studies are needed to determine the following properties: decomposition rates for each waste under different soil regimes and cropping systems; rates at which plant nutrients are mineralized, recycled and utilized by both current and subsequent crops; the potential toxic effects of certain wastes on plants and microorganisms; the impact of organic waste management on the control of plant insects and diseases; and the extent to which different wastes can effect desirable and residual improvement of soil physical properties. Each organic waste has unique properties that should be thoroughly investigated in the soil/water/plant ecosystem.

Some organic amendments are known to mineralize and release available plant nutrients rapidly as a result of microbial attack. In some cases this is desirable, particularly on soils that are already in a state of high fertility and productivity. On the other hand, marginal, erodible, sloping and generally less productive soils would benefit, at least initially, from the application of organic materials having a higher degree of microbial stability in soil. Such materials would release their plant nutrients at a relatively slower rate. Farmers in developing countries often have occasion to use both types of materials in their farming operations, depending on whether there is a need to release nutrients rapidly or to improve the productivity of marginal soils.

Farmers frequently apply organic wastes (including composts) to their fields at rates that are too low or too high for maximum economic return. When the rate is too low, soil

physical properties are not sufficiently improved and the plant nutrient level is inadequate to sustain optimum crop growth and yield. If applied at excessive rates, plant nutrients are not utilized efficiently and contribute to environmental pollution through runoff and leaching. Research is needed to improve the efficient and effective use of organic materials in cropping systems. Such research must consider a number of management factors and how these materials are applied, including: mode or method of application (e.g., surface applied, plowed down, disked in, or sidedressed); rate, time and frequency of application; the soil; and the sequence of crops to be grown. A better understanding of the interaction of these factors should provide a more reliable basis for developing more efficient and effective waste application/utilization programs for agriculture.

The beneficial effects of various organic materials on soil productivity are well known. However, for most organic materials it is very difficult to quantify what portion of the crop yield response is due to the organic matter fraction and what is due to the plant nutrient content. Experiments showed that the economic value of the organic component in different kinds of organic materials can be accurately and meaningfully estimated. This should be done for a number of different crops, soils, management systems and climatic situations. Such data could greatly stimulate the use of organic wastes on agricultural land to control soil erosion and nutrient runoff and to improve soil productivity.

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Management Strategies for Improving the Fertility and Productivity of Upland Soils

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ABSTRACT. Since the diversification of agricultural production has been strongly emphasized in the Fourth National Economic and Social Development Plan and will continue in the Fifth Plan, more and more upland area has been utilized in producing annual field crops in Thailand. Of 7.6 Mha of upland farm holdings, approximately 4.4 Mha are under rainfed cultivation and have been developed through deforestation. Like the tropical regions, this land maintains a good forest vegetation, but rapidly loses its fertility when planted to arable crops. Continuous cultivation in the semiarid tropics under conditions of high temperature, humidity and intense but erratic rainfall presents many problems. Nutrients are lost through crop removal, leaching and erosion from the soils. Soils are predominantly low activity clays having low water and nutrient retention capacity, with very little nutrient recycling. Thus, most upland soils in Thailand are very low in fertility. Plant nutrients added through fertilizer application have increased crop yields by 30 to 100 percent. This paper presents some perspectives and management strategies for improving the fertility and productivity of upland soils.

Introduction

Thailand, with a total area of 51.3 Mha, is divided into four regions: the North, Northeast, Central Plain and South. Each region has its distinct geographic and socioeconomic features, land distribution, productivity and farm income. Land utilization for major crops production in each region during 1980-1981 is shown in Table 1.

During the past twenty years the area of upland agricultural development has increased threefold. The reasons for this include increased demand for upland crop production, the international export market, and the national policy for agricultural production diversification which has been emphasized in the Fourth National Economic and Social Development Plan (1977 to 1981) and in the Fifth Plan. Of 7.6 Mha of upland farm holdings, approximately 4.4 Mha were under rainfed field crop cultivation in 1981. Expansion of the planted area has been achieved by conversion of highly fertile virgin land into cultivated fields. But despite the introduction of advanced agrotechnology, the yield of upland crops such as corn, sugarcane and cassava has not increased but has remained constant, or has shown a gradual decrease (Table 2).

Like other tropical regions, the soils of the upland areas in Thailand which have been developed by deforestation can maintain a good forest vegetation, but their fertility decreases rapidly when planted to arable crops. Continuous cultivation of these areas under the agroclimatic conditions prevailing in the country will cause the production potential of the uplands to decrease through the deterioration of physical, chemical and biological properties of the soils.

In view of the demand for increased agricultural production to meet future needs and the fact that current cultivated lands can not meet these needs, it has become increasingly apparent that the upland area of Thailand will have to be developed for this purpose. A change in the production pattern from extensive to intensive, i.e., improvement in yield per unit area, will be required. This could be achieved through the efficient utilization of land and water resources. However, the development of upland areas has to be a gradual transformation through stepwise improvements in the existing farming system, since the majority of farmers in the area are small subsistence-level operators.

Upland Soils of Thailand

Twelve great soil groups were recognized by Moorman and Rojanasoonthon (1972) in upland areas. They are classified as Alluvials, Regosols, Low-Humic Gleys, Grumusols, Rendzinas, Noncalcic Brown, Brown Forests, Reddish-Brown Lateritics, Red-Yellow

Table 1. Major Crops Production and Percent of Area Planted to Each Crop by Region, 1980-1981 (Centre for Agricultural Statistics, Office of Agricultural Economics, MOAC).

Commodity	Total Annual Production for Kingdom	Regions (Area Planted)			
		North	Northeast	Central	South†
	Mt	..... %			
Rice (wet season)	15.4	27	36	30	7
Rice (dry season)	1.90	10	3	85	2
Cassava	16.5	2	60	38	0
Maize	2.99	50	15	35	0
Sugarcane	19.8	10	11	80	0
Mung bean	0.26	76	2	21	1
Sorghum	0.[illegible]	16	2	82	0
Soybean	0.10	89	1	10	0
Peanut	0.13	53	19	22	5
Cotton	0.19	31	10	59	0
Kenaf	0.21	0	99	1	0

† Regional planted area for rubber was not indicated.

Podzolics, Red-Yellow Latosols, Gray Podzolics and Reddish-Brown Latosols. Most of the upland soils are found along the foot of the mountains, on the slope land of hills, plateaus, river levees and dunes. The total area under cultivation in 1981 was approximately 6.2 Mha, with field crops accounting for 4.4 Mha and horticultural and tree crops for 1.8 Mha. The production of major upland crops such as maize, cassava, kenaf and food legumes is almost entirely under rainfed conditions. Soil classification equivalents in the 1977 U.S. Soil Taxonomy system are shown in Table 3.

The majority of upland soils are dominated by low activity clays, having low water and nutrient retention capacity. Because of the high energy dissipated by tropical rainstorms on soil surfaces, most upland soils are poorly structured and susceptible to crusting. Thus, it is evident that most of the upland soils are poor in both chemical and physical properties as shown in Ogawa *et al.* (1975) and Kubota *et al.* (1979) in Tables 4 and 5.

Constraints of Upland Soil

Upland soils under continuous cultivation with the high rainfall of tropical environments have undergone a drastic change in soil properties. Soils exposed to high temperatures with high-intensity rainfall rapidly lose their productive capacity; organic matter decomposes at accelerated rates; nutrients are leached; soil erosion becomes excessive; and most of the rainfall is lost as runoff. Soil physical properties deteriorate in a short time. In general, the soil becomes marginal for crop production because of chemical and physical degradation.

Table 2. Planted Area and Average Yield of Some Major Field Crops (Centre for Agricultural Statistics, Office of Agricultural Economics, MOAC).

Crops	1962-63		1972-73		1982-83	
	Area	Yield	Area	Yield	Area	Yield
	Mha	*t ha^{-1}*	*Mha*	*t ha^{-1}*	*Mha*	*t ha^{-1}*
Maize	0.33	2.00	1.00	1.30	1.68	1.80
Cassava	0.12	17.1	0.33	12.1	1.24	14.4
Sugarcane	0.06	30.7	0.18	52.5	0.58	41.9
Soybean	0.03	1.08	0.08	0.90	0.12	0.90
Cotton	0.06	0.70	0.06	0.80	0.11	1.10
Peanut	0.09	1.30	0.12	1.30	0.12	1.20
Mung bean	0.05	1.08	0.23	0.90	0.48	0.60
Kenaf	0.11	1.18	0.47	0.90	0.22	0.90

Table 3. Approximate Classification Equivalent Between the Old Dudal and Moorman and New U.S. Soil Taxonomy.

Dudal + Moorman	U.S. Soil Taxonomy
Regosols	Quartzipsamments
Alluvials	Ustifluvents
Grumusols	Typic and Entic Pelluderts, Typic Chromusterts, Typic and Udic Pellusterts
Rendzinas	Typic Calciustolls, Vertic and Typic Haplustolls
Brown Forest	Typic Calciustolls, Vertic and Typic Haplustolls
Noncalcic Brown	Udic and Ultic Haplustalfs
Gray Podzolics	Paleustults, Typic Paleudults, Typic Tropudults, Oxic, Ustoxic and Ustic Dystropepts
Red-Yellow Podzolics	Paleustults, Haplustults
Reddish-Brown Latosols	Haplorthox
Red-Yellow Latosols	Haplustox, Paleustults
Reddish-Brown Lateritics	Paleustults, Paleudults, Oxic Haplustults

Table 4. Some Chemical Properties of Upland Soils in Thailand (After Ogawa et al., 1975).

Great Soil Groups	pH		CEC		Base Saturation				Bray II-P		Exchangeable K	
	X	Range	X	Range	X	Range	X	Range	X	Range	X	Range
			meq 100 g⁻¹		..... %		... % O.M. ...		..... ppm			
Alluvials	7.0	6.3-7.5	10.8	6.5-15.8	122	111-130	2.1	1.4-3.5	108	41-207	196	40-402
Regosols	6.2	5.9-6.7	1.0	0.5- 1.8	253	26-653	0.6	0.5-0.7	4	4- 5	21	10- 30
Low-Humic Gley	5.2	4.5-6.5	2.0	1.0- 4.0	67	21-155	1.1	0.4-1.4	20	2- 36	68	8-308
Grumusols	7.9		43.0		112		1.2		12		200	
Rendzinas	7.5	7.4-7.5	37.2	25.7-48.7	107	86-128	3.7	2.5-4.8	17	14- 19	440	100-780
Brown Forest	6.3	5.7-7.1	16.9	7.6-26.2	96	76-112	0.8	1.5-1.8	8	2- 16	254	200-424
Noncalcic Brown	6.4	5.1-7.8	8.8	2.0-14.6	121	40-188	1.7	0.9-2.6	81	4-340	229	12-558
Gray Podzolics	5.3	4.2-6.6	2.4	0.6- 5.7	90	25-259	1.3	0.4-3.2	27	2-194	64	20-267
Red-Yellow Podzolics	5.4	4.3-7.7	6.8	1.1-23.9	77	8-325	2.8	0.4-5.2	30	4-206	108	30-220
Reddish-Brown Lateritics	5.1	4.7-5.3	8.2	6.8-11.0	62	47- 80	2.3	1.7-2.7	35	3- 90	254	100-369
Reddish-Brown Latosols	5.5		10.8		26		1.8		49		512	
Red-Yellow Latosols	5.7	4.9-6.4	2.8	1.2- 5.6	103	39-161	1.4	0.6-2.5	17	5- 41	74	14-185

Table 5. Physical Properties of Upland Soils in Thailand
(After Kubota et al., 1979).

Great Soil Groups	Bulk Density		Noncapillary Pore		K of Surface Soil‡	AMHC§ 1 m Profile	Dispersibility of Ap Soil to Water¶
	Surface†	Subsoil	Surface	Subsoil			
	... g cm^{-3} ...		... % vol ...		$cm\ s^{-1}$	mm	%
Regosols	1.64	1.66	23.3	23.1	10-3-104	58	68.6
Grumusols	0.97	0.99	7.6	2.5	10-6	107	6.8
Rendzinas	1.19	1.26	-	-	10-5	111	4.7
Brown Forest	1.42	1.23	10.5	7.9	10-5	84	23.7
Noncalcic Brown	1.57	1.61	7.9	4.2	10-3-10-7	106	24.8
Gray Podzolics (SE)	1.70	1.64	9.3	10.9	10-3-10-6	72	39.6
Gray Podzolics (NE)	1.62	1.51	16.8	21.2	10-3-10-4	87	50.1
Red-Yellow Podzolics	1.51	1.47	13.5	14.7	10-3-10-6	85	28.5
Reddish-Brown Lateritics	1.27	1.22	13.8	15.8	10-3-10-5	78	17.0
Reddish-Brown Latosols	0.98	0.96	26.3	29.6	10-3-10-4	80	10.8
Red-Yellow Latosols	1.56	1.42	14.6	20.7	10-3-10-4	106	29.1

† Subsurface layer
‡ Hydraulic conductivity at saturation
§ Available moisture holding capacity
¶ Middleton's method; easily water-dispersible clay + silt/(total clay + silt)

Soil Physical Property Deterioration

Soil physical characteristics have deteriorated in many upland areas due to excessive cultivation. Most of the upland soils in Thailand are prone to crust formation and erosion, and are low in available moisture storage capacity. With unfavorable climatic conditions, upland crops suffer from water stress, and crop production thus becomes uncertain. Changes in the physical properties of a surface Red-Yellow Podzolic soil after reclamation from the forest at Hua Hin are shown in Table 6.

Soil Fertility Depletion with Low Productivity

Traditional agricultural systems based on bush fallow are still practiced in many areas. Bush fallow is a fairly stable system sustaining small populations as long as the fallow period following cultivation is sufficient for soil fertility to be restored. When population density is high, the fallow period is shortened; soil fertility declines and soil stability is lost. Continuous monocropping of major field crops without recycling plant nutrients back to the soils hastens the decline in soil fertility. The amount of nutrients removed from the soil by major crops compared with the amount of plant nutrients applied as fertilizer is shown in Table 7.

Table 6. Changes in the Physical Properties of a Surface Soil After Reclamation From Forest (Red-Yellow Podzolic Soil) (After Morakul *et al.*, 1984).

Soil Physical Properties	Undeveloped Tropical Evergreen Tropical Forest	Years Following Reclamation From Forest and Current Crop Growth		
		1 Year (Sorghum)	5 Years (Cotton)	8 Years (Pineapple)
Particle size				
%Sand	47	59	59	59
%Silt	36	28	24	28
%Clay	17	13	17	13
Bulk density (g cm^{-3})	1.21	1.52	1.36	1.31
Particle density (g cm^{-3})	2.56	2.61	2.62	2.62
Water permeability (mm h^{-1})	4.0	0.4	2.2	0.6

Table 7. Comparison Between Approximate Amount of Nutrients Removed and Fertilizers Applied for Various Crops.

Crops	Nutrients Removed† ($N+P_2O_5+K_2O$)	Fertilizer Applied‡
	..... *kg ha*$^{-1}$	
Maize	221	1
Cassava	230	13
Soybean	209	2
Peanut	265	-
Mung bean	115	-
Kenaf	276	12
Sugarcane	540	200

† Primary figures from Soil Science Division, DOA.
‡ Office of Agricultural Economics, MOAC (crop years 1978, 1979).

Nutrient loss through erosion and leaching due to improper cultivation practices were reported to be a major cause of soil fertility decline. Cassava cultivation in undulating terrain with five to nine percent slope in the relatively dry southeastern province has resulted in a soil loss of up to 67 t/ha/yr (Rimvanich, 1979).

Crop responses to fertilizers show that nitrogen and phosphorous are the key problem elements in almost all soils, while response to potassium is rarely observed. Secondary and trace element deficiencies are usually insignificant or not severe enough for any corrective measures to be profitable. General percentage responses of major field crops to fertilizers applied in various soil groups obtained from the scattering fertilizer field trials from 1981 to 1983 were combined and are shown in Table 8.

Management Strategies

According to Greenland (1975), stable agricultural systems can only be obtained by replacing the nutrients that are removed from the soil by crops and maintaining good physical conditions in the soil, which may require additions of organic matter and erosion control. However, the management of upland soils in Thailand is not satisfying these conditions. The low yield of crops is due primarily to uncertain weather and declining soil fertility which results from poor soil conservation management and inadequate use of fertilizer. Poor soil conservation, in turn, aggravates the effects of moisture stress and makes many areas drought-prone. Irrigation, as well as the improvement of soil moisture regimes (which will not be discussed in this paper), is the best remedy.

Table 8. Percent Responses of Major Field Crops to Fertilizer Applied, 1981-1983 Farmer Field Trials (Soil Science Div., Dept. of Agriculture).

Great Soil Groups	Crops	Percent of Fertilizer Response		
		Nitrogen	Phosphorous	Potassium
Gray Podzolics	Cassava	±†	-	-
	Kenaf	-	-	-
	Sorghum	±	+	-
	Peanut	-	-	-
	Mung bean	-	+	-
Regosols	Cassava	±	-	-
Reddish-Brown Lateritics	Maize	±	-	-
	Sorghum	++	+	-
	Cotton	±	+	-
Noncalcic Brown	Sugarcane	-	-	-
	Maize	++	-	-
	Sorghum	±	-	-
	Cotton	-	-	-

† -, less than 25% response; ±, 25-50% response; +, 50-75% response; and ++, higher than 75% response.

Crop Fertilization

To maintain and improve soil productivity for crop production without the use of mineral fertilizers would be difficult, if not impossible. In Thailand, the use of mineral fertilizer plays a key role for crop yield increases. Results of fertilizer trials conducted on farmers' fields with different soil groups and different crops (Table 9) demonstrate the potential to increase yield 20 to 100 percent, with return profits, determined as the value/cost ratio, ranging from 2.9 to 5.5. Since all mineral fertilizers used in Thailand are imported, the consumption of fertilizer in kg of plant nutrients per ha was only 1.2 kg/ha in 1980/81. This is the lowest in Asia with the exceptions of Burma and Nepal. The use of fertilizer is one of the best ways of improving upland soil productivity. However, the small subsistence-type farmer in the Northeast faces serious constraints on fertilizer use because of high fertilizer/crop price ratios, lack of credit, cropping risks due to erratic and unpredictable rainfall, and inadequate extension programs in fertilizer education for farmers.

Table 9. Nutrient Requirements of Field Crops Calculated From Individual Response Curves From Fertilizer Field Trials 1981-1984 (FAO, 1984).

Crop	Great Soil Group	No. of Site	Requirement of N-P_2O_5-K_2O	Control Yield	Exp. Yield Increase	Profit	Value/ Cost Ratio
			..... *kg ha*$^{-1}$			*B ha*$^{-1}$	
Corn	RB†,BF	39	70-15-0	2920	1360	2120	2.9
Sorghum	GP,RB	21	63-16-21	1610	1640	2750	3.2
Soybean	LH,RP, NC,GP	46	13-61-30	1390	907	4640	4.4
Groundnut	GP,RP	29	22-38-61	1550	703	3850	3.7
Mung bean	GP,RP	25	18-30-44	750	512	2730	3.5
Cassava	GP	16	128-0-55	21000	12800	7450	4.5
	GR	7	47-0-104	15400	8120	4540	3.9
Cotton	RP,RG,BF	22	61-58-31	1360	405	3710	2.9
	RP,GR	7	53-53-75	876	865	9930	5.5
Kenaf	GP	39	47-46-76	1810	1750	5880	3.9

† RB, Reddish-Brown Lateritic; BF, Brown Forest Soil; GP, Gray Podzolic; LH, Low-Humic Gley; RP, Red-Yellow Podzolic; NC, Noncalcic Brown; GR, Regosol; and RG, Regosolic Gray Podzolic.

Low-Input Management Technology

The efficacy of mineral fertilizer, however, does not diminish the usefulness and generally unrecognized potential of organic manure. Nevertheless, until recently the use of organic manure had decreased drastically as mineral fertilizer became more available. The rising costs of mineral fertilizers now make it increasingly important to reexamine the use of organic manure, animal manure, compost, crop residue recycling, green manuring, biological nitrogen fixation and other sources of plant nutrients.

Utilization of Local Rock Phosphate

Rock phosphate deposits in Thailand were estimated by the Department of Geological Resources in 1982 at 300,000 t. The total phosphate content of the material ranges from 10 to 40 percent. Much attention has been given to the utilization of local rock phosphate as a cheaper source of phosphorous especially after the energy crisis of 1971-72. Ground rock phosphate and locally treated rock phosphates have been tested in the field with different crops and for long-term residual effects. Results of these studies on sorghum grown on a Red-Yellow Latosol soil showed that the application of rock phosphate at the rate of 1250 kg/ha could produce yields equivalent to that of 225 kg/ha of P_2O_5 from standard phosphate fertilizer (DSP). The use of rock phosphate at a lower rate (625 kg/ha) together with 56 kg/ha of P_2O_5 DSP provided the best results as shown in Table 10.

Nitrogen Fixation by Legumes

The use of rhizobial inoculants for legumes is the best known low-input nitrogen fertilization measure. The technology has been recognized and widely accepted by innovative farmers in Thailand for decades in the production of upland food legumes. An experiment was conducted by the Soil Microbiology Staff at three locations in the

Table 10. Relative Yield of Sorghum and Soil Phosphorous as Affected by Phosphate Sources on Red-Yellow Latosol (1978) (Soil Science Division, DOA).

P Source	P Rate	Relative Yield	Initial Soil-P		Soil-P After Harvest	
			Bray II-P	Total P	Bray II-P	Total P
	kg ha⁻¹	%	..... *ppm*	.....		
None	0	100	5.7	62.0	6.9	135
RP†	625	132	5.9	72.0	53.5	149
RP	1250	173	6.2	81.2	96.0	225
RP+DSP	625+56	222	6.6	70.0	49.5	191
DSP	225	189	5.4	51.2	7.5	143

† RP, Rock phosphate with 33% of total P_2O_5 and 5% of citrate soluble P_2O_5; DSP, Standard phosphate fertilizer.

Northeast comparing the effectiveness of *Rhizobium japonicum* with nitrogen fertilizers. The results showed that the application of nitrogen fertilizer, regardless of rate, together with the rhizobial inoculant, did not increase soybean yields over inoculation alone. Moreover, inoculation alone resulted in significantly higher soybean yields than the highest rate of fertilizer N applied, 75 kg/ha, without inoculant. The higher rate of 150 kg/ha of N was compared in 1974 and results still confirmed those of 1973. Therefore, it can be concluded that there is no need for nitrogen fertilizers for soybean with rhizobial inoculant (Table 11). Further study indicated that legumes, if inoculated and supplied with 25 to 30 kg/ha of P_2O_5, could meet about 80 percent of their own nitrogen needs through fixation. In addition, there may be a residual effect of 20 to 25 kg/ha of N on succeeding crops. Likewise, when grown in an intercropping system, legumes might also provide some nitrogen to the main crop. Specific research about nitrogen transfer between plant species needs to be investigated.

Table 11. Yield of Soybean as Affected by the Use of Rhizobial Inoculant and Nitrogen Fertilizers in 1973 and 1974.

Rhizobial Inoculant †	Rate of N		Yield of Soybean					
	1973	1974	Roi Et Experiment Station ‡		KK-LD-Centre§		Farmers' Field¶	
			1973	1974	1973	1974	1973	1974
	.. *kg ha*$^{-1}$ ..		..... *t ha*$^{-1}$					
+	0	0	2.76a #	2.12a	2.33ab	2.21a	1.70a	1.60a
+	18.75	18.75	2.74a	1.91a	2.27ab	2.26a	1.73a	1.51a
+	37.5	37.5	2.52a	2.42a	2.48a	2.36a	1.67a	1.51a
+	56.25	75.0	2.37ab	2.31a	2.49a	2.32a	1.70a	1.49a
+	75.0	150	2.42ab	2.40a	2.69a	1.89a	1.69a	1.57a
-	0	0	1.03d	0.60b	1.25d	1.14c	1.20b	0.92b
-	18.75	18.75	1.72c	0.61b	1.50cd	1.20c	1.39ab	1.24ab
-	37.5	37.5	1.84c	0.73b	1.71cd	1.41bc	1.47ab	1.26ab
-	56.25	75.0	1.99bc	0.80b	1.92bc	1.74b	1.47ab	1.38ab
-	75.0	150	2.12bc	0.81b	1.96bc	1.62bc	1.52ab	1.26ab
C.V. (%)			13.1	24.2	13.6	17.3	16.2	22.3

† +, with inoculant; -, without inoculant.
‡ With Low-Humic Gley soil.
§ With Red-Yellow Latosol soil.
¶ With Gray Podzolic soil.
# Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Recycling of Organic Materials

The use of compost and crop residue incorporation are considered to have long-lasting results, affecting both the chemical and physical properties of the soil and maintaining soil fertility through increased nutrient and moisture retention capacity. Such beneficial effects on soil are generally reported in long-term experiments, although no direct measurement can be made. Long-term experiments for studying the effect of compost, cassava stalk incorporation and NPK fertilizer on cassava grown on a Red-Yellow Latosol were started in 1977. Results of 1983 showed that the application of 50 kg/ha/yr each of N and P_2O_5 plus incorporation of cassava stalks, as well as the cassava stalk incorporated alone, could maintain cassava yields at high levels. The application of NPK + 12.5 t/ha/yr of municipal compost produced effects no different from the application of NPK alone (Table 12). The limitation of using municipal compost in farming areas is the cost of transportation, and use of on-farm compost is usually limited to only cash crops of high value such as ornamentals, vegetables and fruit trees. Thus, it would appear that recycling of crop residues in situ with the addition of farmyard manures, if available for composting, and mineral fertilizers would be a more practical and effective practice.

Table 12. Long-Term Effect of NPK, Compost and Stalk Incorporation on Root of Cassava Grown in Yasothon Soil (Red-Yellow Latosol) at Khon Kaen (Field Crops Soils and Fertilizer Research Group, Soil Science Division).

Treatment	Fresh Root		Mean (Seven Consecutive Years)	Index
	1977	1983		
	..... $t\ ha^{-1}$			
Control	28.2	6.25	12.0	100
N†	26.6	7.75	12.3	102
NP	30.8	8.63	14.3	119
NK	30.8	6.81	18.2	152
NPK	29.6	17.1	22.1	184
NPK+BK-2 compost‡	29.0	16.0	21.9	182
NPK+stalk incorporate	25.6	20.2	23.9	199
Stem+leaf incorporate	27.3	19.6	17.9	149
F ratio	1.36 NS	11.0**		
CV (%)	11.3	28.6		

† Rates of N, P_2O_5 and K_2O were 50, 50 and 50 kg ha^{-1} yr^{-1}, respectively.
‡ Rate of Bangkok Municipal-2 compost was 12.5 t ha^{-1} yr^{-1}, respectively.
** Significant at the 0.01 probability level.

Crop Rotation

Crop rotation has been practiced for years especially in areas with supplemental irrigation and areas of less erratic rainfall distribution such as those in the Northern and Central region. In the Northeast region with its variable climate and low soil moisture reserve, crop production is limited to only one crop per year. Farmers usually grow major food and fiber crops continuously for income without legume rotation. However, results of long-term experiments have shown that crop rotation with legumes is possible. Although the rotation system did not have much effect on the soil organic matter content, it did increase farmers' income, especially in the cassava-groundnut system (Table 13).

Mulching

Mulching is already a widespread practice in the northern part of the country where irrigation is available to grow crops in the dry season after broadcasting rice. Rice straw is the main mulching material of the area. Experiments have shown that better moisture conservation is achieved by mulching (Kubota *et al.*, 1979). A mulching and nitrogen fertilizer application study for maize production in Reddish-Brown Lateritic soils concluded that in order to obtain relatively high and stable yields of maize, N-fertilizer should be applied at basal levels and crop residues used as mulches. Proper use of mulches can maintain soil moisture at high levels throughout the year as well as moderate the soil temperature (Virakornpanich *et al.*, 1984). However, straw and other materials for mulching are generally unavailable at times, especially at the beginning of the rainy season. This scarcity of mulching material in combination with the labor required for transporting and spreading the mulch is the main limitation of this practice.

Table 13. Benefit Gained and Soil Organic Matter Status in Cassava-Legumes Rotation on a Red-Yellow Latosol Soil at Khon Kaen, 1976 to 1983 (Field Crops, Soils and Fertilizer Research Group, Soil Science Division).

Cropping System	Average Net Return Per Year	Average Soil O.M.		
		1976	1978-80	1981-83
	B ha^{-1} yr^{-1}	..... %		
Monocassava		0.87		
No Fertilizer	8,040		0.71	0.62
With Fertilizer†	9,230		0.77	0.60
Crop Rotation‡		0.87		
Cassava-Groundnut-Pigeon Pea	10,760		0.75	0.68
Cassava-Mung Bean-Pigeon Pea	5,210		0.75	0.63

† 50 kg ha^{-1} yr^{-1} each N of P_2O_5 and K_2O.
‡ Rotation sequence started with cassava followed by groundnut or mung bean, and pigeon pea another year.

Conclusion and Future Research Needs

From the foregoing discussion it is apparent that increased productivity of upland soils in the Northeast will depend on two major inputs: (1) better soil and water conservation practices and (2) improvement of soil fertility. These can be achieved by appropriate soil management for improving soil physical properties to assure the maximum efficiency of moisture and nutrient use in soils. Proper cultivation and tillage practices together with the recycling of organic material through the use of farmyard manure, compost, direct incorporation of crop residue and mulching are the best possible practices. In order to maintain or improve soil fertility, crop fertilization should be based on the cropping system as a whole for the agricultural year rather than for a single crop in the system. Nutrients should be applied to that crop which makes best use of the nutrients in question, with the best possible residual benefit to the succeeding crop. Maximizing the use of biological nitrogen fixation and local sources of plant nutrients including renewable resources must also be stressed.

More research emphasis should be placed on: (1) soil fertility and fertilizer usage in cropping systems, (2) improvement of biological nitrogen fixation through the use of efficient Rhizobium and Mycorrhizae strains, (3) correlation studies on soil testing and crop responses for specific and better fertiiizer recommendations and (4) soil management practices for minimum disturbance of the soil surface.

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Management Strategies for Improving the Fertility and Productivity of Paddy Soils

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ABSTRACT. The available silica content of soils in the North region is 40 to 62 ppm SiO_2. Criteria established in countries of temperate climates suggest that a response of rice to silica application is likely if the available silica content of the soil is below 110 ppm. Accordingly, most of the soils of the Northeast should respond to silica application. Experiments were conducted from 1975 to 1978 in Sakon Nakhon, Khon Kaen, Ubon Ratchathani, Surin, Kuan Gut, Khok Samrong and Phrae. Response to silica was particularly striking after 1977 when potash application was increased to a rate of 75 kg/ha of K_2O instead of an initial annual rate of 37.5 kg/ha of K_2O. Thus, the low level of available potassium was the principal factor which limited the response of rice to silica applications. Yield data indicate that highly significant responses were obtained by the application of silica only in Sakon Nakhon and Ubon Ratchathani where the available silica content was extremely low. A less striking but significant response was obtained in Khon Kaen. Response at Surin was also positive, but rice yields were not increased by silica application in Phrae, Kuan Gut and Khok Samrong. It is felt that criteria established in countries of temperate climates should be cautiously adopted in tropical countries where the rate of mineral weathering is much faster. This study suggests that the critical levels of nutrients in the tropics could be much lower than in the temperate zone.

Introduction

There are large areas of sandy soils in Thailand, especially in the northeastern part of the Kingdom. According to Motomura (1973), the available silica content of soils in the Northeast region is 40 to 62 ppm SiO_2. Imaizumi and Yoshida (1958) reported that response of rice to silica was likely if the available silica content of the soil was below 110 ppm. Thailand has many soils of sandy texture which contain less than 110 ppm available silica, particularly in the Northeast. Accordingly, most of the soils of the Northeast should respond to silica application. Motomura also concluded that many sandy soils are very low in magnesium and zinc. According to the criteria given by Tanaka and Yoshida (1970) and Yoshida (1975), the contents of these elements in some Thai soils are below the critical levels. Magnesium deficiency in the rice plant is also well-documented (Sako, 1956).

Materials and Methods

Experimental Sites

The experiments were conducted at the following Rice Experiment Stations. The official abbreviations are indicated.

Site	Region
1. Sakon Nakhon (SKN)	Northeast
2. Khon Kaen (KKN)	Northeast
3. Ubon Ratchathani (UBN)	Northeast
4. Surin (SRN)	Northeast
5. Khok Samrong (KSR)	Central Plain
6. Phrae (PRE)	North
7. Nakon Srithamarat (NSR)	South
8. Kuan Gut (KGT)	South

Layout of Experimental Plots

(a) Design: Randomized complete block design.

(b) Four replications

(c) Plot size: 3 m x 5 m.

Layouts were the same at all locations.

Materials Used

N	Ammonium sulphate.
P_2O_5	Triple superphosphate.
K_2O	Potassium chloride.
SiO_2	Slag from Kawatetsu Steel Co. (Japan) was used. This slag contains 30 percent guaranteed weak-acid soluble silica (SiO_2) and is widely used as a silica source for paddy in Japan.
MgO	Magnesium oxide of industrial grade was used.
ZnO	In 1975, zinc chloride of industrial grade was used. After 1975, zinc sulphate of chemical grade was applied.

Cultural Practices

(a) Rice variety: RDI.

(b) Spacing: 25 x 25 cm, 3 seedlings per hill.

(c) Yield measurement: after discarding two border rows of plants, the entire plot was used for yield measurement.

Modification of the Treatment

Analysis of the plants sampled at harvest in 1976 showed that 37.5 kg/ha of K_2O was not sufficient in Ubon and Nakon. Thus, in 1977, K_2O was increased to 75 kg/ha for all locations.

Rice Plant Sampling

In 1976, rice plant samples were taken at harvest from replicated plots and combined for each treatment. Locations sampled were Surin, Khon Kaen, Khok Samrong and Kuan Gut. In 1977, samples were taken at Sakon Nakhon and Ubon. Analytical results from Sakon Nakhon were combined with those of the four locations sampled in 1976 and are shown in Tables 1a and 1b. Plot by plot samples from Ubon were analyzed and the variability in the nutrient content of the straw is shown in Table 2.

Results and Discussions

Rice yields at different locations in this study are reported in Tables 3 through 8 for the years 1975, 1976, 1977 and 1978. The experiment was not conducted at Khok Samrong and Srithamarat in 1975. Experiments were lost at Sakon Nakhon by drought in 1976, and by flood at Khon Kaen in 1977 and at Ubon, Khon Kaen and Khok Samrong in 1978. Experiments at Kuan Gut, Phrae and Nakon Srithamarat were discontinued in 1978 since no significant responses to the treatments were observed.

Table 1a. Nutrient Content of Rice Straw at Harvest at Different Locations in 1976.

Trt. No.†	N					P				
	SRN‡	KSR	KKN	KGT	SKN	SRN	KSR	KKN	KGT	SKN
	.....		%	.....		.....		%	.....	
1	0.637	0.514	0.432	0.699	0.493	0.115	0.055	0.045	0.070	0.430
2	0.459	0.548	0.377	0.713	0.725	0.135	0.070	0.060	0.070	0.919
3	0.425	0.439	0.363	0.613	0.543	0.110	0.050	0.080	0.100	0.606
4	0.411	0.377	0.418	0.802	0.529	0.130	0.055	0.075	0.095	0.782
5	0.466	0.487	0.329	0.754	0.529	0.130	0.060	0.052	0.055	0.723
6	0.535	0.466	0.425	0.603	0.507	0.120	0.075	0.050	0.090	0.704
7	0.439	0.480	0.445	0.754	0.565	0.135	0.055	0.050	0.095	1.075
8	0.466	0.432	0.439	0.603	0.688	0.115	0.060	0.060	0.080	0.684
9	0.459	0.432	0.452	0.775	0.543	0.135	0.052	0.075	0.090	0.528
10	0.528	0.507	0.466	0.768	0.529	0.140	0.070	0.062	0.102	0.626
11	0.473	0.651	0.418	0.830	0.551	0.145	0.071	0.075	0.120	0.782
12	0.514	0.507	0.418	0.679	0.529	0.150	0.055	0.050	0.110	0.567
13	0.377	0.583	0.445	0.830	0.493	0.115	0.075	0.070	0.072	1.017
14	0.480	0.439	0.432	0.768	0.551	0.125	0.060	0.070	0.072	0.841

Table 1a. (Continued)

Trt. No.	K					Ca				
	SRN	KSR	KKN	KGT	SKN	SRN	KSR	KKN	KGT	SKN
	..... %					..... %				
1	0.860	0.920	0.880	1.820	0.430	0.400	0.320	0.320	0.420	-
2	1.000	0.860	1.260	1.440	0.919	0.360	0.360	0.260	0.490	-
3	0.780	0.960	1.360	1.760	0.606	0.400	0.320	0.280	0.470	-
4	0.820	0.860	1.000	1.640	0.782	0.380	0.360	0.360	0.490	-
5	0.820	0.860	1.300	1.440	0.723	0.450	0.360	0.280	0.450	-
6	0.700	0.820	0.860	1.600	0.704	0.320	0.450	0.320	0.420	-
7	1.040	0.960	1.300	1.480	1.075	0.380	0.400	0.320	0.400	-
8	0.780	0.780	0.960	2.560	0.684	0.320	0.470	0.320	0.470	-
9	0.700	0.860	1.520	1.440	0.528	0.400	0.400	0.360	0.490	-
10	0.780	0.860	1.440	2.120	0.626	0.400	0.350	0.450	0.450	-
11	0.860	0.880	0.920	1.400	0.782	0.400	0.400	0.450	0.490	-
12	0.920	0.860	0.740	1.300	0.567	0.470	0.420	0.280	0.490	-
13	0.820	0.860	1.000	1.480	1.017	0.340	0.450	0.400	0.470	-
14	0.860	1.080	0.860	1.360	0.841	0.360	0.340	0.400	0.520	-

† See Table 2 for treatment descriptions.
‡ SRN = Surin, KSR = Khok Samrong, KKN = Khon Kaen, KGT = Kuan Gut, SKH = Sakon Nakhon.

Table 1b. Nutrient Content of Rice Straw at Harvest at Different Locations in 1976.

Trt. No.†	Mg					SiO_2					Zn				
	SRN‡	KSR	KKN	KGT	SKN	SRN	KSR	KKN	KGT	SKN	SRN	KSR	KKN	KGT	SKN
	%					%					ppm				
1	0.090	0.300	0.150	0.080	-	9.45	15.19	8.99	11.49	8.99	20	9	61	96	325
2	0.100	0.320	0.160	0.110	-	8.59	14.69	6.69	9.59	5.67	64	7	52	109	98
3	0.100	0.290	0.200	0.110	-	8.19	14.89	8.69	11.29	11.45	56	5	46	93	130
4	0.115	0.330	0.205	0.100	-	8.59	15.19	8.59	8.59	6.96	48	20	36	75	73
5	0.090	0.320	0.190	0.120	-	7.29	14.79	8.59	11.69	11.56	43	5	48	98	33
6	0.110	0.320	0.190	0.135	-	11.09	15.19	8.99	9.29	9.41	43	7	36	84	30
7	0.090	0.320	0.215	0.115	-	10.29	13.69	9.99	11.59	13.70	36	3	56	80	78
8	0.145	0.390	0.210	0.150	-	9.19	15.89	9.99	12.49	19.05	34	9	36	80	75
9	0.060	0.320	0.180	0.080	-	8.29	14.69	8.49	9.79	8.03	61	7	45	91	85
10	0.080	0.310	0.190	0.100	-	8.89	14.69	8.39	10.29	13.05	70	9	64	98	105
11	0.080	0.320	0.185	0.090	-	8.39	15.49	8.69	16.49	4.92	52	16	64	100	155
12	0.080	0.320	0.130	0.100	-	7.39	15.49	7.69	12.49	7.60	70	16	70	124	138
13	0.080	0.351	0.190	0.110	-	0.99	14.69	8.19	10.49	10.15	48	7	61	138	305
14	0.170	0.280	0.235	0.130	-	8.69	8.79	8.49	9.99	9.95	129	9	80	120	103

† See Table 2 for treatment descriptions.
‡ SRN = Surin, KSR = Khok Samrong, KKN = Khon Kaen, KGT = Kuan Gut, SKH = Sakon Nakhon.

Table 2. Nutrient Content of Rice Straw at Harvest From the Ubon Experiment Station in 1977.

Trt. No.	Treatment Description	N	P	K	SiO_2	Zn
		.....	%	.....		*ppm*
1	No fertilizer	0.57a†	0.11ab	0.82ab	10.9cd	114bcd
2	NPK only	0.58a	0.12a	0.92ab	7.5d	55de
3	NPK + 156 kg Si ha^{-1}	0.62a	0.12a	0.83ab	13.2bc	44e
4	NPK + 156 kg Si ha^{-1} + 50 kg Mg ha^{-1}	0.55a	0.10abc	0.91ab	13.5bc	65de
5	NPK + 312 kg Si ha^{-1}	0.60a	0.09bc	0.98ab	16.6ab	44e
6	NPK + 312 kg Si ha^{-1} + 100 kg Mg ha^{-1}	0.56a	0.10abc	0.95ab	12.0bc	40e
7	NPK + 624 kg Si ha^{-1}	0.61a	0.08c	1.00a	18.5a	47e
8	NPK + 624 kg Si ha^{-1} + 200 kg Mg ha^{-1}	0.59a	0.09bc	0.83ab	16.6ab	41e
9	NPK + 9 kg Zn ha^{-1}	0.51a	0.11ab	0.85ab	8.7cd	104cde
10	NPK + 18 kg Zn ha^{-1}	0.56a	0.12a	0.90ab	10.6cd	175b
11	NPK + 36 kg Zn ha^{-1}	0.53a	0.12a	0.80ab	8.6cd	149bc
12	NPK + 72 kg Zn ha^{-1}	0.58a	0.12a	0.64b	9.9cd	153bc
13	NPK + Si + Zn	0.53a	0.09bc	1.05a	12.1bcd	158bc
14	NPK + Si + Mg + Zn	0.55a	0.10abc	1.08a	16.8ab	278c
	CV (%)	14.2	12.8	23.0	24.1	38.0

† Any two treatment means followed by the same letter are not significantly different at 5% probability level by Duncan's Multiple Range Test.

Table 3. Effect of Silica, Magnesium and Zinc on Paddy Yield, Applied in Combination with NPK at Ubon (UBN)†.

No.	Treatment						Grain Yield		
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	1975	1976	1977
	.....	.....	.....	.....	.....	*kg ha⁻¹*	.....	.....	.....
1	0	0	0	0	0	0	1340f‡	1610g	1760e
2	75	37.5	75	0	0	0	1990de	3360cde	2940cd
3	75	37.5	75	156	0	0	2080cde	3450bcde	3020bcd
4	75	37.5	75	156	50	0	2140bcde	3240cde	3460abc
5	75	37.5	75	312	0	0	2390ab	4040a	3960a
6	75	37.5	75	312	100	0	2230bcd	3390bcde	3660ab
7	75	37.5	75	624	0	0	2540a	3910ab	3760a
8	75	37.5	75	624	200	0	2360abc	3710abc	3960a
9	75	37.5	75	0	0	9	1940de	2650f	2990cd
10	75	37.5	75	0	0	18	2120bcde	2990def	3020bcd
11	75	37.5	75	0	0	36	1870e	2960def	2460d
12	75	37.5	75	0	0	72	2000de	2930ef	2940cd
13	75	37.5	75	312	0	36	2420ab	3710abc	3890a
14	75	37.5	75	312	100	36	2170bcde	3480bcd	3440abc
	CV (%)						9	10	9

† In 1975, the potash rate was 37.5 kg ha^{-1} which was too little for this Station. In 1978, the experiment was lost by flood.

‡ Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 4. Effect of Silica, Magnesium and Zinc on Paddy Yield at Sakon Nakhon (SKN).†

No.	Treatment						Grain Yield		
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	1975	1976	1977
	..... *kg ha*$^{-1}$								
1	0	0	0	0	0	0	2120d‡	1650e	1510d
2	75	37.5	75	0	0	0	3120abc	2480d	1960c
3	75	37.5	75	156	0	0	3340abc	3840bc	2560a
4	75	37.5	75	156	50	0	3080abc	3230bc	2390ab
5	75	37.5	75	312	0	0	3290abc	3500ab	2610a
6	75	37.5	75	312	100	0	2890bc	3520ab	2720a
7	75	37.5	75	624	0	0	3500ab	3960a	2670a
8	75	37.5	75	624	200	0	3030abc	3370bc	2380ab
9	75	37.5	75	0	0	9	2940bc	2580d	2190bc
10	75	37.5	75	0	0	18	2710cd	2860cd	2050bc
11	75	37.5	75	0	0	36	2850bc	2940cd	2040bc
12	75	37.5	75	0	0	72	3160abc	2620d	2050bc
13	75	37.5	75	312	0	36	3720a	3640ab	2640a
14	75	37.5	75	312	100	36	3180abc	3340bc	2660a
		CV (%)					14	12	9

† In 1975, the potash rate was 37.5 kg ha^{-1} which turned out to be the limiting factor in the Station. In 1976, the experiment was lost by drought.

‡ Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 5. Effect of Silica, Magnesium and Zinc on Paddy Yield, Applied in Combination with NPK at Khok Samrong and Khon Kaen†.

No.	Fertilizer Treatment						Paddy					
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	Khok Samrong			Khon Kaen		
							1976	1977	Mean	1975	1976	Mean
	kg ha^{-1}											
1	0	0	0	0	0	0	1810	1390	1600f‡	1910	1320	1610c
2	75	37.5	37.5	0	0	0	3280	2740	3010cd	3630	3540	3590b
3	75	37.5	37.5	156	0	0	3080	2840	2960dc	3730	3820	3780ab
4	75	37.5	35.5	156	50	0	3440	3410	3420abcd	3940	3920	3930ab
5	75	37.5	37.5	312	0	0	3720	3140	3430abcd	3840	4070	3960ab
6	75	37.5	37.5	312	100	0	3580	2980	3280abcd	3950	3880	3920ab
7	75	37.5	37.5	624	0	0	3520	2810	3170bcd	3880	4240	4060a
8	75	37.5	37.5	624	200	0	2820	2430	2620c	3640	4350	3990ab
9	75	37.5	37.5	0	0	9	3240	3460	3350abcd	4190	4120	4160a
10	75	37.5	37.5	0	0	18	3750	3740	3740ab	3710	4100	3900ab
11	75	37.5	37.5	0	0	36	3960	3710	3830a	3780	3740	3760ab
12	75	37.5	37.5	0	0	72	3840	3340	3590abc	3780	4020	3900ab
13	75	37.5	37.5	312	0	36	3790	3240	3510abcd	4010	4200	4100a
14	75	37.5	37.5	312	100	36	3910	3530	3720ab	3830	3900	3860ab

† After 1975, the potash rate was 75 kg ha^{-1}.

‡ Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 6. Effect of Silica, Magnesium and Zinc on Paddy Yield, Applied in Combination with NPK at Surin.

No.	Treatment						Grain Yield			
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	1975	1976	1977	1978
	..... *kg ha* $^{-1}$									
1	0	0	0	0	0	0	1980b†	3090b	2270b	2420ab
2	75	37.5	75	0	0	0	2780a	3880ab	2890ab	3100ab
3	75	37.5	75	156	0	0	2600ab	3820ab	3440a	3630ab
4	75	37.5	75	156	50	0	2780a	3590ab	3270a	3160ab
5	75	37.5	75	312	0	0	2840a	3440ab	3480a	3150ab
6	75	37.5	75	312	100	0	3150a	3820ab	3040ab	3430ab
7	75	37.5	75	624	0	0	2710a	3730ab	3340a	3480ab
8	75	37.5	75	624	200	0	2740a	3480ab	2960ab	3340ab
9	75	37.5	75	0	0	9	3210a	3830ab	3390a	3210ab
10	75	37.5	75	0	0	18	2700a	3780ab	3560a	3340ab
11	75	37.5	75	0	0	36	3140a	3670ab	3110ab	2710b
12	75	37.5	75	0	0	72	2990a	3820ab	3140ab	3280ab
13	75	37.5	75	312	0	36	2730a	3990ab	3230a	3520ab
14	75	37.5	75	312	100	36	3020a	4100a	3510a	3900a
		CV (%)					15	12	10	18

† Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 7. Effect of Silica, Magnesium and Zinc on Paddy Yield, Applied in Combination with NPK at Kuan Gut and Nakon Srithamarat.

No.	Treatment						Grain Yield				
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	Kuan Gut			Nakon Srithamarat	
							1975	1976	1977	1976	1977
	.....	.....	.....	.....	.....	.....	*kg ha⁻¹*	.....	.....	.....	.....
1	0	0	0	0	0	0	1650d†	2320b	1490b	1650b	1380b
2	75	37.5	75	0	0	0	3040abc	3180a	2790a	2730a	2610a
3	75	37.5	75	156	0	0	2800bc	3360a	2840a	2800a	2680a
4	75	37.5	75	156	50	0	3010abc	3290a	2980a	2940a	2420a
5	75	37.5	75	312	0	0	2900abc	3380a	2970a	3050a	2560a
6	75	37.5	75	312	100	0	3010abc	3340a	2960a	3020a	2710a
7	75	37.5	75	624	0	0	2860abc	3460a	2850a	2720a	2650a
8	75	37.5	75	624	200	0	2820bc	3240a	2960a	2930a	2070a
9	75	37.5	75	0	0	9	3100ab	3220a	3110a	2900a	2660a
10	75	37.5	75	0	0	18	2990abc	3360a	2970a	2890a	2590a
11	75	37.5	75	0	0	36	3190a	3090a	3140a	2690a	2620a
12	75	37.5	75	0	0	72	2820bc	3190a	2990a	2890a	2710a
13	75	37.5	75	312	0	36	2720c	3310a	2780a	2990a	2840a
14	75	37.5	75	312	100	36	2990abc	3490a	3130a	2720a	2630a
		CV (%)					8	9	9	9	9

† Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 8. Effect of Silica, Magnesium and Zinc on Paddy Yield, Applied in Combination with NPK (1977) at Phrae.†

No.	Treatment						Grain Yield		
	N	P_2O_5	K_2O	SiO_2	MgO	ZnO	1975	1977	1978
	..... *kg ha*$^{-1}$								
1	0	0	0	0	0	0	2690b‡	3660b	3630b
2	75	37.5	75	0	0	0	3740a	4810a	4010a
3	75	37.5	75	156	0	0	3490a	5190a	3960a
4	75	37.5	75	156	50	0	3740a	5010a	4450a
5	75	37.5	75	312	0	0	3480a	4770a	3860a
6	75	37.5	75	312	100	0	3340a	5050a	3920a
7	75	37.5	75	624	0	0	3360a	4820a	3990a
8	75	37.5	75	624	200	0	3270a	5540a	3970a
9	75	37.5	75	0	0	9	3710a	5300a	4160a
10	75	37.5	75	0	0	18	3630a	4870a	3990a
11	75	37.5	75	0	0	36	3510a	5160a	3890a
12	75	37.5	75	0	0	72	3780a	5580a	4160a
13	75	37.5	75	312	0	36	3380a	5120a	4020a
14	75	37.5	75	312	100	36	3580a	4950a	3920a
	CV (%)						9	12	11

† In 1978, the experiment was discontinued as there was no prospect of special element ever being effective.

‡ Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Table 9. Effect of Silica and Zinc on Paddy Yield, Applied in Combination with NPK at Sakon Nakhon (SKN) and Surin (SRN) in 1978.

No.	Treatment					Grain Yield	
	N	P_2O_5	K_2O	SiO_2	ZnO	SKN	SRN
	.....	.....	.....	*kg ha⁻¹*	.....	.....	.....
1	0	0	0	0	0	1490de†	1980c
2	0	0	0	312	0	1690cde	2090bc
3	0	0	0	0	18	1390e	1990c
4	37.5	37.5	37.5	0	0	2000bcd	2610abc
5	37.5	37.5	37.5	312	0	2690a	2760ab
6	37.5	37.5	37.5	0	18	1810cde	2580abc
7	37.5	37.5	37.5	312	18	2380ab	2380abc
8	75	37.5	75	0	0	2440ab	2450abc
9	75	37.5	75	312	0	2660a	2960a
10	75	37.5	75	0	18	2080bc	2660abc
11	75	37.5	75	312	18	2610a	2780ab
		CV (%)				16	18

† Any two treatment means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test.

Silica

Yield data indicate that there was a significant response to the application of silica at Ubon, Sakon Nakhon and Khon Kaen. Response at Surin was also positive. But at Phrae, Khok Samrong and Nakon Srithamarat there was no significant response to silica.

Response to silica is particularly striking after 1977 when the rate of potash applied was increased from 37.5 kg/ha to 75 kg/ha. Potash appears to have been the main factor which limited the response of rice to silica applications.

Silica is not an essential element; however, its beneficial effect on rice, i.e., increased stem strength, has been established. Rice producing countries now recognize the importance of available silica in paddy fields. For example, Japan currently utilizes about 1 Mt/yr of silica-based fertilizers on rice.

Imaizumi and Yoshida (1958) state that if the silica content of rice straw at harvest is less than 11 percent, "a profitable increase in yield with the highest possibility" is assured. A very marked response of rice to silica occurred at Sakon Nakhon where the silica content of straw at harvest was about nine percent in the absence of fertilizer (NPK) application (Tables 1b and 9). The silica content drops to about five percent when rice is fertilized with 75 kg/ha of N, along with P and K. The probable reason for this is that the rice plant undergoes extra vegetative growth from the nitrogen, but without additional silica. The tables also indicate that the application of silicate material markedly increased the silica content of straw up to 19 percent and also increased the yield of rice.

At Ubon the silica content of straw for the control treatment was about ten percent which decreased to 7.5 percent if NPK was applied without silicate. Silica content of straw at the two locations suggests that in some cases the crop requirement for silica may have exceeded the natural rate of silica release from soil minerals. Thus, paddy yields may be limited by insufficient amounts of available silica. Most farmers in the Northeast are not operating toward the upper end of the yield-response curve. Thus, silica deficiencies in rice are not often apparent. Once farmers start to apply fertilizers, the yield potential will increase and silica deficiencies will be expressed, along with other nutrient deficiencies (Ishizuka and Tanaka, 1959; Kanareugsa *et al.*, 1971).

An experiment was started in 1978 to determine at what level of NPK application silica deficiency is manifested. This experiment was started in Sakon Nakhon, Surin, Ubon and Khon Kaen. The results of the Sakon Nakhon and Surin experiments are shown in Table 9. Because of excessive flooding, results from the other two locations are not available. When no NPK fertilizer is applied, rice response to silica is negligible. However, when 37.5 kg/ha each of NPK was applied, the effect of silica was significant at Sakon Nakhon. In Surin there was a yield response to silica at all levels of NPK fertilizer, especially at the highest rate.

The levels of available silica in soils at various experiment stations are very low according to the following data by Motomura (1973). An exception is the value reported for Nakon Srithamarat which indicates more than 300 ppm of available SiO_2.

Sites	**Available SiO_2**
	ppm
Sakon Nakhon	6
Ubon	7
Surin	13
Phrae	29
Khon Kaen	40
Kuan Gut	48
Khok Samrong	67
Nakon Srithamarat	322

Imaizumi and Yoshida (1958) proposed that when soil contains less than 110 ppm of available silica, yield response to applied silica is likely. If this is applicable to Thailand, there should be a response to silica at all stations, except for Nakon Srithamarat. However, highly significant responses to silica were obtained only at Sakon Nakhon and Ubon where the available silica content of the soil was extremely low. A less striking response, though significant, was obtained at Khon Kaen.

Plant analyses shown in Tables 1b and 3 to 9 suggest that there should be a response to applied silica in Sakon Nakhon, Ubon, Khon Kaen and Surin. There was little response to applied silica at Phrae, Kuan Gut and Khok Samrong as far as paddy yield is concerned, even though the soil analysis data would tend to predict that a positive response was possible. The reasons for this discrepancy are not apparent.

These data indicate that critical nutrient levels established in countries with temperate climates should be adopted with caution in tropical countries. Jackson and Sherman (1953) stressed that weathering of soil minerals under tropical conditions occurred at a much faster rate than in temperate climates. Silica becomes soluble during the weathering process. Therefore, critical levels of nutrients in the tropics would probably be much lower than in temperate regions since nutrients such as silica can be replenished more rapidly from weathering under hot tropical conditions.

There is also a favorable effect of temperature on nutrient absorption. Mitsui (1951) found that the absorption of silica by rice roots in paddy was a metabolic process dependent upon temperature. The optimum temperature for absorption is about 30°, a temperature which often occurs under tropical conditions. Takahashi (1955) found out that the percent silica in rice plants grown under warm conditions was consistently higher than in rice grown under cool conditions. This suggests that tropical conditions are favorable for silica absorption.

Magnesium

No response to magnesium was observed at any site in any year of the present experiment. The magnesium contents of the surface soils of the various experiment stations are shown in Table 10.

Table 10. The Magnesium Contents of the Surface Soils at Various Experiment Stations in Thailand (Motomura, 1973).

Experiment Station	Mg	MgO
	meq 100 g^{-1} soil	*ppm*
Ubon	0.10	20
Sakon Nakhon	0.22	44
Surin	0.29	58
Khon Kaen	0.64	128
Phrae	0.99	200
Kuan Gut	1.49	298
Khok Samrong	3.91	782
Nakon Srithamarat	10.8	2160

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Managing Soil Acidity in Northeast Thailand

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ABSTRACT. The results of soil analyses, field and greenhouse experiments conducted in 1983 and 1984, plus a review of literature will be presented.

Soils of the Northeast generally develop a low pH, approximately 4.5, in the dry season but are not extremely acid. Buffering capacities are low due to low CECs and the pH is easily increased. The liming effects of waterlogging are usually sufficient to raise soil pH above critical levels in both paddy and upland soils.

Animal manures which have been added to the rice seedbeds probably complex soluble aluminum in the soil as well as precipitate aluminum by raising the soil pH.

The pH of rainfed rice paddies declines between rains as the soil dries. Part of the drought damage may be a result of increases in soil acidity and decreases in nutrient availability, particularly phosphorus.

Yield responses to lime have been found for peanuts, watermelons, Cuban kenaf and perhaps for rice. However, it is not known if the responses are due to the increased availability of needed plant nutrients or a reduction in soil acidity.

The ammonium acetate lime requirement test, commonly used in Thailand, grossly overestimates the need for lime.

Generally, lime additions should not exceed 100 kg/rai in order to avoid the possibility of inducing micronutrient deficiencies or imbalances.

Introduction

At first sight, any soil scientist visiting Northeast Thailand would say "These soils need generous additions of everything—lime, fertilizer and organic matter." However, it quickly becomes apparent that the farmers usually cannot afford to purchase any production inputs. In general, the cost of such inputs is too high for the extra production to be profitable. Therefore, an agricultural adviser must look for improvements that can be made with little or no cash invested. In going through such a process in the fall of 1982, the author concluded that better water management was the best low-cost intervention possible. High soil water content directly improves rice yields, increases the availability of plant nutrients and dramatically reduces soil acidity. Therefore, managing rainfall runoff in ways that keep as much land saturated for as long as possible became a project priority. Constructing fail-safe diversion weirs seemed to be the best adjunct to the elaborate bunding system already in place.

Where there is not enough water to keep the soil saturated or submerged, a second best approach appeared to be using some of the country's abundant supply of limestone to neutralize soil acidity.

Thus, the two soil priorities chosen for NERAD were first, the self-liming, self-fertilizing natural process that comes from saturating the soil and second, the use of a naturally abundant supply of calcium carbonate (limestone) that could be provided to farmers at very low cost. The low buffering capacity of these soils means that only small additions of lime are needed to obtain the liming benefit.

To date, our soil fertility and soil chemistry work has characterized soil acidity changes throughout the season, demonstrated how water and lime can substitute for one another, and attempted to partition the benefits of saturating the soil with water between the water needs of the crop and the indirect benefits of correcting soil acidity, e.g., increasing the availability of plant nutrients such as phosphorus.

Characteristics of Northeastern Soils

Analyses of soil samples taken from farmers' fields used in the 1983-84 NERAD cropping system trials are shown in Table 1. The mean soil pHs for Srisaket and Roi Et were below 5.0 whereas those for Chaiyaphum and Nakon Phanom were considerably higher. This difference is most likely due to the large percentage of paddy land in the Srisaket and Roi Et Tambons. Generally, paddy soils have been cropped for much longer than upland soils. Soil test values of less than 10 and 50 ppm are considered to be low for P and K, respectively.

Soil Acidity and Soil Moisture

Most soil samples collected in Thailand are taken in the dry season. This is necessary in order for the soil test results to be used as a guide for fertilizer and lime additions to crops as they are being planted. However, samples collected at the peak of the dry season are more acid than those collected during most of the crop's growing cycle. Soils are more acid in the dry season because the ferrous iron (Fe^{+2}) that accumulates during the wet season is oxidized to ferric iron (Fe^{+3}) as the soil dries and atmospheric oxygen returns to the soil profile (Brinkman, 1978). Two hydrogen ions are produced for each ferrous ion oxidized (see Eq. 1). The pH goes quite low because of the low buffering capacity of the Northeast soils, soils with very low clay and organic matter content.

Ragland *et al.* (1985) measured the pH and exchangeable aluminum level in a Northeast paddy soil and found that measurements fluctuated greatly and the changes closely paralleled changes in rainfall. A summary of the control lime treatment plots for rice and peanut studies is shown in Table 2. The soil pH varied by approximately one pH unit and exchangeable aluminum threefold with time of sampling. It has, therefore, been difficult to establish critical pH and levels for aluminum toxicity.

An additional complication is the variation in soil acidity with the depth of soil sampling as shown in Table 3. Results are for the rice plots described above from 0 to 15 cm soil depth and 0 to 1 cm. On February 13 the soil was more acid in the 0 to 1 cm sample; on May 13 acidity was equivalent at both sampling depths.

These data suggest that as of February 13, the acid-producing ferrous to ferric iron conversion process had not progressed down the entire 0 to 15 cm depth, but had by May 13.

Iron Transformations and Soil Acidity

Brinkman (1979) has unified his work and that of others on iron transformations and soil acidity in seasonally wet and dry tropical soils, in a process named ferrolysis. The overall process is illustrated in Figure 1.

The key reactions involved in the ferrolysis process are the oxidation of ferrous iron by aerobic microorganisms as the soil dries:

$$\underset{\text{(soluble)}}{Fe^{+2}} + \tfrac{1}{4}\,O_2 + 2\tfrac{1}{2}\,H_2O \rightarrow \underset{\text{(insoluble)}}{Fe(OH)_3} + 2H^+; \qquad [1]$$

Table 1. Analyses of Soil Samples From Farmers Fields Used in the 1983-84 NERAD Cropping Systems Trials.

No. of Samples	Province	Tambon	Soil pH			Organic Matter			Phosphorus			Potassium		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
						..... %			..... ppm					
79	Srisaket	Tae	4.7	4.1	6.6	.8	.3	1.7	19	2	104	20	9	81
140	Srisaket	Taket	4.9	4.1	7.1	.6	.2	1.7	17	2	66	18	5	81
62	Roi Et	Nong Kaew	4.9	4.0	6.7	.5	.3	0.7	9	1	25	18	5	36
40	Roi Et	Na Muang	4.6	4.0	5.9	.6	.4	1.0	15	2	46	26	5	81
44	Chaiyaphum	Kwang Jon	5.6	5.1	6.4	.6	.3	1.3	11	1	72	25	11	87
13	Chaiyaphum	Lahan	5.4	4.4	6.4	.9	.3	3.1	16	1	95	64	23	134
31	Nakon Phanom	Na Ngua	5.2	4.5	6.2	.8	.3	1.9	10	3	45	26	9	64
21	Nakon Phanom	Na Thom	5.5	5.1	6.0	2.5	1.3	3.7	6	2	14	128	54	317

Table 2. Changes in Soil pH, Exchangeable Aluminum and Aluminum Saturation of CEC on Unlimed Adjacent Fields Planted to Rice and Peanuts.

Soil Sampling Dates	pH		Al		Al Saturation of CEC	
	Rice	Peanut	Rice	Peanut	Rice	Peanut
			meq 100 g⁻¹		..... %	
July 20 (planting)	5.31	4.94	1.62	2.44	29	44
August 29	5.45	5.13	1.00	2.09	18	37
November 4	5.39	5.36	1.38	1.76	25	31
November 29 (harvesting)	5.25	5.20	1.93	1.25	34	22
January 2	4.94		2.24		40	
February 13	5.08		1.95		35	
May 13	4.67		3.40		60	

Table 3. Differences in Soil pH and Exchangeable Aluminum with Date and Depth of Sampling.

Lime	pH				Exchangeable Al			
	Feb 13		May 13		Feb 13		May 13	
	0-15 cm	0-1 cm	0-15 cm	0-1 cm	0-15 cm	0-1 cm	0-15 cm	0-1 cm
kg rai⁻¹					..... *meq 100 g⁻¹*			
0	5.08	4.62	4.6[illegible]	4.48	1.93	3.37	4.68	5.23
330	5.28	4.65	4.88	4.88	0.85	1.73	3.41	3.65
1100	5.92	5.55	5.55	5.70	0.14	0.53	2.22	1.74

and the reduction of ferric iron by anaerobic microorganisms when the soil is water-saturated or submerged:

$$\underset{\text{(insoluble)}}{Fe(OH)_3} + 3H^+ \rightarrow \underset{\text{(soluble)}}{FE^{+2}} + 3H_2O. \qquad [2]$$

Aerobic and anaerobic conditions in a soil are not simply two distinct states but rather a continuum depending on the degree of water saturation, levels of organic matter and time exposed to wet and dry conditions. The sequence of reactions in Table 4 show the order in which oxidized compounds are reduced as the soil becomes increasingly saturated with water.

Although not shown as a reactant, fresh organic matter must be present as an energy source for the microbes in order for the reactions to proceed. Accordingly, reactions are largely confined to the surface soil layer.

Aerobic microorganisms drive the oxidation reaction with atmospheric oxygen, the electron acceptor in microbial respiration (Patrick and Reddy, 1978). Anaerobic organisms, growing in the absence of atmospheric oxygen, use nitrate, manganese and iron as their major electron acceptors (Patrick and Reddy, 1978). In soils iron is the major reactant because of its abundance. Patrick and Reddy (1978) state that iron usually exceeds the total amount of the other redox elements in the soil by a factor of 10 or more.

An indication of how rapidly these reduction reactions occur in submerged soils is shown in Figure 2 (Patrick and Reddy, 1978).

The important soil fertility changes with flooding are increases in the supply of available N, P, Si, Mo and sometimes K, and reduced Zn and Cu availability (DeDatta, 1981).

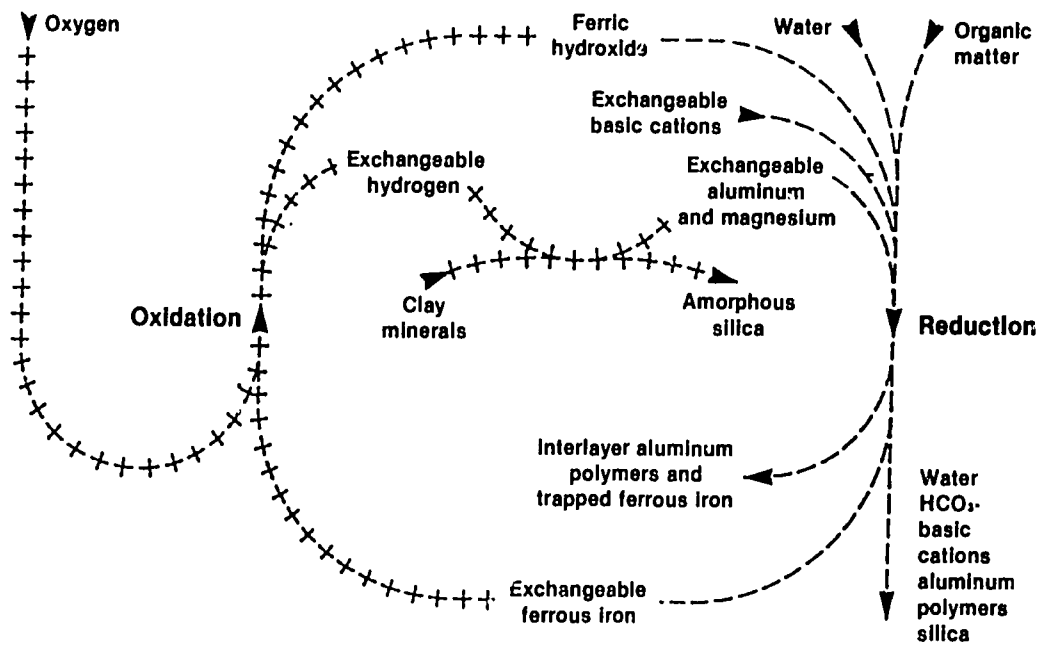

Figure 1. Relationship of the Oxidation and Reduction of Iron to Soil Acidity in Seasonally Wet and Dry Tropical Soils (After Brinkman, 1979).

Table 4. Thermodynamic Sequence of Soil Reduction.

System	E_o†
	V
$O_2+4H^++4e^- = 2H_2O$	0.814
$2NO_3^-+12H^++10e^- = N_2+6H_2O$	0.741
$MnO_2+4H^++2e^- = Mn^{2+}+2H_2O$	0.401
$CH_3COCOOH+2H^++2e^- = CH_3CHOHCOOH$	-0.158
$Fe(OH)_3+3H^++e^- = Fe^{2+}+3H_2O$	-0.185
$SO_4^{2-}+10H^++8e^- = H_2S+4H_2O$	-0.214
$CO_2+8H^++8e^- = CH_4+2H_2O$	-0.244
$N_2+8H^++6e^- = 2NH_4+$	-0.278
$NADP^++2H^++2e^- = NADPH+H^+$	-0.317
$NAD^++2H^++2e^- = NADH+H^+$	-0.329
$2H^++2e^- = H_2$	-0.413
Ferredoxin (ox) $+e^-$ = Ferredoxin (red)	-0.431

† E_O corrected to pH 7.0 (Ponnamperuma, 1976).

Sanchez (1976) summarized the effects of soil flooding, stating that "the main consequences of soil reduction are changes of soil pH to between 6 and 7 regardless of anaerobic pH, denitrification of nitrates and accumulation of ammonium, and increases in the solubility of iron, manganese and, in certain cases, phosphorus. The magnitude of these changes also varies with soil properties, ranging from highly beneficial to neutral and then to highly toxic to the rice plant. Upon drying, these processes are also reversible."

For Northeast Thailand soils, organic matter content is so low that the accumulation of toxic levels of soluble iron or organic acids, alluded to in Sanchez's summary, is not likely. However, the accumulation of toxic aluminum seems almost certain as the reduced soils dry and atmospheric oxygen returns. This situation arises because the hydrogen ion, produced when ferrous iron is oxidized to ferric iron (Eq. 1), is absorbed on the exchange sites of the clay. Hydrogen clay is not stable. A small amount of the clay is decomposed with the release of aluminum and secondary silica. Essentially all of the hydrogen ions are consumed in this process and the soils become acidic due to the acid generating effect of

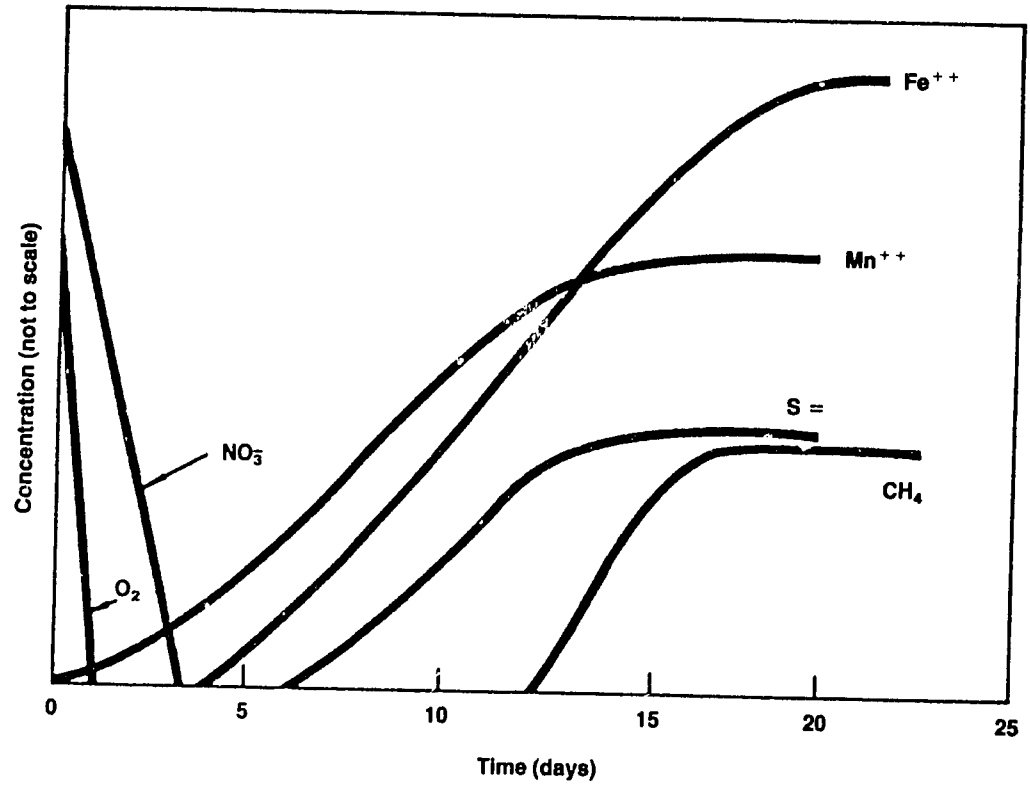

Figure 2. The Sequential Reduction of Several Soil Redox Systems in Rice Soils.

the presence of aluminum. The reason soil water systems, with soluble aluminum present, have low pH is that a small fraction of Al is spontaneously hydrolyzed:

$$Al^{+3} + H_2O \rightarrow Al(OH)^{+2} + H^+ \qquad [3]$$

The small quantity of hydrogen produced from the hydrolysis reaction can be detected by a pH meter. When the pH is 4.5 or less, essentially all of the aluminum remains as trivalent cations (Carson and Dixon, 1979). This aluminum species is toxic to most commonly grown field crops and probably rice as well. If there are enough hydroxyl ions present for the pH to be above 4.5, the aluminum will be hydrolyzed in a stepwise manner. Most aluminum is precipitated when the pH reaches 5.3 to 5.5. Partially hydrolyzed aluminum, hydroxyaluminum, tends to permanently block the cation exchange capacity. Reduced CEC and the long-term consequences of clay decomposition, due to endless repetitions of wet and dry cycles, are seriously degrading tropical soils, especially light-textured ones found in the Northeast. Brinkman (1977) has concluded that the ferrolysis process has reduced the clay content in surface horizons of a Roi Et soil near Kalasin from 20 percent to less than ten percent and reduced its CEC from 10 meq/100 g to 1 to 2 meq/100 g.

A summary of Japanese-Thai soil characterizations (Motomura *et al.*, 1979; Ogawa *et al.*, 1975) of Northeast soils indicates how clay contents in paddy and upland soils vary. A summary of the textural differences in the plow layer of 41 paddy and 13 upland soils appears in Table 5.

Table 5. Textural Differences in the Plow Layer of Northeast Paddy and Upland Soils.

Land Use	Clay	Silt	Sand	pH	N†
	.....	%	.....		
Paddy	10	20	70	4.8	41
Upland	17	21	62	5.1	13

† Number of samples averaged.

Brinkman (1978) summarized the ferrolysis process as follows:

> "In the wet season, reduction of ferric oxides produces dissolved ferrous iron, which displaces and mobilizes exchangeable bases. The bases (and dissolved ferrous iron) are partially removed by leaching. In the dry season, oxidation of exchangeable ferrous iron produces ferric oxides and exchangeable hydrogen leading to partial decomposition of the clay and release of aluminum and silica. Partial neutralization of exchangeable aluminum along with reduction of ferric oxides in the wet season produces relatively stable ferrous-aluminum hydroxide interlayers in 2:1 clays, leading to further decrease of the cation exchange capacity. Ferrolysis is confined mainly to the surface horizons where fresh organic matter is supplied annually."

The last sentence of this statement naturally follows since the microorganisms that cause the iron transformations must have fresh organic matter as a carbon and energy source in order to grow. Brinkman and Dieleman (1977) suggested possible soil management schemes to reduce soil degradation due to ferrolysis, and also specific methods for rehabilitating the acid and saline soils in the Northeast.

Aluminum Toxicity and Liming

The frequent wetting and partial drying of Northeastern soils during the rainy season makes the acid producing part of the ferrolysis process potentially important for the growth and yield of both paddy and upland crops. Our working hypothesis was that part of the drought damage so commonly seen in the Northeast is due to aluminum toxicity and that liming will increase yields in dry years when the soil frequently dries between rains, but not in years of adequate rainfall.Where liming is a common practice, agronomists tend to use pH 5.5 as a critical level and advise farmers to apply enough lime to keep the soil above this level. This is a sound approach for commercial farmers to avoid aluminum toxicities and to increase the availability of phosphorous as illustrated in Figure 3.

In the tropics, where subsistence farming predominates, a more conservative approach must be taken to liming. This caution is evident in the critical pHs reported for tropical soils. For example, Foster *et al.* (1980), reporting the results of twenty fertilizer and liming trials in Malaysia, found that the yields of peanuts, soybeans, maize and mung beans severely declined below pH levels of 4.2, 4.5, 4.8 and 5.1, respectively. Bandy (1983), working in Peru, concluded that the critical pHs for peanuts, maize and rice were 4.6, 4.8, and 5.0, respectively. Kamprath (1980) questioned the usefulness of the critical pH and recommended instead that the percent aluminum saturation of the CEC by aluminum was a more important factor in predicting toxic levels of aluminum. He concluded that toxicity was likely if aluminum saturation of the CEC was greater than

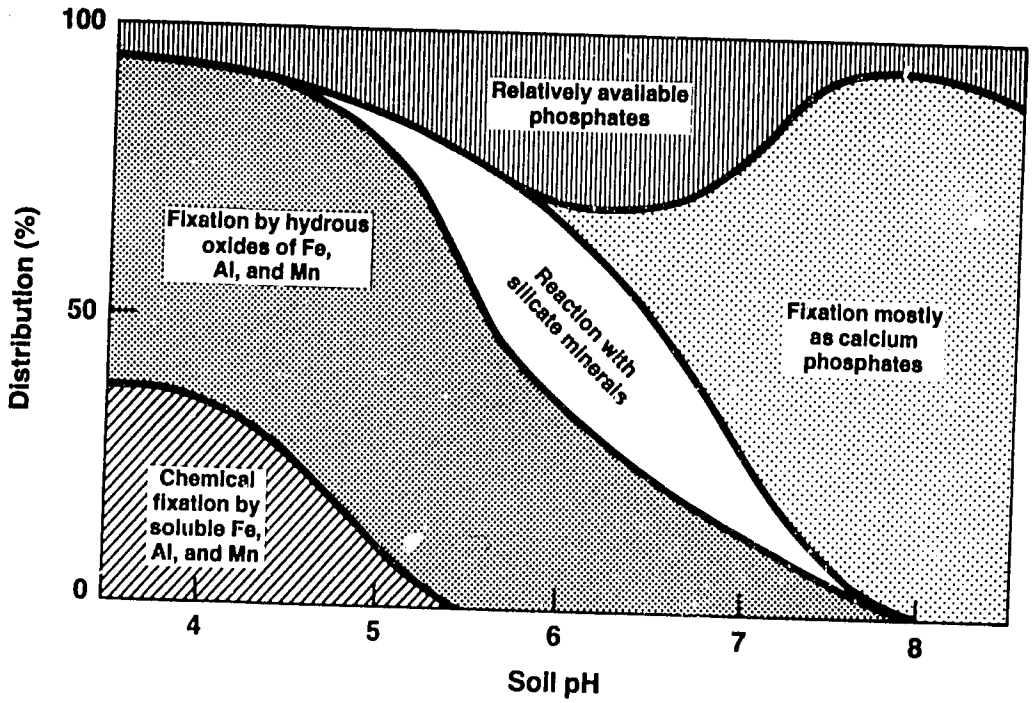

Figure 3. Percent Distribution of Phosphate Species in Soil as Affected by pH (Brady, 1974).

60 percent. This conclusion was based on the work of Nye *et al.* (1961) who found that trivalent aluminum is held so tightly by exchange sites that very little of it is in soil solution until exchangeable aluminum occupies 60 percent or more of the soil's CEC. Others have sought to establish critical percentages of aluminum saturation for different crops. Foster *et al.* (1980) reported that the values for groundnuts, soybeans, corn and mung bean were 65, 45, 25 and 15 percent, respectively.These reports did not describe the moisture status of the soils when they were sampled for the determination of pH and exchangeable aluminum. For tropical soils, this information is absolutely essential because it is the best indication of whether a soil is oxidized or reduced. Without data on whether the sampled soil was wet or dry, i.e., reduced or oxidized, confusion in the literature about critical pH and percent of aluminum saturation could easily arise.

Ragland *et al.* (1985) found no lime response for peanuts or rice where the soil pH was above 5.0 to 5.4 during the growing season. The trials were conducted in 1983, a year with ideal rainfall and constant soil submergence in the rice paddy. In 1984, a soil pH of 4.6 was observed at transplanting and a lime response was obtained. The paddy dried out many times between transplanting and harvest. A 1984 liming study with watermelons on a soil of pH 5.1 gave a 35 percent yield increase from 100 kg/rai (625 kg/ha) of lime. The farmer also reported improvement in the color and sweetness of the melons.

Suwanarit (1985) reviewed the results of several liming studies on yields of various crops grown in Thailand. Soils of pH 5.0 or less generally showed yield responses to lime for mung bean, peanut, soybean and sesame, but not for cassava even on a soil of pH 4.5. One study measured the effects of applying lime and gypsum at the pegging stage for peanuts grown on extremely acid soils. No yield increases were found.

Soil Water-Induced Acidity Changes in Upland Soils

Reducing conditions occur not only in paddy soils. A clay pot study, summarized in Table 6 for a Reneau loamy sand, pH 4.6, revealed the extent to which the pH can change even when the soil is freely drained (Ragland *et al.*, 1985). The soil pH was measured at 11 days after planting Cuban kenaf, October 14, and at 48 days after planting, just after harvest.

These data illustrate how misleading pH measurements taken only at the beginning of an experiment can be, and may account for trials which do not show expected lime responses. Apparently, this soil had such a low buffering capacity (CEC 1.7 meq/100 g, 0.6 percent organic matter and 87, 7.5 and 5.5 percent sand, silt and clay, respectively) that even within the short period of 11 days from planting to the first pH measurements, the soil pH of all treatments had increased to the point that no lime response should be expected. Surprisingly, however, there was a clear yield response under the low-moisture regime as shown in Figure 4.

No explanation for this response is apparent since the pots were uniformly and generously fertilized with N, P and K. The response, nonetheless, was quite real. This apparent lime response was absent when the soil was watered to 32 percent moisture. It should be noted that this was a normal clay pot experiment with free drainage provided to all pots.

A maximum water holding capacity (container capacity) (Cassel and Nielsen, 1986) of 32 percent is approximately average for paddy soils in the Northeast and a little lower than average for upland soils. A summary of the Japanese-Thai soil characterization studies involving the water holding capacities of paddy and upland soils is shown in Table 7

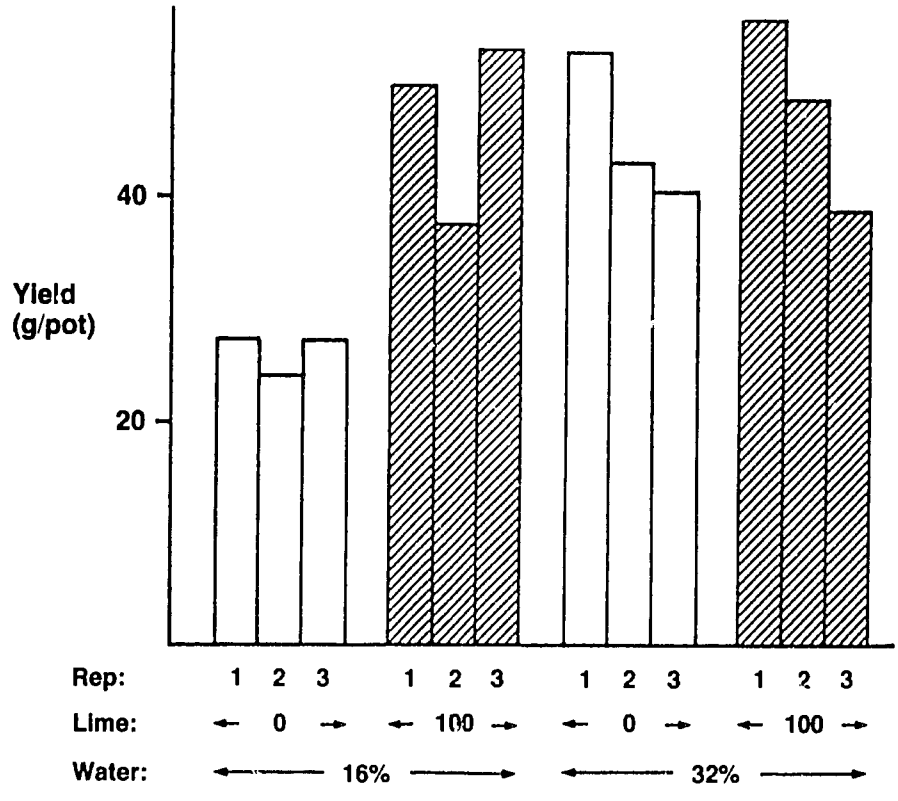

Figure 4. Yield Response of Rice to Addition of Lime in an Unflooded Pot Experiment.

Table 6. Changes in Soil pH During an Unflooded Pot Experiment as Affected by Addition of Lime (Ragland *et al.*, 1985).

Lime Added	Soil Moisture	pH		
		October 3†	October 14	December 20
kg rai^{-1}	%			
0	16	4.6	5.53	6.17
0	32	4.6	5.43	6.40
100	16	4.6	6.27	6.00
100	32	4.6	6.2	6.83

† The initial soil pH before treatments were imposed.

Table 7. Differences in the Water Holding Capacity of Paddy and Upland Soils in Thailand (Motomura *et al.*, 1979; Ogawa *et al.*, 1975).

Land Use	Maximum Water Holding Capacity			Number of Samples
	Ave	Min	Max	
	..... %			
Paddy	34	21	66	41
Upland	40	34	53	13

(Motomura *et al.*, 1979; Ogawa *et al.*, 1975). Based on the pot study and the Northeast soil characterization studies, it seems probable that most upland as well as paddy soils hold enough water to be sufficiently reduced during the rainy season to cause increases in soil pH.

Although partially reduced soil, where upland crops are growing, may solve acid soil problems and increase the availability of needed plant nutrients, the net effect will be negative if waterlogging causes oxygen starvation. Injury from waterlogging is very common in the Northeast, particularly for field crops at the seedling stage. Mung bean seems to be the most sensitive to flooding. Research is needed to establish the positive and negative effects of waterlogging on the oilseed crops being tested as prerice crops. The idea of such crops is to produce a useful product from the unreliable rainfall that begins in April but which is not sufficient for transplanting rice until late July or August.

Discussion

It seems justified to conclude that crops grown in Northeast Thailand respond to liming in the same ways as crops grown throughout the world. Situations exist here, however, that must be understood in order to add lime where it will be profitable and to avoid recommending it where no response will occur. First in this regard is the liming effect routinely derived from reducing conditions that develop when soils are water-saturated or submerged. Both paddy and upland soils in the Northeast are easily saturated because the unique distribution of soil particle sizes causes close packing and results in slow rainfall infiltration and permeability to water. Japanese-Thai profile characterization studies show that soil air volumes average 23 and 14 percent for paddy and upland soils, respectively (Motomura *et al.*, 1979; Ogawa *et al.*, 1975). Distinct plow pans and low organic matter contents also contribute to soil saturation and the reducing conditions that result. Finally, most soils of the Northeast are underlain with laterite and/or layers of clay at approximately 1 m. Perched watertables routinely appear because of this. If the rainfall is frequent enough, all paddies, lower, middle and upper, remain flooded and the area produces a large rice crop. Fukui (1982) has generalized that 2000 mm of rainfall are needed for stable rice production in tropical Asia. Nakon Phanom is the only province in the Northeast that receives this much rain. The other provinces range from less than 1000 to 1500 mm. Therefore, it is easily understood why all but the lower rainfed paddies frequently dry.

When the soil is no longer submerged or saturated, the reduced soil begins to oxidize, soil acidity increases, and the availability of plant nutrients, particularly phosphorus, decreases. Whether or not these changes decrease crop yield depends upon how the soil dries and the stage of plant growth when it does. It is reasonable, therefore, to expect liming to be of greater benefit in the drier years. The question naturally follows: Can lime reduce drought damage to rice and other crops? This question seems worthy of future experimentation.

Northeast farmers traditionally use animal manure on all high-value crops such as vegetables and tobacco grown during the dry season and on rice seedbeds planted early in the wet season. The benefits include increases in plant nutrients supplied, as well as a liming effect. Animal manure in Thailand is almost always allowed to air dry before it is moved to the field, causing much of the nitrogen to be lost as ammonia. This decreases its value as a nitrogen fertilizer, but increases its liming value. A few measurements of dry cattle manure in the Northeast show the pH to be greater than 8. Although the evidence is circumstantial, the patterns followed by farmers suggest that one benefit derived from applying animal manure is the control of soil acidity. Perhaps experiments should be designed to determine if lime increases the value of animal manures for crop production.

Wahab and Lugo-Lopez (1980) found coffee leaves to be very effective in raising soil pH and reducing exchangeable aluminum. Pangola grass was less effective. The liming effect is expected because the organic matter complexes the aluminum and the base-forming cations increase the soil pH.

Conclusions

Not enough liming studies have been done in the Northeast to know if liming is generally profitable or not. It is the author's impression that a majority of the trials reported show no benefit. The remainder range from small to large yield responses (Suwanarit, 1985). It is not known, however, what percent of the trials were on sites where lime responses can reasonably be expected. Too often the trials have been done without any knowledge of soil pH or the amount of exchangeable aluminum present. This has been particularly true of farm trials. Such trials should be stopped unless soil tests are done before the trial. Without soil tests farmers and agricultural advisers conclude that crops generally do not respond to lime in the Northeast. Another complication to trials conducted is that overliming may have occurred because the ammonium acetate lime requirement test, buffered at pH 7, greatly overestimates the lime needed on tropical soils (Kamprath, 1980). The neutral salt leaching procedure is more appropriate because it measures only

the acidity that will be encountered by the crop. The pH 7 buffer method measures the large quantity of pH-dependent acidity between pH 5.5 and 7.0 which does not affect crops growing in tropical soils. Unless the soil is water-saturated or submerged, soil pHs are seldom above 5.5. The following are criteria for where it is reasonable to expect a lime response and where it would be worth the agriculturalist's time to conduct a trial or demonstration:

1) For Northeast rainfed rice, when the dry season soil pH is 4.5 or less. The odds of a lime response under these conditions are increased the more often the paddy dries between rains.

2) For upland crops grown in the paddy, before or after rice, when the dry season pH is 5.0 or less.

3) For upland crops grown on upland sites in the rainy season, when the dry season pH is 5.0 or less.

4) For high-value crops, such as peanuts and watermelons, when the dry season pH is 5.5 or less.

Thailand has an abundance of limestone that could be supplied to farmers at a low cost. What now appears to be needed are more trials and demonstrations with low rates (0 and 100 kg/rai) of lime applied to fields that meet the criteria listed above. An efficient way to do this would be to split the plots of trials that are being conducted as fertilizer or cropping system trials. Such a program should quickly and inexpensively determine if liming would be profitable in the Northeast and establish if a market could be developed that would be large enough to justify establishing limestone crushers and a distribution system.

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Management of Soil Salinity in Northeast Thailand

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ABSTRACT. Salinity in the soils of Northeast Thailand is derived from rocks of the Mesozoic Korat Group in the upper Korat strata. Secondary salinization is caused by both nature and man-made processes such as land clearing, reservoir construction and the salt-making process. It is estimated that 17 percent of the land area of the Northeast region is salt-affected. For management purposes, the land has been classified as heavily, moderately, or slightly salt-affected, and potential salt source areas are designated. Salinity maps have been produced and are used for carrying out the management program by way of three principal approaches, i.e., prevention, reclamation and agronomic measures. All of these can involve soil, water and crop management strategies. Preventive measures are practiced in the potential salt source areas, while reclamation, utilizing leaching and drainage techniques, is conducted on the heavily and moderately salt-affected areas. Short-term salinity control can be achieved on the slightly salt-affected areas with low-cost technology.

Introduction

The Northeast of Thailand lies between 101° and 105° East longitude and 14° and 18° North latitude. It comprises an area of 155,000 km^2. The region consists of one-third of the Kingdom and has a population of about 16.8 million people, or about one-third of the total population of Thailand. However, it produces less than one-fifth of the gross national product. Probable reasons for such a low per capita income are the generally poor agricultural soils, the marked seasonality and variability of rainfall, and the extensive seasonal flooding in parts of the region. Eighty percent of the population is engaged in agriculture which is based primarily on rainfed paddy rice, cassava, kenaf and livestock. Rice is the major crop and is the most important constituent of the local diet, as well as one of the most important export commodities. Most of the productive land in the region is already in use and production can only be increased by raising crop yields on existing farms. In view of the rate of the population increase (approximately two percent per annum) and the likelihood of more area becoming unproductive because of salinity, this problem should be thoroughly investigated and managed at an early stage.

Salt Source and Distribution

The Northeast region of Thailand consists of a plateau with gently undulating topography in its interior. The average elevation of the region is 150 m. The plateau contains two basins: a relatively flat saucer-shaped one which tilts to the southeast called the Korat Basin, and a narrow, smaller one to the north called the Sakon Nakhon Basin. These basins are separated by the Phu Phan mountain range.

Coastal saline soils derive their salt mainly from seawater, while the salinity of the northeastern saline soils originates mainly from rocks of the Mesozoic Korat Group.

Salt-affected soils occur extensively in the Northeast region particularly in the Korat and Sakon Nakhon Basins where there is a high level of poverty. According to LANDSAT imagery of soil salinity, the area of salt-affected soil in the Northeast is approximately 2,850,000 ha or 17 percent of the total area (Sainanuwong *et al.*, 1980). Of the salt-affected area, 1.26 percent is strongly salt-affected, 3.87 percent is moderately salt-affected, and 12.9 percent is slightly salt-affected; the potential salt-affected areas comprise 15.54 percent of the area (Department of Land Development, 1980). Soils range from slightly (4 to 8 mmhos/cm) to moderately (8 to 16 mmhos/cm) to heavily salt-affected (16 mmhos/cm). A soil salinity distribution map of Northeast Thailand on a scale of 1:500,000 has been prepared through the interpretation of satellite imagery and compatible computer tapes (Figure 1). Soil salinity distribution maps on the scale of 1:250,000 are also available by province.

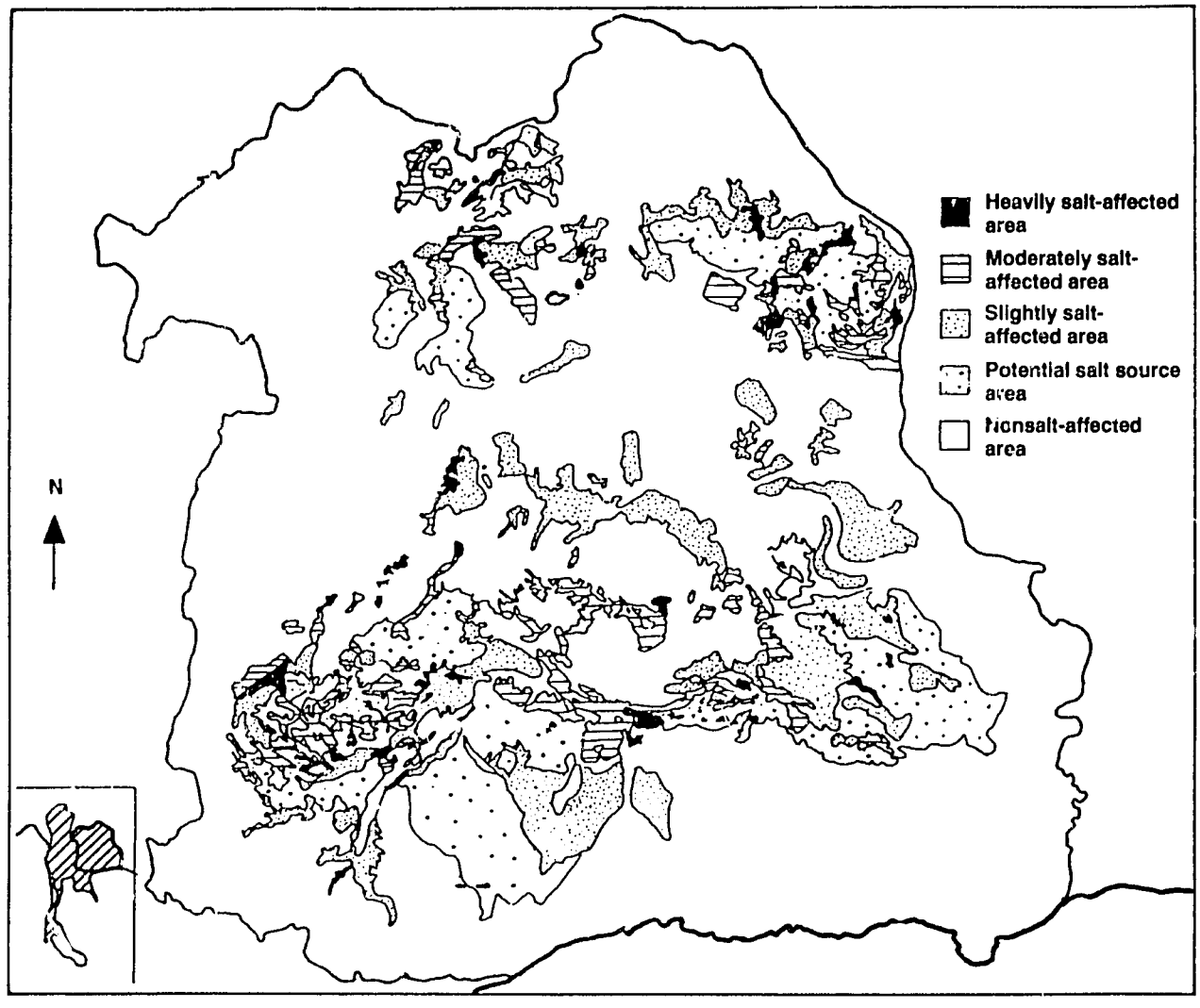

Figure 1. Soil Salinity Distribution in the Northeast (Arunin, 1984).

Field evidence shows that reservoirs constructed at or near potential salt source areas, and at sites with shallow saline groundwater, can cause increased salinization below the reservoirs. Moreover, the water in the reservoirs becomes saline within a few years after construction.

Another case of man-made salinization is at Borabue where the salt-making process involves the pumping of saline groundwater (50 to 60 mmhos/cm) from depths of 20 m or more, flooding the soil surface and allowing the saline water to evaporate, leaving the salt behind. This industry causes adjacent and downstream lands to become saline.

Secondary salinization in irrigated areas was reported at a number of irrigation projects, including Nong Wai near Khon Kaen, Kumphawapi south of Udon, the Lampao irrigation scheme at Kalasin and Un in Sakon Nakhon. Seventy one observation wells were installed in the Nong Wai area to study fluctuations of the groundwater table and water quality. The monthly fluctuation of groundwater quality and watertable levels were recorded. While much of the area is subject to flooding during the wet season when rice is grown, the

groundwater table drops during the dry season, but usually by only 1 m or less. Eleven observation wells showed that the average electrical conductivity of groundwater exceeds 10 mmhos/cm (Department of Land Development, 1980).

Most of the salinization of soils occurs in the Korat and Sakon Nakhon Basins which are underlain by an evaporite salt-bearing formation with beds and lenses of halite up to 250 m thick. These beds generally occur at depths of more than 30 m below the surface. Wells drilled deeper than 20 m are likely to encounter highly saline water.

Upland areas containing saline Mesozoic rock are designated as "salt releasing" while lowlands, either eluvial or alluvial plains, are denoted "salt receiving." Uplands and lowlands are thus separated into entirely different categories (El-Swaify *et al.*, 1983).

Although deep weathering has removed much of the salt from rocks in the upper part of the salt formation, it is likely that sufficient salt remains in this formation to cause soil salinization by seasonal movement or lateral seepage from shallow groundwater. Salt remains in the subsoil during the wet season and appears on the ground surface only during the dry season. Surface salinity is thus seasonal, controlled by the monsoon cycles. Soil salinity, however, is most deleterious during the dry season (Sainanuwong and Takaya, 1974).

Natural salinization has been minimal where a thriving forest vegetation has covered the landscape. Unfortunately, extensive deforestation has increased the rate of salt release from this salt-laden strata. Changes in hydrologic conditions following land clearing can result in rising watertables that are capable of dissolving residual salts and carrying them through seepage to lower slopes and bottomlands. Thus, forest clearing and subsequent use of land for paddy rice cultivation, and upland cultivation of cassava and kenaf, have contributed to rising upland groundwater levels and, in turn, increased soil salinity. It is also likely that lateral movement from adjacent clayey soil takes place at some locations. The deeper saline groundwaters are well beyond the range of capillary movement, but, as they are commonly artesian, it is possible that saline groundwater moves by upward pressure through joints and fissures of sedimentary rocks. In localized areas, shallow saline groundwater may be formed as the groundwaters flow through salt domes. Water can rise from depths of 10 to 15 m due to the prevailing pressure head differences and diffusion gradients. This can occur where there is significant permeability, topographic slope and upward head (Tuckson *et al.*, 1982).

Management Planning

The criteria used for management of soil salinity follow the basic principles of rural development, taking into consideration the high level of poverty in the region and the extent of salt. The management goals are to reclaim the salt-affected land so that productivity can be restored or increased, to prevent further spread of salinity, and to exploit the land effectively and efficiently so as to increase crop yields and net income of the farmers. Thus, the Land Development Department of the Ministry of Agriculture has designed a project for soil salinity research and reclamation in the Northeast. This project seeks to develop a complete management program for the Northeast which will follow a three-pronged approach of prevention, reclamation and agronomic management.

Agronomic Management

Agronomic management is considered to be low-cost technology which is transferred to farmers through training and extension programs. In slightly or moderately salt-affected areas, which are used mainly for rice, an agronomic management package of improved cultivation practices and water conservation are recommended. This will help to maintain rice yields and prevent further soil degradation.

Leaching

During the long dry season, salt accumulates at the soil surface. The salt can be removed through flushing and leaching, by controlling surface water and mitigating flooding. Planting should be delayed until early rains have reduced the salt content of the soil. The saline water flushed or drained from the field will be diluted by rainwater to natural streams. Water in the streams is sometimes used for supplementary irrigation of rice by downstream farmers. This practice may enhance leaching of soluble salts, but will raise groundwater levels, especially in areas where shallow groundwater occurs, or where internal drainage is inadequate.

Leveling and Surface Mulching

In actual land preparation, leveling of the microrelief in the rice field is often done to eliminate differences in rainfall infiltration, to remove salt from the soil surface and to ensure the uniform growth and yield of crops. Although previous experiments in Ban Don Pimai, Roi Et Province showed no significant difference between leveled and nonleveled areas, the leveled land gave higher yields (2.9 t/ha) compared with nonleveled land (2.5 t/ha) (Department of Land Development, 1983).

Surface mulching is also recommended to achieve lower soil surface temperatures and to decrease the evaporative loss of water, thereby preventing capillary rise of salt. Minimizing the accumulation of salt at the soil surface during the dry season also enhances the removal of salt during the wet season by leaching. Mulch materials that are most available are rice hulls and rice straw, although any other available plant residue can also be used. Surface mulch applied after harvesting and left on the soil during the dry season can be plowed in before the following growing season to provide a source of organic matter for the soil. The highest rice yield of 3.15 t/ha was achieved with rice hull mulch applied at a rate of 37.5 t/ha. Yields obtained with mulches of 25 t/ha of rice hulls, 12.5 t/ha of rice straw and 12.5 t/ha of rice hulls were 3.02, 2.87, and 2.77 t/ha, respectively. While there appeared to be an effect of mulching rate on yield, there was no significant difference in yields from these four treatments. The control plot which received no mulch gave the lowest yield of 2.28 t/ha but was not statistically different from the plots where straw was applied at 6.25 and 9.375 t/ha. It appears that higher rates of mulch tend to give higher rice yields irrespective of the type of organic amendment used. Higher rates of rice straw mulch, and low to high rates of rice hull mulch, gave higher yields which were significantly greater than the control. However, in actual practice rice hulls are an unavailable resource because of the high price they command for other uses (Department of Land Development, 1983).

Organic Amendments

Organic amendments can be applied to soils to compensate for fertility losses. Amendments such as compost, animal manure and green manure will also improve soil physical properties. Conventional rates of fertilizer are recommended to ensure optimum rice yields.

Results from experiments using animal manure, green manure and compost as organic amendments are of interest. Animal manure applied at a rate of 12.5 t/ha gave the highest yield, 1.7 t/ha. However, when manure was applied at rates of 25 and 37.5 t/ha, yields were somewhat lower, i.e., 1.5 and 1.4 t/ha, respectively. All yields from manure were significantly higher than those of the control, 0.9 t/ha, where no organic amendments were applied. The highest rice yield from compost, 1.2 t/ha, was obtained from applying 25 t/ha of compost. Rice yield was somewhat higher, i.e., 1.6 t/ha, when 37.5 t/ha of green manure was applied.

Results, however, tend to be rather variable because of spatial variability in salt concentration in the experimental plots (Department of Land Development, 1983)

Depth of Plowing

Deeper plowing depths would help to increase infiltration rates and lower the concentration of soluble salts. It would also aid in the leaching of salts from the soil-root zone by precipitation prior to the planting season.

Experiments were conducted using different plowing techniques and at different depths using the buffalo plow, disk plow, and ripper plow. Plowing depths of 5, 15 and 30 cm were evaluated. First year results showed that rice yields differed significantly with plowing depth. Rice hulls were also applied at different rates to accelerate the leaching process.

Ripper plowing gave a yield of 3 t/ha of rice, a significantly higher yield than the other treatments, but impractical for farmers to use. Plowing depths of 5 and 15 cm gave yields which were not significantly different. Disk plowing to a 15 cm depth tended to produce higher yields.

Rice hulls applied at rates of 6.25, 18.75 and 31.25 t/ha gave yields of 2.4, 3.4 and 3.1 t/ha, respectively, and were significantly different from that of the control or unamended treatment, i.e., 1.6 t/ha. Rice hulls applied at the rate of 18.75 t/ha gave a yield that was significantly different from the control, but was not significantly different from rice hulls applied at 31.25 t/ha.

The interaction between deep plowing and rice hulls applied to soil provides beneficial results including increased rice yields. Rice hulls applied to the soil decompose slowly and, when incorporated into soil by plowing, greatly reduce surface crusting, increase water infiltration and increase soil porosity. This enhances the removal of soluble salts by leaching and provides greater root penetration and development. Analysis of variance indicated that there was no interaction between quantity of rice hulls and plowing depth relative to yield.

Salt Tolerant Rice Varieties

Different crops have varying degrees of salt tolerance. There are also differences in salt tolerance among varieties of the same crop. Since rice is no exception, screening rice varieties for salt tolerance is essential especially for their adaptation to the salinity problem in Northeast Thailand. The salt tolerance screening programs for rice conducted from 1976 to 1980 indicated that the following varieties are well suited for the Northeast: Kao Ruang, Jak Kradod, Kam Pae 41, Khao Dogmali Klang, RD 1 and Neo San Pa Tong.

Older Seedlings

Seedlings tend to become more salt tolerant as they get older. Thus, transplanting of rice seedlings at about 35 to 40 days after germination is also recommended as a means of overcoming the salt sensitivity of some varieties (Department of Land Development, 1980).

Higher Seed Rates

Using relatively higher seeding rates to compensate for reduced germination due to salinity, transplanting rice at closer spacings, and increasing the number of seedlings per hill will help to increase yields by increasing the number of plants per unit area. The higher plant population should help to increase rice yields per unit area.

Increasing the number of seedlings per hill significantly increases grain yield of rice by increasing survival rate. Transplanting five and eight seedlings per hill gave the highest yields, 1.78 and 1.96 t/ha, respectively, significantly higher than using two and four seedlings per hill. The yields from using either two or four seedlings per hill were not significantly different (Department of Land Development, 1980).

Current Research

In severely salt-affected areas, crops cannot be grown unless reclamation measures are taken which include controlling the groundwater levels and promoting the downward leaching and removal of salt. Furthermore, in preventing the movement of salt from the potential salt source areas, a knowledge of the recharge and discharge of groundwater flow, together with research on revegetation, is essential.

Such information is required to select proper methods of reclamation. For example, one needs to know whether or not to change cropping practices in groundwater intake areas, or to use subsurface drainage or a combination of these. Moreover, it has been reported that substantial salt discharge occurs when a drain is placed 3 m deep in sand in the bottom of a seepage area. Drains must be at a sufficient depth to reduce seepage, particularly when salt seepage from the upland is the predominant cause of soil salinization. Deep drainage to enhance flow through impervious subsoil is often of economic benefit.

Landscape Salinity

A study covering an area of 485 km^2 is being conducted in Amphur Non Thai and Kam Thale So in Nakon Ratchasima Province. One hundred and fifty piezometers were installed at depths from 5 to 18 m at sites with different landforms, soil types, salinity levels and land use patterns. To obtain samples from an extensive physical environment, 90 piezometers were installed at a site having both upland and lowland areas. Depth of piezometer nests at some sites will vary from 5 to 20 m to locate the aquifer. The stratigraphy of the underlying rock can be studied while making borings for the piezometers. The objective of this study is to assess the effect of groundwater on the genesis and distribution of saline soils in Northeast Thailand.

Water Resource Development Location Research

This research is aimed at selecting sites for reservoir construction and is based more on the potential salt source areas such as areas of shallow saline groundwater on elevated areas composed of saline Mesozoic rock. The effect of site and capacity on the spread of salinity is being studied. Water is the most important resource that is lacking in the Northeast and, therefore, reservoirs are needed, but salinization needs to be avoided. Thus, this study is essential to eliminating secondary salinization from reservoir construction.

The study involves the selection of sites through the interpretation of satellite images, topographic maps, aerial photographs and soil salinity distribution maps in coordination with data available from the Royal Irrigation Department, Office of Accelerated Rural Development and Department of Land Development. Important parameters include the surface area of the water body, capacity, topographic location and date of reservoir construction.

Sites for the study have been selected in Nakon Ratchasima, Khon Kaen, Kalasin, Maha Sarakham and Tung Kula Ronghai. The effect of the environment on the reservoir and the contribution of both to secondary salinization will be studied. The size and capacity of reservoirs in relation to the topographic location, soil type, underlying geology, and vegetation will be assessed. Water samples from the reservoir, from nearby village wells and also groundwater will be taken for chemical analysis and electrical conductivity measurements. Soil samples will be collected from around the reservoirs and analyzed for chemical changes. The data will be coded and computerized, providing information for planners on selection of sites for reservoir construction in order to minimize risk and the probability of soil and water salinization.

Revegetation

The use of well-adapted, deep-rooted, salt tolerant perennial plants can also help to minimize secondary salinization. Plants can markedly increase water use in upland areas through transpiration, thus reducing groundwater seepage to low lying areas. Small blocks of trees and shrubs can be planted immediately upslope from identified areas of seepage to intercept and use the water. This, in turn, should also reduce the salinity of the streamflow into surface water bodies. In areas with a shallow groundwater table, the growth of perennial plants also will be beneficial for lowering the groundwater level (El-Swaify *et al.*, 1983).

The following plant species have been selected, on the basis that they are fast growing and salt tolerant and, thus, will adapt to establishment on salt-affected soils. They have been divided into the following three categories (Limpinuntana and Arunin, 1984):

1) **Native species.** *Dipterocarpus alatus, Dipterocarpus intricatus, Dipterocarpus tuberculatus, Dipterocarpus obtusifolius, Anisoptera glabra, Melia axedarach* Linn, *Cassia siamea* Britt, *Afzelia spp., Peltophorum dasyrachis, Pterocarpus macrocarpus* Kurz., *Azadirachta indica*, A. Juss.

2) **Food species.** *Leucaena leucocephala* De Wit., *Sesbania grandiflora, Cassia siamea* Britt, *Tamarindus Linn., Pithecollobium dulce* (Roxb) Benth., *Moringa oleifera* Lamk., *Azadirachta indica* A. Juss., *Anacardium occidentale* Linn.

3) **Utility species.** *Leucaena leucocephala* (Lam) De Wit., *Azadirachta indica* A. Juss., *Gliricidia sepium, Tamarindus indica, Pithecollobium dulce, Moringa oleifera, Eucalyptus camaldulensis, Melia axedarach, Melia dubia, Melia toosendan, Acacia catechu, Casuarina equisetifolia, Cassia siamea, Casuarina junghuhniana, Acacia auriculiformis, Acacia mangium, Cassia fistula.* The utility species serve many purposes such as medicinal herbs and fuelwood.

In addition to the studies already mentioned, research into salt tolerant rice varieties and other crops is needed. The development of improved cultural practices and field trials to determine the most effective method, time and rate of applying organic amendments to the soil are also going forward. Such information is vital to further minimize the adverse effects of soil salinity to the growth and yield of crops.

Future Prospects and Research Needs

More research on soil, water and crop management needs to be done relative to the control and prevention of salinity in agricultural soils of the Northeast Region, and to the development of practical corrective measures as well. In many cases, a systems approach to resolving these problems seems most appropriate. Important research needs are:

Soil Management

1) To monitor salt and water movement in the soil profile throughout the cropping season. To improve fertility management for maximum yields and develop soil management techniques that would effectively utilize organic amendments to reduce soil salinity.

2) To investigate the effects of soil properties and their interactions on soil salinity and the root-soil interface.

3) To study the cause-and-effect relationships of iron and manganese concretions in salt-affected soil profiles.

4) To study the nutrient balance-imbalance in soil affected by salinity.

Water Management

1) To develop a hydrosalinity mode to improve methods for surveying salinity and measurement of water use by forest plants.

2) To determine the feasibility of using saline water for irrigation of crops and for fish culture.

3) To reclaim and restore the productivity of salt-affected land through major drainage works.

Crop Management

1) To select and screen varieties of rice and other crops such as legumes, forage plants and tree species for salt tolerance.

2) To develop soil and crop management practices that would effectively control the watertable and, thus, minimize salt movement to the soil surface by preventing groundwater rise.

Systems Approach

1) To conduct socioeconomic surveys on the scope and impact of the salinity problem.

2) To develop strategies for increasing the biological productivity of salt-affected areas through overall yield improvement.

The data obtained from ongoing and future reclamation research should advance the development of effective practices for managing soil salinity in Northeast Thailand. Comprehensive land uses in developed areas in the Northeast must be considered with a view toward long-term planning objectives. For example, while salt-making appears to be of immediate economic benefit to the entrepreneur, it is in direct conflict with sustained agricultural productivity. Policymakers and planners must formulate realistic plans that take into account all the pertinent socioeconomic parameters, including community educational campaigns. Land tenure provisions may be necessary to protect the large investments necessary to develop the Northeast into a viable and sustainable agricultural region.

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Soil and Water Management Problems Associated with Deforestation in Northeast Thailand

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ABSTRACT. A longitudinal study on the ecological aspects of upland farming was conducted at three different locations in Northeast Thailand. In this report, cultivation practices in relation to soil-water management problems that are associated with deforestation are discussed. Results indicated that clearing and burning the forest induced a high rate of organic matter decomposition. Soil fertility was improved by the addition of ash and ammonification accelerated by burning the forest trees. The extent and duration depended mainly on the type of forest, soil and climate. Physical properties of soils deteriorated as a result of soil compaction and low water holding capacity. Shifting cultivation with no tillage and dibbling practice caused relatively little disturbance to the soil. The merit or precise advantage of practicing shifting cultivation is the maintenance of better soil physical properties and prevention of soil loss. However, runoff and initial soil loss due to premonsoon rains was considerable and appeared inevitable and intrinsic to shifting cultivation in the monsoon tropics.

Introduction

Deforestation of both evergreen and deciduous forests in Northeast Thailand has increased at an alarming rate. An estimation from LANDSAT imageries indicated that during a five-year period (1972-76), a total forest area of 169,000 km^2 was reduced to 41,500 km^2, or 4.9 percent per year. The cause of this rapid decrease was attributed to an expansion of the cultivated area, exploitation of timber, the need for fuel, or some combination of these factors. On a global basis, Edouard Saouma, the Director-General of FAO, recently confirmed that one of the primary reasons for this is the conversion of forest to agricultural land in order to meet the world's growing food needs. This system of farming has become the subject of serious concern with respect to soil-water management problems that are associated with deforestation (Pairintra, 1981).

Shifting cultivation or swidden agriculture is a traditional agricultural practice that has been followed for centuries. It is a rational system of cultivation, in a very extensive way. The system usually involves clearing, burning, growing and fallowing. Problems encountered are poor soil fertility, poor soil tilth and susceptibility to soil erosion.

With this in mind, an ecological study on shifting cultivation was conducted under different forest, soil and climatic conditions in Northeast Thailand. The research was carried out as an international cooperative project between Thai and Japanese scientists at Nam Phrom, Chaiyaphum Province (Kyuma *et al.*, 1983). In addition, a group of Thai scientists with an interdisciplinary approach performed a similar study at Kalasin and Sakon Nakhon Provinces (Pairintra *et al.*, 1982).

Description of Experimental Site

The Nam Phrom experiment is situated upstream on the Nam Phrom River at an elevation of 800 m above sea level. The topography is rolling to hilly. The forest vegetation is an ecotone between dry evergreen and mixed deciduous forest. The climate is subhumid tropical. Mesozoic sandstones and shales are the base rocks. The soil is in the Haplustalfs great soil group.

At Kalasin, the experimental site was established on Pafag Mountain. The elevation is approximately 350 m and the topography is rolling to hilly. The forest association is classified as dry, mixed deciduous. The climate is that of a tropical savanna. The parent material is mainly residuum and colluvium of sandstone. According to the new U.S. System of Soil Taxonomy, this soil is among the Haplustults.

The experimental site at Sakon Nakhon is located in the Phu Phan Mountain Range at an elevation of approximately 200 m. The topography of the area is rolling. The vegetation of the site is highly diversified. The forest type is dry, mixed deciduous with two distinct structures. Climatically, it is tropical savanna with distinct wet and dry seasons. Colluvia of sandstone with very stony and rocky components are widespread. The soil at the subgroup level is Lithic Dystropepts.

Layout of Experiment

In order to facilitate a discussion of the soil-water management system, this report will concentrate on a comparison among different cultural practices. A map of experimental plots appears in Figure 1.

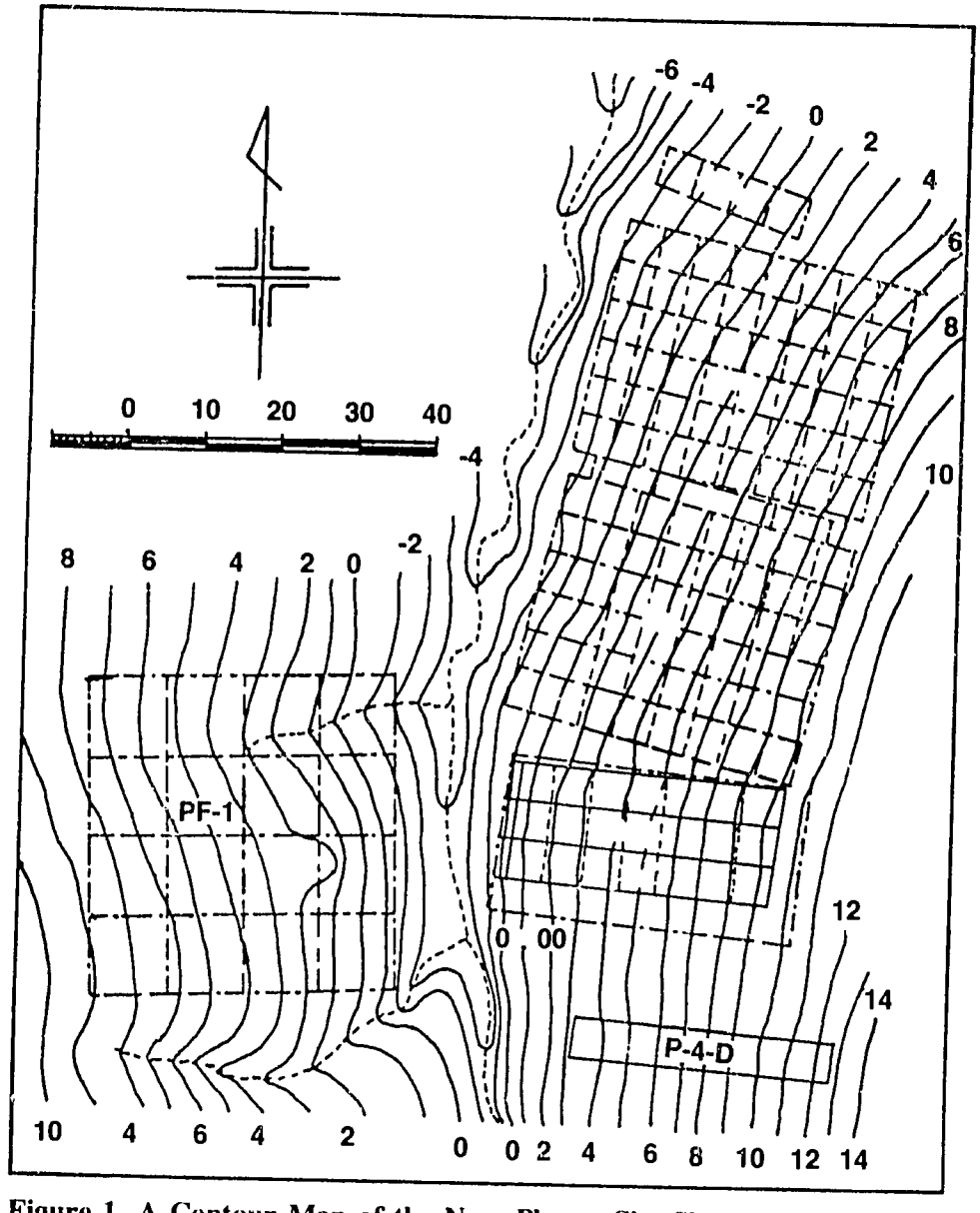

Figure 1. A Contour Map of the Nam Phrom Site Showing Allotment of the Experimental Plots (Kyuma and Pairintra, 1983).

Results and Discussions

Soil fertility

Changes in the soil fertility status at Nam Phrom as a result of forest clearing and crop cultivation with time are presented in Table 1 and Figure 2, respectively. In order to clarify the soil fertility transition after forest clearing by burning and during crop cultivation, the soil was sampled at different times from P-1, P-2 and P-3. Altogether eight sampling times were set as follows:

I Immediately after felling (December 22, 1979)

II Immediately after burning (January 22, 1980)

III Immediately after sowing the first crop of maize (April 21, 1980)

IV Immediately after harvesting maize (August 21, 1980)

Table 1. Changes in Soil Chemical Properties Due to Felling and Burning Forest Trees (Kyuma and Pairintra, 1983).

Item of Analysis	Surface Soil			Subsurface Soil		
	Before Felling	After Burning	Comparison	Before Felling	After Burning	Comparison
pH	6.2	7.2	**	5.4	6.1	**
Total carbon (%)	4.6	5.9	*	1.3	2.5	**
Total nitrogen (%)	0.32	0.40	**	0.11	0.20	**
C/N	14.3	14.8		11.8	12.2	
NH_4-N (mg 100 g^{-1})	2.0	6.2	**	1.2	3.8	**
NO_3-N (mg 100 g^{-1})	0.5	0.8		0.3	0.7	**
Available P (ppm)	7.2	109	**	1.4	7.7	*
CEC (meq 100 g^{-1})	20.9	23.7	*	13.5	16.1	**
Extractable						
Ca (meq 100 g^{-1})	17.0	36.3	**	6.3	10.6	**
Mg (meq 100 g^{-1})	5.6	7.5		2.4	3.6	
K (meq 100 g^{-1})	0.4	1.9	*	0.2	0.4	**
Na (meq 100 g^{-1})	0.3	0.4	**	0.2	0.2	

* Significantly different at the 5% probability level.
** Significantly different at or below the 1% probability level.

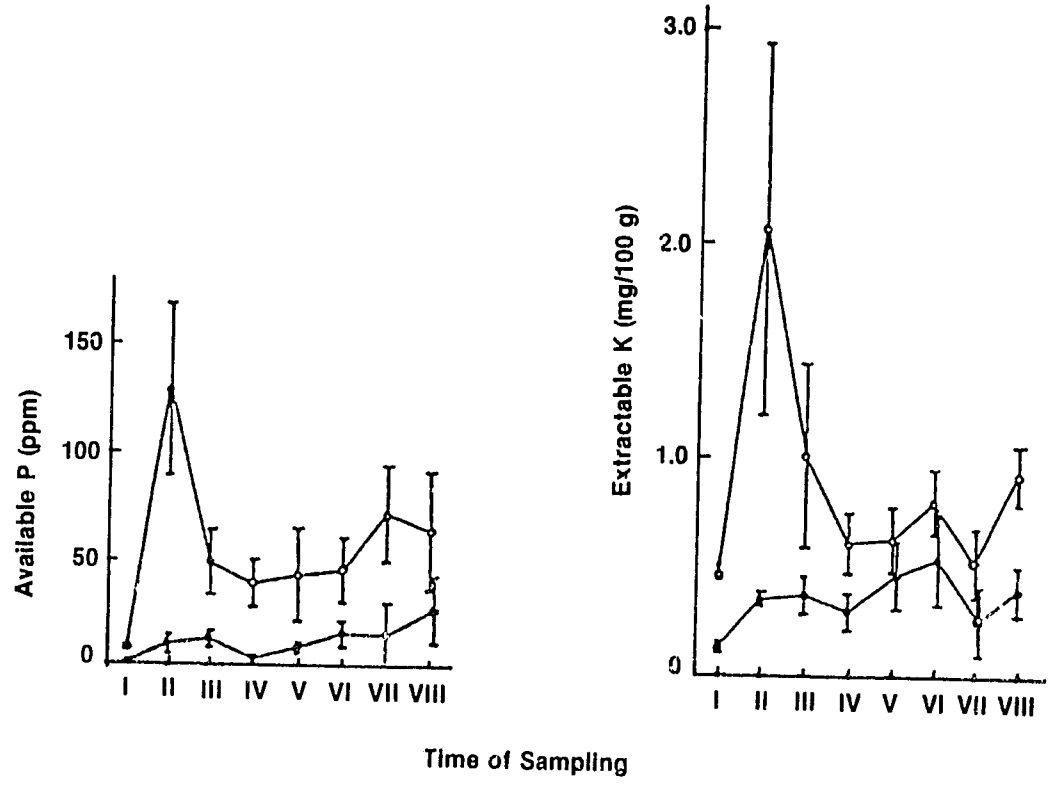

Figure 2. Changes in Soil Fertility Characteristics in the Course of Forest Clearing and Crop Cultivation in P-2 at Nam Phrom (Kyuma, 1983).

V One year after felling (December 22, 1980)

VI Immediately after sowing the second crop of maize (March 25, 1981)

VII Immediately after harvesting maize (July 25, 1981

VIII About two years after felling (November 12, 1981)

Except for a few items such as the C/N ratio and extractable Mg, all the soil chemical properties were significantly altered and most often were substantially increased. It is somewhat difficult to explain the significant increase in total C (TC) and total N (TN). Probably, it was due to the addition of litter that was left unburned. Furthermore, partially carbonized litter was also added to the soil. This may account for the increase in organic matter. The increase in NH_4-N was due to the soil-burning effect, a kind of partial sterilization. This, together with a marked increase in available P, should contribute positively to the cropping phase of shifting cultivation. In addition, an increase in CEC might be attributed to the increase in free Ca compounds in the ash that were extractable with the 1N NaCl solution used to displace adsorbed Ca.

The changes in pH and other chemical properties, except for NO_3-N, were due to the release of nutrients by burning. There was a sharp increase from period I to period II and then a decrease during period III. Between these two periods there were several rainshowers which undoubtedly washed down the sand and loose surface soil, thus causing a marked decrease in the soil nutrient content. The changes after period III were much less

dramatic and reflected soil management practices. Nitrate nitrogen (NO_3-N) exhibited a different pattern. By the time of sowing (periods III and IV), NO_3-N had increased substantially, and then decreased during the cropping period.

Soil Respiration and Organic Matter Decomposition

In order to obtain an estimation of the rate of organic matter decomposition, the total respiration for a 12-month period was calculated. The estimates for the four plots for the period of one year were as follows:

	From Feb. 1980	From Nov. 1980
	t C ha^{-1}	*t C ha^{-1}*
Forest with litter	13.0	11.8
Forest without litter	11.7	11.3
P-1 (Shifting cultivation)	17.1	12.8
P-2 (Upland cultivation)	16.5	11.7

The results clearly indicate that a substantial amount of soil organic matter decomposed in the first year. Using soil respiration data from a forest ecosystem, Tulapitak *et al.* (1984) reported that the rate of organic matter decomposition was doubled in the first year. He found that 30 percent of the total organic matter content of the forest soil was decomposed in the first two years of cropping.

Physical Properties of Soil

Bulk density, moisture content and three-phase distribution of the soil samples taken from three locations are presented in Table 2. Also, changes in soil physical properties, density and porosity, in the course of crop cultivation, are illustrated in Figure 3.

Bulk density, moisture content and three-phase distribution of the surface soil samples from shifting, upland and bare soil treatments were slightly higher than the forest plot. This indicated that after clearing and burning, the soil tends to become increasingly compacted by cultivation practices. Again, Figure 3 shows the decrease in porosity and increase in bulk density that occurs, and suggests a serious deterioration of soil physical properties (Kyuma, 1983). In addition, about 50 percent of the soil particles are composed of water-stable aggregates larger than 0.02 mm. Therefore, both dispersion and erosion ratios indicated relatively low values ranging from 10 to 20 percent, which would imply relative stability of the soil against erosion.

Additional evidence of deterioration of soil tilth is based on measurements of soil moisture retention characteristics as shown in Figure 4. A comparison of these data suggests that tillage operations caused deterioration of both capillary and noncapillary pores.

Runoff and Soil Loss

Soil erosion results from initial dispersion of soil aggregates due to the impact of raindrops and then by transport of sediment in the runoff water. Therefore, runoff must be one of the most important factors in soil erosion. Figure 5 shows typical hydrographs of runoff from each plot.

Table 2. Bulk Density, Moisture Content and Three-Phase Distribution of the Surface (0-5 cm depth) Soil Samples.

Location	Treatment	Bulk Density	Moisture Content	V_s†	V_w	V_a
		$g\ cm^{-3}$	..... %	.....		
Nam Phrom	Shifting	1.137	9.0	49.9	10.3	39.8
	Upland	1.247	8.8	49.5	11.0	39.5
	Bare	1.060	12.7	44.2	13.5	44.3
	Forest	1.002	10.2	40.0	10.2	49.8
Kalasin	Shifting	1.350	15.2	51.0	20.5	28.3
	Upland	1.320	17.5	49.8	23.1	27.0
	Bare	1.290	19.2	46.2	23.5	30.2
	Forest	1.300	16.2	48.9	21.1	19.9
Sakon Nakhon	Shifting	1.364	22.9	51.5	31.2	17.3
	Upland	1.287	22.1	48.5	28.5	22.9
	Bare	1.415	21.7	53.4	30.7	15.9
	Forest	1.001	14.0	39.5	14.0	46.5

† Subscripts s, w and a denote solid, water and air, respectively.

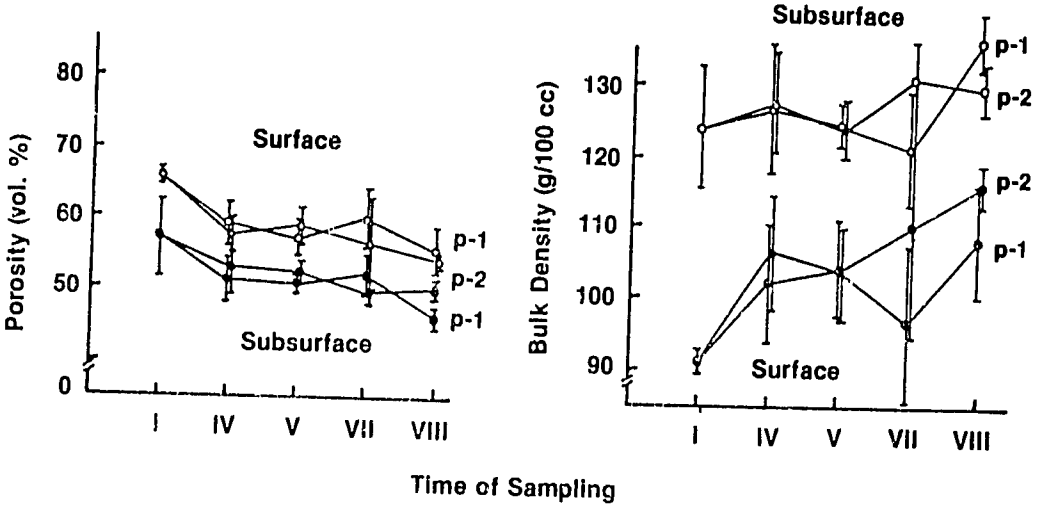

Figure 3. Changes in Soil Physical Properties in the Course of Crop Cultivation at Nam Phrom (Kyuma, 1983).

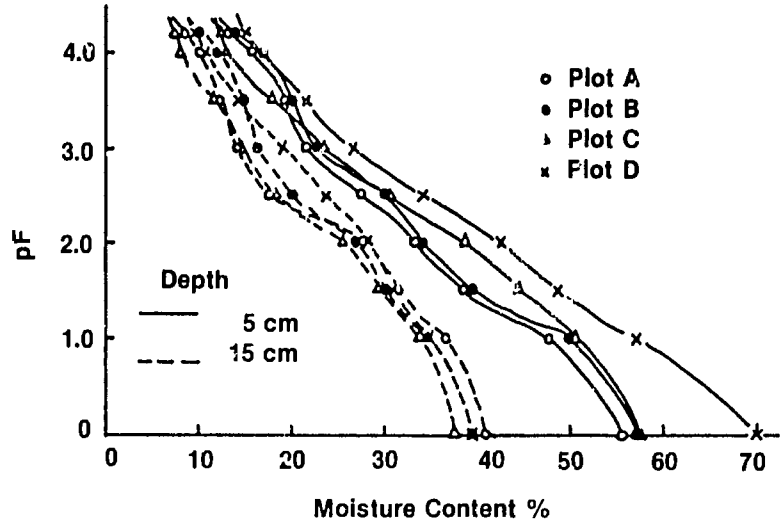

Figure 4. Soil Moisture Retention Curves of the Soil Samples Taken at Nam Phrom in P-3 and P-4 on August 7, 1980 (Kyuma, 1983).

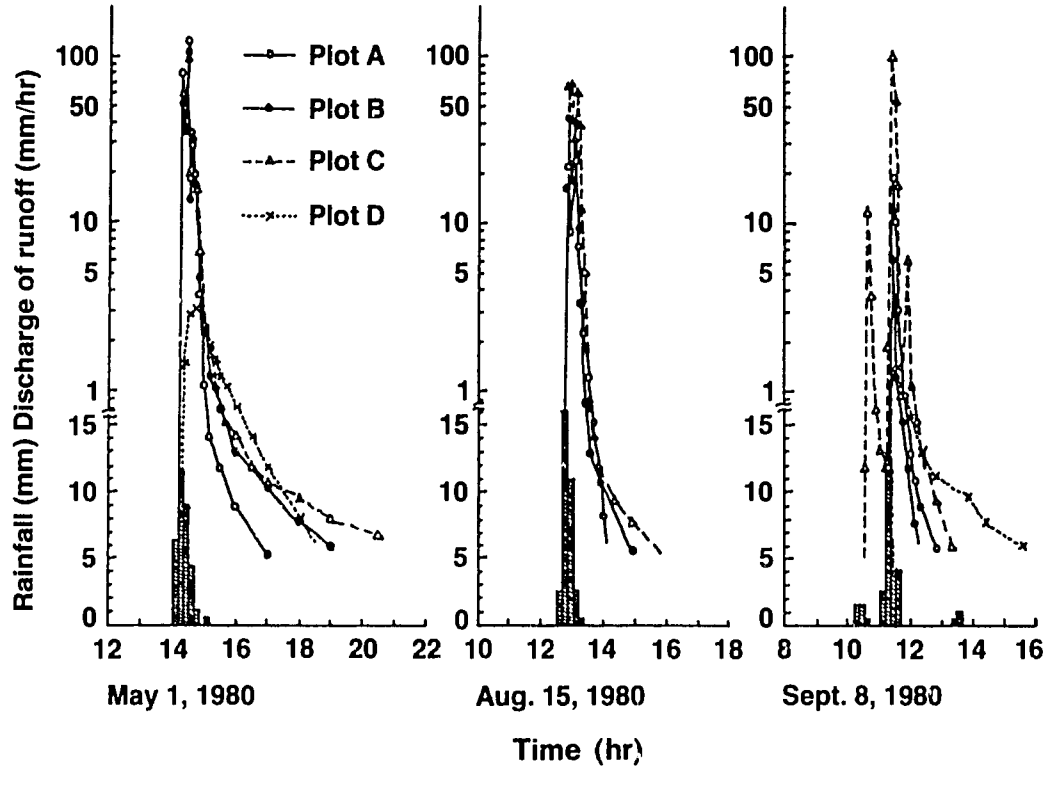

Figure 5. Typical Examples of Hydrographs of Runoff from Each Plot at Nam Phrom (Kyuma and Pairintra, 1983).

The hydrographs were recorded with rainfall of 33 mm, 10 days after seeding of maize. The curves from plots A, B and C showed a high peak discharge and marked fluctuation corresponding to rainfall, although there were no great differences. On the other hand, the curve for plot D under natural forest changed slowly with a low peak discharge.

Generally speaking, the amount of soil loss is determined by the conditions of rainfall, i.e., intensity and distribution, and also by soil properties such as erodibility or stability of soil aggregates. By using the Wischmeier and Smith equation (1958) with some modifications in I per 60 min, relationships between soil loss and accumulated EI values were determined as shown in Figure 6.

It is apparent that soil loss from bare soil plot C increased almost linearly in proportion to the accumulated EI values. On the contrary, soil losses from plots A and B were much less as the crop became established and leveled off after harvesting. In shifting cultivation practice, trees are felled in the early part of the dry season and left on the ground to dry until they are burned near to the end of the dry season. Crops can be grown only with

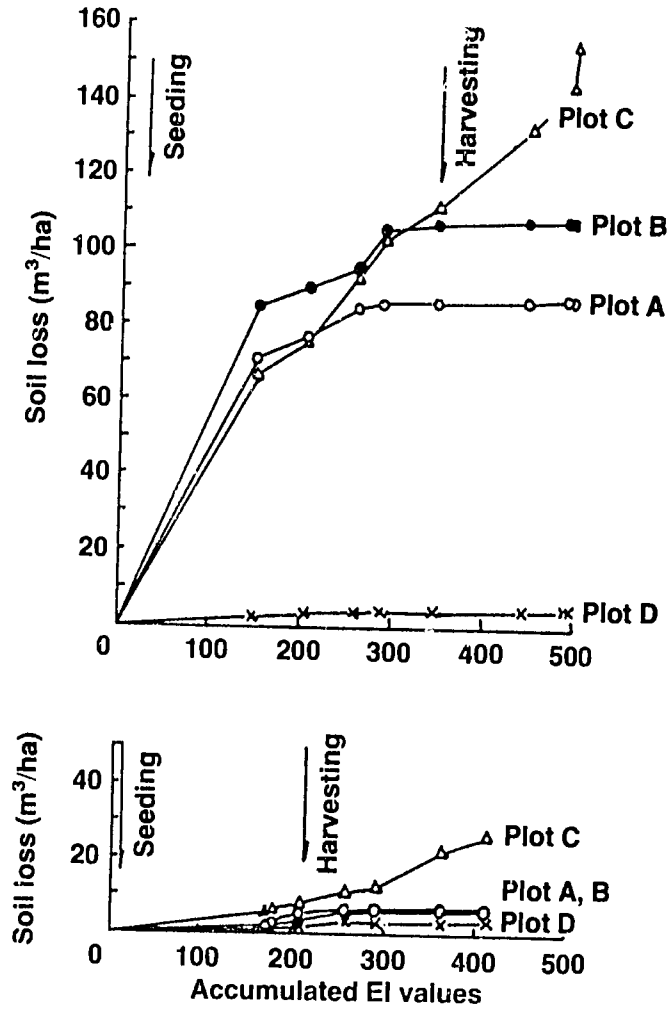

Figure 6. Accumulated EI Values and Amounts of Soil Loss From the Four Plots at Nam Phrom in 1980 and 1981 (Kyuma and Pairintra, 1983).

assured rains. Therefore, a few monsoon showers, often with intensities greater than 3 mm/10 min, can cause a severe loss of ashes and loose surface soil. This initial damage, though serious, seems almost inevitable and intrinsic to shifting cultivation in the tropical monsoon climatic regions. The experiment at three locations supported this and data are shown in Table 3.

Table 3 reports estimates of the total soil loss. In comparing the three locations, soil loss was much less in the second year at Nam Phrom. This is because of the stability of the soil surface at that location. Deforestation of the primary evergreen forest (Nam Phrom) caused a greater amount of total soil loss than deforestation of secondary forests (Kalasin and Sakon Nakhon). Although total rainfall at Kalasin was much higher than at Sakon Nakhon, total soil loss was less on upland and bare soil at Kalasin because of the higher water-stability of soil aggregates. It should be noted that the relative advantage of the shifting cultivation practice with no-tillage and minimum disturbance was obvious.

Conclusion

Results of research conducted at Nam Phrom, Kalasin and Sakon Nakhon can be summarized as follows:

1) Soil fertility was improved by the addition of ash and ammonification accelerated by burning the forest trees. Enhancement of the rate of soil organic matter decomposition was observed in the first year but then rapidly decreased one and one-half years after deforestation. Nutrients were initially increased, but the extent and duration of soil fertility improvement depends mainly on the type of forest, soil and climate. Generally, the decline of soil fertility was quite rapid because much of the ash and surface soil were lost by premonsoon rains before establishment of crop cover.

2) Physical properties of soils were affected by clearing and burning. As a result of high soil temperature, bulk density was increased due to compaction of the soil surface. This clearly shows deterioration of soil tilth. Low values of dispersion and erosion ratios were associated with greater aggregate stability and less soil erosion. Soil moisture retention characteristics indicated that tillage operations decreased the capillary and noncapillary pore spaces.

3) The experiment at Nam Phrom proved that a few monsoon showers, often with intensities higher than 3 mm/10 min, can cause a severe loss of ashes and loose

Table 3. Total Soil Loss at Three Locations.

Location	Annual Rainfall	Total Soil Loss			
		Shifting	Upland	Bare Soil	Forest
	mm	.....	*t ha*$^{-1}$	.....	
Nam Phrom†	1540	87.6	107	154	4.7
	1010	6.9	6.4	25.9	2.9
Kalasin	1200	16.4	17.9	20.9	4.5
Sakon Nakhon	940	15.5	23.6	24.8	2.4

† Assume B.D. = 1 g cm^{-3}

surface soil. The total soil loss in weight was estimated at 76 t/ha for shifting cultivation, 91 t/ha for upland cultivation, 144 t/ha for bare soil and only 6 t/ha for the forest plot.

The points that were clarified here could be regarded as the rationale that has made shifting cultivation a long-lasting and widely adopted practice throughout the world. The real challenge for future research is how this rationale can be transferred to the establishment of sustained upland farming.

Based on the findings obtained in this research, Kyuma (1984) made the following recommendations:

1) The cultivated use of steep slopes must be greatly restricted. In view of the extraordinary and intense nature of rainfall in the monsoon tropics, the maximum slope gradient on cultivated land should not exceed ten degrees or 17 percent.

2) As a measure to minimize soil erosion, zero- or minimum-tillage as practiced in shifting cultivation merits serious consideration for adoption.

3) Mulching should be combined with zero-tillage to suppress weed growth. It is also effective in minimizing the destructive impact of rainfall on the soil surface, promoting biological activity and thus leading to better soil structure and a higher water holding capacity.

4) Cropping systems must be developed to maintain the diversity and complexity of the biotic community as a safeguard against pests and diseases. In this regard, mulching materials and utilization of plants for biological nitrogen fixation should be emphasized.

5) Fast-growing leguminous trees, such as *Gliricidia* and *Leucaena*, could be intercropped or planted separately in abandoned barren lands, both for pruning shoots, for mulching and manuring, and for rehabilitation of degraded lands.

6) To supplement those plant nutrients supplied by burning in shifting cultivation, a minimal use of chemical fertilizer, particularly phosphate, must be considered.

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Soil Organic Matter Management for Improving Soil Productivity

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ABSTRACT. Cultivated soils of Thailand are generally of low fertility. One of the major reasons for this is the low content of organic matter, the result of improper management over a long period of time. Organic matter serves mainly as a source of plant nutrients and also as an indispensable amendment that promotes the formation of soil structure favorable for plant growth. The application of organic amendments, i.e., compost, green manure and crop residues through soil incorporation and/or mulching has proven to be an effective method for maintaining soil productivity. This paper reports the results of both basic and applied research studies on the utilization and management of organic materials for improved soil productivity. The topics discussed include: (1) accumulation of soil organic matter and humus composition of major soils, (2) utilization of organic matter for increasing soil productivity for field crops, (3) effect of organic matter recycling to heavy clay paddy soils on improving soil physical properties and crop production, (4) effect of organic matter on soil water retention and plant growth, and (5) utilization of organic materials by Thai farmers.

Introduction

Thailand is an agricultural country which has a total cultivated area of 17.5 Mha, with more than 80 percent of the farmlands under rainfed conditions. Because of increased population pressure, crop production in Thailand increased tenfold during the past two decades. Since the 1960s, increased crop production has come about mainly by clearing of forest lands for cultivated crops. Since the expansion of cultivated land reached its limit in the late 1970s, the government has taken steps to minimize the development of forest lands for cultivated crops. Improper management of agricultural lands has resulted in a marked decrease in soil fertility. Another common characteristic of soils reclaimed from forest lands is their very low organic matter content. It is known that organic matter provides a source of plant nutrients, regulates soil chemical and biological reactions, and improves soil physical properties that are favorable to plant growth. Proper management of organic materials such as crop residues, compost and green manures can reduce soil erosion, increase water retention, and improve soil fertility and productivity. The purpose of this paper is to discuss the significance of past research on organic matter management for improving the productivity of agricultural soils. The research was conducted jointly by the Department of Agriculture of Thailand and the Tropical Agriculture Research Center of Japan.

Organic Matter Content of Major Soil Groups

Suzuki *et al.* (1980) studied the accumulation of organic matter in representative soils of twelve great soil groups in Thailand. The results obtained are summarized as follows: 1) the organic carbon content of upland soils is generally low, seldom exceeding three percent on an oven-dry weight basis; and 2) when the organic matter content of surface soils and subsoils is considered, the great soil groups can be divided into three principal groups as follows:

Group I. Both the surface soil and subsoil contain rather high levels of organic matter. These include Grumusols, Rendzinas, Brown Forest Soils, Reddish-Brown Latosols and Lava soils.

Group II. Only the surface soil contains high amounts of organic matter. These include Fresh Water Alluvial soils, Red-Yellow Podzolic soils, and Reddish-Brown Lateritic soils.

Group III. Both the surface soil and subsoil contain comparatively low levels of organic matter. These include Noncalcic Brown soils, Red-Brown Earths, Gray Podzolic soils, and Red-Yellow Latosols.

Utilization of Organic Matter for Increasing Soil Productivity for Field Crops

Inoue *et al.* (1984) conducted a three-year experiment on the improvement of soil productivity for corn, sugarcane and cassava using three different soil groups, i.e., Reddish-Brown Lateritic soils for corn, Noncalcic Brown soils for sugarcane, and Gray Podzolic soils for cassava. The results obtained are summarized as follows:

Improvement of Soil Productivity for Corn by Mulching and Nitrogen Fertilizer

A factorial experiment was conducted for three years (1981 to 1983) at Phra Phuttabat Field Crop Experiment Station to determine the effect of mulching and N fertilizer levels on corn yield and the succeeding mung bean yield, as well as the long-term change in soil productivity. The three levels of N were 0, 50 and 100 kg/ha. A Reddish-Brown Lateritic soil was mulched with 5.0 t/ha of communist grass (*Pennisetum pedicellatum* Trin) which is easily obtained from farm fields as weed. After corn was harvested, cornstalk mulch was applied to the succeeding mung beans. The results in Figure 1 show a highly beneficial effect of mulching on crop yield. The highest corn yields were obtained when 100 kg/ha of N fertilizer and cornstalk mulch were applied to mung bean. Rather high amounts of plant nutrients (N, P, K) could be returned to the field through utilization of mulches prepared from cornstalks and communist grass. For example, in this experiment the amounts are equivalent to 29 to 82 kg/ha of N, 15 to 34 kg/ha of P_2O_5 and 54 to 205 kg/ha of K_2O.

Improvement of Soil Productivity for Sugarcane by Mulching and Nitrogen Fertilizer

Inoue *et al.* (1984) initiated an experiment in 1981 on a Noncalcic Brown soil at the Suphan Buri Field Crop Research Center. The purpose of this study was to investigate the long-term effects of sugarcane trash mulch on sugarcane yields under rainfed conditions. The experimental plot was treated with and without the mulch at a rate of 5.0 t/ha. Two cane cultivars, F 140 and Q 83, and three N fertilizer levels, i.e., 0, 75 and 150 kg/ha

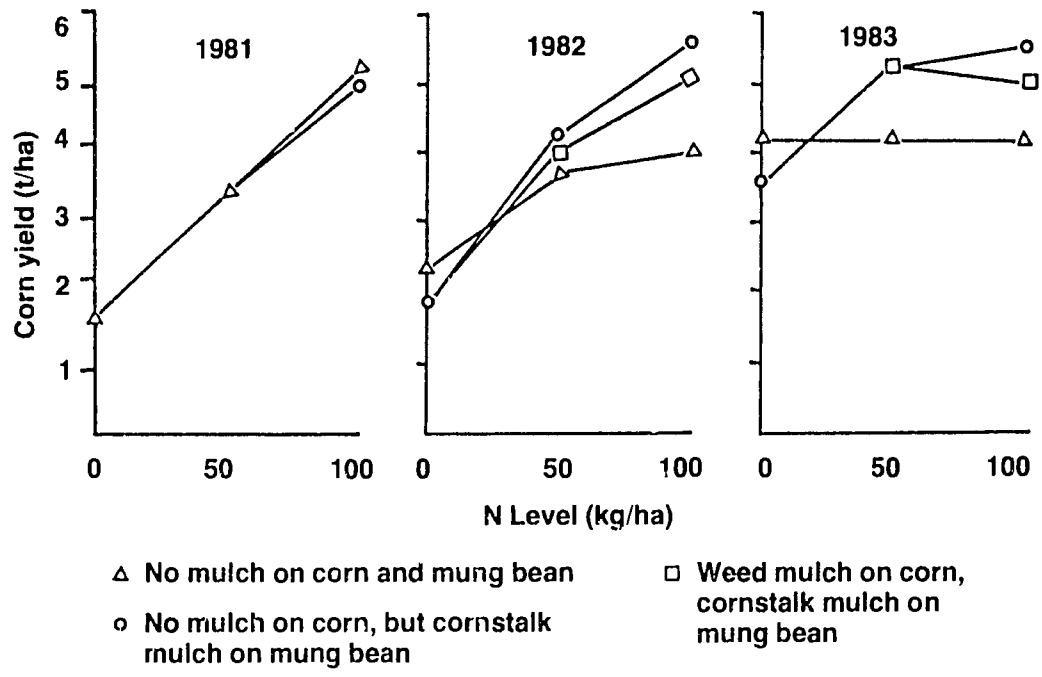

Figure 1. Effect of Weed Mulch and the Levels of N Fertilizer on Yield of Corn Grown on a Reddish-Brown Lateritic Soil in 1981 to 1983 (Inoue *et al.*, 1984).

were applied, with a basal level of P_2O_5 and K_2O (75 kg/ha). The results from two years of cultural practice (Figure 2) indicated that cane trash mulch was able to increase sugarcane yields by more than 10 t/ha compared with the unmulched treatment. This yield increase was equivalent to 5400 B/ha of farm income based on 1982 prices. The beneficial effect of the cane trash mulch on yield was attributed to its capacity to increase infiltration of rainfall to the soil, to minimize evaporative water loss, and to decrease water and nutrient runoff losses. Cane trash mulch was able to maintain soil surface structure, preventing crust formation when the soil was exposed to the impact of raindrops. There was little crop response to applied N unless the soil contained sufficient available moisture. Thus, crop response to N was attributed mainly to the mulching practice. The growth and yield of sugarcane were actually reduced by N fertilizer application when available water was limiting.

Cassava-Based Cropping Systems and the Use of Organic Matter for Increasing Soil Productivity

Inoue *et al.* (1984) conducted field experiments in 1982 to 1983 at Huai Pong Field Crop Research Center, at Rayong where soils were classified in the Gray Podzolic group. The objective was to maintain and improve soil productivity and crop yields by the use of organic materials on cassava-based cropping systems, which included cereal crops and sorghum. Sorghum was planted before cassava so as to obtain mulching material under fertilization, and a cover crop (*Mimosa sp.*) was also utilized. The experimental design is described in Table 1.

From the results shown in Figures 3 and 4 it is apparent that none of the cropping systems was highly successful the first year. The most likely reason for this is that increased soil productivity would be attained gradually from the long-term use of organic residues. The

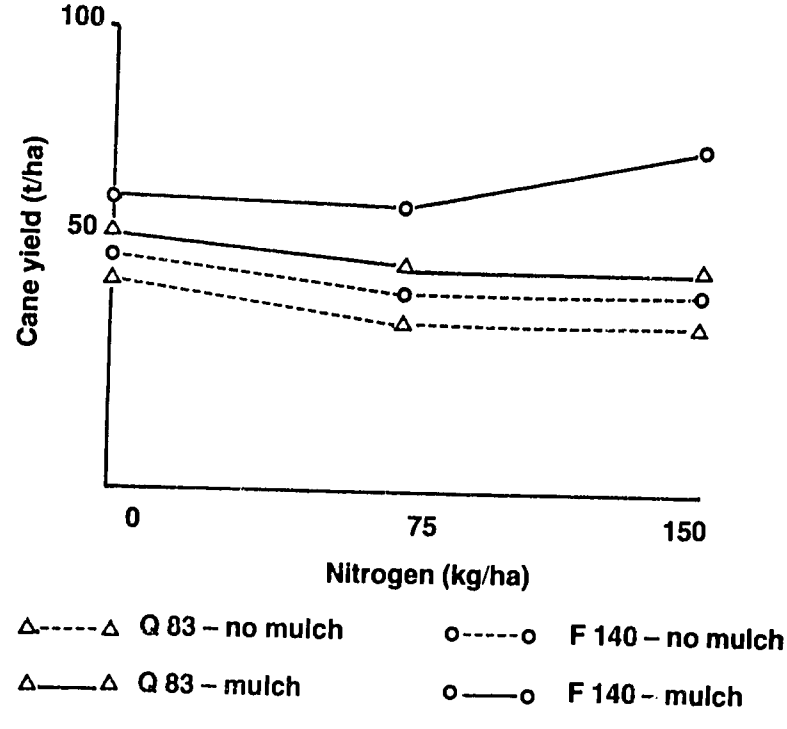

Figure 2. Effect of Cane Trash Mulch and Nitrogen Fertilization on the Yield of Two Sugarcane Cultivars (Q 83 and F 140) During 1981 to 1982.

Table 1. Experimental Design at Huai Pong Field Crop Research Center at Rayong During 1982 to 1983 for Cassava-Based Cropping Systems Using Sorghum for Surface Mulch and Mimosa Cover Crop. *Mimosa sp.* was Harvested at the Time of Cassava Harvest. (After Inoue *et al.*, 1984).

Cropping System	N-Levels	Cover Crop Planted	5 May	18 May	28 May	11 Aug	25 Aug	2 Mar	2 Jan
	kg ha⁻¹								
1	50,100	None				.... Cassava (R1)†			
				.... Sorghum					
2	50,100	10 Sep				..... Cassava (R1)			
				.... Sorghum					
3	50,100	None	..... Cassava (R1)						
4		10 Jun	..... Cassava (R1)						
5	50,100	None				..... Cassava (H5)			
				.... Sorghum					
6	50,100	10 Sep				..... Cassava (H5)			
				.... Sorghum					
7	50,100	None	..... Cassava (H5)						
8	50,100	20 Jun	..... Cassava (H5)						

† R1, Rayong 1; and H5, Huai Pong 5.

Rayong 1 (R1) cultivar, which is widely used in most of the cassava growing areas of Thailand, is not suitable for intensive cropping systems since it is a slow-growing variety that does not respond well to soil management. However, it is possible to utilize Rayong 1 in intensive cropping systems if sorghum or other suitable crops can be grown to provide surface mulching material prior to planting cassava to enhance soil and water conservation.

Effect of Organic Matter Application to Heavy Clay Paddy Soils on Improving Soil Productivity and Crop Yields

Akiyama *et al.* (1979) conducted research at Suphan Buri Rice Experimental Station from 1974 to 1977 to establish an effective technical system for paddy farming. Their objectives were to 1) develop cropping systems for rotating field crops with rice, 2) increase water use efficiency by crops, and 3) increase soil fertility and productivity.

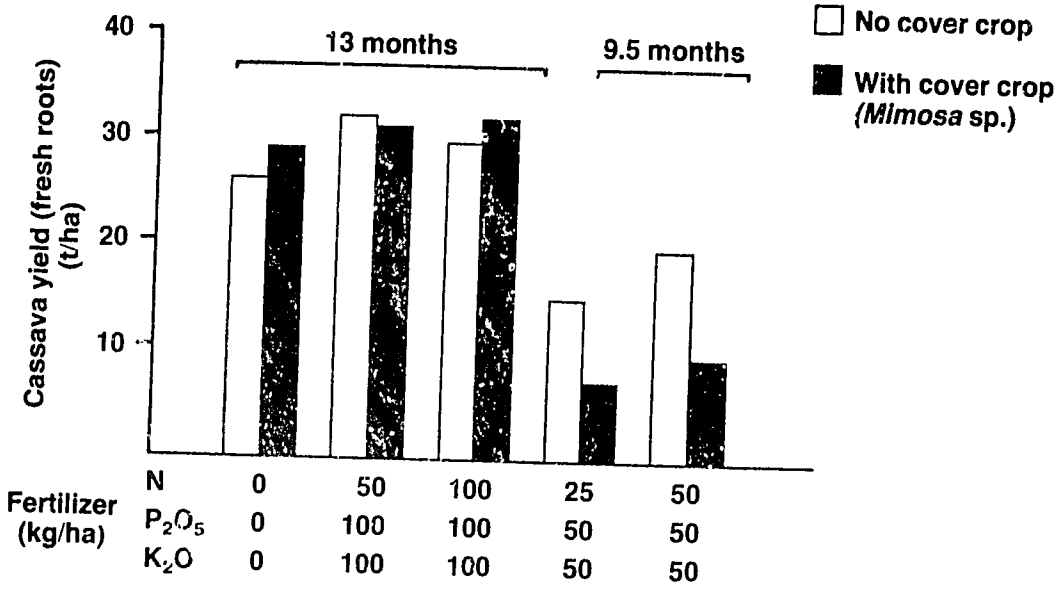

Figure 3. Growth and Yield of Cassava (Rayong 1) After 13 and 9.5 Months (1982).

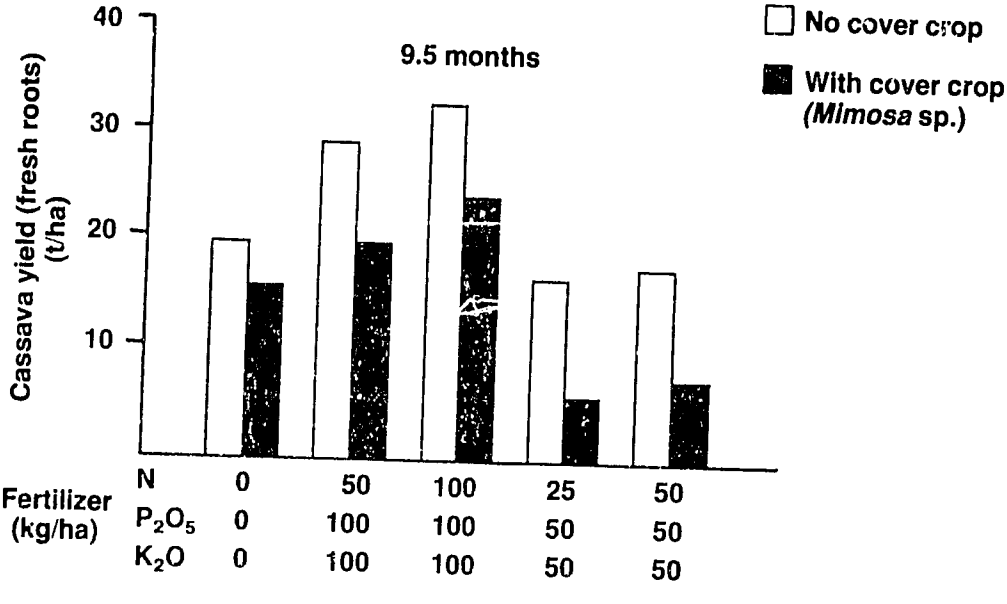

Figure 4. Growth and Yield of Cassava (Huai Pong 5) After 9.5 Months (1982).

The heavy clay paddy soil at Suphan Buri Rice Experimental Station has very poor physical characteristics. While it does have the potential for acceptable crop yields, it is likely that soil productivity can be improved by long-term organic matter treatments. The organic materials in the field trials included rice straw, rice hulls, cornstalks, sawdust and farmyard manure. These were applied and incorporated into the soil 40 to 45 days before planting corn during December to May. After corn was harvested the cornstalks were

incorporated into the plot. Rice was sown, harvested in November, and rice straw residues were then incorporated. Soil samples were collected periodically to assess changes in physical properties. Application of the organic materials resulted in decreased bulk density and increased moisture holding capacity of the plow layer. However, corn yields were not significantly increased by the organic amendments with the exception of farmyard manure in which case yields were increased. The poor corn growth may have been due to a nitrogen deficiency caused by the microbiological immobilization of inorganic N in the decomposition of organic matter. Rice yields were increased by the organic amendments. The apparent nitrogen deficiency and low yield of corn associated with organic matter applications can be avoided by delaying the time of sowing. The crop residues should not be plowed into the soil before submergence, but should be applied in the form of farmyard manure after harvesting rice.

Effect of Organic Matter on Soil Water Retention and Plant Growth

Ueno *et al.* (1983) conducted an experiment on Reddish-Brown Lateritic soils in 1981 to 1982 to determine the effect of cornstalk mulch, cornstalks incorporated (unmulched), weed mulch, minimum tillage and green manuring on soil moisture retention and the growth of corn and mung bean. The organic materials were applied at the rate of 5.0 t/ha. The weed mulch consisted of *Imperata cylindrica* and the green manure was *Crotalaria juncea*. The results shown in Figures 5 and 6 indicate that the weed and cornstalk mulching practices effectively increased soil moisture retention, whereas the incorporation of cornstalks had little effect. The planting of *Crotalaria* increased the risk of drought from moisture competition with corn. About 4.5 t/ha of corn grain were obtained in the weed and cornstalk mulch treatments. There were no significant differences in mung bean yields among the treatments. These results indicate that the corn growing on the mulched

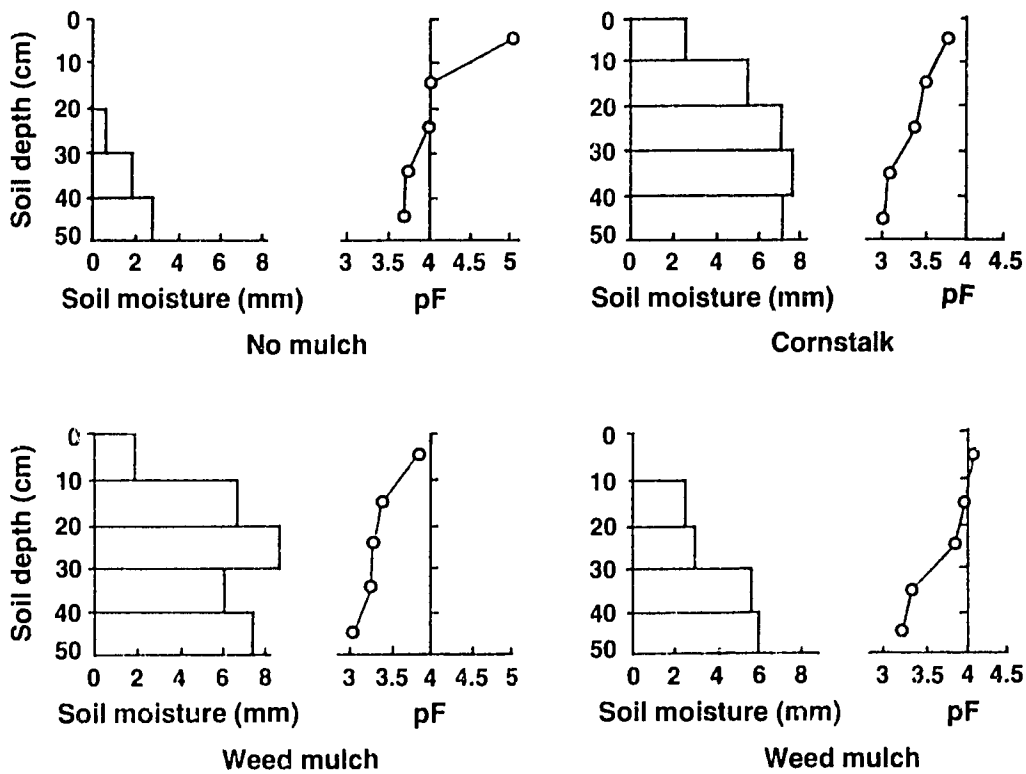

Figure 5. Soil Moisture Status as Affected by Mulching Practices Observed on July 9, 1982 at Phra Phuttabat (After Ueno *et al.*, 1983).

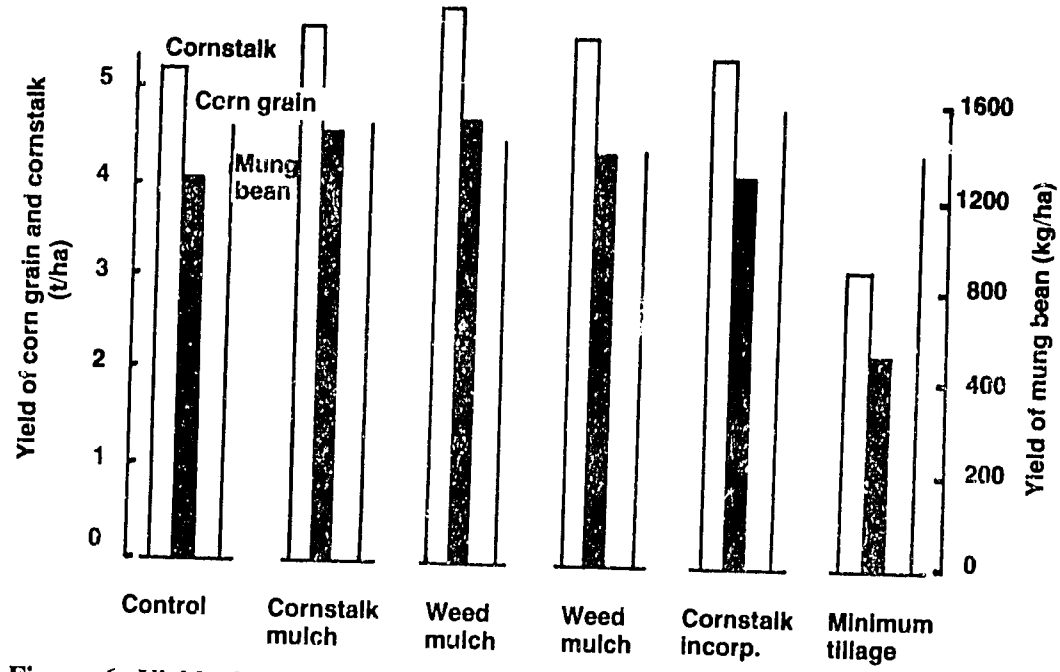

Figure 6. Yield of Corn, Grain Cornstalks and Mung Bean at Phra Phuttabat in 1981 as Affected by Organic Amendments and Minimum Tillage (After Ueno *et al.*, 1983).

plots was protected from moisture stress and drought injury because of the increased level of moisture retention and availability, whereas corn crops in the unmulched plots were not.

Utilization of Organic Materials on Soil Thai Farms

Suzuki *et al.* (1980) conducted a survey on the use of organic materials by farmers which he divided into four categories as follows:

Use of Crop Residues

Thai farmers generally harvest the rice crop about 40 cm from the top of the plant. After threshing, the straw is stored in piles to be used as fodder for cattle. This practice allows long stubble to remain in the field, providing an important source of fodder for cattle. In Thailand, rice straw is generally plowed into the soil at the beginning of the rainy season. In the central plain, it is commonly burned after harvest and during the dry season to avoid tillage problems. Rice straw is also widely used for mulching by vegetable farmers throughout the country. As for upland crops, the corn stover is usually plowed into the soil after harvest, while sugarcane trash is left in the field after harvest and then burned before the field is prepared for the next crop. With cassava, the organic matter returned to the soil consists only of the fallen leaves.

Use of Farmyard Manures

Farmyard manures are not usually applied to paddy fields but are most often utilized in rice nurseries. Poultry dung, pig dung and bat guano are commonly used on vegetables and, to a limited extent, for corn and sugarcane. The application rate of poultry dung ranges from 7 to 18 t/ha/yr. Farmyard manures are also commonly used in orchards where they are applied at a rate of 60 to 70 t/ha/yr around the leaf canopy. The compositions of animal manures commonly used by Thai farmers are listed in Table 2.

Table 2. Compositions of Farmyard Manures Commonly Used by Thai Farmers (After Suzuki *et al.*, 1980).

Samples		Moisture	pH	C/N Ratio	Elemental Composition†					Sampling Site and Use
					C	N	P	K	Ash	
					.....%.....					
Buffalo	1	7.0	7.5	23	11.0	0.47	0.23	0.76	86.1	Sericulture Exp. Stn., Surin
	2	81.3	7.8	21	26.2	1.23	0.49	0.88	23.1	Rice Exp. Stn., Rangsit (Fresh)
	3	54.1	7.7	17	22.7	1.37	1.42	1.91	40.9	Orchard at Klang, Rayong
	4	36.3	8.6	12	9.8	0.81	0.19	1.57	64.4	Nursery bed for rice at Gunthorawichar, Maha Sarakham
Cattle	1	59.6	8.3	17	18.5	1.09	0.53	1.68	71.6	Hang Chat Exp. Stn., Lampang
	2	34.9	7.4	16	21.4	1.32	0.32	2.71	60.4	Orchard at Thamai, Chanthaburi
	3	51.9	8.2	14	12.2	0.86	0.58	0.80	76.7	Maejo Exp. Stn., Chiang Mai
	4	39.2	8.3	13	15.7	1.20	0.34	1.56	67.3	Orchard at Thamia, Chanthaburi
Swine	1	45.3	5.7	16	16.0	1.30	2.69	0.63	44.2	Orchard at Klang, Rayong
	2	14.5	7.8	14	22.8	1.68	2.69	1.34	51.9	Vegetable farm at Kamnoensaduak
	3	29.9	8.5	14	17.4	1.25	1.74	0.92	57.8	Ratchaburi
Duck	1	7.0	8.3	29	21.2	0.74	1.39	1.26	58.4	Vegetable farm at Taling Chang, Bangkok
	2	25.3	6.8	20	24.7	1.26	1.41	0.69	53.5	Vegetable farm at Nong Khaem, Thon Buri
	3	34.3	8.8	17	18.4	1.08	1.36	0.75	68.0	

† Oven-dry basis.

Use of Compost

The use of compost is not widespread among Thai farmers. The city compost which is produced in Bangkok is mainly used by gardeners and vegetable growers located nearby. However, many experiment stations are now producing different composts by using various kinds and combinations of organic wastes and residues. The compositions of some of these composts and their chemical properties are shown in Table 3.

Table 3. Compositions of Composts Sometimes Used by Thai Farmers (After Suzuki *et al.*, 1980).

Samples	Moisture†	pH	C/N Ratio	Elemental Composition†					Original‡ Materials Composted
				C	N	P	K	Ash	
	%			..... %					
1	62.0	7.6	14	16.7	1.23	0.29	0.75	66.1	RS + BD
2	79.7	7.4	14	27.0	1.93	0.41	1.88	49.4	Grass + BD
3	54.1	6.6	18	18.7	0.93	0.33	0.88	63.5	Peanut hull + BD
4	34.4	8.3	13	15.8	1.20	0.35	2.46	69.2	RS + Grass + BD
5	58.4	7.5	16	10.6	0.65	0.25	0.47	76.7	RS + RH + BD
6	59.8	7.2	17	18.8	1.12	0.35	1.26	64.2	RS + RH + Grass + BD
7	66.7	5.8	13	13.4	1.00	0.25	1.81	72.3	RS + Grass + Sorghum + BD
8	71.8	7.5	21	27.8	1.31	0.50	1.10	27.0	RS + Lime + BD
9	77.5	8.9	22	21.2	0.95	0.20	1.69	55.0	RS + BD
10	44.2	7.9	16	8.0	0.50	0.14	0.40	85.1	Peanut hull + Kenaf + BD

† Oven-dry basis

‡ Kenaf refers to the wastes left after removing fiber from the plant; BD, Buffalo dung; RS, Rice straw; RH, Rice hulls.

Use of Organic Wastes

Organic wastes that have been commonly used by farmers, depending on availability and cost, include: sawdust, rice mill dust, sugarcane press cake, fermentation residues from industrial alcohol production, waste from production of seasoning powders, activated sludge from soft drink factories, castor bean cake, fish cake waste, and rice straw compost from mushroom cultivation. The compositions of these composted materials are listed in Table 4.

Those materials with a very high ash content such as rice mill dust-1 and fish cake may not be good organic matter sources. Crops could be injured by fish cake which contains very high amounts of salt and, consequently, sodium. Therefore, the application of large amounts of fish cake waste to upland crops should be avoided. The use of organic materials which have very high C/N ratios such as sawdust should be accompanied by the

Table 4. Compositions of Organic Wastes Commonly Used by Thai Farmers (After Suzuki *et al.*, 1980).

Materials	Moisture†	pH	Elemental Composition†					C/N Ratio
			C	N	P	K	Ash	
	%		.....	.....	%	.....	.....	
Sawdust	7.9	4.7	34.1	0.11	0.02	0.03	1.8	310
Rice mill dust-1	6.5	7.0	14.6	0.96	0.33	0.51	69.9	15.2
Rice mill dust-2	73.8	5.2	31.7	2.71	3.24	0.82	46.6	11.7
Sugarcane press cake	70.1	8.5	37.5	1.93	2.36	0.28	32.4	18.9
Fermentation residues from brewing industry	8.0	4.0	41.1	2.10	0.11	2.21	12.0	19.6
Activated sludge from soft drink industry	8.3	6.8	31.7	3.71	1.52	0.21	23.1	8.5
Rice straw compost from mushroom cultivation	75.9	6.2	36.0	2.14	1.80	2.28	30.6	16.8
Fish cake‡	18.7	7.5	20.5	2.16	2.86	0.24	64.7	9.5

† Oven-dry basis.
‡ Waste of NAM PLA manufacture (Na content = 27.8%).

application of N fertilizers, or the material should be co-composted with other wastes that would supply N so as to lower the C/N ratio before it is applied to the field. Failure to do this could immobilize inorganic N in soil, resulting in a temporary N deficiency for crops.

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ABSTRACT. In Thailand there are about 225 million rais or 70 percent of the total area that has been impacted by such soil degradative processes as erosion, salinization and acidification. Most of these deteriorated soils are low in both fertility and organic matter content. The level of organic matter in soils of some 91 million rais ranges from 0.3 to 0.5 percent. The Land Development Department has decided that the easiest and most cost-effective way of improving the productivity of these degraded soils is to use composts prepared from mixtures of crop residues, animal manures and nitrogenous fertilizers. If farmers so desire, quality composts can be obtained in a very short period of time by the use of a microbial inoculant as a starter. The first microbial inoculant or microactivator used for producing compost in Thailand was introduced from Japan in 1979. The trade name of this activator was "F" and it was a culture of the fungus Aspergillus oryzae Fujita. Inoculation with this fungus caused extensive decomposition of crop residues such as para grass, and rice husk and sawdust within 20 and 45 days, respectively. Later, a bacterial culture from the U.S. under the trade name "Agromax" was used which decomposed sugarcane bagasse within 90 days instead of a one-year period without inoculation. The microactivator currently recommended by the Land Development Department is a U.S. product called "B-2" which is cultured in Thailand. This product contains bacteria, fungi and actinomycetes which can decompose cornstalks in 30 days with the maximum release of plant nutrients.

Compost utilization in Thailand depends on soil conditions and the cropping system. For paddy rice and field crops grown on sandy soil, 3 t/rai of compost are recommended, and 2 t/rai on clayey soil. The highest yields are obtained when these rates of compost are applied with chemical fertilizers at one-half their recommended rates.

The government of Thailand has now established a policy to promote the on-farm production and use of compost by farmers throughout the country. The objective is to utilize organic residues and wastes in the most practical and cost-effective manner to improve and maintain the tilth, fertility and productivity of agricultural soils.

Introduction

The Soil Survey and Classification Division, Department of Land Development, has estimated that approximately 225 million rais, or about 70 percent of the total area of Thailand, are in a state of deterioration from erosion, salinization and depleted soil fertility. Also, they estimated that 191 million rais, or about 85 percent of the affected area, have serious problems that are attributed to a low level of soil organic matter (Dhanyadee, 1984). Since soil productivity is highly correlated with the soil organic matter content (Parr, 1981) it is important to maintain an adequate level of organic matter by periodic additions of organic materials such as crop residues, manures, food processing wastes and municipal wastes. In addition to macronutrients such as NPK, compost provides secondary and micronutrients to soils (Alexander, 1977; Gibbons, 1984; Kunda and Gue, 1982; Logsdon, 1976; Ojeniyi and Agbute, 1980). Composts also improve soil chemical and physical properties such as aeration, water holding capacity, bulk density, aggregation and cation exchange capacity, and enhance the activity of beneficial soil microorganisms. Composts also provide a stabilized form of organic matter that imparts longer-lasting residual effects to soil than that obtained from the addition of uncomposted raw materials (Dhanyadee, 1979; Panitsakpatana, 1984; Vangnai, 1984).

While composting is an ancient practice that goes back perhaps several thousand years, Sir Albert Howard is credited with the development of the process technology that has led to modern-day composting methods. In the 1920s Howard developed a method of composting

in which different types of organic materials, including crop residues and animal manures, were layered one after another and then turned twice during the decomposition process to enhance aerobic conditions. The method became known as the "Indore Method," named after the state in India where he did his work. Later, the Indian Center for Agricultural Research at Bangalore improved Howard's method by including a phase of anaerobic decomposition. To achieve this, the compost pile was covered with soil, which slowed the composting time, but required less labor to maintain. This method became known as the "Bangalore Method."

During 1920 to 1930, several European countries developed mechanized systems for composting city refuse or garbage. The most successful process was found by Dr. Giovanni Beccari in Italy and utilized anaerobic conditions for the initial stage of decomposition, and then changed to aerobic conditions for the final stage. This method was widely known as "The Process." Later in France this method was improved by using high-pressure pumping systems for aeration and drainage and became known as the "Verdier Process " In 1931 Jean Dordas further modified the Indore Method by omitting the initial stage of anaerobic decomposition, but still maintained a pile configuration. Subsequently, the modified Indore Method was used extensively in the Netherlands for composting city refuse or garbage. The method utilized a shredder to reduce materials to a smaller and more uniform size, and very large, high piles that had to be provided with drainage and means for remoistening. During the 1940s in the U.S., J.I. Rodale promoted the use of organic matter for improving soil productivity in lieu of chemical fertilizers. He also focused on the Indore Method of Howard and supported research to improve it.

For more than 20 years, Thailand, especially the Land Development Department, has conducted research on making composts. At first, the research was concerned only with residues that took a long period of composting to obtain a finished product. Eventually, crop residues were mixed with animal dung in a ratio of 10:1 (by weight) and after that crop residues, animal dung and chemical fertilizer were mixed in a ratio of 100:10:1, respectively (Dhanyadee, 1979; 1980). However, these methods take so much time that the compost cannot be used in the current cropping season. For this reason farmers are discouraged from making compost (Dhanyadee, 1979; MOAC, 1981).

Inoculants and Activators for Compost Production

Inoculants and activators for composting are of four types:

1) Animal dung, organic fertilizer or compost.

2) Chemical fertilizers, especially nitrogen fertilizers such as urea and ammonium sulphate, at ratio of 16-20-0, 20-20-0, 15-15-15 mixed in a proper ratio with the organic materials to be composted.

3) Enzymes that will digest cellulose, hemicellulose, proteins, lignin and lipids. These preparations are used in small amounts, but can help to speed up the composting process. For example, if the raw aterial is high in cellulose, an enzyme preparation containing cellulase should be used. These products are quite expensive.

4) Microbial activators can enhance the decomposition of crop residues and impart a good quality to the compost. These products and preparations can be especially helpful when the bulk of material to be composted is a crop residue having a wide C/N ratio. Such materials often lack the array of microorganisms necessary to ensure rapid and complete composting. The process can be naturally enhanced when inoculated with animal manures or soil slurry of finished compost.

The Land Development Department has used three kinds of microbial activators for producing composts, as follows:

1) F product (*Aspergillus oryzae* Fujita) is a fungal culture introduced from Japan which can accelerate the composting process. For example, for crop residues such as para grass and rice straw, the time for producing compost is 20 days while for rice husk and sawdust composting takes 45 days to complete the compost as shown in Table 1. The product is used in a ratio of crop residue:animal dung:chemical fertilizer:F product, 1000:200:2:1 kg.

2) Agromax-cellostat is a microbial culture from the U.S. which consists of a mixed culture of bacteria, fungi and actinomycetes. Four treatments were carried out as follows:

Treatment 1: bagasse, 1 t; duck dung, 200 kg; urea, 2 kg; rock phosphate, 2 kg.

Treatment 2: bagasse, 1 t; duck dung, 200 kg; urea, 2 kg; rock phosphate, 2 kg; Agromax-cellostat, 180 g.

Treatment 3: bagasse, 1 t; duck dung, 200 kg; urea, 2 kg; rock phosphate, 2 kg; Agromax-cellostat, 360 g.

Treatment 4: bagasse, 1 t; duck dung, 200 kg; urea, 2 kg; rock phosphate, 2 kg; Agromax-cellostat, 540 g.

As shown in Table 2, when the Agromax-cellostat product was mixed with the bagasse at the high rate of 540 g, the composting was completed in 90 days.

Table 1. Decomposition Time and Chemical Quality of Compost From Various Crop Residues (Dhanyadee, 1980).

Treatment	Time of Decomposition	C/N Ratio	Chemical Quality of the Compost			pH
			N	P_2O_5	K_2O	
	days		..... %			
1. Para grass/duck dung/urea/ F product	20	19	1.17	3.46	2.17	8.3
2. Rice straw/duck dung/urea/ F product	20	15	1.53	2.41	2.87	9.0
3. Rice husk/pig dung/urea/ F product	45	12	2.43	11.8	1.81	8.4
4. Sawdust/duck dung/urea/ F product	45	20	2.17	6.97	1.96	8.3

3) B-2 is a microbial activator which enhances the rate of crop residue decomposition when used as follows: crop residue/animal dung/chemical fertilizer/B-2 product, 1000 kg/200 kg/1 kg/1 set (one set of B-2 product consists of 300 g of B-2 and 1 kg of a protein powder preparation). The results shown in Table 3 indicate that the B-2 product mixed with cornstalks decreased the C/N ratio to 18 after 40 days of composting. In the absence of B-2 the C/N ratio had only decreased to 32, indicating a low rate of composting.

Modern Method for Compost Production

There are two principal methods for utilizing microbial activators in compost production. First, if the crop residues are bulky such as rice straw and water hyacinth, they are heaped into layers which, in turn, are trampled and watered. The thickness of the layers is approximately 30 to 40 cm. Each layer is then covered with animal dung and chemical fertilizer and the activators are applied. Other layers are done in the same procedure until

Table 2. Effect of the Agromax-Cellostat Mixed Microbial Culture on the Composting of Sugarcane Bagasse After 90 Days.

Treatment	C/N Ratio	C	N	P_2O_5	K_2O
		.....	%	.....	
Treatment 1	29	31.4	1.08	2.52	0.10
Treatment 2	27	29.2	1.08	2.52	0.12
Treatment 3	21	21.4	1.02	2.43	0.11
Treatment 4	20	20.3	0.99	2.91	0.12
Bagasse residue	164	59.0	0.36	0.04	0.29

Table 3. Effect of the B-2 Product as an Activator for Composting Cornstalk Residue.

Treatment	Time of Decomposition	C/N Ratio	N	P_2O_5
	days		..... %	.....
1. Cornstalk, 100 kg; duck dung, 10 kg; urea, 0.25 kg	40	32	1.31	1.12
2. Cornstalk, 100 kg; duck dung, 10 kg; urea, 0.25 kg; B-2 product	40	18	2.25	1.17
3. Cornstalk residue		42	1.17	0.46

the pile is approximately 1.0 to 1.5 m high. The surface of the pile is then covered with top soil to a depth of 1 inch (Dhanyadee, 1976; 1979; 1980).

Second, if crop residues are chopped and ground rather fine, they are mixed manually with animal dung and chemical fertilizer in predetermined proportions. During the mixing operation the biomass is moistened and the activator is incorporated.

Time Required for Compost Production

Generally, it takes from one to three months to produce compost, depending on the following considerations:

1) *Type of crop residue.* Each crop residue has a characteristic C/N ratio as shown in Table 4. Residues with a high C/N ratio decompose more slowly than those having a low C/N ratio. Optimum composting occurs at a C/N ratio of about 25:1.

2) *Conditions of composting.* The composting process proceeds at the most rapid rate when optimum conditions are maintained in the pile for aeration (this should essentially be aerobic most of the time), moisture (50 to 60 percent by weight) and temperature (thermophilic range of 55° to 65° C) (Dhanyadee, 1984).

Table 4. Some Chemical Properties of Various Organic Materials (Dhanyadee, 1976; 1984).

Kind of Organic Materials	N	P_2O_5	K_2O	C/N Ratio	pH
	.....	%	.....		
1. Farm wastes					
Rice straw	0.55	0.09	2.39	89	8.2
Cassava peel	1.82	0.48	1.99	27	8.5
Corn residue	0.53	0.15	2.21	62	8.2
Soybean residue	3.34	1.04	2.54	16	8.1
2. Industrial wastes					
Bagasse	0.40	0.15	0.44	146	6.0
Sawdust	0.32	0.16	2.45	196	5.4
Coconut dust	0.36	0.03	2.49	167	6.1
Rice hull	0.36	0.09	1.08	152	6.1
3. City waste					
Municipal waste	1.20	1.56	10.34	39	5.9
4. Others					
Water hyacinth	1.27	0.71	4.84	34	7.8
Peat soil	1.10	0.04	0.26	41	3.5
Azolla	2.98	0.61	2.05	14	6.8

To further promote the composting of various organic wastes and residues for beneficial use on agricultural soils in Thailand, it is essential to know the kind and amount of different materials that are produced annually, and which might be utilized for this purpose. Table 5 shows that the total current annual production of crop residues, industrial wastes, municipal wastes, animal wastes and night soil is some 139 Mt. Certainly, many of these materials would not necessarily be available for composting because of competitive, social and transportation constraints.

Table 5. Kinds and Amounts of Various Organic Materials in Thailand (Dhanyadee, 1984).

Kind of Solid Wastes	Amounts
	$t\ yr^{-1}$
1. Crop Residues	
Rice straw	43,000,000
Corn residue	1,000,000
Soybean and mung bean residue	500,000
Water hyacinth	1,000,000
Sugarcane residue	2,000,000
Tree leaves around resident area	1,000,000
2. Industrial wastes	
Bagasse	6,000,000
Sawdust	30,000
Coconut dust	30,000
Rice hull	5,000,000
Others	30,000
3. Municipal wastes	
Municipal wastes (Bangkok and main cities)	3,000,000
4. Animal wastes	
Cattle manure	30,000,000
Pig manure	30,000,000
Poultry manure	5,000,000
Other animal manure	500,000
5. Night soil	11,000,000
Total amount	139,090,000

Determination of Compost Maturity

After the composting is apparently completed, it should be evaluated for its relative state of maturity. Reliable indexes are as follows:

1) Color of the raw material is mostly changed to dark brown or black.
2) Temperature in the compost pile should have cooled to near the ambient temperature.
3) Mature compost will be softer and finer than at the initial stage.
4) C/N ratio should have decreased to at least 20 or lower.
5) Malodors should no longer be detectable.

Compost Quality

The quality and chemical properties of compost depend on the kind and chemical composition of starting materials that were used (Tables 4 and 6) and the conditions of aeration, moisture and temperature that prevailed during the composting period. Some chemical properties of various composts are listed in Table 7.

Compost Utilization

Compost utilization in Thailand depends upon soil conditions and cropping systems.

Compost For Rice

Research conducted at Pathumthani (Table 8) shows that the application of 2 t/rai of compost significantly increased the yield of paddy rice to 733 kg/rai, or approximately 55 kg more than the control. The highest yield of rice (886 kg/rai) was obtained when half the recommended rate of chemical fertilizer (20 kg/rai) was applied with the compost. The yield obtained with the recommended rate of chemical fertilizer (40 kg/rai) and no compost was 723 kg/rai, and was actually less than the yield with compost alone. Thus, the application of compost at a rate of 2 t/rai with half the recommended amount of chemical fertilizer can substantially reduce the cost of fertilizer, while ensuring maximum yields.

Table 6. Some Chemical Properties of Animal Manures
(Dhanyadee, 1984).

Types of Manure	N	P_2O_5	K_2O	pH
	.....	%	.....	
Chicken manure	1.67	3.32	2.41	7.6
Duck manure	0.78	0.96	0.74	6.8
Pig manure	2.71	3.35	0.98	6.8
Cattle manure	1.58	0.70	1.62	8.3
Horse manure	0.60	0.25	0.56	slightly basic
Bat manure	0.74	9.95	6.26	6.3

Table 7. Some Chemical Properties of Various Composts (Dhanyadee, 1984).

Kind of Compost Material	N	P_2O_5	K_2O	pH
	.....	%	.....	
1. Farm compost				
Rice straw compost	1.02	0.43	3.85	8.5
Cob compost	1.07	0.51	1.19	–
2. Industrial waste				
Bagasse	0.87	0.25	0.98	8.2
Sawdust	0.51	0.16	0.43	7.6
Coconut dust	0.61	0.14	2.03	7.2
Rice hull	1.23	4.03	1.29	8.3
3. City compost				
Municipal waste	0.981	1.04	1.06	–
4. Others				
Water hyacinth	1.19	0.87	3.06	7.9
Peat compost	0.96	0.38	0.70	6.0

Table 8. Effect of Compost and Chemical Fertilizer on Paddy Rice (*Oryza sativa* var. Asia 90) Yields in Pathumthani on a Clayey Soil (MOAC, 1981).

Treatment	Grain Yield
	kg rai^{-1}
1. Control	677
2. Compost 2 t rai^{-1}	733
3. Compost 2 t rai^{-1} + chemical fertilizer† 20 kg rai^{-1}	886
4. Chemical fertilizer 40 kg rai^{-1}	723

† Chemical fertilizer, 16-20-0.

Similar results were obtained when compost was applied to paddy rice at Maha Sarakham. Grain yield was highest (592 kg/rai) when compost was applied at 3 t/rai with half the recommended rate of chemical fertilizer (25 kg/rai). Rice yield with compost alone was equal to that obtained with a full application of chemical fertilizer. Here again, compost can substantially reduce the amount and cost of chemical fertilize. applied to rice (Table 9).

Table 10 shows similar results from the application of compost at 3 t/rai with chemical fertilizer at Khumpangpet. Some 710 kg/rai of rice were obtained with compost and half the recommended rate of chemical fertilizer, which represents a substantial reduction in fertilizer cost, that is, about 50 percent.

Table 9. Effect of Compost and Chemical Fertilizer on Paddy Rice (*Oryza sativa* var. Horm Mali) Yields in Maha Sarakham on a Sandy Soil (MOAC, 1981).

Treatment	Grain Yield
	kg rai^{-1}
1. Control	320
2. Compost 3 t rai^{-1}	452
3. Compost 3 t rai^{-1} + chemical fertilizer† 25 kg rai^{-1}	592
4. Chemical fertilizer 50 kg rai^{-1}	460

† Chemical fertilizer, 16-20-0.

Table 10. Effect of Compost and Chemical Fertilizer on Paddy Rice (*Oryza sativa* var. R.D. 7) Yields in Khumpangpet on a Silty Clay Loam (MOAC, 1981).

Treatment	Grain Yield
	kg rai^{-1}
1. Control	430
2. Compost 3 t rai^{-1}	600
3. Compost 3 t rai^{-1} + chemical fertilizer† 25 kg rai^{-1}	710
4. Chemical fertilizer 50 kg rai^{-1}	580

† Chemical fertilizer, 16-20-0.

Compost for Field Crops

The yield responses of cassava and corn to compost (3 t/rai) and chemical fertilizer at one-half the recommended rate, i.e., 25 kg/rai, are shown in Tables 11 and 12 for locations at Buriram and Chiang Rai, respectively. The highest yields were obtained with the application of compost and one-half the normally recommended rate of chemical fertilizer. Yields obtained with compost alone and the full recommended fertilizer rate were essentially the same. Thus, the combination of compost at 3 t/rai and chemical fertilizer at 25 kg/rai gave the highest yields, and allowed a 50 percent reduction in chemical fertilizer costs. The higher yields which resulted from this combination of compost and chemical fertilizer seem to provide evidence that organic amendments can markedly increase fertilizer use efficiency by crops.

Table 11. Effect of Compost and Chemical Fertilizer on Cassava Yields in Buriram on Sandy Soil (MOAC, 1981).

Treatment	Bulb Yield
	kg rai^{-1}
1. Control	2480
2. Compost 3 t rai^{-1}	3740
3. Compost 3 t rai^{-1} + chemical fertilizer† 25 kg rai^{-1}	4400
4. Chemical fertilizer 50 kg rai^{-1}	3620

† Chemical fertilizer, 16-20-0.

Table 12. Effect of Compost and Chemical Fertilizer on Corn Yields in Chiang Rai on a Sandy Loam Soil (MOAC, 1981).

Treatment	Grain Yield
	kg rai^{-1}
1. Control	240
2. Compost 3 t rai^{-1}	262
3. Compost 3 t rai^{-1} + chemical fertilizer† 25 kg rai^{-1}	276
4. Chemical fertilizer 50 kg rai^{-1}	264

† Chemical fertilizer, 16-20-0.

The current policy of the government of Thailand is to provide technical assistance to farmers throughout the country for making composts to improve the tilth, fertility and productivity of their soils. During the past five years some 38 provinces have been involved in this program which is summarized in Table 13, Figure 1 and Figure 2.

Table 13. Target Plan for Implementation of Organic Recycling for Improvement of Soil Productivity (1982 to 1986).

Activities	Project Implementation (5 years)	Targets				
		1982	1983	1984	1985	1986
1. Training						
1.1 Officials (person)	2,100	300	300	500	500	500
1.2 Farmers (person)	1,700	—	—	500	600	600
2. Organic Fertilizer						
2.1 Compost						
Demonstration (t)	20,000	4,000	4,000	4,000	4,000	4,000
Extension (t)	365,000	50,000	75,000	60,000	80,000	100,000
2.2 Green Manure						
Demonstration (rai)	14,000	4,000	4,000	2,000	2,000	2,000
Extension (rai)	125,000	250,000	25,000	25,000	2,500	2,500
3. Seed production (t)	274.5	127.5	55.5	30.5	30.5	30.5
4. Research for organic recycling (projects)	6	6	6	6	6	6

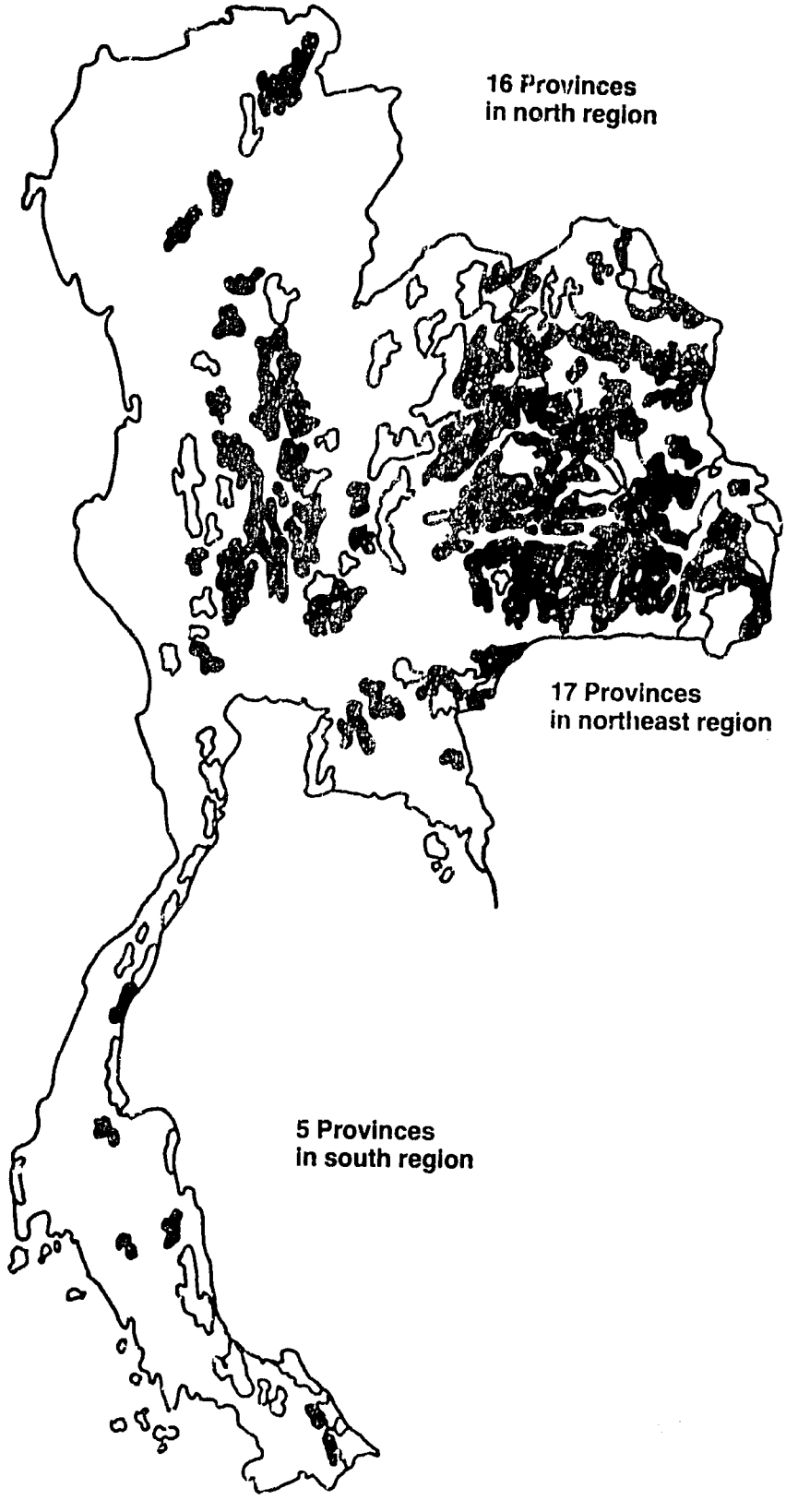

Figure 1. The Distribution of Low Soil Organic Matter Content Areas in Thailand.

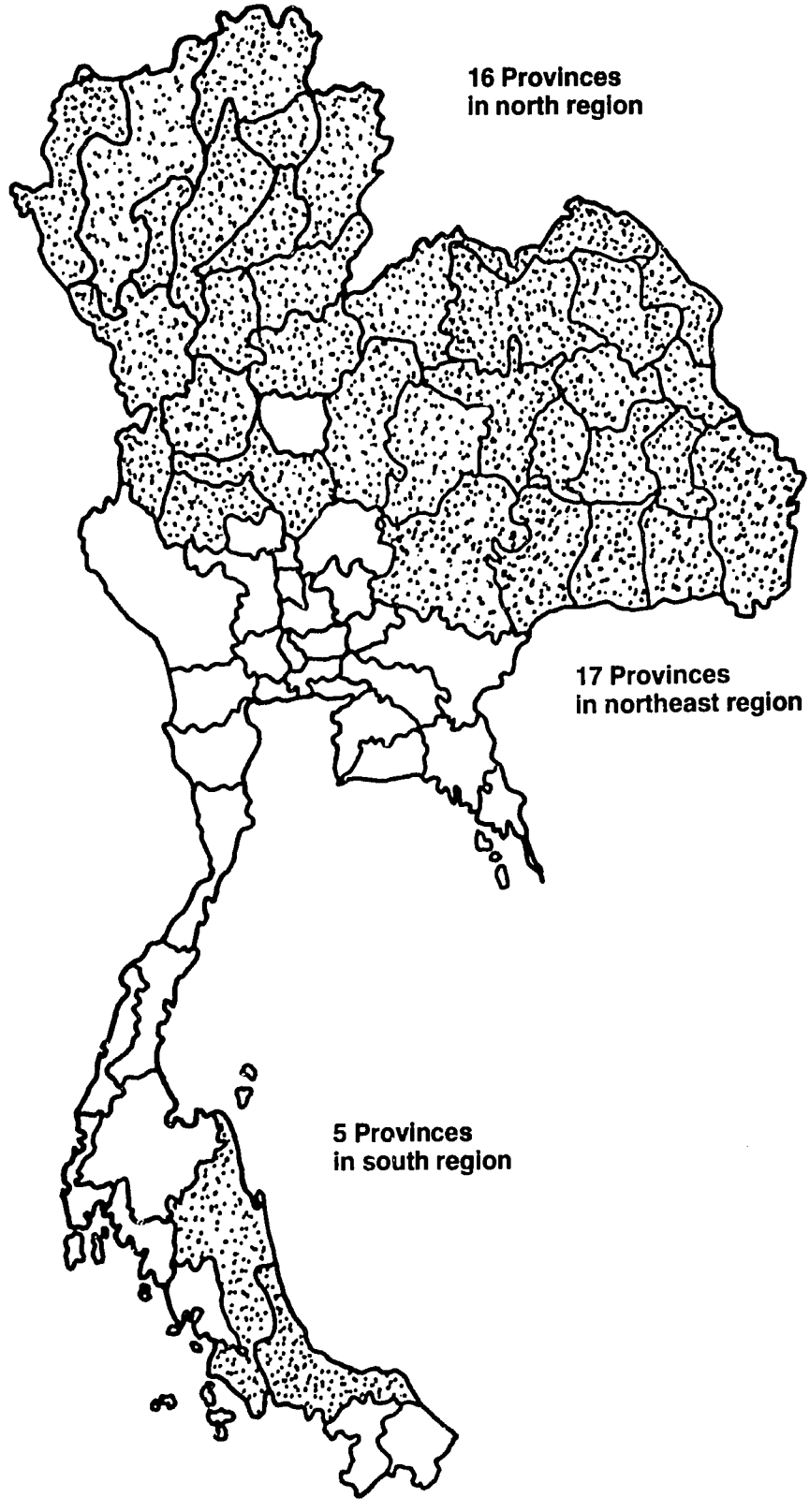

Figure 2. Implementation Areas for Soil Productivity Improvement by Organic Recycling (1982 to 1985).

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The No-Tillage System for Corn (*Zea mays* L.)

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ABSTRACT. The two methods of seedbed preparation, conventional versus no-tillage, and the N fertilizer requirement for corn (Zea mays L.) grown on Pak Chong soil were investigated at Farm Suwan beginning in 1984. Results from the first year experiment showed that neither growth, grain yield, nor N fertilizer response characteristics differ markedly under these two tillage systems. This was attributed to the high fertility status of the soil and the relatively uniform distribution of rainfall with a short-term drought period only in the early vegetative growth stage. Nonetheless, greater water conservation in the top 30 cm soil layer and higher water use efficiency were found associated with the no-tillage practice. The use of N fertilizer also resulted in higher water use efficiency of the corn plant for both tillage systems.

Introduction

The term "no-tillage," as defined by Jones *et al.* (1968), designates a procedure whereby the crop is planted directly into chemically killed vegetation or crop residue without any prior mechanical seedbed preparation. Corn (*Zea mays* L.) grown under the no-tillage system usually yields higher, particularly in fine-textured, well-drained, fertile soil (Blenvins *et al.*, 1971; Jones *et al.*, 1986; Phillips *et al.*, 1980; Triplett *et al.*, 1964). The increased yields in corn crops grown under the no-tillage system result in part from the conservation of soil water due to the reduction in evaporation (Na Nagara, 1972). Thus, more soil water is available for transpiration by the plant. This soil water conservation should lessen the damaging effect of short-term droughts which often occur in rainfed agricultural areas.

Phillips *et al.* (1980) reported that the no-tillage system reduced the energy input into corn and soybean production by 7 and 18 percent, respectively, when compared to the conventional tillage system. However, a disadvantage of the no-tillage system is excessive leaching of nitrate nitrogen following each rainfall event (Thomas *et al.*, 1973). Therefore, this method is not suitable for a low fertility, coarse-textured soil, which would require a high rate of nitrogen fertilizer (Na Nagara *et al.*, 1984).

The objectives of this investigation were to profile and compare soil water distribution, plant water use, water use efficiency, and growth and grain yield of corn under the no-tillage and conventional tillage systems when seven fertilizer levels were superimposed.

Materials and Methods

The experiment was conducted on Pak Chong soil which belongs to the family of very fine clayey, kaolinitic, acid Oxic Paleustults (Department of Land Development, Soil Classification Sheet on Soil Series). Corn was planted on August 15 and harvested on November 12, 1984 at the National Corn and Sorghum Research Center, Pak Chong, Nakon Ratchasima. The soil in the plot area was relatively fertile (Table 1) and was not cultivated in the previous season.

A split plot design with four replications was used. The main plot consisted of two tillage treatments, conventional and no-tillage. Subplots consisted of seven fertilizer levels, 0-0-0, 0-10-10, 10-10-10, 20-10-10, 30-10-10, 20-10-0 and 20-10-20 kg (N-P_2O_5-K_2O)/rai. The conventional tillage consisted of two plowing and two disking operations in preparation of the seedbed. For the no-tillage system, a mixture of paraquat (138 g a.i./rai) and atrazine (357.5 g a.i./rai) was used to kill the weeds 14 days prior to planting. After planting, 240 g a.i./rai of alachlor were applied to assure good control over preemerged weed seeds for the entire experimental plot.

Table 1. Chemical and Physical Soil Properties at the Experimental Site at Farm Suwan.

Soil Property	Soil Depth					
	0-10	10-20	20-30	30-50	50-70	70-90
	....cm....					
O.M. (%)	3.6	2.1	3.0	0.9	0.7	0.8
P (ppm)	95	12	5	8	1	3
K (ppm)	230	80	40	40	20	30
Vol. soil water content (%)						
0.3 bar (37.7 cm)	34.2	39.8	45.0	40.6	42.7	43.8
15 bar (26.1 cm)	21.0	28.0	30.5	29.5	31.0	30.5
PAW† (11.6 cm)	13.2	11.8	14.5	11.1	11.7	13.3
B.D. (g/cm)	1.06	1.30	1.33	1.27	1.25	1.25
Particle size distribution (%)						
Sand	13.0	12.1	11.7	6.3	7.8	6.7
Silt	6.0	7.9	7.3	5.1	1.7	1.2
Clay	81.1	80.0	81.0	88.6	90.5	92.1
Texture	HC	HC	HC	HC	HC	HC

† PAW, Plant Available Water; HC, Heavy Clay; B.D., Bulk Density; and O.M., Organic Matter.

Corn (Suwan 1, cycle 9) was planted with a planting stick at 75 × 25 cm spacing in subplots of 6 × 10 m. After seed placement, furadan (3 kg/rai) was applied to control insects and pests. The seedlings were thinned to one plant per hill (8530 plants/rai) 13 days after planting, then sidedressed 10 cm from the corn row with mixed fertilizer, at rates according to the planned treatments.

Soil and plant material were periodically sampled to determine the soil water content and plant dry matter production. Gravimetric soil samples were collected at depths of 0-10, 10-20, 20-30, 30-50, 50-70 and 70-90 cm on August 15 (planting), August 28 (thinning), September 20 (eighth-leaf stage), October 11 (70 percent silking) and November 22 (physiological maturity).

Results and Discussion

The Soil Profile Water Content

In the first year experiment, the amount and distribution of rainfall were normal when compared to the ten-year average (Figure 1). Figure 2 illustrates the higher soil water content that is achieved under the no-tillage system during the lower rainfall period on August 15 (planting), August 28 (thinning) and November 22 (physiological maturity). During the period of good rainfall distribution samples were taken on September 20 and

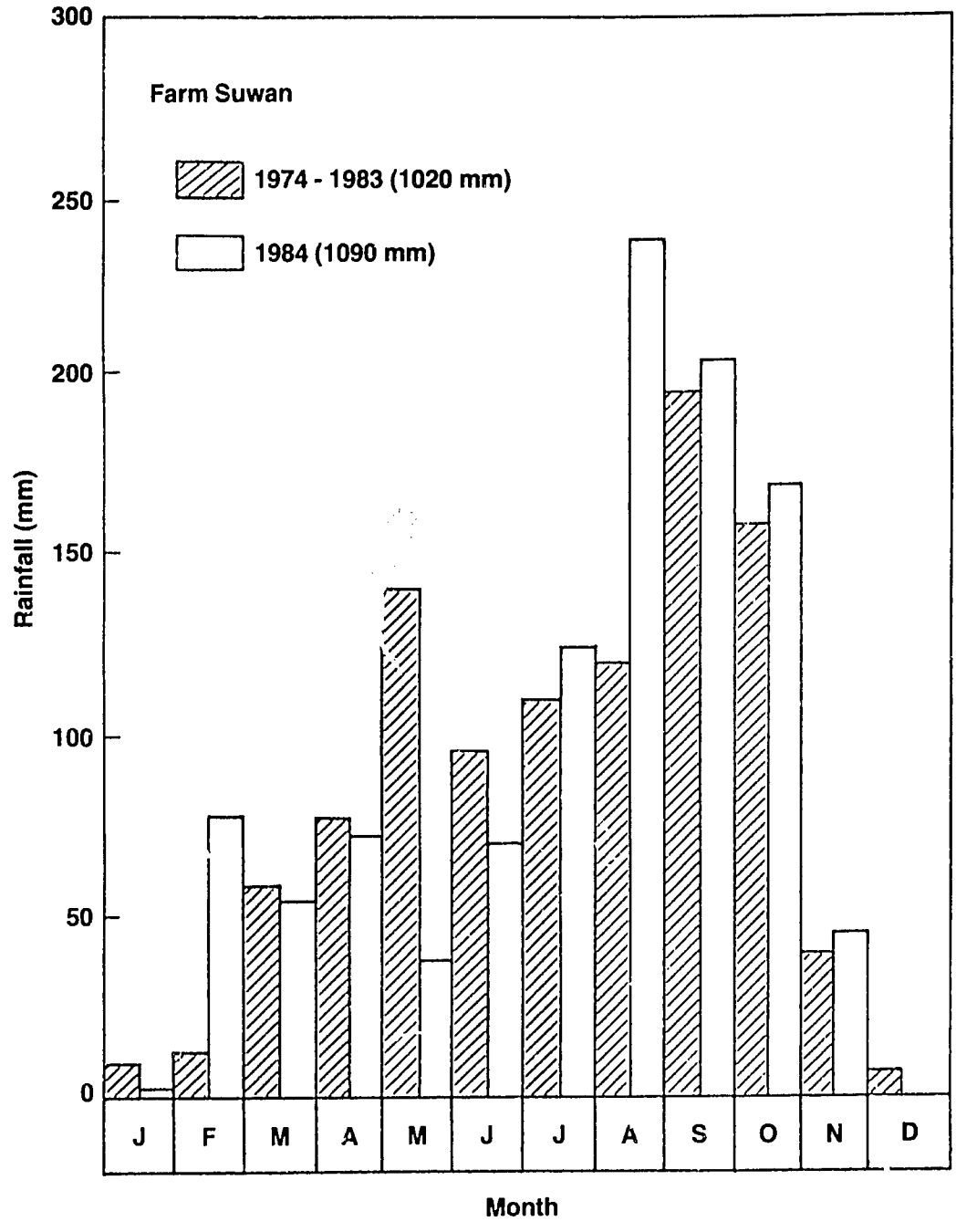

Figure 1. Rainfall Distribution at Farm Suwan.

October 11. The soil water content of the two tillage systems was practically identical at these times.

Soil water profiles from August 28 and November 22 under the two systems are compared in Figure 3, demonstrating the greater water conservation in the top 30 cm soil layer with no-tillage. This characteristic is attributed mainly to the effectiveness of the killed-sod mulch in reducing the evaporative loss of soil water from the no-tillage system. This comparison also indicates that corn extracted more water from deeper in the no-tillage

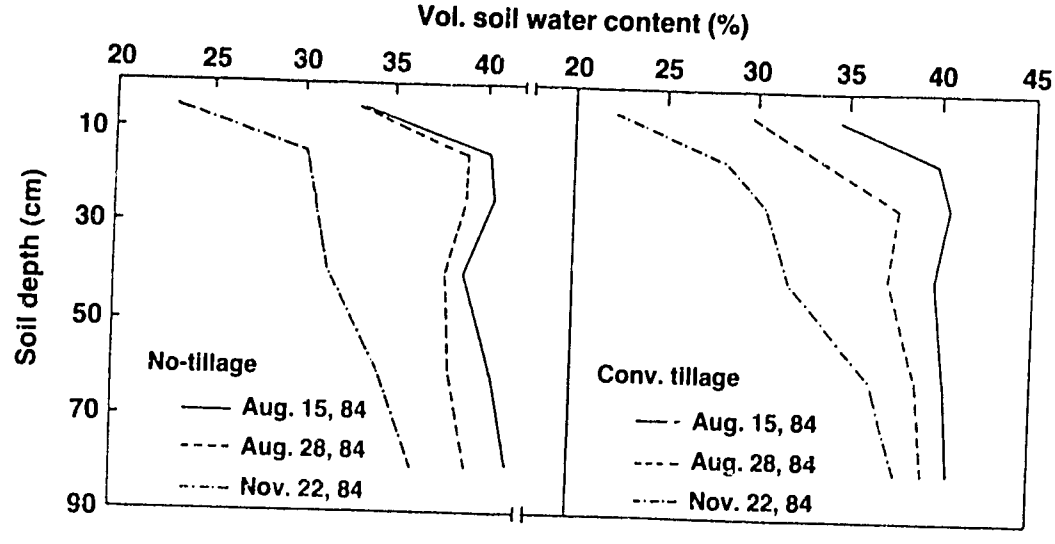

Figure 2. Soil Profile Water Content Under No-Tillage and Conventional Tillage for Corn in the 1984 Growing Season at Farm Suwan.

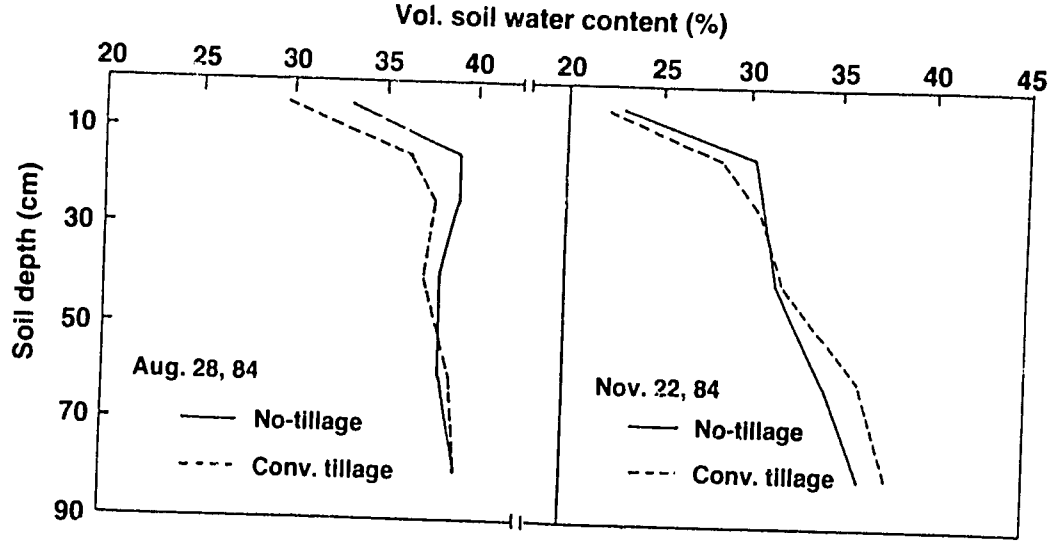

Figure 3. Soil Profile Water Content as Affected by Tillage Practices for Corn in the 1984 Growing Season at Farm Suwan.

profile than in the conventional tillage profile. This phenomenon is attributed to better root growth and development under the no-tillage system and the fact that the crop was essentially unaffected by drought during the early growth stages.

Figure 4 indicates that there were only two periods during the growing season when moisture stress was likely, one from late August to early September and a second from late October to early November. Only the first stress period, however, had observable effects on crop growth and development since this was the seedling stage when the plant roots were still confined to the topsoil. The soil water profile for the total 0 to 90 cm

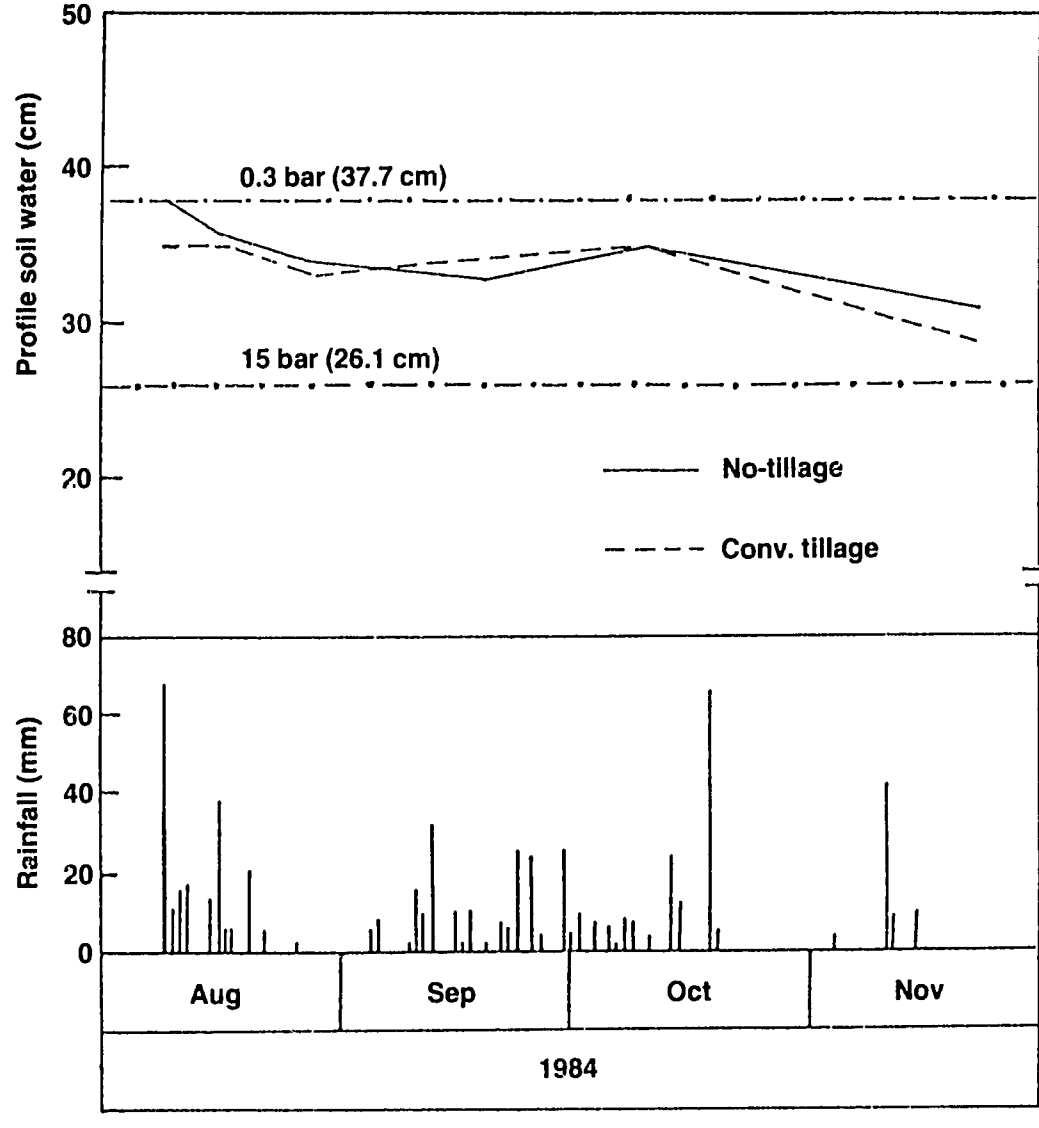

Figure 4. Soil Profile Water Distribution Under No-Tillage and Conventional Tillage in the 1984 Growing Season at Farm Suwan.

depth, illustrated in Figure 4, indicates that there was no severe stress under either system at any time during the entire growing season. The total 90 cm water profile of this Pak Chong soil at field capacity (0.3 bar) and wilting point (15 bars) was 37.7 and 26.1 cm, respectively. Thus, the plant available water (PAW) in this soil is approximately 11.6 cm, which is rather low compared to some other heavy clay soils.

Growth and Grain Yield of Corn

During the growing season, plant growth was observed periodically. The stand established under both tillage systems was quite uniform due to relatively good rainfall distribution following planting. After August 21, however, only 2.4 mm of rainfall was measured over the seven-day period to August 28, the date of thinning. This mild stress period resulted in a noticeably poorer stand of corn seedlings under the conventional tillage system while

seedlings in the no-tillage plots were larger, greener and apparently unaffected. Total dry matter production at this stage (13 days after planting) was 5.0 and 3.2 kg/rai under no-tillage and conventional tillage, respectively.

The rainless period continued until September 3 after which the rainfall distribution was quite uniform; rainfall measured 100 mm to the September 20 plant sampling date. On September 20, the no-tillage plants were taller than those under conventional tillage (Table 2). Application of N fertilizer markedly increased the plant height ($P<0.01$), particularly for those plants under the wetter no-tillage treatment. Irregular N responses under the conventional tillage system were due to moisture stress that occurred during the early plant growth stage. Consequently, the interaction between tillage practice and fertilizer level was significant ($P<0.05$) as shown in Figure 5.

The differences in plant height between the two tillage systems on October 11 were less marked due to the relatively uniform distribution of 150 mm rainfall between the two sampling dates. Nevertheless, fertilizer application significantly increased the plant height at this stage ($P<0.05$), particularly in the no-tillage system.

The effect of tillage system on the total dry matter production was similar to its effect on plant height, but was even more pronounced (Table 3). The mean total dry matter

Table 2. Height of Corn (Suwan 1) as Affected by Tillage Treatment and Fertilizer Level at Two Sampling Dates in the 1984 Growing Season at Farm Suwan.

Sampling Date and Tillage	Fertilizer Level (kg rai^{-1})							Mean
	0-0-0	0-10-10	10-10-10	20-10-10	30-10-10	20-10-0	20-10-20	
	..... *cm*							
Sept. 20, 1984								
No-tillage	103b†	103b	119a	116a	124a	126a	120a	116
Conv. tillage	93c	95bc	107ab	111a	100abc	103abc	106abc	102
Mean	98	99	113	114	112	115	113	
C.V. (%)	Tillage = 24.1, Fertilizer = 7.0, Tillage x Fertilizer = 4.7 ($P<0.05$)							
Oct. 11, 1984								
No-tillage	219b	221b	243a	250a	245a	241a	247a	238
Conv. tillage	216b	231a	244a	239a	237a	236a	237a	234
Mean	218b	226b	244a	245a	241a	239a	242a	
C.V. (%)	Tillage = 5.6, Fertilizer = 4.0, Tillage x Fertilizer = 2.6							

† In a row, means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test (DMRT).

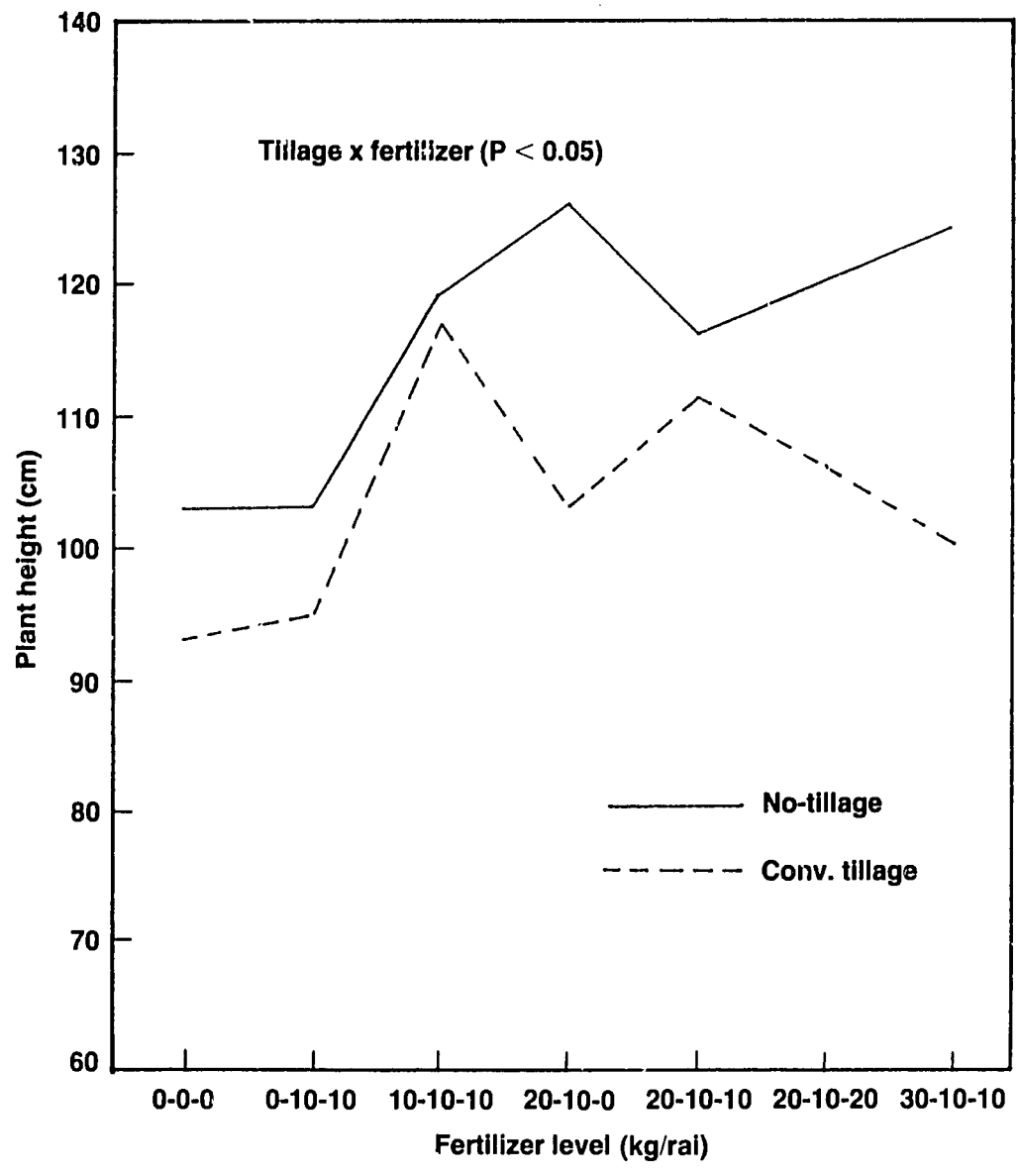

Figure 5. Height of Corn (Suwan 1) Grown on Pak Chong Soil at Farm Suwan on September 20, 1984 (36 Days After Planting).

production under no-tillage and conventional tillage on September 20 was 337 and 249 kg/rai, respectively. The effect of nitrogen fertilizer on total dry matter production was significant ($P<0.01$), particularly in the no-tillage system, but also for conventional tillage at high nitrogen levels.

At silking, October 11, 82 percent of the plants grown under the no-tillage system had silk visible outside the husk, while only 57 percent of the plants under conventional tillage showed visible silk. At this stage, neither tillage system nor fertilizer level affected the total dry matter production of the corn, but the interaction between the tillage practice and fertilizer level was significant ($P<0.01$) as shown in Figure 6.

Table 3. Total Dry Matter Production of Corn (Suwan 1) as Affected by Tillage Treatment and Fertilizer Level at Three Sampling Dates in the 1984 Growing Season at Farm Suwan.

Sampling Date and Tillage	Fertilizer Level (kg rai^{-1})							Mean
	0-0-0	0-10-10	10-10-10	20-10-10	30-10-10	20-10-0	20-10-20	
	..... *kg rai^{-1}*							
Sept. 20, 1984								
No-tillage	281a†	269b	364a	356a	376a	368a	343a	337
Conv. tillage	227bc	211c	288a	247ab	253abc	236bc	256abc	249
Mean	254b	240b	326a	315a	315a	302a	300a	
C.V. (%)	Tillage = 20.4, Fertilizer = 9.9, Tillage x Fertilizer = 13.1							
Oct. 11, 1984								
No-tillage	900a	735a	1160a	1140a	982a	1060a	1010a	997
Conv. tillage	779a	915a	1010a	970a	1050a	996a	994a	959
Mean	840	825	1280	1060	1020	1030	1000	
C.V. (%)	($P<0.01$) Tillage = 15.1, Fertilizer = 17.0, Tillage x Fertilizer = 8.8							
Nov. 22, 1984								
No-tillage	1350a	1450a	1590a	1710a	1600a	1730a	1790a	1600
Conv. tillage	1310a	1380a	1660a	1530a	1480a	1560a	1670a	1510
Mean	1330a	1420a	1620a	1620a	1540a	1640a	1730a	
C.V. (%)	Tillage = 12.6, Fertilizer = 16.4, Tillage x Fertilizer = 7.4							

† In a row, means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test (DMRT).

The data obtained from the final harvest on November 22 also showed no significant differences in the total dry matter production with regard to the tillage and fertilizer treatment, although corn grown under the no-tillage system tended to higher dry matter production (Table 3). Grain yield showed the same trend (Table 4). This was attributed to the relatively high fertility status of the Pak Chong soil.

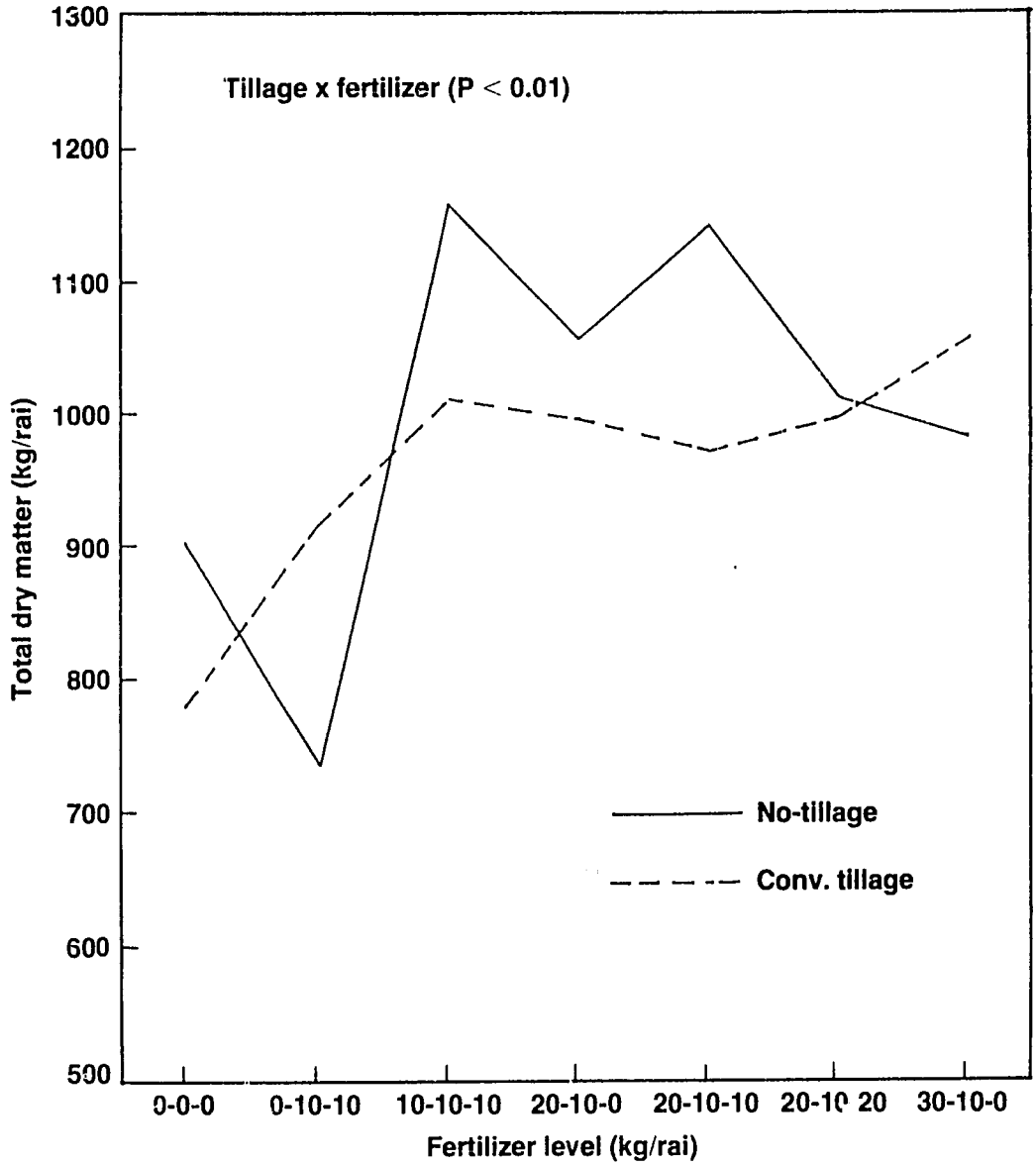

Figure 6. Total Dry Matter Production of Corn (Suwan 1) Grown on Pak Chong Soil at Farm Suwan on October 11, 1984 (57 Days After Planting).

Water Use and Water Use Efficiency of Corn

The actual values of evapotranspiration could not be calculated since the amount of rainfall percolation below the 90 cm depth was not measured. Therefore, in this investigation the term "water use" is defined as the evapotranspiration plus the amount of water percolated below the 90 cm soil layer, i.e., the sum of soil water depletion from 0 to 90 cm plus rainfall. In the 1984 growing season, the term "water use" should closely approximate the evapotranspiration because there was only one rainfall event on October 19 (64.8 mm) that might have caused water to percolate below the 90 cm depth. The amount percolated,

Table 4. Grain Yield of Corn (Suwan 1) as Affected by Tillage Treatment and Fertilizer Level in the 1984 Growing Season (Aug. 15 to Nov. 22) at Farm Suwan.

Tillage Practice	Fertilizer Level (kg rai^{-1})							Mean
	0-0-0	0-10-10	10-10-10	20-10-10	30-10-10	20-10-0	20-10-20	
	..... *kg rai^{-1}*							
No-tillage	515a†	513a	563a	607a	565a	613a	633a	573
Conv. tillage	471a	493a	588a	544a	524a	552a	593a	538
Mean	493a	503a	576a	576a	545a	583a	613a	
C.V. (%)	Tillage = 13.2, Fertilizer = 16.6, Tillage x Fertilizer = 7.7							

† In a row, means followed by the same letter are not significantly different at the 5% probability level by Duncan's Multiple Range Test (DMRT).

however, could not have exceeded 3 to 4 cm and one would expect slightly lower percolation under the drier conventional tillage system (Figure 4). It was assumed that there was no runoff occurring at any given rainfall event. This is a valid assumption since the experimental plots were located on a land surface of essentially zero slope.

The water use efficiency of corn was calculated by dividing the grain yield and/or the total dry matter production in kg/rai (6.25 rai = 1 ha) with the plant water use in cm. In other words, it is the grain yield and/or the total dry matter production per unit of water use (kg/cm/rai).

Table 5 reports the water use and water use efficiency of corn in the 1984 growing season (August 15 to November 22). Neither the tillage system nor the fertilizer application level caused a drastic change in the water use of corn. This result, however, was not surprising in view of the uniform rainfall distribution which prevailed during this period. This distribution enhanced the uniform growth and development of the corn plants. The water use of corn in the first year experiment was 56.6 cm.

In contrast, the water use efficiency of corn under the no-tillage practice was consistently greater than that for the conventional tillage system at all fertilizer levels. The mean water use efficiency for the conventional and no-tillage systems was 9.5 and 10.2 kg (grain)/cm/rai, and 26.6 and 28.5 kg (total dry matter)/cm/rai, respectively. Also, the use of fertilizer, particularly nitrogen, tended to increase the water use efficiency of corn (Table 5). This was attributed to the lower water use rate of corn (total dry matter produced/unit of water use/day) associated with the no-tillage and fertilizer treatment at all growth periods (Table 6). Table 6 also indicated that the water use rate of corn drastically decreased with time. The plant water use rate was calculated by the following equation:

$$U = \frac{(W_2 - W_1)\ \ln(M_2 / M_1)}{(t_2 - t_1)(M_2 - M_1)},$$

Table 5. Water Use and Water Use Efficiency of Corn (Suwan 1) as Affected by Tillage Treatment and Fertilizer Level in the 1984 Growing Season at Farm Suwan.

Tillage Practice	Fertilizer Level (kg rai^{-1})							Mean
	0-0-0	0-10-10	10-10-10	20-10-10	30-10-10	20-10-0	20-10-20	
Water use	..... *cm*							
No-tillage	54.8	56.9	53.4	57.1	56.6	57.1	56.9	56.1
Conv. tillage	55.9	57.6	61.6	55.1	56.4	56.1	56.1	57.0
Mean	55.4	57.3	57.5	56.1	56.5	56.6	56.5	56.6
Water use efficiency	..... *kg cm^{-1} rai^{-1}*							
Grain Yield								
No-tillage	9.4	9.0	10.5	10.6	10.0	10.7	11.1	10.2
Conv. tillage	8.4	8.6	9.5	9.9	9.3	9.9	10.6	9.5
Mean	8.9	8.8	10.0	10.3	9.7	10.3	10.9	9.9
Total dry matter								
No-tillage	24.7	25.5	29.7	30.0	28.2	30.3	31.4	28.5
Conv. tillage	23.4	24.1	27.0	27.9	26.3	27.7	29.8	26.6
Mean	24.1	24.8	28.4	29.0	27.3	29.0	30.6	27.6

where U is the plant water use rate (g/g/day), W is the plant water use (g/rai), M is the total dry matter production (g/rai), and t is plant age (day). The subscripts refer to the successive harvests. The equation allows for the exponential nature of plant growth. This equation was also used by Na Nagara and DeDatta (1984) for the uptake rate of plant nutrients by rice.

Table 6. Water Use Rate of Corn (Suwan 1) as affected by Tillage Practice and Fertilizer Level During the 1984 Growing Season at Farm Suwan.

Treatment	Water Use Rate		
	28 Aug-20 Sep	20 Sep-11 Oct	11 Oct-22 Nov
	..... $g\ g^{-1}\ day^{-1}$		
No-tillage			
0-0-0	110	20	7.4
30-10-10	80	18	6.6
Mean	95	19	7.0
Conv. tillage			
0-0-0	110	24	8.4
30-10-10	120	21	6.6
Mean	110	22	7.5
Mean	100	20	7.3

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Effect of Soil Crust and Mechanical Impedance on the Emergence of Corn Seedlings

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ABSTRACT. General information about soil crusting, the nature of its occurrence, some physical properties and the results of experiments on the effects of soil crusting on the emergence of plant seedlings are discussed.

A prototype of a pneumatic penetrometer was developed. The instrument was designed to measure the resistance to penetration of a thin soil crust in the laboratory. Thrust of the probe was tested as it operated against an electrical top-loading balance. Test results were satisfactory. The pneumatic penetrometer was used to measure the penetration resistance of soil crust at different moisture contents. Curvilinear relationships were observed for the maximum penetration resistance and the penetration energy as functions of crust moisture content. Emergence of corn seedlings was tested in a small wooden box. At a crust moisture content of 15 percent, the emergence of corn seedlings was severely obstructed. As estimated from the equations at this moisture content, corn seedlings which emerge must develop a thrust of 8.56 N (1.92 lb) and spend a mechanical energy of 5.32 N cm (0.0532 J). The breaking pressure of corn coleoptiles through soil crust under these conditions was found to be 27.6 bars.

Introduction

Soils classified as the Kampangsan (Ks) series cover large areas of the Kampangsan Campus. Although these soils are potentially productive according to their P and K status, hard surface crusts are readily formed on them and this poses a serious constraint to crop production. For reasons yet unknown, the surface aggregates are not stable in water. As it rains or as the soils are irrigated, soil particles disperse and then reorient, resulting in a dense layer a few centimeters thick at the soil surface. This layer becomes hard upon drying and forms a strong crust. Severe impedance to the emergence of seedlings has been observed.

Some physical properties related to the strength of the crust were examined. The penetration resistance and the penetration energy exerted by corn seedlings when emerging were predicted by means of a pneumatic penetrometer. Experimental tests on the emergence of corn seedlings were also performed.

Literature Review

Causes and strength of crusts were studied by Carnes (1934) for several types of soil. It appeared that crust strength depended to a certain degree on silt content. Changes in physical properties of the crust were observed by Lemos and Lutz (1975). They showed that the fraction of finer particles in crusts tended to increase and that larger particles tended to decrease.

A common method used to produce crusts in the laboratory is to soak soil in water (Carnes, 1934; Lemos and Lutz, 1957; Morton and Buchele, 1960). Crusts prepared differently yield different strengths. High modulus of rupture was the result of surface disturbance (Lemos and Lutz, 1957). Moisture content is negatively correlated with crust strength (Bennett *et al.*, 1963; Hanks and Thorp, 1956; Lemos and Lutz, 1957).

Two indices are normally used to describe crust strength. These are the modulus of rupture (Allison and Moore, 1956; Carnes, 1934; Hanks and Thorp, 1957; Lemos and Lutz, 1957) and the penetration resistance (Drew *et al.*, 1971; Hanks and Harkness, 1956; Morton and Buchele, 1960; Terry and Wilson, 1953). Morton and Buchele (1960) and Drew *et al.* (1971) fabricated penetrometer probes to simulate a corn seedling emerging through a soil crust. The emergence force of seedlings may be measured directly with a

ring-force transducer (Drew *et al.*, 1971; Rathore *et al.*, 1981). Some workers have reported that the thrust exerted by plant seedlings to emerge upward through a crust depends on species and existing crust strength. For example, a thrust of 0.6 lb (2.7 N) was reported for cotton (Drew *et al.*, 1971), while a 50 percent reduction in the emergence rate of the same species was predicted for 1.6 lb (7.1 N) of crust strength (Bennett *et al.*, 1963). A 50 percent reduction in emergence for sorghum was found at 500 mbars modulus of rupture (Hanks and Thorp, 1957). Rathore *et al.* (1981) found that the maximum thrust for soybean seedlings was between 127 and 190 g (1.25 to 1.86 N) depending upon variety.

The size of laboratory experiments on the emergence of seedlings is limited (Bennett *et al.*, 1963; Hanks and Thorp, 1956). Limitations are due mainly to difficulties in preparing crusts. Differences were reported concerning the effect of depth of seed on emergence (Drew *et al.*, 1971; Hanks and Thorp, 1957; Morton and Buchele, 1960).

Materials and Methods

The Pneumatic Penetrometer

Assembly of the pneumatic penetrometer is shown in Figure 1. The penetrometer probe was fabricated to simulate the average size and shape of a corn coleoptile (0.2 cm in diameter, 4.3 cm in length, solid brass cylinder) except that it had a flat tip. This instrument is operated with the pressure manifold of a pressure membrane apparatus. As compressed air is conducted through a set of two regulators into the chamber, the thrust created causes the piston (and the probe) to move against friction and spring recoil (the total resistance). The total resistance was evaluated as the penetrometer operates with no load, and was then established as a linear function of probe displacement. Total resistance could be predicted at a given displacement by the use of a calibration equation (Eq. 3). Another equation provides for calculating the net force at the probe tip (Eq. 1). The range of validity of measurement was tested with a 2 kg (19.62 N), 0.1 g sensitivity, top-loading balance.

Preparation and Testing of the Crusts

Soil was sieved through a 0.5 mm sieve. Crust was prepared in a box (Figure 2a) by the addition of water to field capacity and then puddling while the surface was wet. Crusts of different moisture contents were obtained by varying the time of evaporation in the laboratory. Tests for penetration resistance were done on a test bench (Figure 2b). Selected crust was wrapped with a sheet of aluminum foil, 2 holes (1 cm diameter) were cut on opposite sides to allow passage of the probe. The crust was laid upside down on the bench and after the holes were aligned, the probe was moved through it.

Tests on Soil Physical Properties

The particle density of the soil was determined by the pycnometer method and bulk density by the paraffin method. Mechanical analysis was done by the conventional pipette method. Time intervals of suspension sampling ranged from 5 s to 48 h, and particles were graded from 0.1340 to 0.0007 mm in equivalent spherical diameters.

Moisture characteristics were obtained at 6 pressure increments, from 1 to 15 atm. Saturation pore diameter (d, μ), corresponding to a pressure (P) in atm, was estimated from:

$$d = \frac{0.3 \times 10^4}{1033\ P}. \qquad [1]$$

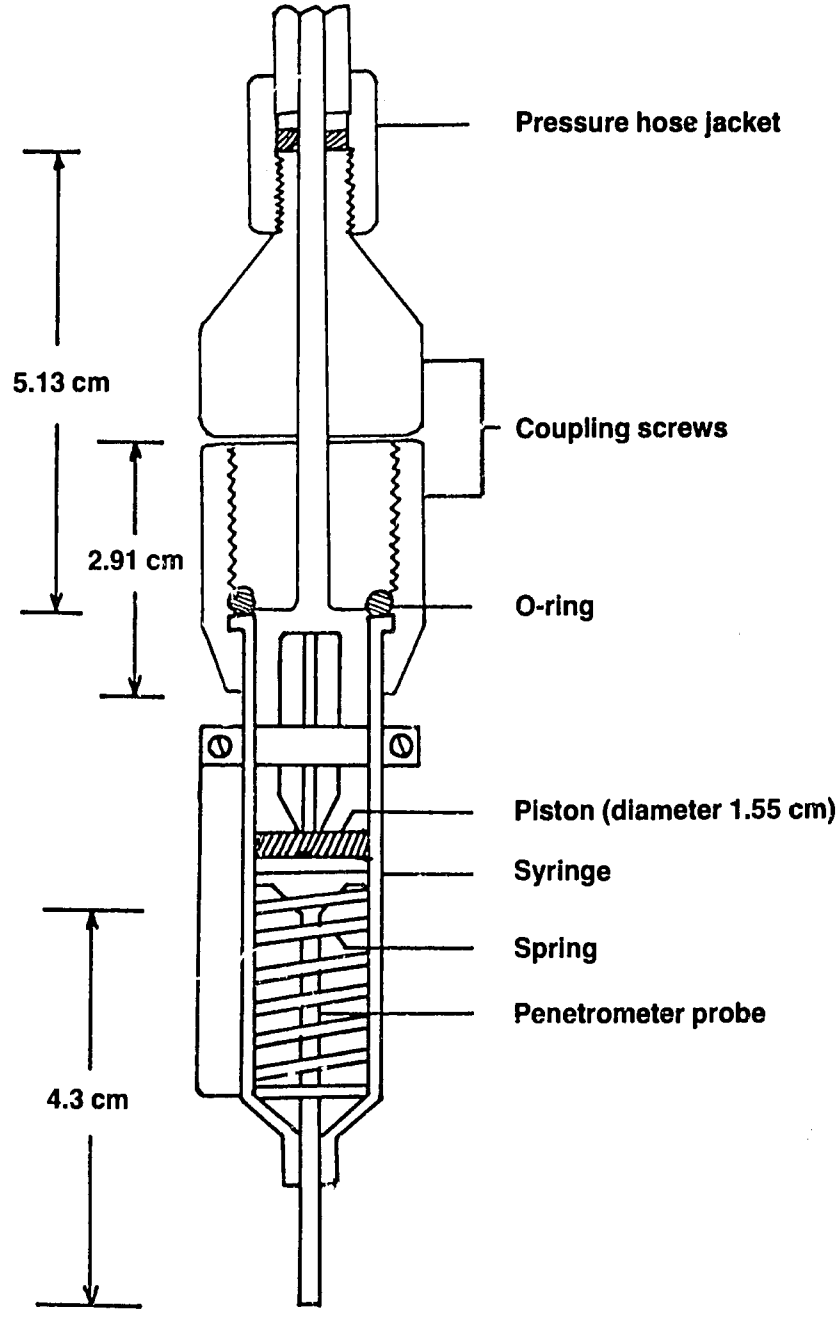

Figure 1. The Pneumatic Penetrometer Assembly.

The volume percentage of pores smaller than d, X, was estimated from:

$$X = \frac{v \times 100}{E}, \qquad [2]$$

where v = moisture by volume, and E = total porosity of the moist soil.

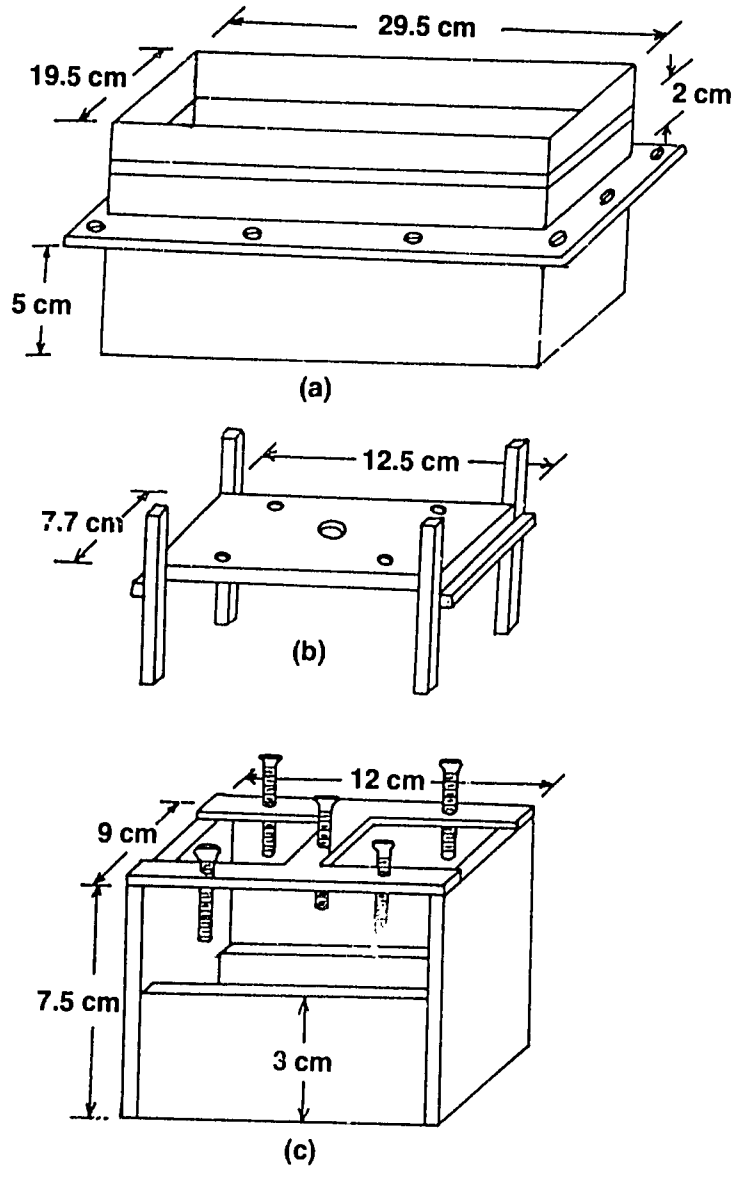

Figure 2. (a) The Crust Preparation Box (b) the Test Bench and (c) the Press Bed.

Seedling Emergence Test

The effects of impedance of crust on the emergence of corn seedlings were tested in a press bed (Figure 2c). Foundation soil, prepared to the size of the frame, was wrapped with aluminum foil. Three holes in each of two rows were punctured through the foil and germinated corn seeds (var. Suwan 1) were embedded in them. A perfect crust plate was laid on top of the foundation soil and pressed firmly by means of screws. The whole unit was kept in a moist plastic bag for seven days before the emergence test. Remnants of the crustplate were collected for moisture determination.

Results and Discussion

Physical Properties

Stratification into layers was induced in the crust as observed in Table 1 and Figures 3 and 4. It seemed that the crust was divided into two layers at a 1 cm depth. The unintended layering may have occurred through puddling. Ignoring the appearance of this boundary, it seemed that sand was accumulated at the bottom (0.5 to 1 and 1.5 to 2 cm depth intervals) and silt at the surface (0 to 0.5 and 1 to 1.5 cm depth intervals) of the crustplate. Clay, on the other hand, accumulated in the middle of the crust. These phenomena could be explained by the fact that as soil particles dispersed, the faster settling velocity of sand caused it to deposit underneath the silt. Clay, having the slowest settling velocity, ought to have accumulated on top of the other particles unless its size was smaller than the voids between the silt and sand. It appeared that clay could be leached to a certain depth through the voids.

Table 1. Physical Properties of Soil Crust as Compared to the Ks Soil.

Particle Size	Depth Interval (cm)				Ks soil
	0-0.5	0.5-1	1-1.5	1.5-2	
mm	%				
0.5- 0.02	40.00	42.50	39.50	43.00	-
0.02-0.002	28.10	23.25	26.25	[illegible]	-
<0.002	31.90	34.25	34.25	33.00	-
	Bulk Density				
	$g\ cm^{-3}$				
	1.661	1.602	1.558	1.552	1.561
	Porosity, E				
	%				
	35.07	37.37	39.09	39.38	38.98
Pore Size	**Distribution**				
μ	%				
>10	24.75	28.25	30.30	33.00	29.75
10-0.2	39.45	38.85	39.70	38.75	41.25
<0.2	35.80	32.90	30.00	28.25	29.00

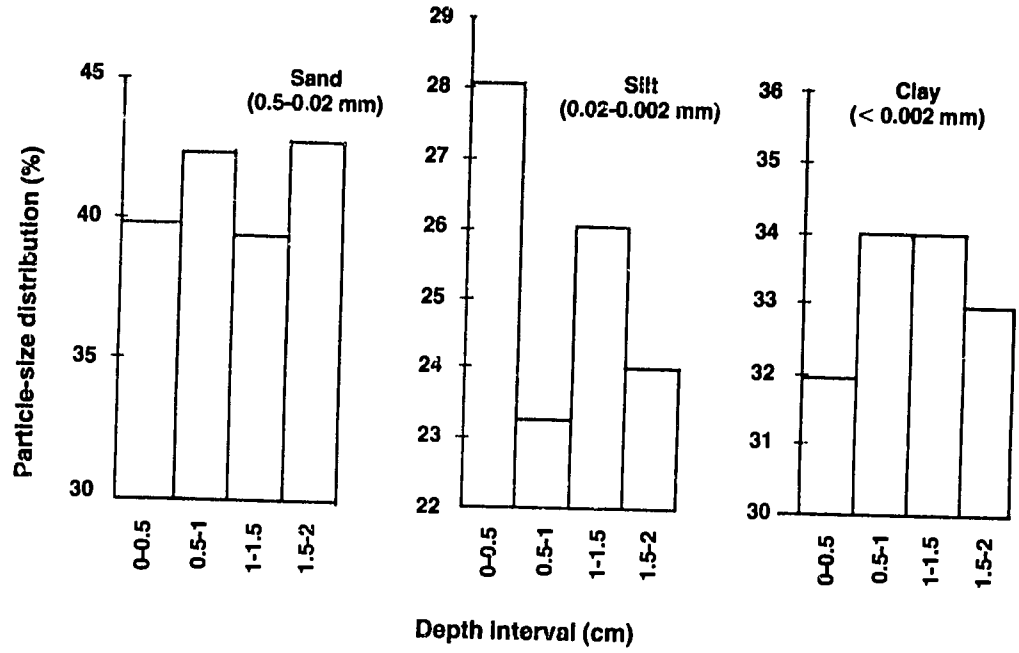

Figure 3. Particle-Size Distribution in Crust Slices, 0-0.5, 0.5-1, 1-1.5, and 1.5-2 cm Intervals.

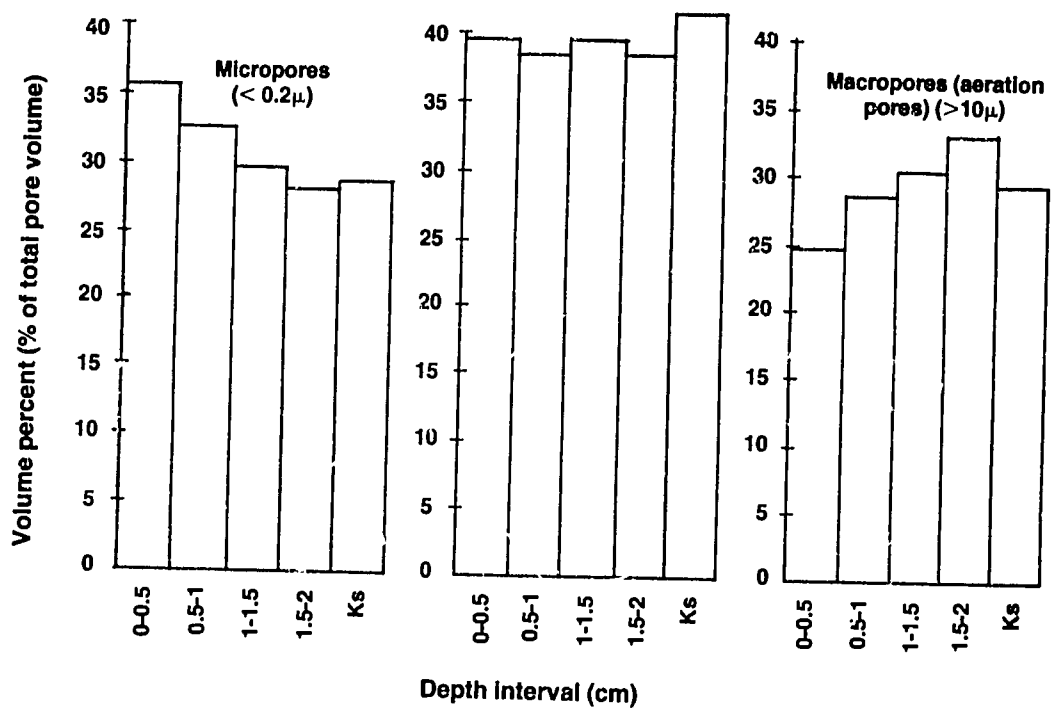

Figure 4. Pore-Size Distribution in Crust Slices, 0-0.5, 0.5-1, 1-1.5, and 1.5-2 cm Intervals as Compared to the Original Ks Soil.

The crust appeared to be most dense at its surface and the density decreased with depth (Table 1). The packing density of soil particles in the crust was confirmed by pore-size distribution (Figure 4). Bulk density of the crust plate was slightly higher than that of the original soil at the same moisture content.

Performance of the Pneumatic Penetrometer

The relationship between total resistance (friction + spring recoil) and probe displacement is shown in Figure 5. Total resistance (R) in N can be described as a linear function of displacement (X) in cm as follows:

$$R = 2.071 + 6.895\ X\ (r = 0.991^{**}). \qquad [3]$$

From this relationship, the friction and the spring constants are 2.071 N and 6.895 N/cm, respectively.

As the penetrometer is operated against load, the net force (F) at the probe tip is the difference between air thrust and the resistance. In other words,

$$F = 4.446\ PA - R \qquad [4]$$

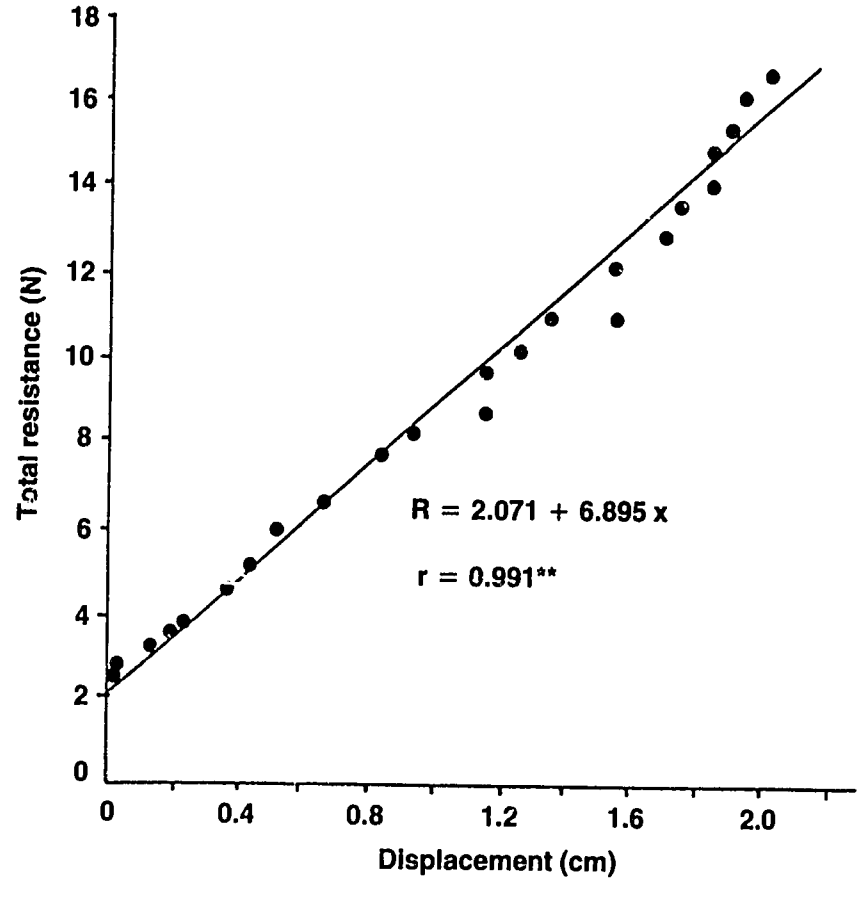

Figure 5. Relationship Between the Total Resistance (R) and the Displacement (X) of the Penetrometer Probe.

P and A represent air pressure (psi) and the area of the piston (in^2), respectively. The coefficient of the first term on the right of Eq. 4, 4.446, is the erosion factor in lb or N.

Substituting for values of R and A, Eq. 4 becomes

$$F = 1.298\ P - 6.895\ X - 2.071. \qquad [5]$$

Equation 5 is used to estimate the net force at the probe tip from the displacement of the probe and the air pressure in the piston chamber.

Figure 6 illustrates the relationship between the force calculated and the corresponding load as thrust is applied against the balance pan. A very close one-to-one relationship indicates that the penetrometer can be used with confidence for measurements of crust penetration resistance.

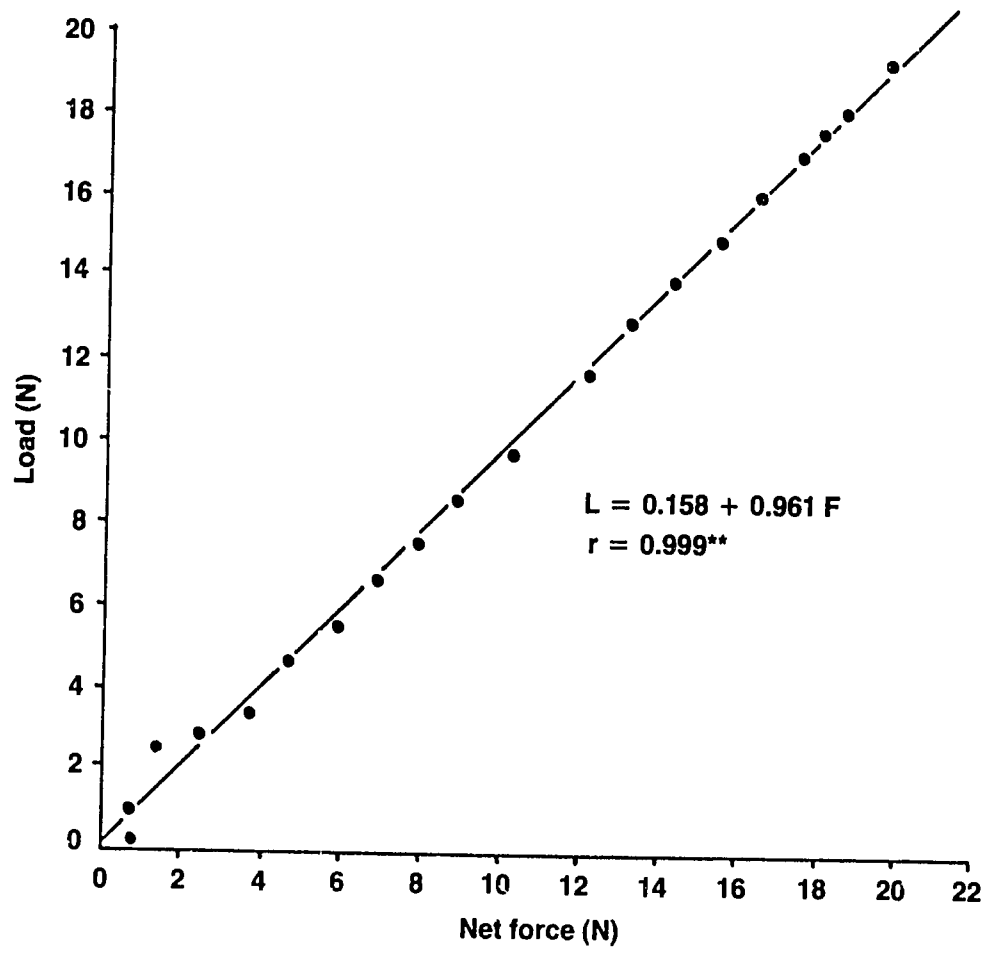

Figure 6. Validity Test of the Pneumatic Penetrometer. Load was Measured with a 0.1 g Sensitivity Electrical Balance and Net Force was Calculated by Equation 5.

The force needed for the probe to penetrate through the crusts at various moisture levels was plotted against depth of penetration (Figure 7a, b). Failure to emerge depended upon crust moisture. For crust moisture contents higher than 12.73 percent the crusts appeared to bear some resistance after shearing. At this moisture content and lower, the crusts sheared abruptly after the maximum penetration force was obtained. The remaining resistance could be attributed to the friction between the soil mass adhered to the metal skin and that in the traveling path of the probe. Also, it appeared that for crust moisture contents lower than 17.14 percent, thrust per unit increment of depth increased significantly.

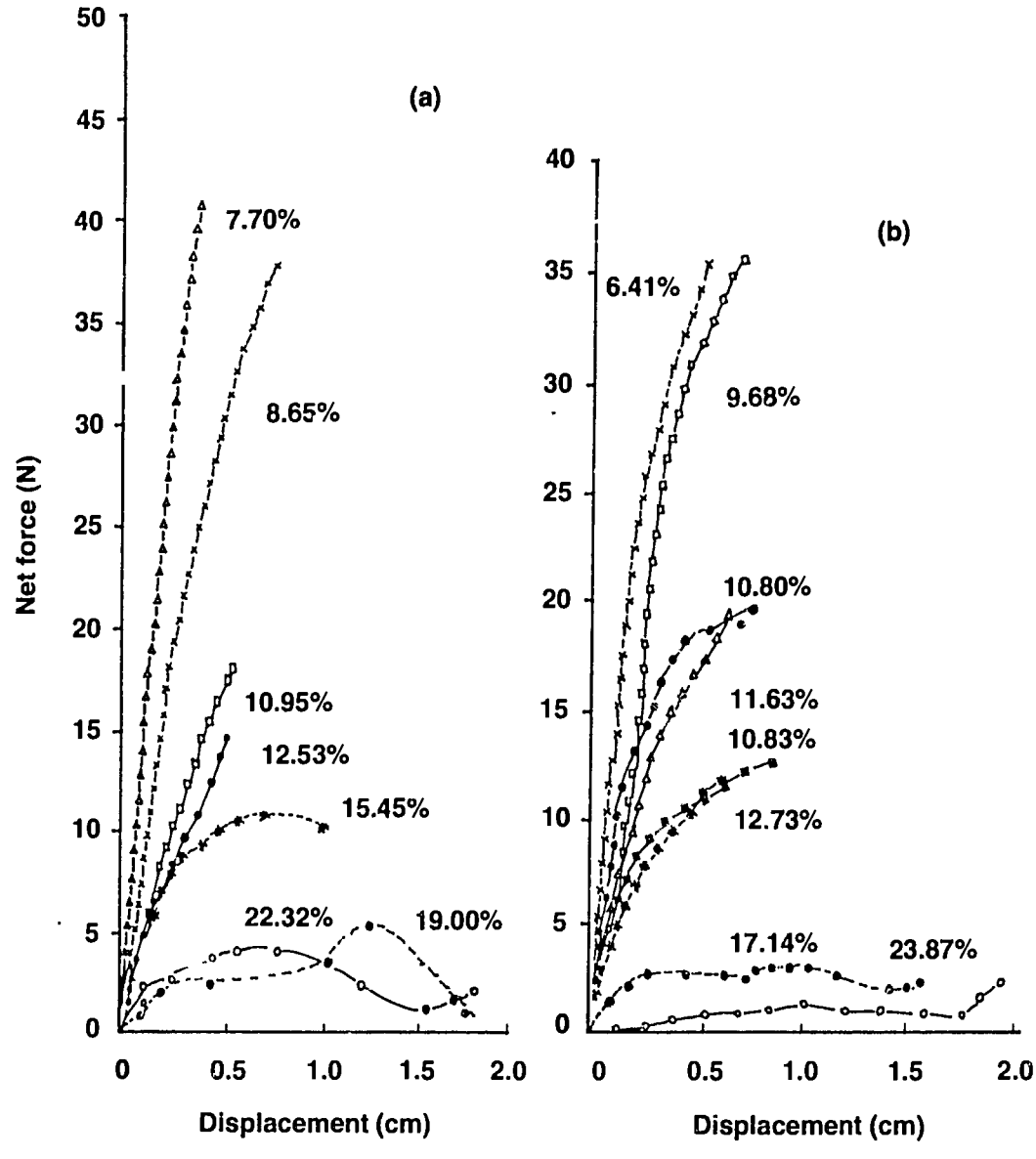

Figure 7. Development of Penetration Force as the Penetrometer Probe Moved in the Upward Direction Into the Crusts at Different Moisture Contents.

In order to demonstrate the effect of crust moisture on the emergence force of the probe, the maximum penetration resistance (max. PR) was plotted against moisture content (θ_w) (Figure 8). The exponential increase of max. PR upon reduction of crust moisture can be described by

$$\ell n\ (\text{max. PR}) = 8.327 - 2.72\ \ell n\ (\theta_w)\ (r = 0.958^{**}). \qquad [6]$$

The mechanical energy required for emergence of the probe is defined as the area underneath the penetration force displacement curve from zero displacement (2 cm depth) to shearing position. This is the penetration energy (PE). The negative exponential relationship of PE with θw can be represented by

$$\ell n\ (\text{PE}) = 6.465 - 1.762\ \ell n\ (\theta_w)\ (r = 0.830^{**}). \qquad [7]$$

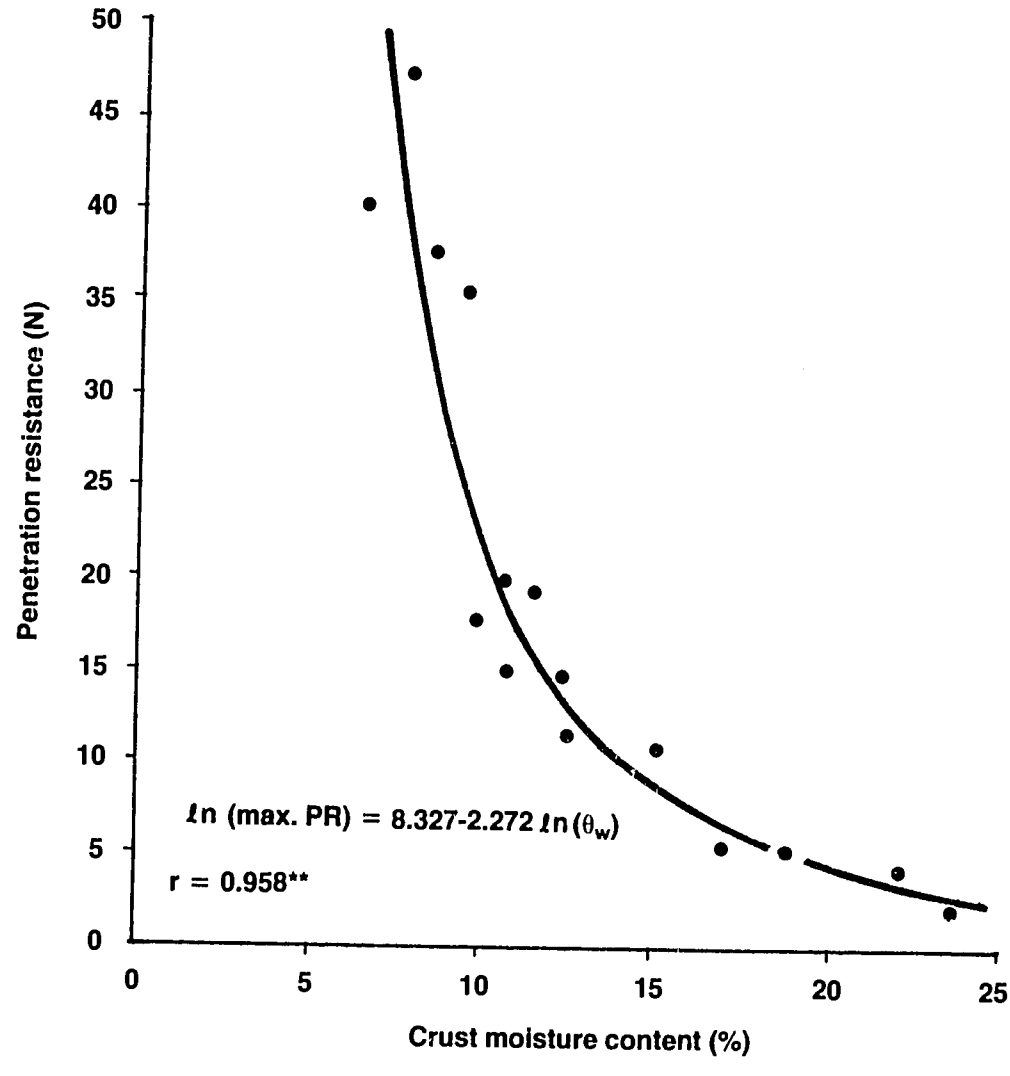

Figure 8. Dependence of the Maximum Penetration Resistance (max. PR) on the Moisture Content of the Crust (θ_w).

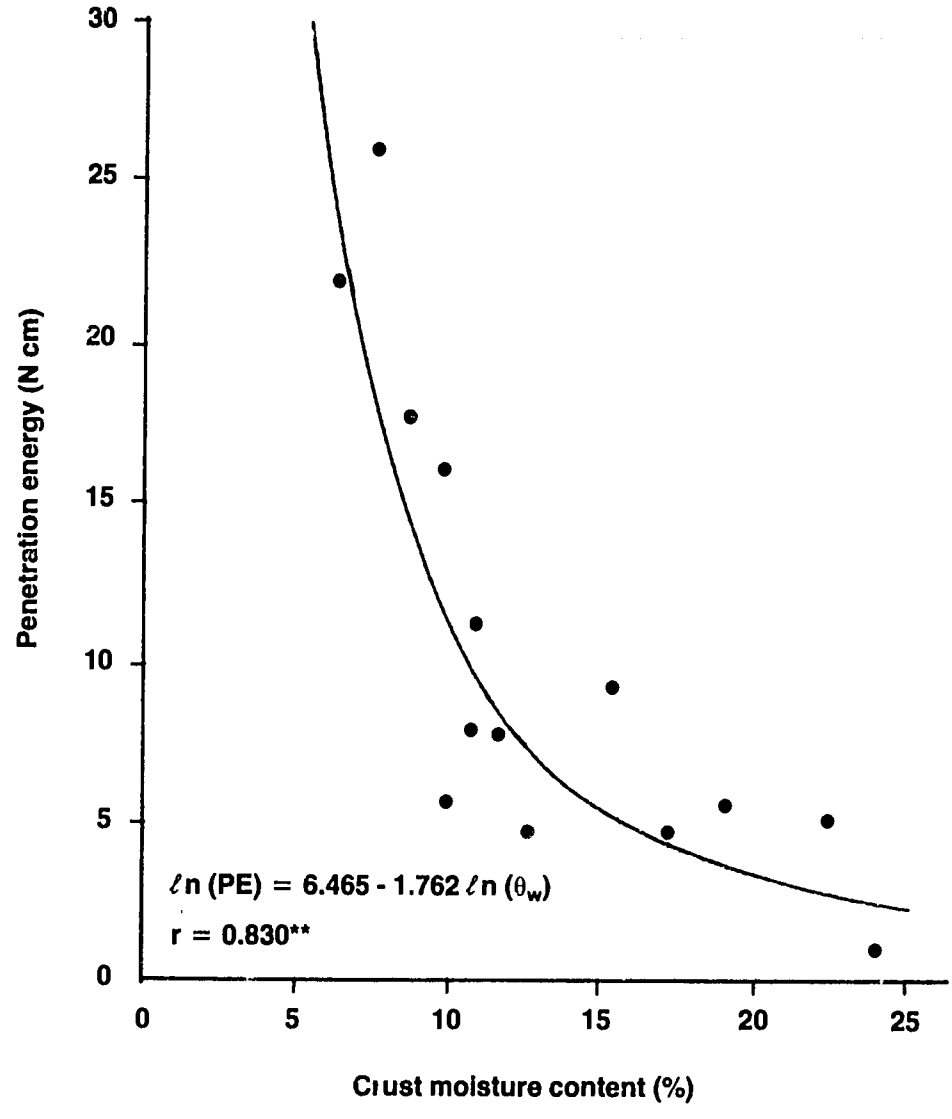

Figure 9. Dependence of the Penetration Energy (PE) on the Moisture Content of the Crust (θ_w).

Ranges of max. PR observed were 2.104 to 40.013 N and 1.000 to 21.981 N cm for PE in response to reduction of moisture from 23.87 percent to 6.41 percent. A thrust equivalent to 129.07 bars was required to push a cylindrical object through the crust. It was observed that moisture content at the flex points on the two curves was around 15 percent. Since this value denoted a sharp increment in the resistance, it seemed to be a critical crust moisture level for seedling emergence.

Results of emergence tests of corn seedlings revealed that impedance began as crust moisture decreased to 20.87 percent and became pronounced at 15.18 percent (Table 2). The critical moisture for emergence coincided with the moisture content at the flex points of the max. PR and PE curves. At this critical moisture level, a corn seedling that emerges from the crust must exert a thrust of 8.56 N or an equivalent apical pressure of 27.61 bars. Corn seedlings must also develop a mechanical energy of 5.32 N cm (0.0532 J) for emergence from 2 cm underneath the crust at critical moisture. These

Table 2. The Effect of Impedance of Soil Crust on Emergence of Corn Seedlings.

Moisture	Max. PR†	Penetration Pressure‡	PE§	No. of Emerged Corn Seedlings¶
% by wt	*N*	*bars*	*N cm*	
9.80	27.5	88.8	13.2	0
13.8	10.2	34.2	6.29	1
15.2	8.56	27.6	5.32	0
20.9	4.15	13.4	3.04	4
23.4	3.22	10.4	2.49	6

† *ln* (max. PR) = 8.327—2.272 *ln* (θw)
‡ Penetration pressure = 3.226 (max. PR) bars
§ *ln* (PE) 6.465—1.762 *ln* (θw)
¶ Out of a total of six sprouting seeds

values were predicted from Eqs. 6 and 7, respectively, and are assumed to be the limits for corn seedling emergence. Bennett *et al.* (1963) reported values of 7.1 N for 50 percent reduction of cotton seedling emergence and Rathore *et al.* (1981) reported a maximum emergence force between 1.24 and 1.86 N for soybean seedlings. If the areas of the emerging organs of cotton and soybean seedlings were two and four times the area of the probe tip used in this experiment, the estimated apical pressure of the two species would be 11.45 and 1.25 bars, respectively. Corn seedlings appear to endure a higher magnitude of crust impedance than soybean seedlings.

Conclusion

The soil crust was found to be stratified after preparation in the laboratory. Sand had a tendency to be accumulated at the bottom, silt at the surface, and clay in the middle of the crust plate. Bulk density was highest at the crust surface and decreased with depth. Pore-size distribution data confirmed the density of particle packing.

Penetration resistance was inversely related to crust moisture. The maximum penetration resistance and the penetration energy were found to increase exponentially as crust moisture decreased. Flex points on the two curves occurred at the moisture content at which the emergence of corn seedlings was inhibited. The results of the seedling emergence tests suggested that the moisture of the surface layer of this soil must be kept higher than 20 percent during the emergence of corn seedlings. This might be accomplished by frequent watering, mulching, or treating the soil surface with chemicals of high hygroscopicity. Emergence and growth of seedlings in the field might be simultaneously controlled by such factors as climate, management practices and the soil itself.

Suggested Research

First Category—Nature and properties of crust on soil of various textures. Topics might include:

- Stratification of soil crust into layers, and the relationship of crust strength to moisture content.
- Interrelationships among factors affecting strength and seedling emergence. Such factors include moisture content, bulk density, O_2 diffusion rate, depth of seed sowing, and others.
- Development of methods to measure crust strength *in situ* that correlate well with emergence of plant seedlings.

Second Category—Assessment of mean maximum thrust of seedlings of cash crops. Ways to do this might be:

- To grow seeds under crust blocks of known weight, or a ring-force transducer.
- To grow seeds under crusts of various strengths to determine zero emergence.

Third Category—Methods to overcome crust impedance. Possible ways to do this might be:

- To avoid crusting conditions (in rainfed agriculture), sow seeds in moist soil with the expectation of no rain during the emergence period.
- To decrease crust strength by:
  - managing the moisture content of the topsoil, or
  - applying a soil conditioner (organic matter, or flocculating cations) to the soil surface.

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Soil, Water and Fertilizer Management for Corn- and Sorghum-Based Cropping Systems

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ABSTRACT. Corn and sorghum have been consistently grown in the lower parts of the North and Northeast regions, and the upper central plain. Major soils of the corn and sorghum belt are Reddish-Brown Lateritic, Grumusol, Rendzina soils and Brown Forest soils, while the major soils of the Northeast are Gray Podzolics, Red-Yellow Podzolics and Red-Yellow Latosols. Available moisture capacities of major soils of the corn and sorghum belt are low and those of the major soils of the Northeast are even lower—so low, in fact, that soil may supply water to corn for only 15 days or less. In addition, the major soils of the Northeast are highly erodible and highly susceptible to surface crust formation.

Both the major soils of the corn and sorghum belt and those of the Northeast were often found to be deficient in N and P. Some of these, especially the light-textured ones tend to be deficient in K. Sulfur deficiencies were found on some acidic soils, whereas Zn deficiency has been noted on some calcareous soils.

Mathematical equations for calculating the quantity of fertilizer to be applied for corn and sorghum from soil chemical tests have been established for P, but not for N and K. Appreciable research has been devoted to the selection of soil tests for N, P and K but further research is still needed. Variety/cultivar was shown to be a factor affecting fertilizer rate. Delayed application of NP or NPK fertilizer may be superior to early application when crops are under moisture stress. Research has shown that the best application methods are banding for N and broadcasting for P, but banding for both N and P are recommended when ease of application is considered, because the advantage of placement is slight. NO_3-N seems to be superior to NH_4-N, but this needs further study. Rock phosphate is slightly less effective in acid soils than readily soluble phosphate fertilizers, and is most effective when mixed with readily soluble phosphate. Research is needed to determine the efficiency of this material in neutral and calcareous soils. Similar fertilizer management is recommended for corn- or sorghum-based intercropping.

Shallow plowing or hoeing to break surface crusts, changing land surface features to plateaus or ridges, and plant residue mulch and/or incorporation are recommended, especially for major soils of the Northeast.

Introduction

Since 1977 the areas consistently producing corn have been, in descending order of total area, Phetchabun, Nakon Ratchasima, Lopburi, Loei, Nakon Sawan, and Saraburi, whereas those producing sorghum have been Lopburi, Nakon Sawan, Saraburi, Phetchabun, Nakon Ratchasima, Uthai Thani, and Srisaket (Anonymous, 1982). Detailed Reconnaissance Soil Maps of these provinces published by the Department of Land Development indicate that the major soils of the corn and sorghum belts of Thailand are, in descending order of total area, Reddish-Brown Lateritic soils (Oxic Paleustults), Grumusols (Typic Chromusterts), Rendzinas (Typic Calciustolls), Brown Forest soils (Typic Ustropepts), Noncalcic Brown soils (Lithic Haplustalfs) and soils with lighter textures ranging from sandy loam to loamy sand which include Gray Podzolic soils (Oxic Paleustults), Red-Yellow Podzolic soils (Oxic Paleustults and Typic Plinthustults), Red-Yellow Latosols (Oxic Paleustults) and Low-Humic Gley soils (Plinthaquults). The dominant soil series consistently devoted to corn and sorghum production are Pak Chong, Loei, Chok Chai, Chai Badan, Takhli and Lopburi. Nevertheless, the major soil series of Northeast Thailand are Korat, Roi Et, Phon Phisai, Nam Phong, Ubon, Warin, Satuk, Phen, Yasothon, Phimai and Tha Tum (see Table 1 for taxonomy); the percentage in each series by total area of the Northeast is 20.1, 16.5, 9.3, 3.0, 2.5, 2.0, 1.8, 1.3, 1.2, 1.2, and 1.0 percent, respectively. The major soils of Northeast Thailand are, therefore, not the major soils of the corn and sorghum belt.

Table 1. Soil Series Covering One Percent or More of the Total Area of Northeast Thailand
(Keeratikasikorn, 1984)

Soil Series	Great Soil Group (USDA, 1938)	Great Group (US Soil Taxonomy	Percent of Total Area of the Northeast
1. Korat (Kt)	Gray Podzolic	Paleustults	20.05
2. Roi Et (Re)	Low-Humic Gley	Paleaquults	16.47
3. Phon Phisai (Pp)	Red-Yellow Podzolic	Plinthustults	9.34
4. Nam Phong (Ng)	Regosol	Quartzipsamments	3.0
5. Ubon (Ub)	Hydromorphic Regosol	Dystropepts	2.46
6. Warin (Wn)	Red-Yellow Podzolic	Paleustults	2.00
7. Satuk (Suk)	Red-Yellow Podzolic	Paleustults	1.83
8. Phen (Pn)	Low-Humic Gley	Plinthaquults	1.31
9. Yasothon (Yt)	Red-Yellow Latosol	Paleustults	1.18
10. Phimai (Pm)	Hydromorphic Alluvial	Tropaquepts	1.20
11. Tha Tum (Tt)	Low-Humic Gley	Paleustults	1.03
		Total	59.87

Since the major soils of the Northeast are not the major soils widely used for corn and sorghum production, the discussion which follows will distinguish these two groups of soil.

Physical Properties of the Soils

Available moisture capacities of the major soils of the corn belt are low, ranging from 58.2 to 111 mm/m soil. The capacities of the major soils of the Northeast are even lower, ranging from 28.5 to 50.1 mm/m soil (Table 2). Kubota *et al.* (1979) estimated that these soils would supply water to plants for only about 15 days or less and that most field crops, except for sorghum and sugarcane which are deep rooting, would suffer from water stress if dry spells continued for more than three weeks during the growing period. This has actually been observed in the field.

From studies on physical properties of soils, Kubota *et al.* (1979) concluded that, with the exception of Grumusols, Rendzinas, Reddish-Brown Latosols and clayey Reddish-Brown Lateritic soils, most of the upland soils were highly erodible and highly susceptible to crust formation or soil sealing, which markedly decrease infiltration of rainwater in the soil.

Table 2. Available Moisture Capacities of Major Corn Belt Soils and Major Upland Soils of Northeast Thailand (Kubota *et al.*, 1979).

Great Soil Groups	Available Moisture Capacity	
	Mean	S.E.
	..... *mm m^{-1} soil depth*	
Corn Belt Soils		
Regosol	58.2	3.0
Grumusol	107	-
Rendzina	111	13.5
Brown Forest	83	-
Noncalcic Brown	106	26.5
Reddish-Brown Lateritic	87.3	12.9
Reddish-Brown Latosol	80.5	39.4
Major Upland Soils of the Northeast		
Gray Podzolic	50.1	19.2
Red-Yellow Podzolic	28.5	14.5
Red-Yellow Latosol	29.1	11.6

Deficiencies in Major Nutrient Elements

Corn

Results of fertilizer trials on Reddish-Brown Lateritic, Noncalcic Brown and Brown Forest soils in farmers' fields of the corn belt during the past 10 years indicated that the soils were appreciably different in their macronutrient status, especially for N and P. For instance, Thawornmas *et al.* (1975), Panitchkul *et al.* (1976) and Boon-ampol *et al.* (1981b) reported large responses to either N or P fertilizer or both, in Lopburi, Nakon Ratchasima, Phitsanulok and Nakon Sawan. However, Boon-ampol *et al.* (1978b) and Meesawat *et al.* (1981a) conducted trials in the same provinces as the preceding workers, but reported large responses to N or P fertilizer or both at some sites and little or no response at others. Boon-ampol *et al.* (1981b) were the only investigators to assess the response to potassium of corn, which they grew on Reddish-Brown Lateritic soils at 15 sites. They concluded that the soils were not deficient in K. The NH_4OAc-extractable K of the soils was in the range of 40 to 313 ppm K, though appreciable increases in yield were obtained from K fertilization. Extractable K was in the range of 57 to 400 ppm (Boon-ampol *et al.*, 1977; Boon-ampol *et al.*, 1978b; Meesawat *et al.*, 1981a; Panitchkul *et al.*, 1976; Thawornmas *et al.*, 1975).

Few investigations have been reported on the response of corn to fertilizer on major soils of the Northeast. Suwanarit *et al.* (1979c) obtained large responses to N fertilizer on Korat series soil at the Northeast Agricultural Center (the Regional Office of Northeast Agriculture and Cooperatives) at Tha Pra, Khon Kaen, Buangpatra and Osotsapar, and obtained positive responses to phosphate fertilizer applied to soils of the Korat (at Khon Kaen) and Yasothon series. Guramarohit *et al.* (1979) also reported positive responses to double superphosphate by corn grown on a Korat series soil. Based on a pot experiment, Suwanarit and Narkviroj (1975) reported that soils of the Korat series were too low in K for optimum corn production.

Sorghum

During the past ten years, only a few trials on crop response to fertilizers were conducted on major soils of the corn and sorghum belt, while an appreciable number of trials, mostly at experimental stations, were conducted on major soils of the Northeast.

Results of trials on major soils of the corn and sorghum belt generally indicated deficiencies in N and P (Boon-ampol *et al.*, 1978a, Jermplung *et al.*, 1979; Meesawat *et al.*, 1978; Meesawat *et al.*, 1981b; Panitchkul *et al.*, 1979). However, the fertility level of soils varied to such an extent that the grain yields differed by a factor of four- to five-fold (e.g., Meesawat *et al.*, 1978). No trials were found which involved K.

On major soils of the Northeast, a number of trials were conducted with sorghum, most of which were devoted to N and P. Trials on soils of the Korat, Roi Et and Yasothon series seemed to indicate appreciable variation in response to applications of primary nutrients at different sites. There was less response of sorghum to N and P fertilizer on soils of the Korat and Yasothon series compared with soils of the Roi Et series (Boon-ampol *et al.*, 1976; Panchaban and Pipatveerawat, 1975; Thawornmas *et al.*, 1976; Thawornmas *et al.*, 1977a; Thawornmas *et al.*, 1977b). In most cases, the Roi Et series soils responded to the application of N and P fertilizers (Boon-ampol *et al.*, 1975; Panitchkul and Boon-ampol, 1976; Boon-ampol *et al.*, 1977; Boon-ampol *et al.*, 1978d). Positive crop responses were also obtained in several trials where K fertilizer was applied to Roi Et soils (Boon-ampol *et al.*, 1979a; Boon-ampol *et al.*, 1979b).

Deficiencies in Secondary and Trace Elements

In the past, investigations on secondary and trace elements were mostly on corn. Results of the trials demonstrated deficiencies in S and Zn at some locations in both major soils of the corn and sorghum belt and major soils of the Northeast. Sulphur seemed to be deficient in some of the acid soils whereas Zn was limiting in calcareous soils.

Guramarohit *et al.* (1977) conducted trials in farmers' fields in the corn and sorghum belt and found increases in corn grain yields with application of secondary nutrients (Ca, Mg and S applied together) on Pak Chong series soils at some sites, but no response at other sites. On Lopburi, Ban Chong and Sataheep series soils they found positive responses to both secondary and trace elements. Results obtained by Siddhipote *et al.* (1970), Phetchawee *et al.* (1971), Guramarohit *et al.* (1976), and Guramarohit *et al.* (1977) indicated strong responses to sulphur on soils of the Korat (one site), San Pa Ton and Sappraya series, and positive trends on soils of the Yasothon, Warin and Korat series. Besides variation in response to sulphur among different soils and at different sites, variation in response to sulphur among corn cultivars was indicated from the results of Guramarohit *et al.* (1976). These workers found significant responses to sulphur by sweet corn but found only slight responses by field corn in adjacent plots.

In a pot study, Vacharotayan *et al.* (1972) found positive crop response to Zn applied to Pak Chong series soil that was collected from the National Corn and Sorghum Research

Center. Field trials on Grumusols and Rendzina soils indicated strong responses to Zn at four sites, and positive trends at five sites (Ratanarat *et al.*, 1980; Ratanarat *et al.*, 1981).

In another pot study, Vacharotayan *et al.* (1972), reported positive responses of sorghum to S and Zn fertilizers which were applied to soils of the Loei, Pak Chong, Takhli and Korat series.

Fertilizer Management

Kinds of Fertilizer

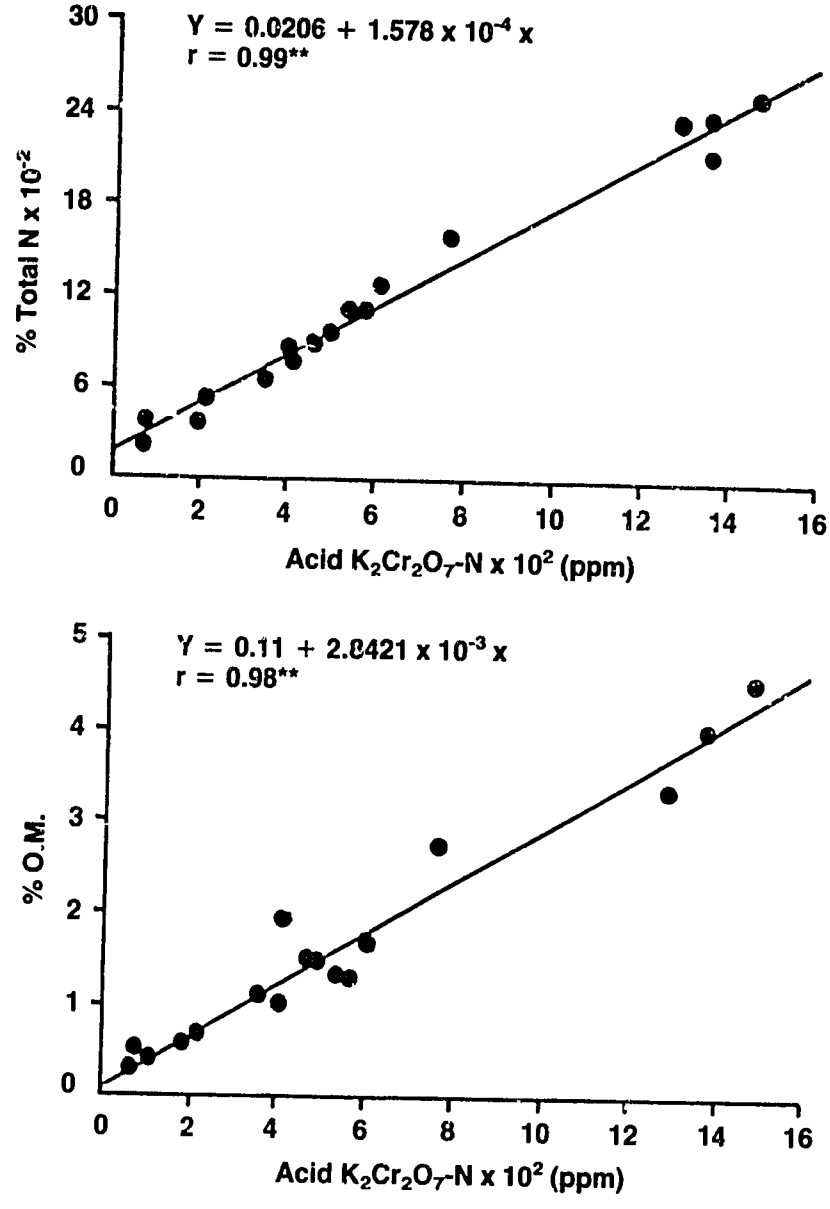
From the earlier discussion, it can be concluded that nutrient deficiencies in soils both in the corn and sorghum belt and in the Northeast occur more frequently for N and P and less frequently for K, S and Zn. Thus, the N and P status of soils should receive primary focus when addressing infertility problems of soils for corn and sorghum production. Potassium fertilization is more likely to be necessary when corn and sorghum are grown on sandy soils like those of the Korat, Yasothon and Roi Et series. Sulphur fertilization should be considered for acid soils, especially those that have been cultivated without application of S-containing fertilizers for a long time. Zn fertilization should be considered for calcareous soils, especially when applying P fertilizer. P can induce a Zn deficiency in crops.

Rates of Fertilizers

On-farm trial responses of corn to fertilizer have been used to formulate general recommendations for each group of similar soils. For example, Meesawat *et al.* (1981a) conducted 15 trials on Reddish-Brown Lateritic soils in farmers' fields and recommended that 85-45.6-33.75, 94.4-50-50.6 and 93.1-82.5-14.4 kg/ha of N-P_2O_5-K_2O be applied to soils in Lopburi, Nakon Sawan and Nakon Ratchasima, respectively. Panitchkul *et al.* (1976) conducted eight trials on Reddish-Brown Lateritic soils (Pak Chong series) and concluded that 93.8-93.8-0 to 125-125-0 kg/ha of N-P_2O_5-K_2O were the best recommendations for corn grown on soils in Lopburi and Nakon Ratchasima Provinces, but no N, P, or K fertilizers were recommended for soils in Uthai Thani and Petchabun Provinces. One must conclude that these are but temporary recommendations which could change considerably depending on factors such as intensity of cropping, pattern of land use, tillage system, residue management and residual nutrient status of the soils.

Laboratory tests. Laboratory soil tests are regarded as a more rapid and less costly means of acquiring basic data upon which to make fertilizer recommendations, and have received considerable attention. However, most of this work has been devoted to major soils of the corn and sorghum belt.

1) *Soil test for N.* A comparison of seven promising soil test methods was conducted in a pot study by Chaiyo and Suwanarit (1984) using 18 soils covering a wide range of texture (clayey to sandy) and organic matter content (0.31 to 4.56 percent). These included some major soils of the corn and sorghum belt and some major soils of the Northeast. An acid $K_2Cr_2O_7$ method modified from the method of Sahrahwat and Burford (1982) and the acid $KMnO_4$ method of Stanford and Smith (1978) were found to give the highest correlations of corn yields with nitrogen uptake. These methods were easier and less time-consuming than the Kjeldahl total-N method, and gave a very close relationship to percent total N and percent organic matter as determined by the Walkley and Black rapid titration method (Figures 1 and 2). Taking into account the cost of chemicals and labor, the authors recommended determination of soil organic matter and, where percent total N was required, the modified acid $K_2Cr_2O_7$ method was recommended. From this study, the authors concluded that 5.4 percent O.M., 200 ppm acid $KMnO_4$-N and 1700 ppm acid $K_2Cr_2O_7$-N were critical values for maximum corn grain yields.



igure 1. Relations Between N Extracted by Modified Acid $K_2Cr_2O_7$ and Percent Total N and Percent O.M. (Chaiyo and Suwanarit, 1984).

Soil test for P. The Mitscherlich-Bray equations for calculating from soil analysis the amount of P fertilizer needed to obtain 87 percent of maximum corn and sorghum grain yields are presented in Table 3. These equations were satisfactorily tested on Reddish-Brown Lateritic soils.

Suwanarit and Pantanahiran (1984) conducted pot studies with corn to compare five soil test methods for P: the Bray II method (Bray and Kurtz, 1945); Olsen's method (Olsen *et al.*, 1954); Sissingh's water extraction method (Sissingh, 1971); the anion exchange resin extraction method of William (1965); and the equilibrium method of Ozanne and Shaw (1968). Twelve soils of different series were used, including Korat, Yasothon, Phon Phisai, Nam Phong and Loei, with pH values ranging from 4.8 to

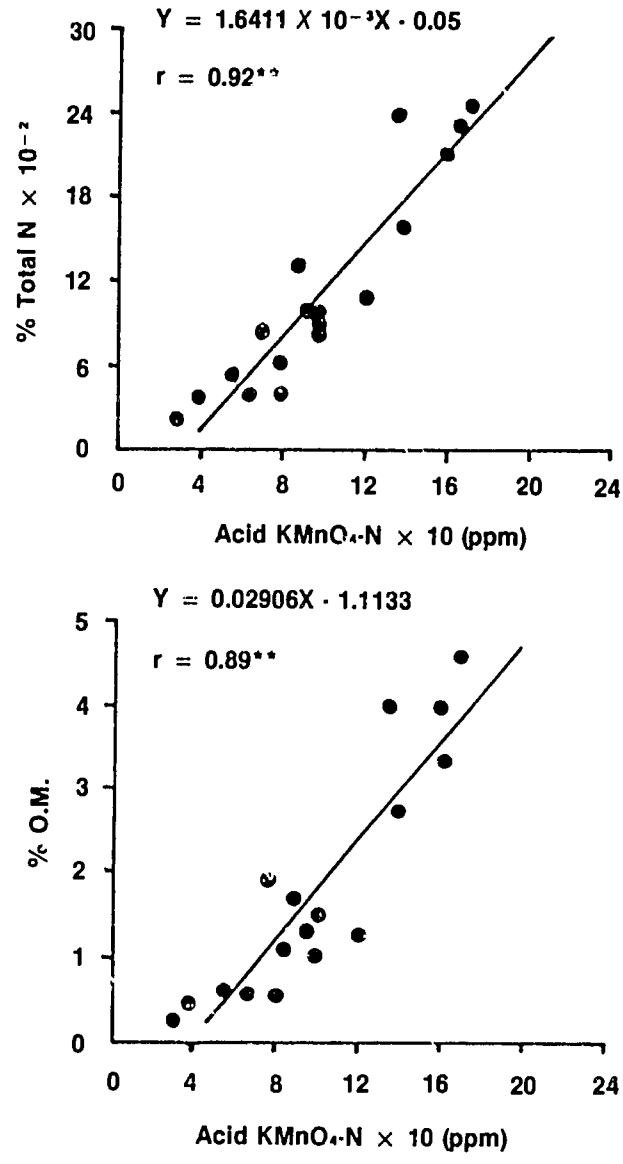


Figure 2. Relations Between N Extracted by Acid $KMnO_4$ and Percent Total N and Percent O.M.
(Chaiyo and Suwanarit, 1984).

7.8, and textures ranging from clay to sandy loam. The descending order of correlation coefficients for the P soil test was: Olsen-P > anion exchange resin extracted P > equilibrium P-concentration in conjunction with buffering capacity > Bray II-P > water extracted P > equilibrium P-concentration. However, in correlations between soil P test values and total P uptake, the descending order of correlation coefficients was: equilibrium P-concentration in conjunction with buffering capacity > anion exchange resin extracted P > Olsen-P > Bray II-P > water extracted P > equilibrium P-concentration. When the ease of performing such tests is considered, the authors concluded that Olsen's method was most acceptable followed by the Bray II method and the anion exchange resin method. They concluded that 22 ppm Olsen-P and 27 ppm Bray II-P were critical values for corn grain yields at 95 percent of maximum yield.

Table 3. Mitscherlich-Bray Equations for Calculating the Amount of P Fertilizer Required for Corn and Sorghum.

Equation†	Soil Type and Reference
Corn:	
$\log (100-y) = \log 100 - 0.00627b - 0.0402x$	Reddish-Brown Lateritic soils (Meekangwan, 1969)
Sorghum (var. Late Hegari and KU 257):	
$\log (100-y) = \log 100 - 0.0792b - 0.0360x$	Reddish-Brown Lateritic soils (Meesawat, 1969)

† y grain yield, % of maximum yield; b, amount of Bray II P_2O_5; x, amount of available P_2O_5 to apply in the same unit weight per unit area as b.

3) *Soil test for K.* Meekangwan (1969) and Meesawat (1969) attempted to establish Mitscherlich-Bray equations for K with corn and sorghum but the results were not satisfactory. This may be attributed to the fact that there was little or no increase in yield by corn and sorghum when K fertilizer was applied to the soils that were studied. However, data from field trials by Boon-ampol *et al.* (1981b), shown in Figure 3, indicated that the critical level for corn grain yield at 100 percent maximum yield was in the range of 50 to 80 ppm exchangeable K for Reddish-Brown Lateritic soils.

A number of workers have reported that the extraction of soil K with H-saturated resin produced the narrowest range of critical K levels for corn grown on widely different soils. It follows that this particular test method was least soil type-specific for evaluating the K status of soils (Suwanarit and Chunyanuwat, 1983; Suwanarit and Narkviroj, 1975; Wiwutwongwana and Suwanarit, 1979).

Varietal Considerations. Differences in response to fertilizer among varieties/cultivars of corn and sorghum have been reported (e.g., Boon-ampol *et al.*, 1978a; Senanarong *et al.*, 1971; Suwanarit *et al.*, 1984b). These are illustrated in Figures 4 and 5. Data obtained by Meesawat *et al.* (1978) on testing of the Mitscherlich-Bray equation for sorghum (Table 3) are also of interest. These data show that the relationship between calculated yields and actual yields for the Late Hegari variety was closer ($r = 0.91$) than for the KU 257 variety ($r = 0.73$). The equation was originally established with the Late Hegari sorghum variety. Crop variety/cultivar should, therefore, be taken into consideration when determining application fertilizer rates for different soils.

Time of Application

Past research on the time of fertilizer application was devoted to soils of the corn and sorghum belt. Results indicated that a 1:1 split application of NPK fertilizer at planting and at one month after planting was the best practice. Where crop yields were likely to be limited by moisture stress and drought, omitting fertilizer at planting was also recommended.

N and P Fertilizers. Songsasen *et al.* (1974) conducted trials on Pak Chong series in Lopburi Province and the responses of corn to N were observed. Applying all of the N (112.5 kg/ha) at one month after planting was superior to applying all of the N at planting and when N was applied at planting and at the one-month growth stage. Thawornmas and

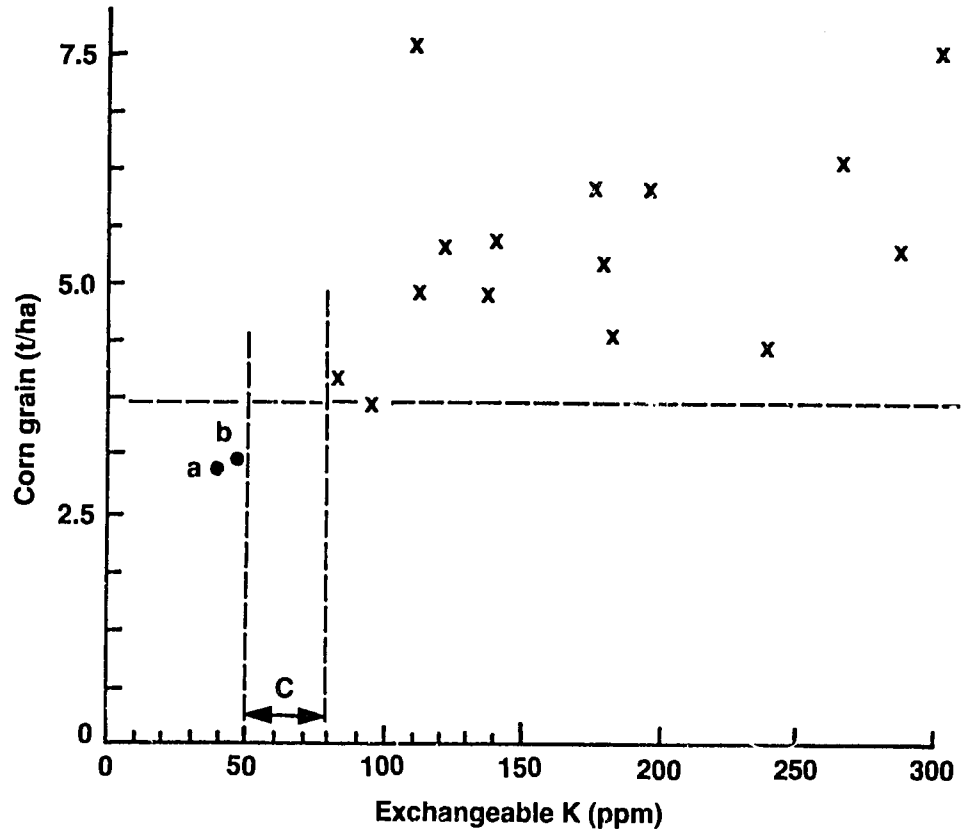


Figure 3. Relations Between NH_4O-Exchangeable K and Grain Yield of Corn Grown on Reddish-Brown Lateritic Soils (Adapted from Data by Boon-ampol *et al.*, 1981b). Data from soils that produced (a) 45% and (b) 21% increases in grain yield upon application of 62.5 kg/ha of ET_0. (x) Data from soils that showed no appreciable increase in grain yield on application of 31.3 and 62.5 kg/ha of K_2O. (C) Range covering critical level at 100% of maximum yield.

Boon-ampol (1975) conducted trials on Pak Chong soils at five sites in Saraburi and Lopburi and obtained strong responses to N fertilizer at all sites. They observed little difference in corn grain yields when 112.5 kg/ha of N was applied at planting, at one month after planting, or in a 1:1 split application at planting and at one month after planting.

Evidence for the most suitable time for P fertilizer applications is not available. However, data from trials on the effect of time of application of NP and NPK fertilizer are available. Results of such studies on Pak Chong and Korat series soils are summarized in Table 4. These data indicate that the application of NP fertilizer could be delayed until at least 30 days after planting without significant reduction of grain yields. Moreover, a split application with one-half at about 30 days after planting and the other half at about 45 days after planting was superior to early application, especially when the crop suffered from drought at tasselling. Results by Suwanarit *et al.* (1977a) from a pot experiment indicated that a split application of NP fertilizers with one-half at planting and one-half 30 days later was more effective than either all applied at planting or all applied at the 30-day growth stage. With irrigated corn and sorghum, a split application, 1:1, at planting and 30 days after planting, was also found to be superior (Chaiwanakupt *et al.*, 1973a; 1973b).

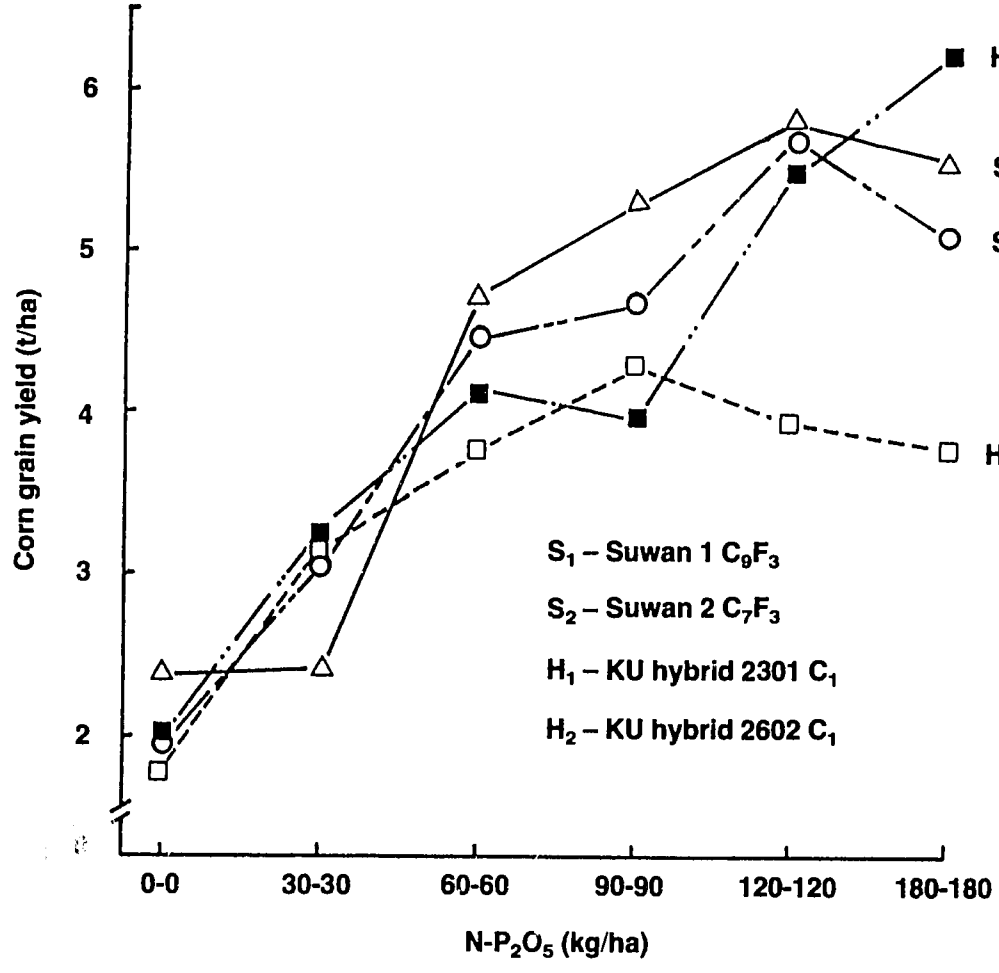


Figure 4. Comparative Response of Four Corn Cultivars to the Level of Soil Fertility (Suwanarit *et al.*, 1984b).

Trials on effect of time of application of K fertilizer are also lacking. Studies with irrigated sorghum on Roi Et series soils reported by Senanarong *et al.* (1971) and Boon-ampol *et al.* (1979a) suggested that a split application, 1:1, at planting and at the 30-day growth stage was generally recommended.

Methods of Application

A number of trials have been conducted on the method of application of N and P fertilizers on Pak Chong series soils. For N fertilizer, banding application is generally superior to broadcasting, but for P fertilizer (as double superphosphate or triple superphosphate), broadcasting is slightly superior to banding. Results obtained by Guramarohit *et al.* (1979) with polyphosphate (heat-treated rock phosphate) on Pak Chong, Loei and Korat series soils at eight sites support this. They found that the broadcasting of polyphosphate was either comparable or slightly superior to banding. No trials on method of K application to soils have been found.

Forms of Fertilizers

Very few investigations have been conducted to determine the response of crops to various forms or sources of N, P and K fertilizers.

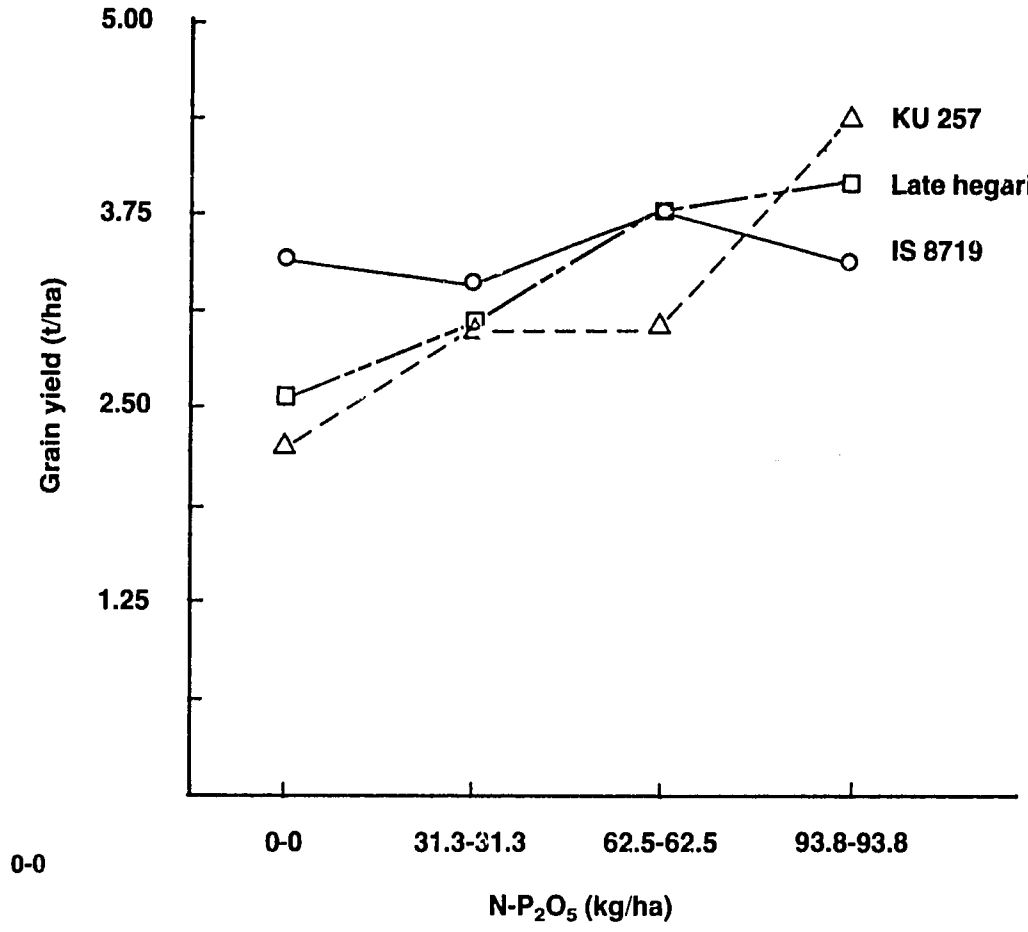


Figure 5. Comparative Response of Three Sorghum Varieties to Fertilizer Rate (Adapted from Data by Boon-ampol *et al.*, 1978a).

In a pot study on soils ranging in pH from 6.0 to 8.0, Suwanarit *et al.* (1979c) found that NO_3 fertilizer produced higher N uptake by corn and lower gaseous loss of N than NH_4 fertilizer (Figures 6 and 7). This suggests that NO_3 fertilizer may be superior to NH_4 fertilizer and soluble NH_4-producing fertilizer. Although NH_4-N would be subjected to rather rapid conversion to NO_3 by nitrifying bacteria in upland soils, gaseous losses of NH_3-N could occur before this transformation, especially when soil pH was neutral to alkaline.

Results of P fertilizer field trials on Reddish-Brown Lateritic soils and Yasothon series soils indicate that the application of rock phosphate is slightly less effective than double superphosphate when comparison is based on available phosphate in the materials. Application of rock phosphate in combination with double superphosphate was found to support the highest crop yields, but the most suitable ratio of the two materials was not determined (Boon-ampol *et al.*, 1978c; Meesawat *et al.*, 1977a; Panitchkul *et al.*, 1977; Panitchkul *et al.*, 1978; Thawornmas *et al.*, 1975). Polyphosphate applied to acid soils has been found to be slightly less effective than double superphosphate when applied at half the rate (based on available phosphate), but more effective when applied at the same rate as double superphosphate (Guramarohit *et al.*, 1979). Suwanarit *et al.* (1975) reported that 312.5 kg/ha of rock phosphate was slightly more effective than 93.8 kg/ha of P_2O_5 from a 20-20-0 fertilizer when applied to a calcareous soil of pH 7.9.

Table 4. Mean Grain Yields of Corn Obtained with Different Times of Application of NP Fertilizer (Vacharotayan *et al*, 1972, Suwanarit *et al*, 1974, Suwanarit *et al.* 1977a).†

Fraction of N-P Fertilizer Applied at Different Days After Planting				National Corn and Sorghum Research Center§				Northeast Agricultural Research Center¶ Khon Kaen	
0	28	42	56	1972	1974	1975	1976	1975‡	1976
				..... *kg ha*$^{-1}$					
1	0	0	0	4,200a	4,980a	3,840a	-	264a	-
1/2	1/2	0	0	4,220a	4,830a	4,660b	3,400a	323a	2,640a
1/3	1/3	1/3	0	4,080a	-	4,390b	-	296a	-
0	1	0	0	-	4,970a	-	3,330a	-	2,140a
0	1/2	1/2	0	-	-	4,540b	3,430a	857b	2,360a
0	0	1	0	-	-	-	3,390a	-	1,600b
0	0	1/2	1/2	-	-	-	3,470a	-	1,680b

† Data followed by the same letter do not differ at $P \leqslant .05$.
‡ The plants were subjected to severe drought at tasselling.
§ Pak Chong series soil.
¶ Korat series soil.

Fertilizer Management for Intercropping

A few trials which considered the management of N and P fertilizers for intercropping have been reported, but none that involved the management of K fertilizers has been found.

Suwanarit *et al.* (1977b) conducted studies on intercropping legumes (mung bean, soybean or peanut) with corn rows and concluded that the intercropping legumes did not affect the N fertilizer requirement of the intercrop corn. However, in a study involving a Korat soil, Suwanarit *et al.* (1979a) found increased N uptake by corn where it was intercropped with mung bean, soybean or peanut, and when N fertilizer was not applied. No such beneficial effects were found when N fertilizer was applied (Table 5). These results suggest that the intercrop legumes supply N to corn when the soil is very low in N, but do not do so when the soil contains higher levels of available N. Thus, in intercropping it is a good rule to apply N fertilizer to the intercrop cereal only. When mung bean was intercropped between corn rows (1.0 m spacing), and ^{15}N-labelled urea was banded below the cereal seed rows at planting, a higher fertilizer use efficiency was achieved than with other methods of application (Suwanarit *et al.*, 1983a; 1984a).

In a similar experiment on intercropping corn with mung bean, soybean or peanut, Suwanarit *et al.* (1979b) reported that there were no effects of intercropping legumes on the response by intercropped corn to P fertilizer.

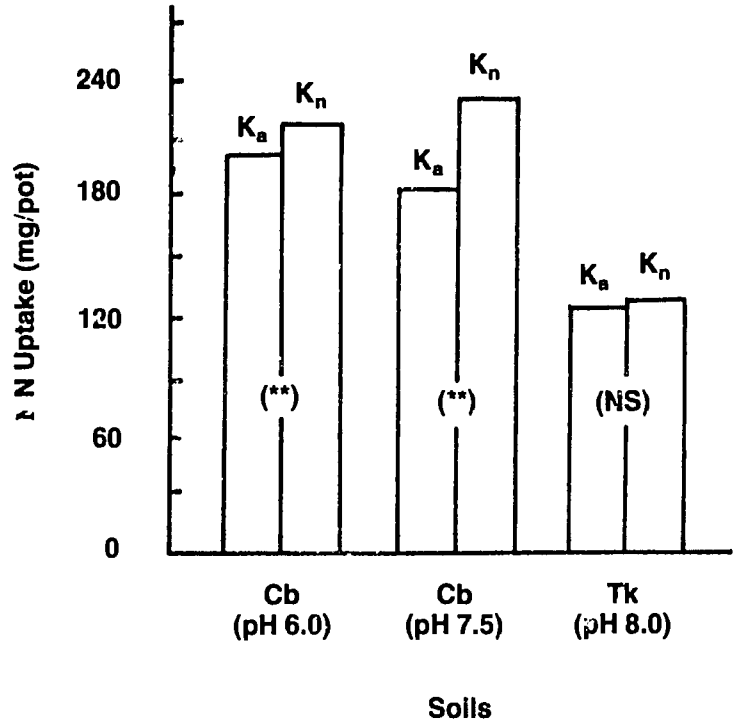


Figure 6. The Amounts of Nitrogen in Corn Plants at Tasselling Stage Grown in Soils of Different pH Levels with Ammonium and Nitrate Fertilizers (Suwanarit *et al.*, 1979c). NS, no significant difference at the .05 probability level; **, significant at the .01 probability level; K_a, $(NH_4)_2SO_4$; K_n, KNO_3; Cb, Chai Badan series soil; Tk, Takhli series soil.

In a sorghum-mung bean intercropping system on a sandy loam soil, Boon-ampol *et al.* (1981a) found that application of NP fertilizers below the sorghum seed row at planting gave higher grain yields of sorghum and mung bean than broadcasting the fertilizers uniformly over the entire plot.

These data suggest that for a corn-sorghum-mung bean intercrop, both N and P fertilizers should be applied to the intercrop cereal and not to the intercrop legume. Information on time and method of application of N and P fertilizers for the monocrop of corn discussed earlier would suggest banding placement for N fertilizer, and broadcasting placement for P fertilizer at either planting or 30 days after planting. Banding application of N and P fertilizers to the cereals is recommended when ease of application is taken into account.

Soil and Soil Water Management

Seedbed Preparation

For Pak Chong series soils, conservation tillage or no-till system weed control was reported to be either comparable or superior to conventional tillage for producing corn yield and increasing water conservation and storage. When soils were moderate to high in available N, conservation tillage was superior to conventional tillage, but when soils were very low in available N, conventional tillage was superior to versions of conservation tillage (Chandraparnik *et al.*, 1979; Jootanon and Tiraporn, 1970; Masangsawan *et al.*, 1981; Tongyai *et al.*, 1980). No-tillage cropping systems on Pak Chong and Tab Kwang

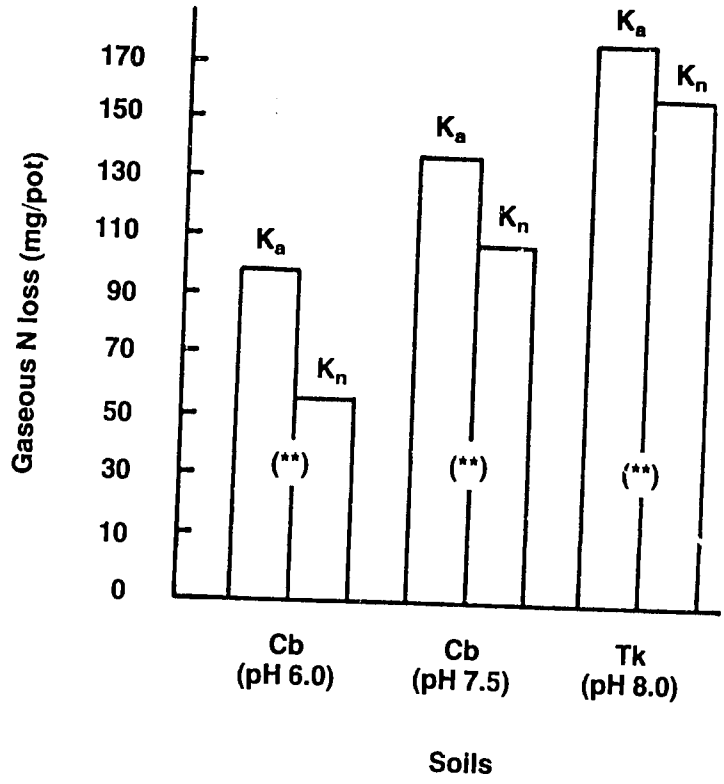


Figure 7. Amounts of Nitrogen Lost in Gaseous Forms as Affected by Form of Nitrogen Fertilizer Applied to Soils of Different pH Values (Suwanarit *et al.*, 1979c). K_a, $(NH_4)_2SO_4$; K_n, KNO_3; **, significant at the .01 probability level; Cb, Chai Badan series; Tk, Takhli series.

soils are reported to increase the water use efficiency of corn. Certainly soils are prone to develop surface crusts that increase runoff and decrease infiltration of water and aeration, as some of the major soils of the Northeast. Tillage operations to reduce crusting are absolutely essential. Results of a study on effects of plowing and hoeing a poorly structured sandy loam soil showed that plowing that inverted the profile to a depth of 30 cm with subsoil then positioned at the surface, drastically decreased water infiltration into the soil. Hoeing, however, slightly increased water infiltration into the unplowed soil and drastically decreased water infiltration into the plowed soil (Table 6). Shallow plowing or surface hoeing just enough to break the surface crust would appear to be a most desirable operation in seedbed preparation.

Land Surface Features

With conventional tillage, sowing seeds on flat land or on ridges has been reported to produce corn yields comparable to grain yields of corn grown on Pak Chong soil and to produce higher yields than sowing in furrows (Sarakul and Imsupasit, 1977). No such studies with corn and sorghum have been reported on major soils of the Northeast. However, results reported by Abdalla (1974) have shown that planting of soybean on plateaus and ridges produced higher yields than when it was planted on flat land. These results are shown in Figures 8 and 9 and Table 7. The effects of plateau and ridge planting varied with height. The highest grain yield was obtained by planting on plateaus 20 cm in height, followed by ridges 30 cm in height, and plateaus 30 cm in height. Considering the average distance between plateaus, and between ridges and the

Table 5. Total Nitrogen Uptake of Corn at Harvest as Affected by Rate of Nitrogen Fertilizer and by Intercropping Legumes (Suwanarit *et. al.*., 1979a).

Fertilizer Rate	Crop Combination				Average
	Corn	Corn + Soybean	Corn + Mung bean	Corn + Peanut	
	..... *kg ha⁻¹ N*				
0	14.0	17.2	22.6	23.3	19.4
30	38.6	30.6	31.8	32.4	33.3
60	31.0	22.9	44.4	30.8	33.3
90	49.8	33.7	42.1	35.4	40.3
Average	33.4	27.6	35.2	30.5	

	Fertilizer rate (F)	Crop combination (C)	F °C
L.S.D. .10	-	-	9.34
.05	5.64	5.64	(NS)
.01	7.65	(NS)	(NS)
CV (%)	21.1		

recommended row spacing for corn and sorghum, ridges of about 30 cm in height (70 to 75 cm between ridges) and plateaus of about 40 cm in height (each ridge accommodates two plant rows) would be suitable for corn. For sorghum, ridges of about 55 cm in height and plateaus of about 30 cm would be recommended.

Mulching and Incorporation of Organic Materials

Mulching of agricultural soils with plant residues has been widely demonstrated as a best management practice for controlling erosion, reducing water evaporation and decreasing runoff and nutrient losses (e.g., Meesawat *et al.*, 1977b; Phetchawee *et al.*, 1979; Thawornmas *et al.*, 1977b; and Veerakornpanich *et al.*, 1981). As shown in Table 8 and Figure 10, mulching was found to be slightly more favorable than residue incorporation to the growth and yield of sorghum and corn on a Pak Chong series soil, especially when fertilizer was applied. However, mulching of residues seemed to be less effective than incorporation when residues were applied to a Yasothon series soil, a soil that readily develops surface crusts when subjected to rain. Mulching, however, showed no significant effect on yield of corn grown in Pak Chong soil when rainfall was favorable. The effects of surface mulch and incorporation of crop residues were attributed mainly to an increased supply of soil moisture to the crops. The incorporation of crop residues with wide C/N ratios, such as those cited in Table 8 and Figure 10, may enhance microbial immobilization of inorganic N. Therefore, it is likely that less N would be immobilized by mulching than by incorporation. However, incorporation may be more feasible for residues with narrow C/N ratios.

Table 6. Effects of Soil Turning, CaO Application and Hoeing† on Water Infiltration of Sandy Loam Soil at the Kalasin Experimental and Demonstration Farm After a Paddy Crop (Abdalla, 1974).

Cultivation Treatment	Water Infiltration	
	With CaO (4 t ha^{-1})	Without CaO
	..... *mm* h^{-1}	
Turned soil‡		
Without hoeing	1.68	0.96
With hoeing	0.89	0.81
Unturned soil		
Without hoeing	3.72	2.97
With hoeing	4.01	2.68

† Hoeing the surface to 5 cm done before determination.
‡ The surface layer was turned deep to 30 cm to be replaced by the upper subsoil.

Mulching with living plants, i.e., live mulches, may be another approach for managing soil moisture. Suwanarit *et al.* (1983b) reported that a corn-mung bean intercrop tended to have lower evapotranspiration losses than corn alone (Figure 11). The comparative evapotranspiration may, however, be dependent on many factors, including the crop or crops, tillage system, crop density, row spacing, water use efficiency, soil fertility level, and weather and climatic factors. These remain for future research.

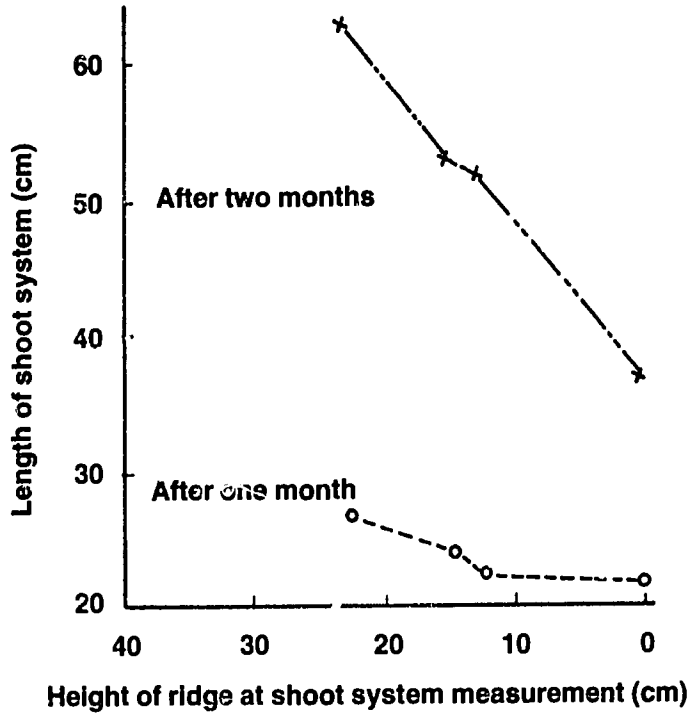


Figure 8. Effect of Height of Ridge on Length of Shoot of Soybean Grown on Sandy Loam Soil at the Kalasin Experimental and Demonstration Farm (Abdalla, 1974). (See Table 7 for details.)

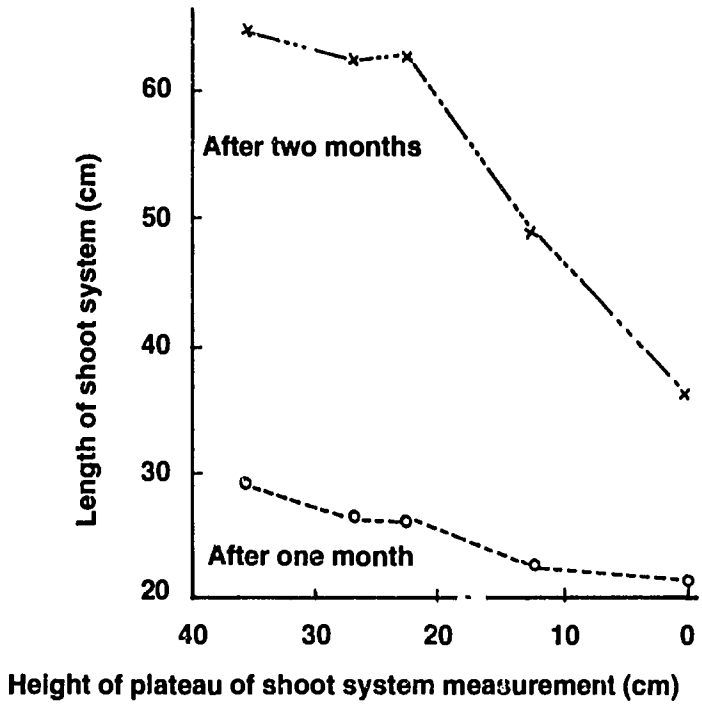


Figure 9. Effect of Height of Plateau on Length of Shoot of Soybean Grown on Sandy Loam Soil at the Kalasin Experimental and Demonstration Farm (Abdalla, 1974). (See Table 7 for details.)

Table 7. Effect of Land Surface Feature on Seed Weight and Seed Yields of Soybean Grown on a Sandy Loam Soil at the Kalasin Experimental and Demonstration Farm (Abdalla, 1974).

Treatment†	Weight of 100 Seeds	Seed Yield	Area Factor‡	Seed Yield§
	g	*kg ha⁻¹*		*kg ha⁻¹*
Plateau, 40 cm height	10.1	930	.90	836
Plateau, 30 cm height	9.8	1120	.60	669
Plateau, 20 cm height	9.7	1520	.45	685
Plateau, 10 cm height	9.2	1020	.40	408
Flat land	9.2	608	.45	274
Ridge, 30 cm height	10.1	1230	.70	862
Ridge, 20 cm height	9.7	1100	.55	604
Ridge, 10 cm height	9.4	1070	.45	483

† Figures in cm are the heights of plateau and ridge. The average distances between the centers of two plateaus were 180, 120, 90 and 80 cm for those with 40, 30, 20 and 10 cm heights, respectively. Distances between two ridges were 70, 55 and 45 cm for ridges with 30, 20 and 10 cm heights, respectively. Each plateau accommodated two rows of plants whereas each ridge accommodated one row of plants.

‡ Obtained by measuring the overall distance between the centers of two plateaus or ridges and then dividing it by the number of rows. On each plateau, two rows of soybean plants were accommodated whereas one row was accommodated on each ridge. Plant populations in rows were similar in all treatments.

§ Obtained by multiplying seed yield (kg ha^{-1}) by the area factor.

Table 8. Effects of Mulching and Incorporation of Organic Materials on Growth and Yield of Sorghum Grown on a Yasothon Series Soil (Thawornmas *et al.*, 1977b).

Treatment†	Plant Height at 120th Day of Age	Grain Yield
	cm	*kg ha⁻¹*
Control	127	944
RSM	141	1480
RSI	165	1500
GMI	126	638

† Control, no mulch and organic incorporation; RSM, Rice straw mulch, 12.5 t/ha; RSI, Rice straw incorporation, 12.5 t/ha, one month before sowing; and GMI, Green manure incorporation.

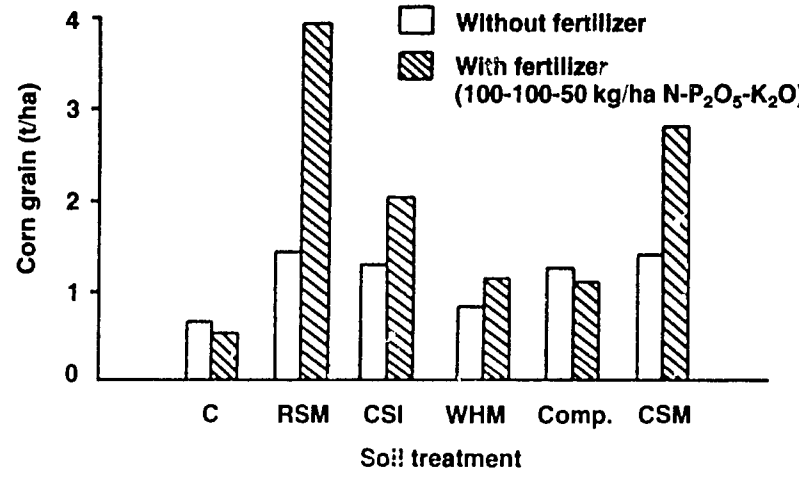


Figure 10. Third-Year Effects of Mulching and Incorporation of Organic Materials on Grain Yield of Corn Grown on a Pak Chong Series Soil at the Phra Phuttabat Field Crop Experimental Station (Phetchawee *et al.*, 1979). C, control (no mulch or compost); RSM, rice straw mulch, 4 t/ha; CSI, corn stalk incorporation, 4 t/ha; WHM, water hyacinth mulch (4 t/ha) replacing vinyl sheet mulch of previous years; Comp., compost incorporation, 20 t/ha; CSM, corn stalk mulch, 4 t/ha.

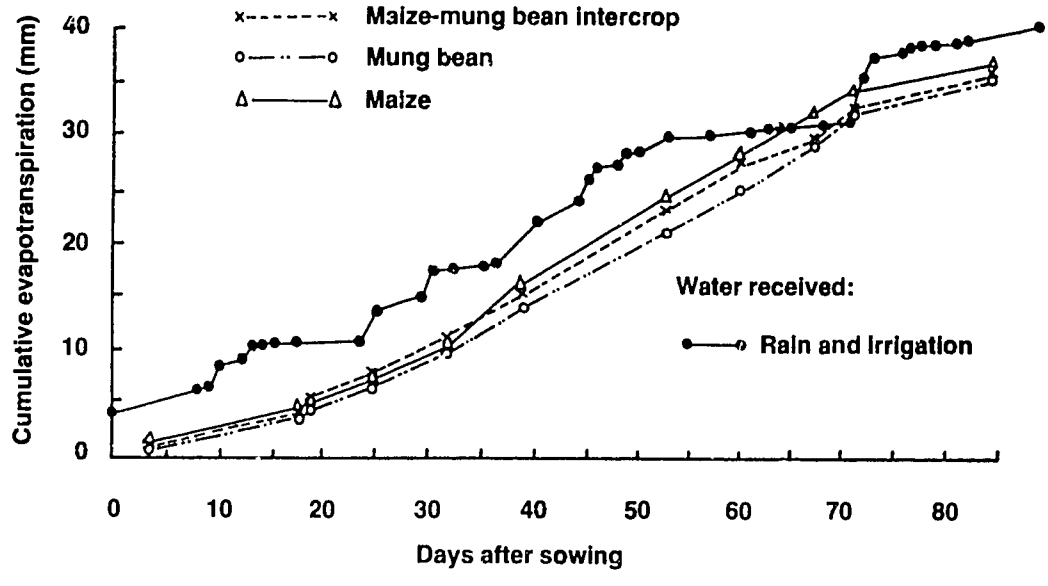


Figure 11. Mean Cumulative Evapotranspiration of Maize, Mung Bean and Maize-Mung Bean Intercrop, and Cumulative Water Received. Values for the Intercrop Were Means of Three Fertilizer Treatments and Those for the Monocrops Were From One Treatment; All Treatments Were Replicated Three Times. The Differences in Cumulative Evapotranspiration at Each Plant Age Were Not Significant at the $P \leqslant .05$ level. (Suwanarit *et al.*, 1983b)

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Soil Erosion and its Countermeasures

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ABSTRACT. The "International Workshop on Soil Erosion and Its Countermeasures" was held in Chiang Mai, Thailand from November 11-19. Total attendance at the workshop was 127 including 87 Thais from 19 different government agencies and 40 foreign participants from 14 different countries. The workshop format included two days of formal paper presentations, a field trip in the Chiang Mai area, followed by a one-day discussion workshop on "Problems and Constraints of Soil Conservation in Developing Countries." The weekend following the conference was also devoted to a field trip to the underdeveloped Southeast coast resettlement area near Rayong.

The organizers of the workshop drew attention to the similar socioeconomic constraints that exist among countries in various stages of development. In fact, problems of farmer acceptance of conservation policy are ubiquitous. The technical session of the workshop was divided into four topics which included assessment, prediction, impacts and control.

There is much soil conservation technology available for land suitable for agriculture, but little technology for unsuitable land. There is need for a greater understanding of the objectives and applications of predicting models for soil erosion. Research work on the loss of soil nutrients is urgently needed for tropical farming systems.

For erosion control, the workshop emphasized erosion control for cassava fields and roadside embankments. Successful soil conservation practices in Malaysia and Taiwan were mentioned. Local environmental conditions and farming systems need to be taken into account in order to adapt conservation technology and make it more appropriate. The value of using the media to promote soil conservation was stressed at the meeting.

Soil erosion control is urgently needed for all countries but it must be country-specific and region-specific or economic sector-specific. A well-defined soil conservation policy should be established in all countries. A national forum should exist in each country for advising research on benchmark soils and local farming systems, and training priorities. An international formalized group should be established to promote international cooperation. A technical workshop should be held on the specific topic of soil conservation.

Introduction

In the formal oration at the beginning of this workshop, Mr. Sanarn Rimvanich asked us to address the problem of finding appropriate technological and social solutions to the control of soil erosion. The context for the workshop was set in the opening address. Dr. T.C. Juang pointed out that soil erosion has been with us ever since man started cultivating land. Despite a long history of the problem, Mr. Aram Iam-arun, Deputy Governor of Chiang Mai Province, asked why soil conservation measures were not implemented. Were the measures proposed too complex or too costly? In trying to answer these questions, Dr. Prasan Yingchol hoped that great benefits would come from this opportunity to exchange experiences and views.

In drawing conclusions from the workshop, this report first summarizes the main points which have emerged as having common interest and then it presents a set of recommendations.

Summary of the Sessions

Assessment

There is a need when assessing erosion to distinguish between those problems which relate to the misuse of the land and those that are associated with cultivation of land suitable to that purpose. One example of the first case is where population pressures force people onto marginal land. This is a socioeconomic problem and should be dealt with as such. There is little that soil conservation technology can offer. If attempts to implement soil erosion technology are made, the cost will be high and, since the land is marginal, the return on investment will be low. For the second case, however, there is much that technology can offer.

Prediction

Attempts are being made to predict erosion by adapting models developed in one country for use in another. This often involves extrapolation beyond the data base of the original model and tends to be unsatisfactory. There is a need for greater understanding of the objectives and applications of models so that users know more of the models' limitations and possibilities, avoid their misuse and make more realistic predictions.

Impacts

Little is known about the loss of soil nutrients under tropical farming systems. In view of pollution and loss of soil productivity, research is urgently required to collect this information.

Control

Two specific examples of erosion control received emphasis in this workshop: erosion control associated with growing cassava and roadside embankments. There are questions regarding the cultivation of cassava. Should the crop continue to be grown or should alternative crops be sought? If we continue to grow it, what is the most effective erosion control measure? Examples of successful control of erosion on road embankments occur in Taiwan and Brunei but to judge from the evidence of other countries, there is a need to promote soil conservation in these areas more widely.

On the more favorable side, we heard many examples of successful soil conservation practices in Taiwan and Malaysia. We also saw examples in Thailand during the field visits. Another encouraging fact is the increasing attention being devoted to woodlots using species of *Leucaena*, *Acacia* and *Eucalyptus* to provide fuel. This will hopefully reduce the rate of destruction of the tropical rain forest.

A comparison of soil conservation experiences in different countries highlighted the difficulty of transferring technology from one country to another. Local environmental conditions and farming systems need to be taken into account in order to make appropriate technological adaptations. Acceptance of technology is enhanced if the originator and receiver of the ideas work together as seen in the research and demonstration activities carried out under the Thai-Australia project.

Several times during the week the value of using the media to promote soil conservation had been stressed. Attention should be focused on using the basic educational system to teach the importance of soil conservation and radio, television and newspaper media to disseminate specific practices to farmers.

Recommendations

Several of the above-mentioned themes received renewed airing during the workshop sessions which followed the field visits. Views were exchanged on the planning and implementation of soil conservation, and extension. As a result of these discussions, several recommendations are made.

There is an urgent need for soil erosion control in all countries but the planning and implementation of soil conservation must of necessity be country-specific and sometimes region-specific or economic sector-specific.

Every country should have a well-defined policy with respect to political and financial support of land use strategies, legislation and the organization of appropriate soil conservation services. Local circumstances should dictate whether the legislation should be by incentive or computation and whether the soil conservation service should be a single or multiple body.

Each country should decide its own priorities for research taking into account representative or benchmark soils and local management or farming systems.

A national forum should exist in each country to establish research and training priorities. Its membership should include the government, university/college, private and extension sectors. There should be an exchange of information within the forum between farmers and researchers.

The national forum should promote active contact with politicians and those charged with allocating funds. International and national workshops and seminars may aid this contact.

A formal group should be established at the international level to promote conferences, training workshops, exchanges of scientists and an information newsletter. The group should be based on ASEAN, or a wider geographical identity such as ASPAC, depending upon available funding.

Technical workshops should be held on the application of the Universal Soil Loss Equation, criteria for soil loss tolerance, incorporation of the small farm sector into soil conservation programs, the role of the mass media in promoting soil conservation, extension methods, and procedures for monitoring the success or failure of soil conservation techniques. Care should be taken to ensure that appropriate people attend the workshops; in some cases this will be research scientists and in other cases, technical support staff or extension staff.

Conclusions

In this workshop we have had almost two days of varied and interesting papers from participants from fourteen countries. We have seen in the field examples of both research and conservation practices. We have had lively workshop discussions and a valuable session on the comparison of soil conservation work in different countries. The results of these activities have led to a set of recommendations.

These achievements illustrate the value of international workshops of this type. They also reflect the respective inputs of the sponsors in making the meeting possible, the Thai hosts for getting everyone assembled and for providing a conducive technical and social environment, and the participants for their enthusiastic involvement. All have contributed to a most successful and stimulating workshop.

A Brief Overview of the Agricultural Development Research Project in Northeast Thailand

S. Hatta
Agricultural Development Research Center, Khon Kaen, Thailand

The Northeast constitutes one third of both the population and land area of the whole Kingdom but is responsible for only 15 percent of the gross domestic product. The region has developed rapidly since the late 1940s with increasing immigration from the surrounding areas. The land has been reclaimed for human livelihood beyond its capacity. The occurrence of alternate droughts and floods every year accelerate degradation of the natural environment and land productivity.

Objectives

The Agricultural Development Research Project in Northeast Thailand was initiated in December 1983 to strengthen research activities in the region through assessing the natural environment and resources to plan proper land use, identifying and eliminating existing production constraints, as well as developing agronomic technology adaptable to each locality.

Organizational Arrangements

The project is implemented as a tripartite cooperation project under which Japan and the United States of America (USA) jointly assist the Royal Thai Government on aspects of agricultural development. Under this arrangement, the USA mainly assists Khon Kaen University, concentrating on the socioeconomic aspects of agriculture in the Northeast. Japan assists both the Ministry of Agriculture and Cooperatives (MOAC) and the university, focusing on scientific and technical aspects.

Thus, the Project is implemented by three institutions, the Department of Agriculture (DOA) and the Department of Land Development (DLD), both of MOAC, and the Faculty of Agriculture, Khon Kaen University (KKU) with assistance and cooperation extended by the Japan International Cooperation Agency (JICA).

Under the Project, ongoing research activities in the Northeast will be strengthened by the Agricultural Development Research Center in Northeast Thailand (ADRC), a new research facility constructed under the grant aid program of the Project. DOA is responsible for the development of agronomic technology, DLD for planning proper land use, including land conservation, and KKU for fundamental studies related to soil-plant-water relationships.

The USAID project provides total research funds of US$2 million for Khon Kaen University to strengthen its interfaculty and departmental research activities as well as 12 man-month short-term consultants to ADRC activities during the period 1983-1989.

To coordinate these research activities in pursuance of the common objectives mentioned above, and in accordance with the development policies of Thailand, the Coordinating Committee, chaired by the Permanent Secretary of MOAC, was established. Under the guidance of the Coordinating Committee, the Research Committee is responsible for planning and implementing the Project by convening a meeting for open discussions among the personnel concerned every two or three months.

Facilities

The following facilities were donated by the Government of Japan under the grant aid scheme totaling approximately US$5.4 million.

Buildings

ADRC Main Building

Conference hall, exhibition hall, visiting scientists room, seed storage, laboratories for plant and soil research, etc.

KKU Annex Building

USAID Project room, visiting scientist room, laboratories for plant and soil research, etc.

Auxiliary Facilities

Dormitory, garage/workshop, soil sample storage, net house, etc.

Equipment

Laboratory equipment for:		Audiovisual materials	1
Plant breeding/agronomy	1 set	Tractors	2 unit
Plant physiology	1	Bulldozer	1
Agroclimatology	1	Wheel loader with backhoe	1
Soil chemistry	3	Vehicles	18
Soil physics	3		
Soil microbiology	3		
Soil survey	1		

Experimental Field

Japanese Experts

Team Leader	1	Pedologist	1
Plant Breeder	1	Chemical Engineer	1
Agronomist	1	Coordinator	1
Soil Scientist	1		

In addition to these long-term experts, several short-term experts will be assigned according to necessity.

Research Program

Assessment of Environment and Resources

1) Land classification and land use planning (DLD) - Trials for land classification and planning land use will be made focusing on problem soils in the Northeast.
2) Stochastic analysis of rainfall (KKU) - An analysis of rainfall patterns of the Northeast both in locality and time sequence with special reference to cropping seasons will be made.

Improvement of Crop Performance

1) Interactions among environment, water stress and crop performance (KKU). The study of factors such as climate, topography and soil and their relation to water stress and plant growth.
2) Development of drought-tolerant crops in the Northeast (DOA, KKU). Selection of annual/perennial crops suited to localities and genetic improvement of some selected crops. Vegetable soils substitution for fossil oils will also be explored.

Improvement of Soil Conditions

1) Amelioration of soil salinity (DLD).

   Carry out an ectomorphological survey of salt-affected areas and some agronomic trials for amelioration of soil salinity.
2) Recycling of organic materials (DLD, KKU).

   Examine available materials for making composts and their effects on soil productivity. Study decomposition of organic materials under different conditions and changes in soil properties due to the application of amendments.
3) Conservation of soil fertility (DOA).

   Study soil and water management at the farm level and conservation of soil fertility by identifying and eliminating production constraints to each soil type in the Northeast.

Research institutions in parentheses indicate those mainly responsible for the research subjects concerned.

Section VI
Conclusions and Recommendations

Conclusions and Recommendations of the Working Groups

J.F. Parr and C. Pairintra
USDA/USAID Dryland Agriculture Project, Agricultural Research Service, Beltsville, Maryland, USA and Khon Kaen University, Khon Kaen, Thailand

At the conclusion of the presentation of seminar papers, three working groups comprised of seminar participants were organized to discuss the data presented in the technical papers and the data base document, and to draw conclusions and recommendations (priorities) for future research on aspects of soil, water and crop management systems for rainfed agriculture in Northeast Thailand. The major topics of the working groups were: soil-water relationships, agroclimatology and cropping systems, and soil fertility management. The deliberation and recommendations of the working groups are as follows.

Group I - Soil-Water Relationships

Introduction

Agriculture in Northeast Thailand is characterized by an emphasis on rainfed rice production for subsistence. Rice is grown on all lowland areas and on as much of the middle and upper terraces as rainfall will permit. The amount of middle and upper terrace lands transplanted to rice varies greatly from year to year because of erratic rainfall. Therefore, soil-water research efforts in support of rice production should emphasize how to maintain water saturation and flooding for the time between rains. This work should concentrate on lowland and middle terrace land.

Second to rice, the emphasis is placed on field crops produced for cash. These crops are primarily grown on uplands but many development projects have shown how to increase land use intensity by producing these crops in the paddy as prerice or postrice crops. If field crops are to be grown successfully on uplands, the soil-water research emphasis should be on increased retention and storage of plant available water in the soil. This will require attention to infiltration and water holding capacity as well as efforts to avoid prolonged soil saturation after a period of heavy rainfall.

For field crops grown as prerice crops in the paddy, the research emphasis should be to manage the soil to maximize soil saturation and flooding for subsequent rice production, and to ensure sufficient soil water for the prerice field crop without losing stands or adversely affecting yields from soil waterlogging.

Objectives

1) To obtain a better understanding of soil and water relationships in major soils of the Northeast region.
2) To develop management techniques to increase the retention and storage of plant available water in major Northeast soils.

Research Priorities

1) Soil-water retention and storage.
2) Conservation tillage.
3) Increased infiltration of water into soil.
4) Decreased evaporative loss of water.

5) Recharge/leaching.

6) Water balance.

Recommendations for Research and Collaboration

1) To conduct studies on hydraulic properties of soils both in the laboratory and field, including water holding capacities, infiltration, percolation, water extraction patterns, depth of watertable, evaporation and actual water storage.

2) To establish relationships between soil conditions and soil hydraulic properties, both in the laboratory and the field under different management regimes.

3) To conduct studies on the effects of tillage (methods, degree or intensity, and time), surface mulches, composts, crop residues, animal manures and other organic wastes on soil hydraulic properties and other physical properties, infiltration, water retention and storage, and the growth and yield of crops.

4) To establish water balances for major soils and crops under different management systems and for both lowland and upland terraces.

5) To conduct adaptable on-farm trials and demonstration of promising new soil-water conservation techniques.

6) To encourage DOA, DLD and universities to engage in collaborative efforts to increase the stability, efficiency and productivity of farmer's cropping systems in the Northeast region.

Recommendations for Education and Training

1) To provide support to researchers for study, training, educational tours and for attending technical conferences so that they may be better informed of research being conducted at other locations within the nation, region, or world.

2) To encourage DOA, DLD, and universities to include DOA personnel in on-farm adaptive research and demonstrations.

Recommendation for Networking

To identify researchers working in areas of soil-water relationships for rainfed agriculture in Thailand, the region (i.e., Southeast Asia) and the world. Also, to provide mechanisms for exchanging information on research results, methods and techniques, and for establishing research priorities.

Group II - Agroclimatology and Cropping Systems

Introduction

The erratic rainfall patterns and poor soils have placed tremendous constraints on the farmers of Northeast Thailand. Over the centuries farmers have evolved various strategies to cope with these constraints. Cropping patterns are used which appear to efficiently use residual soil moisture or utilize water from the watertable. But these practices are not widespread throughout the region.

The challenge remains for research and extension to study the rainfall and soil moisture characteristics and the existing farming practices and locations where there is presently efficient use of available technology and where transfer of technology might be feasible. Needless to say, the research will have to take an integrated approach, involving all aspects of soil water, fertility and management in the program.

Research findings should be simplified for the purpose of transferring those existing technologies to suitable locations. Therefore, research and extension programs need to be developed which can facilitate the technology transfer and dissemination process.

Improvements in cropping patterns are needed which maximize stability as well as productivity. These include efficient utilization of available water resources such as rainfall, soil moisture, watertable, shallow wells, ponds or tanks.

Objectives

To review existing research data bases concerning agroclimatology and cropping systems in Northeast Thailand and to identify and prioritize research needs for developing new technologies to use water resources more efficiently.

Research Priorities and Recommendations

1) To determine crop water requirements under existing soil and water management systems and with improved systems. Develop and/or utilize models to characterize relationships between variables involving the soil, water, atmosphere (climate) and plant.
2) To define soil, water and plant relationsnips based on agroecological zoning.
3) To develop crop management systems and strategies in relation to agroecological zoning including careful consideration of agroclimatic factors, improved crop calendars and crop sequencing for more efficient utilization of stored water, i.e., water use efficiency.
4) To conduct studies for on-farm verification of agroclimatic models and crop models that would lead to the development of more stable, efficient and productive farming systems.
5) To foster regular meetings between university scientists at KKU and Government agencies who are working on agroclimatic models and farming systems, and extension specialists so that advisory materials can be prepared for use by farmers.

Group III - Soil and Water Management

Introduction

The inherent fertility of most major Northeast soils has long since been depleted and/or exhausted from long-term cropping without sufficient replacement of plant nutrients, and from long-term degradative processes such as soil erosion, nutrient runoff losses and organic matter depletion. Consequently, the tilth, fertility and productivity of Northeast soils are low. Probably the best means of restoring the fertility and productivity of these soils is through the effective and efficient use of traditional agricultural organic material (i.e., crop residues, animal manures, green manures and composts) in proper combination with judicious amounts of chemical fertilizer. Indeed, the use of these organic amendments should greatly enhance the crop plant use efficiency of chemical fertilizers and result in a substantial reduction in fertilizer costs. In addition to providing plant nutrients to crops, organic materials vastly improve soil physical properties such as increased soil aggregation, water holding capacity and permeability, and decreased bulk density, surface crusting and compaction. All of these can greatly improve the productivity of the Northeast soils.

Objectives

To identify and characterize soil fertility problems, and to propose counter measures to alleviate such problems by proper utilization of organic wastes and residues, chemical fertilizers and soil amendments.

Research Priorities

1) Research to increase the organic matter in major Northeast soils.
2) Research on soil fertility evaluation and efficient use of fertilizer.
3) Research on soil acidity and salinity problems to overcome constraints to efficient and productive agriculture in the Northeast.

Major Recommendations

1) To conduct surveys (on-farm) of how farmers are utilizing organic wastes/residues on land (farmers' attitudes).
2) To conduct basic research on organic matter decomposition in major Northeast soils and those factors affecting decomposition.
3) To conduct basic research on compost process technology for different organic materials including on-farm wastes, municipal wastes and industrial wastes.
4) To investigate the best selections of green manure crops that can be adapted to specific cropping systems in the Northeast.
5) To conduct basic research and on-farm research on the amount of various types of crop residues needed to maintain tilth and productivity of problem soils, e.g., those affected by salinity.
6) To conduct basic research and on-farm research on the effect of organic matter additions (rate/mode/time of application) on alleviating soil salinity in Northeast soils. Short-term and long-term studies are needed.
7) To determine the practical and workable balance between organic fertilizer sources and chemical fertilizers that would provide sufficient levels of plant nutrients to specific crops grown in a particular system or sequence.
8) To determine the use efficiency by crops of plant nutrients contained in chemical fertilizers when they are applied to soil with and without organic residues and amendments.

Other Recommendations

9) To evaluate and assess the lime requirement of crops and the effect of lime on plant growth and yield.
10) To determine the CEC at native soil pH for estimating percent base saturation.
11) To establish N-response curves for crops to determine the critical crop requirement fo P and K and soil test procedures for better correlation with P and K.
12) To determine the nitrogen contribution of legumes in cropping systems.
13) To determine the extent of fixation and release of P and K in cropping systems as affected by soil and water management practices.
14) To assess and evaluate the crop requirement for micronutrients and secondary nutrients in Northeast soils. Such deficiencies in these nutrients should be expected as the yield potential of a crop is increased by good management practices.

Section VII
Additional Papers

Background Report

Dr. Nopadol Tongsopit
Rector
Khon Kaen University
Khon Kaen, Thailand

Your Excellency, the Permanent Secretary
of the Ministry of University Affairs
The USAID's Representatives
The USDA's Representatives
Distinguished Participants
Ladies and Gentlemen,

On behalf of Khon Kaen University, I wish to extend a cordial welcome and appreciation of your participation in this first KKU-USAID International Seminar on "Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand." Also, I would like to take this opportunity to express my sincere appreciation to the United States Agency for International Development (USAID) and the United States Department of Agriculture (USDA) for their great contributions and efforts without which this important event would have never been made possible.

Initially, the USAID bureau and mission in the Near East, Asia and Africa recognized the need to develop and adopt technologies to increase agricultural crop production per unit of land and water, with a special focus on sustained production in rainfed areas. Such need is particularly true and important for the developing nations.

Fortunately, there is a vast reservoir of experience and knowledge in the United States possibly useful in dealing with the problems of dryland agriculture. Some of the principles of soil, water and crop management systems developed for the Great Plains and Pacific Northwest regions of the United States can be applied to the development of rainfed agriculture in developing countries.

Consequently, a series of workshops that would serve as a forum for discussion and exchange of ideas between U.S. scientists and LDC's scientists is recommended. The proposed specific objectives are as follows:

1. To evaluate the data bases for soil and water resources and the methodologies for assessing and managing these resources.
2. To determine the state-of-the-art of management systems for crop production under dryland conditions.
3. To determine specific research needs for problems relating to more efficient use of water in dryland areas.
4. To investigate the feasibility of a research network that can extend the knowledge and experience base on dryland agriculture.

Moreover, each workshop will focus largely on one country as a means of providing sufficient background information and dialogue to identify and address specific research needs, and will be held under the auspices of the United States Agency for International Development, and under the advice and recommendation of the United States Department of Agriculture.

Needless to say, this first KKU-USDA/USAID International Seminar is one of the workshops recommended. I do hope that the outcome of this seminar is what we all expect. Particularly, the specific objectives just mentioned should be met.

Ladies and Gentlemen, I do hope that you will have a wonderful time during your stay in Khon Kaen. KKU's staff will do the best to help you enjoy your stay. And again, I wish to thank everyone and welcome you to the seminar.

Opening Address

His Excellency, Dr. Arthon Chonhenchob
The Permanent Secretary
of
The Ministry of University Affairs
Thailand

Mr. Rector
Mr. Vice Rector
The USAID's Representatives
The USDA's Representatives
Distinguished Guests
Ladies and Gentlemen,

It is indeed my great pleasure to have an opportunity to address this distinguished gathering today.

First of all, I wish to extend a cordial welcome to all participants, particularly to the foreign delegates who have come a long way to join this first KKU-USDA/USAID International Seminar on "Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand." It is also a pleasure to express my hearty appreciation to the United States Agency for International Development, the United States Department of Agriculture and Khon Kaen University for making this important event possible.

I am so delighted to hear that there is a growing awareness of the importance of dryland agriculture. It is the dryland areas of the world that will in the future produce the vast majority of food grains upon which a rapidly expanding world population is dependent for subsistence. This is very true for many of the less-developed countries. Therefore, the assistance provided by the United States Government via USAID and USDA in establishing the cooperative efforts between scientists on this subject is vital. It is a great privilege and honor to offer my sincere hope for the success of the program.

Ladies and gentlemen, now time has come for a very auspicious moment. It is a great privilege for me to officially declare the first KKU-USDA/USAID International Seminar on "Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand" open and wish all of you to have the most successful event ever.

Keynote Speech

J.F. Parr
Coordinator of the USDA/USAID
Dryland Agriculture Project
Agricultural Research Service
Beltsville, Maryland, USA

Late in 1983 an agreement was reached between the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) and the U.S. Agency for International Development (USAID), whereby ARS would provide technical input to USAID projects in need of expertise for improving soil and water management in dryland or rainfed agricultural systems. This decision reflects not only a growing awareness that such systems provide most of the world's basic food crops, but that increased production is often limited by constraints in soil and water management. It also indicates a shift in emphasis away from large-scale irrigation projects which have become so costly to the donor organizations, as well as to the countries involved. The USDA/USAID Dryland Agriculture Project focuses on three geographic regions where there is a critical need to increase the production of diversified agricultural crops, i.e., the Near East (or Middle East), Sub-Saharan Africa and Southeast Asia. In brief, the project is directed toward improved soil management, water conservation and storage, and the proper selection or sequencing of crops that use water efficiently.

The workshop is co-sponsored by Khon Kaen University (our official host institution), the Department of Agriculture (DOA), the Department of Land Development (DLD), Kasetsart University, the Northeast Rainfed Agricultural Development Project (NERAD) and USAID. The objectives of the workshop are threefold:

1. To review and discuss major problems and constraints in soil/water/crop management in rainfed agricultural systems with particular reference to Northeast Thailand. Regional experiences from Sri Lanka and India will also be presented.
2. To review available data bases and current research activities, and to develop strategies for resolving major problems through research and agrotechnology transfer.
3. To consider the development of an effective and comprehensive research and training network which includes scientist-to-scientist linkages between national/regional scientists and with U.S. scientists working on similar problems of dryland or rainfed agriculture.

Closing Address

The Honorable Boonchuay Srisarakarm
Governor of Khon Kaen Province
Khon Kaen, Thailand

Mr. Vice Rector
The USAID's Representatives
The USDA's Representatives
Distinguished Guests
Ladies and Gentlemen,

I am deeply pleased and consider it a great honor to address you all for the closing ceremony of the first KKU-USDA/USAID International Seminar on "Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand."

It hardly seems that the five days allotted for this seminar have already passed. The time has gone quickly, but I do believe that the seminar's objectives have been successfully met. On behalf of the citizens of Khon Kaen Province and those of other provinces in the Northeast I do wish to express a hearty appreciation to all of you, USDA and USAID in particular, for all your concern and effort in struggling for the development of rainfed agriculture in this region.

I do wish you a safe return to your home countries. And now, I officially declare this seminar closed, and hope to see you again.

Thank you.

List of Participants

Thailand

1. **Ministry of University Affairs**

   H.E. Dr. Arthon Chonhenchob

2. **Khon Kaen University**

   Mr. Prasit Chaisil
   Dr. Terd Chareonwatana
   Dr. Pimpun Chermsawadipongse
   Dr. Niphon Chandrapho
   Dr. Kavi Chutikul
   Dr. Keith Fuglie
   Mr. Anan Hiransalee
   Dr. Chakrit Homchandra
   Dr. Narong Hutanuwatr
   Mr. Reangsak Katawetin
   Mr. Taweesak Keawsim
   Mr. Soonthon Kingsangwan
   Dr. Manochai Kiratikasikorn
   Dr. Permpoon Kiratikasikorn
   Dr. Viriya Limpinuntana
   Dr. Vitaya Ma-Sena
   Dr. Charat Mongkolsawat
   Dr. Chaitat Pairintra
   Dr. Santipab Panjapun
   Mrs. Pongsiri Pochpricha
   Mr. Apai Prakorbphol
   Dr. Pakarat Ratakett
   Dr. Suraphol Ratansophol
   Mr. Rojanachai Satarawaha
   Dr. Surasak Seripongse
   Mr. Prarinya Srisawangwongse
   Dr. Amnuaysilp Suksri
   Dr. Ponpimon Suriyajantratong
   Mrs. Bupha To-Pak-ngam
   Mr. Rachit Triputharatana
   Mr. Tepparit Tulapitak
   Mr. Sithisak Upariwongse
   Dr. Nimit Vorasoot
   Dr. Pana Waikakul
   Mrs. Sasudee Wanapat
   Dr. Boonler Wilaipol
   Mrs. Nualchandr Wilaipol

3. **Northeast Regional Office of Agriculture (Tha Pra)**

   Mrs. Ladda Boonpakdee
   Dr. Utai Pisone
   Dr. Vawchak Pongpolprom
   Mr. Chalermchai Prasartsri
   Mrs. Wilai Prasartsri
   Mr. Paiboon Ratanaprateep

4. **Prince of Songkhla University**

   Dr. Yves Crozat
   Mr. Amnuay Sithi-Chareonchai
   Mr. Charnchai Tanavuthi

5. **Department of Forestry**

   Mr. Jesada Leung-Cham

6. **Department of Land Development**

   Mr. Surachart Amornrattanasak
   Dr. Somsri Arunin
   Mr. Surachitr Chaisiri
   Mr. Somsak Chaiyana
   Mr. Amnuay Chumsamut
   Mr. Prachaya Dhanyadee
   Mr. Somrote Kantanikool
   Mr. Pradit Keaw-On
   Mr. Choompol Kolasilp
   Mr. Sutham Paladsongkram
   Mr. Nirat Palasuwan
   Dr. Samarn Panichapong
   Mr. Rungrochana Perngpun
   Mr. Prayong Puengpun
   Mr. Narong Rouysoongnern
   Mrs. Pranee Rungsangchandra
   Mr. Padet Satan
   Miss Suda Sawattanakoon
   Mr. Sarote Singtothong
   Mr. Pisit Sittiwong
   Mr. Terdsak Subhasaram
   Mr. Patana Suk bumrung
   Mr. Boonchoom Ta-in
   Mr. Jira Tasananchalee
   Mr. Wanlert Wanapiyaratana

7. **Agricultural Technology and Vocational College**

   Mr. Viratana Amornchayakit
   Miss Supanong Sriyong
   Mr. Chitdee Toatongchai

8. **Kasetsart University**

   Dr. Soontari Akatanukul
   Dr. Piya Duangpatra
   Dr. Somjate Jantawat
   Dr. Supamard Panitsakpatana
   Dr. Ngam-Cheun Ratanadilok
   Dr. Amnart Suwanarit
   Dr. Rachente Tiraporn

Thailand (Continued)

Dr. Visoot Verasan
Dr. Somsak Wang-nai

9. **Department of Agriculture**

Dr. Samrit Chaiwanakupt
Dr. Chob Kanareugsa
Dr. Tawachai Na Nagara
Mr. Somnoa Phetchawee
Dr. Cherdchati Samitobol
Mr. Chote Sithibutsa
Dr. Chakranopakhun Tongyai

10. **Department of Agricultural Extension**

Mr. Kaladilok Kewprapan
Mr. Vitaya Palayeim
Mr. Niphon Simla
Mr. Songsak Suratikul
Mr. Danai Taipanich

11. **Chiang Mai University**

Dr. Methi Ekasingh
Mr. Sittiporn Sukasem

12. **Member of Parliament**

Mr. Suwit Koonkiti

13. **Northeast Regional Office of Agriculture (Kalasin)**

Mr. Vorawuthi Eiam-somphol
Mr. Samnak Gayapard
Mr. Samer Jullavanich
Mr. Somnuke Sriplung

14. **Royal Irrigation Department**

Mr. Nukul Tongtawee

United States

Dr. Charles Alton
Dr. Jack Bond
Dr. Earl Burnett
Dr. Brent Cluff
Dr. Iain Craig
Dr. H. Eswaran
Dr. James F. Parr
Dr. John Ragland
Dr. B.A. Stewart
Dr. Paul Unger

Sri Lanka

Mr. Abeywardena
Mr. M.S. Banda
Mr. W.M.S. Bowatte
Mr. P.B. Dharmasem
Dr. H. Somapala

Japan

Dr. Sadao Hatta
Dr. Hidetochi Matsuo
Dr. Masanori Mitsuchi
Dr. Masanori Yoshilka

India

Dr. J. Venkateswarlu
Dr. S.M. Virmani