Soil Constraints on Sustainable Plant Production in Thailand

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ABSTRACT

Thailand's agriculture can be characterized by a rainfed traditional production system. More than 80% of the total cultivated land area has been under cropping risk due to drought hazards. Despite continuous cropping for generations, fertilizers and appropriate conservation measures have seldom been used by the farmers. Consequently, there has been a reduction of crop yields due to mineral stress, water stress and erosion hazard. These three major soil constraints and their importance in the agricultural development of Thailand are outlined. Methods of improvement with emphasis placed on low-input technology and sustainable crop production are reviewed.

To obtain a clear picture of the potential for increased production, land use and soils of Thailand are also described.

Introduction

The Kingdom of Thailand which is located in Southeast Asia between approximately latitudes 5° to 21°N and longitudes 97° to 106°E covers about 51.3million hectares of total land area. Thailand is bordered in the West and North by Burma, in the Northeast by Laos, in the Southeast by Cambodia, and in the South by Malaysia. Thailand comprises four geographical regions, i. e. the central plain, the northeastern, the northern and the southern regions, though according to landform, soil, vegetation and climatic conditions, it could be divided into six physiographical regions (Moormann and Rojanasoonthon, 1972) i.e. the Central plain, the Southeast coast, the Northeast plateau, the Central Highlands, the North and West continental highlands, and Peninsular Thailand (Fig. 1).

The climate of Thailand is tropical with two major rainfall distribution patterns, i.e. a monsoon type with distinct rainy and dry seasons affecting the greater part of the country and an equatorial type with an indistinct short to very short dry season in the Southeast coast and in Peninsular Thailand. The general climatic characteristics of the six physiographical regions are summarized in Table 1. Maps indicating the average annual rainfall and mean temperature in Thailand are also presented in Figures 2 and 3. It appears that the annual variations of temperature in Thailand are small throughout the country with somewhat wider variations in the northern region at higher altitudes. The average annual rainfall ranges from 1,100 to 1,500mm. The amounts of rainfall are thus sufficient to support most of the cultivated lands in the country. The southern and southeastern regions show higher amounts of rainfall than others. The variability in the amounts of annual rainfall usually ranges from 20 to 30%, though it can be as high as 40% in abnormal years. Unfortunately, the annual rainfall distribution which is more important for crop production is quite variable, especially in the northeastern and northern regions.

Under the prevailing climatic conditions, Thailand's soils are characterized by three major moisture regimes: the aquic, udic and ustic soil moisture regimes, though more

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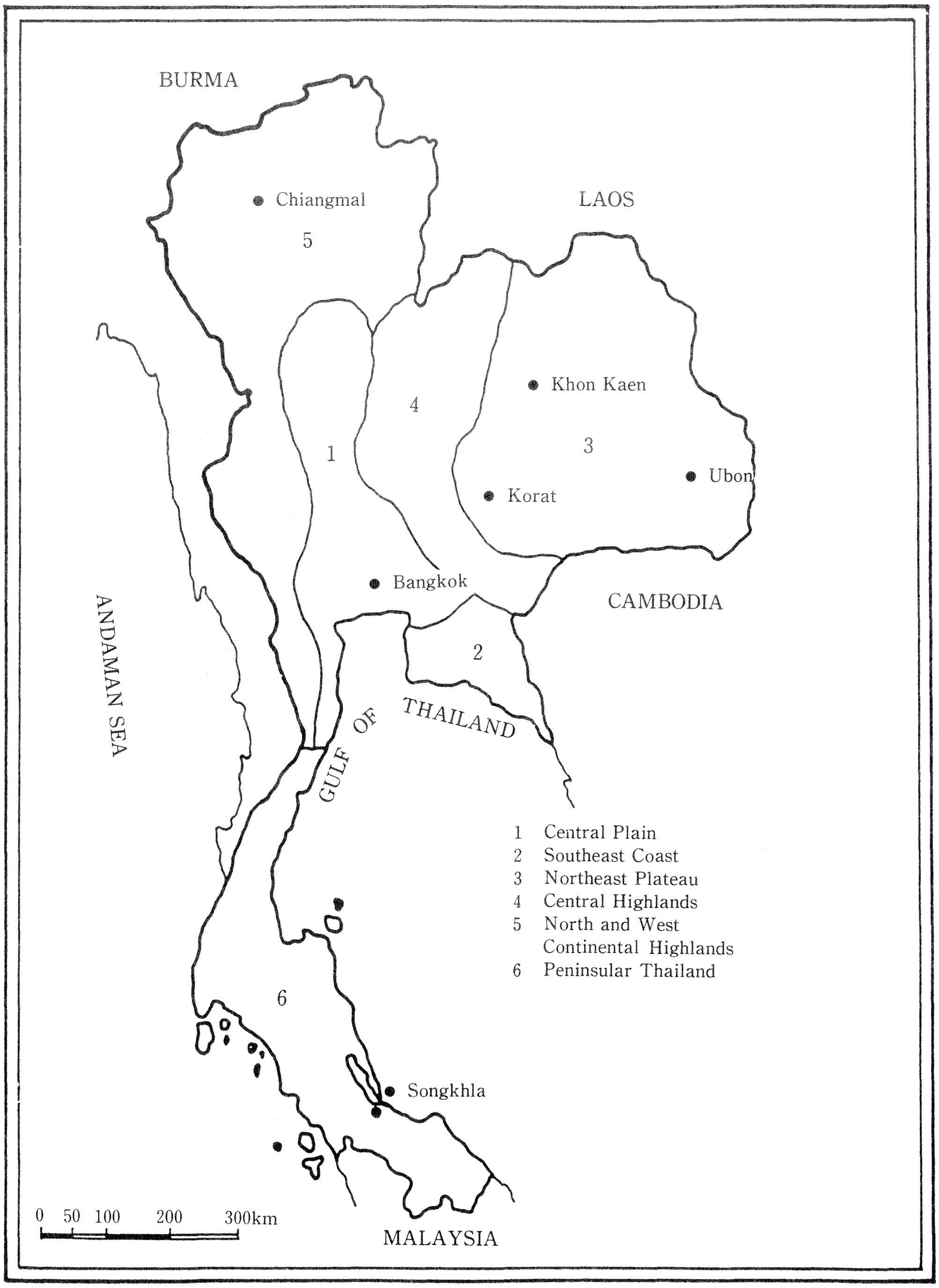

Fig. 1 Physiographical regions of Thailand
(After Moormann and Rojanasoonthon, 1972).

Table 1 Generalized climatic data for the six physiographical regions of Thailand

	Central plain	Southeast coast	Northeast plateau	Central highlands	North and West continental highlands	Peninsular Thailand West coast	Peninsular Thailand East coast
Annual rainfall (mm)	1220-1592	1312-4456	1089-2163	1352	1045-1744	2177-5106	1018-2568
Annual mean humidity (%)	64-74	74-78	68-73	70-73	71-75	77-83	78-82
Annual mean temperature (C)	27-29	27	26.7-27	26-28	24-28	27	27-28
Absolute maximum temperature (C)	39-44	38	42-43	41-43	40-43	35.5	38-39
Absolute minimum temperature (C)	5-12	9	2-4	2-7	2-6	19	14-18

Source: Cited from Moncharoen (1983).

divisions have been proposed by Moncharoen (1983). The aquic soil moisture regime occurs predominantly in the rice-growing areas in the low-lying lands throughout the country. The udic soil moisture regime characterizes the southern peninsula, the Southeast coast, and the North and West continental highlands. The other areas are classified under the ustic soil moisture regime (Fig. 4).

Soils of Thailand as most of tropical soils are highly leached, resulting in low soil fertility or rapid decrease of the amount of plant nutrients after continuous cropping. In addition, the degradation of the soil physical, chemical and biological properties due to misuse and mismanagement of cultivated land can aggravate the situation and decrease the quality of the land resources. Due to the need for increasing food and fiber production to meet the requirements of the growing population and improve farmers' income, land use for crop production has become very critical. To date, since there is no way to obtain new lands suitable for crop production, the lands presently cultivated should be improved. Major soil constraints and their improvement for sustainable crop production in Thailand will be discussed in this report.

Land use

Thailand has for a long time been known as an agricultural country. Presently, more than 60% of its population is engaged in agriculture and agricultural products account for about 50% in value of exported goods. According to the Agricultural Statistics of Thailand shown in Table 2, land use in Thailand can be divided into three main categories: farm-holding land, forest land and unclassified land which account for 40.5, 28.6 and 30.9% of the country's total land area, respectively. The unclassified land covers swamp land, sanitary district area, municipal area, railroads, highways, real estate, public area, etc. The farm-holding land includes cropland area, idle land, grassland, farmhouse area and miscellaneous land. Total cropland in Thailand including land areas for rice, field crops, fruit trees, tree crops, vegetables and flowers, covers 19,322,000ha which account for 37.7% of the total land area.

Changes in land use since 1976 which corresponded to the end of the 3rd National Economic and Social Development Plan (1972-1976) indicated a rapid rate of forest clearing for crop cultivation and other uses. During the period of 1976 to 1987, the reserved forests of the whole country had been depleted by 5,176,000ha, corresponding to about 26% of the

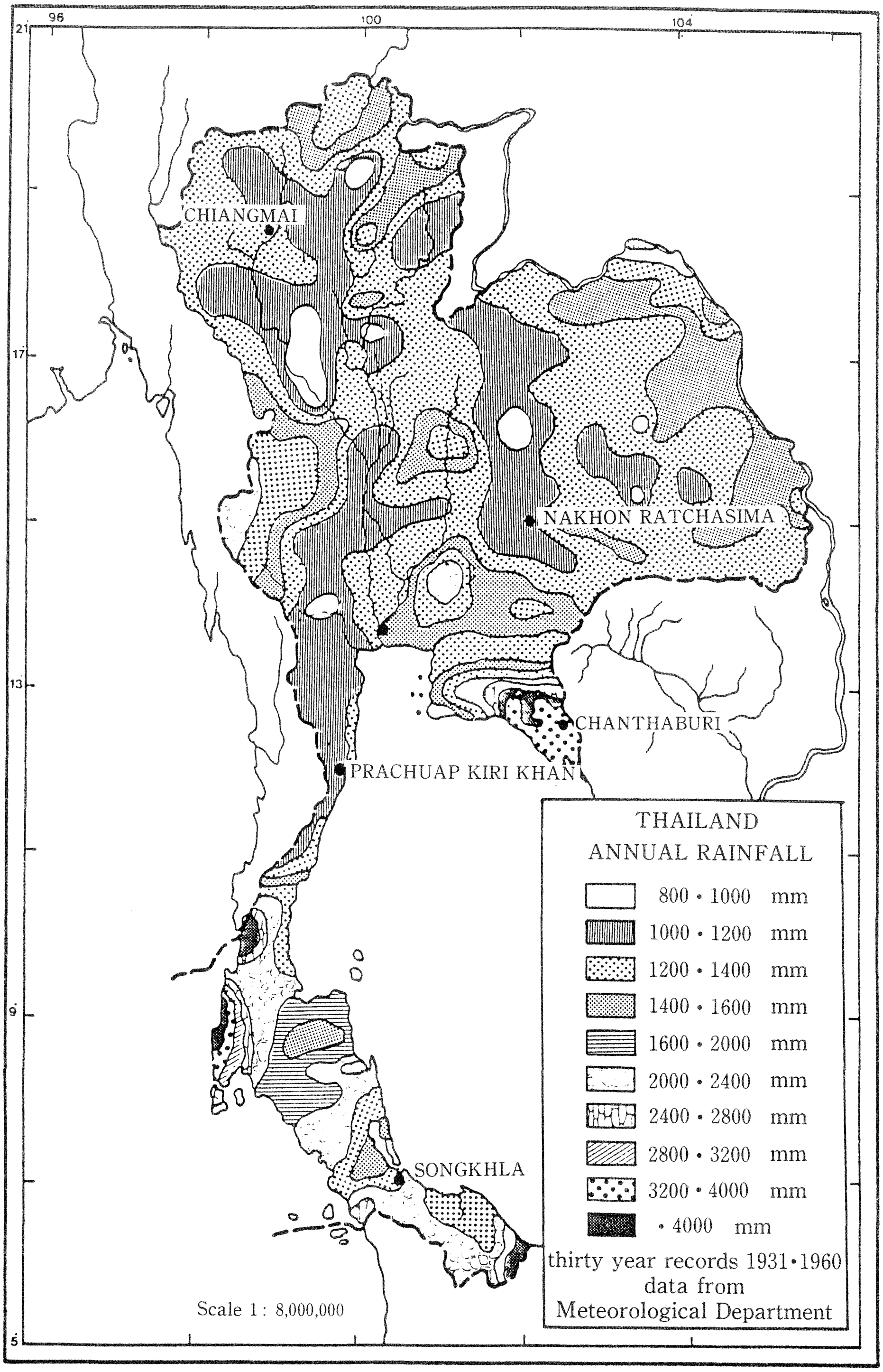

Fig. 2 Isohyetal map of Thailand
(After Royal Thai Survey Division, 1969).

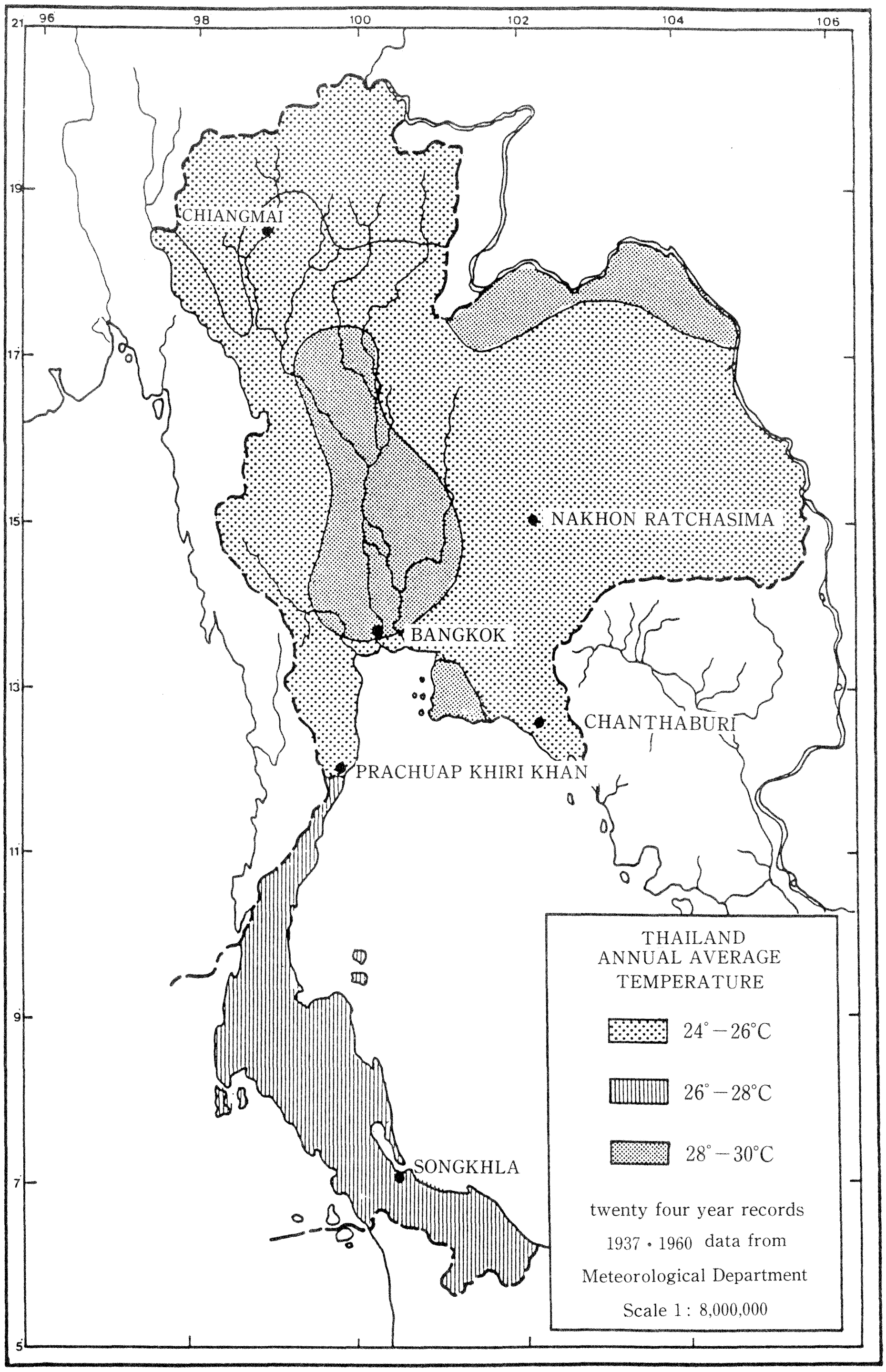

Fig. 3 Mean annual temperature of Thailand
(After Royal Thai Survey Division, 1969).

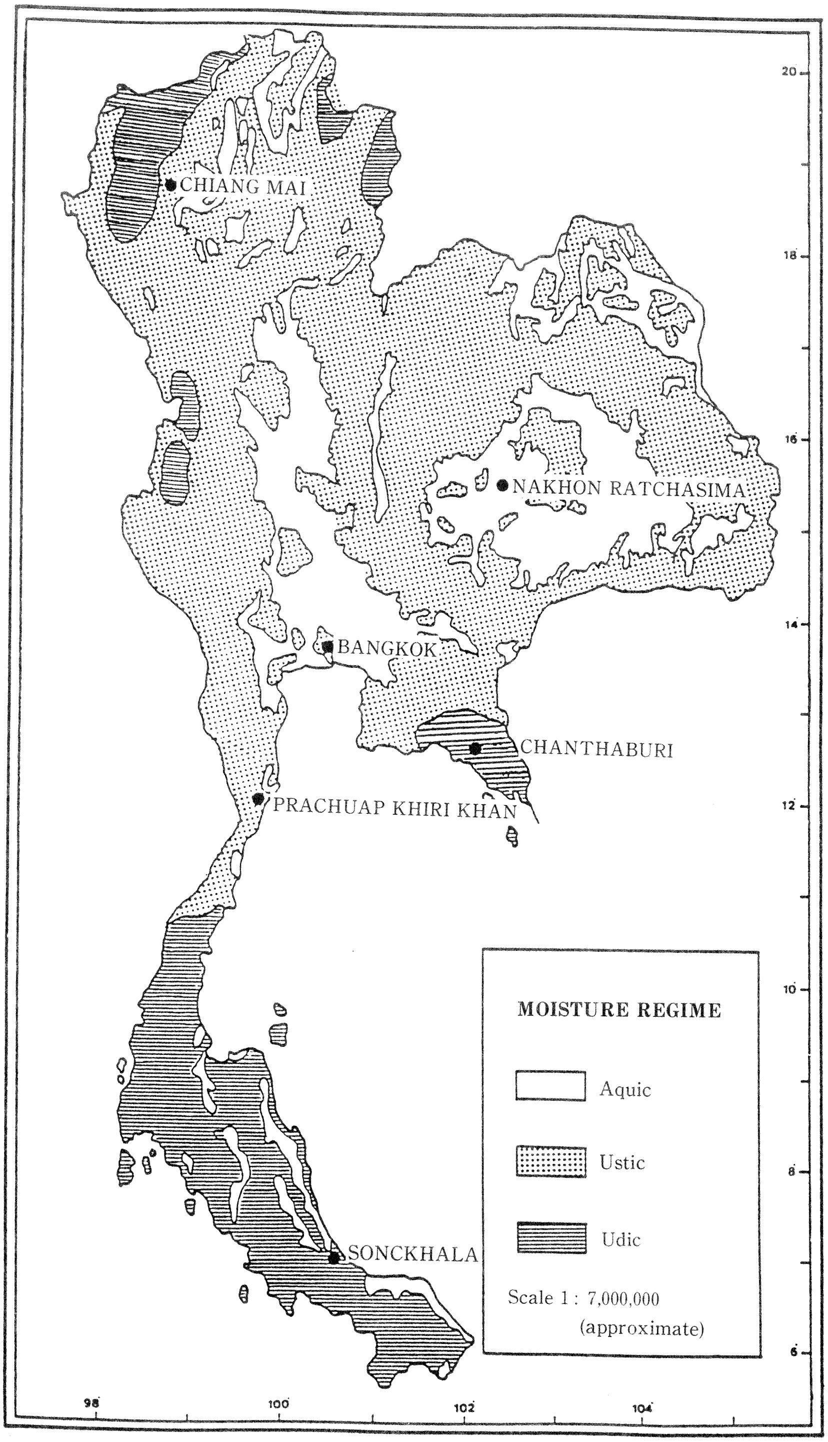

Fig. 4 Inferred soil moisture regime of Thailand
(After Department of Land Development, 1978).

Table 2 Land use in Thailand and its change during 1976 and 1986

Land use	Region, 1986 (thousand ha)				Whole kingdom, 1986		Change, 1976-1986	
	North-eastern	Northern	Central plain	Southern	thousand ha	%	thousand ha	%
Farm-holding land	8,992	4,640	4,698	2,445	20,775	40.5	+2,677	+ 14.8
Cropland	8,256	4,408	4,414	2,244	19,322	37.7	+2,790	+ 16.9
Rice	5,992	2,709	2,399	778	11,878	23.2	+ 467	+ 4.1
Field crops	2,086	1,498	1,523	24	5,131	10.0	+1,713	+ 50.1
Fruit trees and tree crops	152	180	459	1,436	2,227	4.3	+ 581	+ 35.3
Vegetables and flowers	26	21	33	6	86	0.2	+ 29	+ 50.9
Idle land	347	69	79	73	568	1.1	− 88	− 13.4
Grassland	85	13	31	16	145	0.3	+ 79	+119.7
Farmhouse area	179	123	121	68	491	0.9	+ 56	+ 12.9
Miscellaneous land	125	27	53	44	249	0.5	− 160	− 39.1
Forest land	2,370	8,296	2,481	1,518	14,665	28.6	−5,176	− 26.1
Unclassified land	5,524	4,028	3,211	3,108	15,871	30.9	+2,499	+ 15.7
Total area	16,886	16,964	10,390	7,071	51,311	100	0	

Source: The Agricultural Statistics of Thailand, Office of Agricultural Economics (1977 and 1987).

total forest land area in 1976 (Table 2), of which 1,779,000, 1,937,000, 964,000 and 496,000ha had been located in the northeastern, northern, central plain and southern regions, respectively. These figures account for the depletion of 43% for the northeastern region, 19% for the northern region, 28% for the central plain and 25% for the southern region. The large reduction in forest land area in the northern region is due in part to shifting cultivation. Since, most of the soils under these newly opened lands are either too shallow or too steep for cultivation, they have been abandoned and converted to unclassified land. Considerable areas are now under cogongrass (*Imperata cylindrica*) mixed with other grass and bamboo species which hamper the reestablishment of the forest. Fortunately, the remaining forest lands have strictly been under reservation by law since 1989, and a reforestation program is also underway. Thus, it appears that the increase of crop production through the expansion of the cropland area is impossible even though reports in recent years have indicated that the area suitable for crop cultivation amounted to 52.4-66.3% (Panichapong, 1982 ; Panichapong and Hemsrichart, 1983).

Total area for rice fluctuates from year to year, showing an increasing trend during the preceding decade. The total area accounted for 61% of the total cropland area in 1986 or 23. 2% of the country's total land area. Distribution of the rice area among the geographical regions in 1986 indicated that about 50% of the total rice-growing area was located in the northeastern region, whereas the northern, central plain and southern regions accounted for 23, 20 and 7% of the country's total rice land area, respectively. During the ten-year period from 1976 to 1986, the cultivated land area for rice increased by 467,000ha or by about 4% of the total cultivated area for rice in 1976. Total production of rice during the same period also increased considerably from 15.1 million tons in 1976 to 18.9 million tons in 1986 (Table 3). The upward trend is primarily due to the enlargement of the planted rice area. However, the average yield of rice per unit area has also gradually increased since the beginning of the 1st National Economic and Social Development Plan (1962-1966) due to the introduction of high-yielding varieties, increasing application of chemical fertilizers and implementation of pest control. Among these factors, varietal improvement seems to be the major contributor to yield improvement. Nevertheless, the national rice yield average is still low when compared with other rice-producing countries and was 2.05 tons per ha in 1986. Among all the geographical regions, the northeastern region recorded the lowest rice yield. Low rice yield may be ascribed to various factors, such as variability of climatic conditions, water supply resources, fertilizer application techniques, cultivation practices, variety use, soil fertility

Table 3 Actual planted area, production and average yield of rice and major field crops of Thailand in 1976, 1981 and 1986

Crop	Planted area (thousand ha)			Production (thousand tons)			Average yield (t/ha)		
	1976	1981	1986	1976	1981	1986	1976	1981	1986
Rice	8,575	9,595	9,851	15,068	17,774	18,868	1.76	1.95	2.05
Maize	1,285	1,567	1,951	2,675	3,449	4,309	2.08	2.36	2.38
Cassava	692	1,270	1,240	10,230	17,744	15,255	14.78	14.28	12.66
Surgarcane	499	617	539	26,094	30,200	24,450	52.29	49.24	47.01
Sorghum	143	280	194	148	274	211	1.04	1.03	1.15
Mungbean	223	486	508	125	284	301	0.56	0.62	0.61
Soybean	102	128	288	114	132	356	1.12	1.05	1.26
Groundnut	122	122	126	152	147	169	1.24	1.25	1.36
Cotton	25	155	50	27	176	57	1.09	1.16	1.18
Kenaf	164	187	205	186	194	266	1.14	1.09	1.12

Source: The Agricultural Statistics of Thailand, Office of Agricultural Economics (1977, 1982 and 1987).

management, etc. (Cholitkul and Sangtong, 1988).

Land use for crops other than rice which accounts for 7,444,000ha or about 39% of the total cropland area can be classified into land for the cultivation of annual field crops, 5,131, 000ha (69%), fruit trees and tree crops, 2,227,000ha (30%), and vegetables and flowers, 86, 000ha (1%). Permanent tree crop plantations which account for 4.3% of the national land area are mainly found in the southern region where rubber, coconut, oil palm and fruit trees account for 64% of the total planted area. A similar land use pattern is also observed in the physiographical region of the Southeast coast which is included in the central plain region of the Agricultural Statistics and/or geographical regions.

The increase in the acreage of field crops has been remarkable in recent years, namely 10% of the total land area of the country in 1986. For instance, the acreage increased by 1, 713,000ha in the ten-year period from 1976 to 1986, that is, the acreage of field crops in 1986 was greater than that in 1976 by about 50%. This increase was observed in the northeastern, northern and central plain regions corresponding to 45, 31 and 23% of the total increase for the same period of time, respectively. The southern region is of minor importance in this respect. The major field crops of Thailand include maize, cassava, sugarcane, sorghum, mungbean, soybean, groundnut, cotton and kenaf, among which the acreage of the first three accounted for 73% of the total field crop land area in 1986 (Table 3). Table 3 indicates that the acreage of maize, cassava, mungbean, soybean and cotton increased remarkably in the preceding ten years. If we take the acreages in 1976 as 100, the acreages of maize, cassava, mungbean, soybean and cotton in 1986 were 152, 179, 228, 282 and 200, respectively. These figures are the so-called acreage index numbers in the Agricultural Statistics of Thailand. Meanwhile, the acreage of other field crops tended to increase slightly or remain constant during the same period of time. Table 3 also shows that the total production of major field crops during the past decade increased considerably, especially in the case of maize, cassava, mungbean, soybean and cotton. The corresponding production index numbers for these crops in 1986 when taken in 1976 as 100 were 161, 149, 241, 312 and 211, respectively. The average yield per unit area of most major field crops, on the other hand,remained essentially constant with the exception of cassava and sugarcane which showed a reduction in yield in that period. These figures, clearly show that the expansion of the cropland area was the main reason for the increased production of the field crops during the past decade. The increase in the proportion of cropland area for vegetables and flowers which is also remarkable due to the increase in the local consumption, is negligible area-wise.

Soils of Thailand

According to the soil survey and classification of the Land Development Department (1980), Thailand's soils can be classified into nine soil orders which account for 70.1% of the total area of the whole Kingdom, whereas the rest of the area is occupied by slope complexes (29.2%) and water bodies (0.7%). The soil orders found in Thailand are Ultisols, Inceptisols, Alfisols, Entisols, Mollisols, Vertisols, Spodosols, Oxisols and Histosols. The area of the first six covers almost 70% of the national total area, of which some 47% of the total is dominated by Ultisols. Inceptisols, Alfisols, Entisols, Mollisols and Vertisols occupy about 9, 9, 3, 1 and 1% of the total, respectively. Less important in terms of the extent they cover are Spodosols, Oxisols and Histosols, all of which contribute for less than 1% to the total area of the country. Distribution of these soils from the generalized soil map is briefly outlined as follows:

Ultisols occur in a significant proportion in the northeastern plateau, the Southeast coast and the northern part of central highlands. Smaller areas of Ultisols are scattered in the northern and western continental highlands and Peninsular Thailand.

Inceptisols occupy the southern half of the central plain and land strips along the Chi and Mun rivers and their tributaries in the Northeast plateau.

Alfisols cover most of the northern and western parts of the central plain. They are also found in small areas in the northern continental highlands.

Entisols predominate along the coastal areas, in large patches in the Northeast plateau and in small areas to the West of the central plain.

Mollisols as well as Vertisols which developed mainly on dissected erosion surfaces are found in the central part of the central highlands. Mollisols also occur, but only to a limited extent, in the southwestern part of the central plain.

Spodosols occupy a small area. The most extensive area of Spodosols is found in the southern part of Peninsular Thailand. They also occur on the beach and sand dunes along the gulf of Thailand.

Oxisols occur only on the small area associated with basalts.

Histosols or organic soils which also occur only on a limited area of the Kingdom are commonly found in the depression among dunes in the southeastern part of Peninsular Thailand.

1 Paddy soils

Most of the submerged rice in Thailand is grown on Ultisols, Inceptisols and Alfisols. To a smaller extent some other soil groups such as Entisols and Mollisols are also used for rice cultivation (Table 4). The paddy soils account for approximately 102,434km^2 (10,243,400ha) or 20% of the total area of the country. Region-wise about 49% of the paddy soils is located in the northeastern, 27% in the central plain, 15% in the northern and 9% in the southern regions. Among the major paddy soils, Ultisols which are less fertile than Inceptisols and Alfisols account for 52% of the total paddy soils. Ultisols appear to be the dominant lowland soils of the northeastern region. Inceptisols which are second only to Ultisols in terms of the extent they cover occupy 37% of the total, and are the major paddy soils of the central plain. Alfisols account for about 9% of the total and occur most extensively in the northern region. Entisols are found only in the southern region whereas Mollisols are only found in the central plain, each of which accounts for approximately 1% of the total paddy soils in Thailand. Verapattananirund (1986) reported that 58% of the paddy soils found in Thailand was clayey in texture, 41% was loamy, and 1% consisted of sandy and skeleton soils. The clayey-textured soils predominated in the central plain and the northern region, whereas the loamy

Table 4 Distribution of lowland and upland soils by order in Thailand in different geographical regions (km²)

Soil	North-eastern	Northern	Central plain	Southern	Whole kingdom
Entisols					8,826
Lowland	0	0	0	1,064	1,064
Upland	4,880	187	1,377	1,318	7,762
Inceptisols					47,204
Lowland	10,689	5,564	18,661	3,045	37,959
Upland	3,546	3,139	1,735	825	9,245
Mollisols					5,902
Lowland	0	0	878	0	878
Upland	271	2,222	2,531	0	5,024
Alfisols					33,882
Lowland	1,837	3,885	2,968	362	9,052
Upland	5,083	11,539	8,208	0	24,830
Ultisols					237,963
Lowland	37,752	5,714	5,185	4,830	53,481
Upland	92,632	33,944	27,825	30,081	184,482
Vertisols					4,126
Lowland	0	0	0	0	0
Upland	371	407	3,348	0	4,126
Spodosols					592
Lowland	0	0	0	0	0
Upland	0	0	76	516	592
Oxisols					144
Lowland	0	0	0	0	0
Upland	0	0	144	0	144
Total	157,061	66,601	72,936	42,041	338,639
Lowland	50,278	15,163	27,692	9,301	102,434
Upland	160,783	51,438	45,244	32,740	236,205
Slope complexes	17,882	85,297	20,394	25,584	149,157

Source: Cited from Verapattananirund (1986).

soils were found mainly in the northeastern region.

The morphological characteristics and fertility status of paddy soils in Thailand had been summarized and discussed by Cholitkul and Sangtong (1988) in their country report on paddy soil fertility and fertilizer use in Thailand. More detailed information about the paddy soils of Thailand had been reported elsewhere (Kawaguchi and Kyuma, 1969; Takahashi *et al.*, 1979; Moncharoen, 1979 and Motomura *et al.*, 1984).

2 Upland soils

In Thailand all the soils except Histosols are used for upland crop production. Upland soils cover approximately 236, 205km^2 (23,620,500ha) or 46% of the total area of the country. Upland soils are widely distributed all over the country. The northeastern, northern, central plain and southern regions account for 45, 22, 19 and 14% of the total upland soils, respectively (Table 4). Also, the extent and distribution of each soil vary among the regions. For instance, Ultisols which are the most extensive upland soils of the country as well as of the northeastern region account for 78% of the country's upland soils, while Alfisols which are the second most extensive ones cover only 10%. Other soils which are utilized for upland crop production are Inceptisols (4%), Entisols (3%) and Mollisols (2%). The remainder which accounts for about 1% of the total consists of Spodosols and Oxisols. Ultisols which are the major upland soils of Thailand occupy 87% of the upland soils found in the northeastern region. They also account for about 66, 62 and 92% of the upland soils in the northern, central plain and southern regions, respectively.

In terms of particle-size classes, it appears that the upland soils of Thailand which are predominantly loamy in texture, account for about 51% of the total. Skeleton soils, clayey soils and sandy soils account for 33, 12 and 4% of the total land area covered with upland soils in the Kingdom (Verapattananirund, 1986). Additional information on upland soils of Thailand had been published by several investigators (Ogawa *et al.*, 1975 ; Kubota *et al.*, 1979 ; Vicharnsorn, 1979 and Verapattananirund, 1986). Main constraints and improvements of these soils will be outlined and discussed later.

Soil constraints

The terms "soil constraints" are very broad since they may involve both the direct and indirect characteristics of the soils which exert a detrimental effect on crop yield under cultivation. Panichapong (1982) classified problem soils which are the cause of direct constraints in Thailand into seven categories, namely saline and sodic soils, acid sulphate soils, sandy soils, organic soils, skeleton soils, Vertisols and Ground Water Podzols. However, in general the problem soils are not utilized extensively for agriculture, because they require special management practices for improvement and, usually suitable practices are uneconomical. Fortunately, these soils cover only 108,846km^2 (Panichapong, 1982). From the viewpoint of low-input and sustainable crop production, these problem soils will not be included in the discussion, since their distribution, characteristics and utilization had already been reported in detail by Panichapong (1982). Methods of improvement of some of these soils had also been discussed in recent years by Prabuddham (1982), Arunin (1984) and Chaturongakul (1984).

The indirect soil constraints and/or soil-related constraints which are normally associated with some particular soil characteristics are more important, because these indirect limiting factors have had a great impact on the agricultural development in Thailand. As already discussed in detail, the soil-related constraints of tropical soils (IRRI, 1980), involve mineral stress, water stress, waterlogging, acidity, salinity, crust formation, compaction, erosion, etc. However, the most critical constraints which hamper crop production in Thailand are mineral stress, water stress and erosion hazard. Mineral stress alone which is usually associated with acidity was estimated to account for 59% of the total land area of Southeast Asia (Dent, 1980). Only 14% of the soils did not show serious limitations and 2% showed drought hazards.

For a stable agricultural system as proposed by Greenland (1975), it is necessary that nutrients removed by crops be replenished into the soil, that good tilth and suitable level of soil humus content be maintained and that soil erosion be controlled. However, under the present land use in Thailand, these conditions are not satisfied. In the light of the present knowledge, under the current land use, most of the cultivated soils have been misused or mismanaged. For instance, rice straw is simply burned off after harvesting, thus accelerating the depletion of organic matter and nitrogen. The use of green manure or legumes as a sequence in crop rotation is almost non existent. Contour ploughing is seldom practiced whereas up and down slope ploughing is instead a common practice. Despite continuous cropping for many generations, fertilizers and conservation measures have seldom been applied by the farmers. Besides, most of the cultivated soils in Thailand are characterized by a low inherent fertility due to prolonged pedogenesis and/or strong weathering under the humid tropical climate. Clay minerals are predominantly low-activity clays of the 1 : 1 types resulting in low CEC which is the case for Ultisols and Alfisols. These soils which have coarse-textured surface layers and a low organic matter content tend to form a surface crust which limits the penetration of water into the soil and, thus accelerates runoff and erosion hazards. Consequently, there has been a considerable reduction of crop yield due to mineral stress, erosion and inappropriate management practices. The deterioration increased rapidly year after year unless proper control measures were taken.

Among all the limitations affecting the stability of crop production systems in Thailand, water is also one of the major limiting factors due to the unfavourable rainfall distribution, topography and soil itself. Thailand's agriculture mainly depends on rainfall, because only 20% of the total cultivated land area is irrigated. The risk of crop failure due to frequent drought hazards plays a key role in the reluctance of the farmers to adopt modern technology in addition to the poverty of the farmers themselves. Although, irrigation is the best remedy to solve this problem at present it is difficult to irrigate all the cultivated lands. Therefore, any soil water management practice in rainfed farming that promotes efficient use of soil water is worth considering. In fact, soil water management implies not only the improvement of the soil water economy for achieving higher yield but also protection measures against soil deterioration which are essential for stabilizing agriculture (Kubota *et al.*, 1982).

Relevant research

With a low inherent soil fertility, Chaiwanakupt and Tongyai (1982) reported that the traditional bush fallow rotational system which has been practiced by the Thai farmers was a fairly stable system as long as the fallow period following cultivation was sufficient for soil fertility to be restored. This was also recognized by Kyuma (1984) for swidden or shifting cultivation which has been widely practiced throughout the tropics. However, since shifting cultivation is advantageous only under a short cropping-long fallow system, it is unsuitable for increasing production.

Continuous monocropping of major field crops either with negligible or minimal recycling of plant nutrients into the soil accelerates the decrease of soil fertility. Table 5 indicated that

Table 5 Nutrient removal by crops and its replenishment by chemical fertilizers

Crop	Yield t/ha	Nutrient removal	Nutrient replenishment
		kg($N+P_2O_5+K_2O$)/ha	
Maize	1.9	113	1
Sugarcane	42.5	213	200
Cassava	12.0	174	13
Soybean	0.9	166	2
Kenaf	1.0	102	12
Cotton	1.2	89	1

Source : Cited from Chaiwanakupt (1986).

the amount of nutrients removed by the major upland crops except for sugarcane was far greater than the amount returned to the soil by fertilizers (Chaiwanakupt, 1986). A similar difference between nutrient removal and replenishment is also expected for rice. Cholitkul and Sangtong (1988) indicated that only 2.3kg per ha fertilizer was applied on the average for rice and that the northeastern region recorded the lowest rate of usage. Nutrient loss through runoff and erosion due to improper management practices was also reported to be another major factor contributing to the rapid decline of soil fertility. Monocropping of cassava on a 5-9% slope in undulating terrain in a relatively dry southeastern province resulted in a soil loss of more than 6 million tons per ha per year (Chaiwanakupt, 1986). Crop response to added fertilizers, showed that nitrogen and phosphorus were the key problem elements in most soils while the response to potassium was rarely observed. Also, secondary and trace element deficiencies were neither significant nor severe enough to adopt corrective measures that would be profitable in upland soils. In paddy soils however, potassium should be added into the soils, particularly the loamy or sandy-textured soils in northeastern Thailand due to their pedogenesis (personal communication with Dr. Chob Kanareugsa, Deputy Director of Soil Science Division, Department of Agriculture). In an attempt to improve paddy yield, research has been carried out extensively in the field of soil fertility and fertilizer usage in addition to varietal improvement, as reported recently by Takahashi *et al.* (1979) and Cholitkul and Sangtong (1988). Unfortunately, limited information in other fields of research has been reported for lowland rice. Fertilization and management of upland soils for field crop production in Thailand had recently been subject to detailed discussions by Chaiwanakupt and Tongyai (1982) and Chaiwanakupt (1986).

Mineral fertilizer use plays an important role in the increase of crop yield. Fertilizer consumption for agriculture in Thailand is one of the lowest among Asia's countries. Fertilizer use in this respect has reached 2 million tons in recent years, out of which 60% was used for rice and the remainder for crops other than rice, especially field crops. Results from fertilizer trials conducted in farmer's fields with different soils and crops under the FAO fertilizer program demonstrated that fertilizer application may enable to increase crop yield up to 100% with an acceptable profit. However, the small subsistence-type farmers in rainfed agriculture still face serious constraints on fertilizer use due to the high fertilizer/crop price ratios, lack of credits, inadequate extension program in fertilizer education for farmers, coupled with cropping risks due to erratic rainfall distribution and drought hazards. Thus, the value of organic fertilizers should be reassessed for supplementary use, especially *in situ* organic recycling and biological nitrogen fixation. The beneficial effects of organic matter application had already been pointed out by Greenland and Dart (1972).

Soil erosion situation in Thailand which had recently been reviewed by Anecksamphant in 1984 (also see Table 6) showed that under the prevailing land use in Thailand, the potential for soil erosion hazard was extremely high due mainly to the monsoon rainfall with a high erosive power and misuse and mismanagement of the lands. However, this problem could be alleviated through crop management practices, such as surface mulching and no-tillage practices. These soil conservation managements together with soil erosion control measures wherever required could delay the decrease in productivity from existing cropland and prevent further degradation of soil productivity. Though terracing and contour bunding with graded furrows are efficient mechanical methods for the prevention of soil erosion, they require high initial capital input and regular maintenance. If the system collapsed either due to poor construction or inadequate maintenance, soil erosion hazard could be even more serious than without the system at all (Chaiwanakupt, 1986). Against this background, contour strip cropping should not be overlooked as an alternative. It was estimated that the rate of erosion in the northern region was about 100-940ton soil per km^2 per year, in the northeastern region about 127-700tons per km^2 per year, and in the central plain region about 125-600tons per km^2 per year. Thus, it can be expected that the longer the erosion continues

Table 6 Soil erosion situation in Thailand by geographical region

Region	Erosion hazard			Total	
	Moderate	Severe	Very severe		
	thousand ha			thousand ha	%
Northeastern	1,174	2,037	3,660	6,871	41*
Northern	824	2,877	983	4,684	28*
Central plain	489	2,004	1,376	3,869	37*
Southern	1,769	76	61	1,906	27*
Total	4,256	6,994	6,080	17,330	34**

Source : Cited from Anecksamphant (1984).
* Percentage of total regional area.
** Percentage of total country's area.

the poorer the quality of the land will become.

As discussed previously, there are many problems other than soil constraints involved in the development of Thailand's agriculture. Modern technologies are most of the time inapplicable for a small farmer who has only about 4.5ha of farmland on the average to cultivate and also has economic problems. The provision of appropriate low-cost technology under sustained basis is therefore essential for the nation's future well-being.

1 No-tillage system

The no-tillage and/or minimum tillage practices have recently been introduced to Thailand's agriculture due to their advantages, such as conservation of soil water, alleviation of detrimental yield effects due to the occurrence of short-term dry spells, erosion control, control of soil surface compaction associated with raindrop action and saving of time and labor for seedbed preparation. The long-term no-tillage system for corn has been implemented for clayey soils since 1984. The results indicated that the yield of corn grown under the no-tillage system was usually equal to or higher than that achieved by conventional tillage (Na Nagara *et al.*, 1986). The superiority of the no-tillage system was due to the effective control of soil water loss through evaporation, particularly at the early stage of plant growth. The intake of rain water by the soil was also improved by this cultural practice. This soil water conservation method thus could alleviate the damaging effect of short-term dry spells which often occur in rainfed agricultural areas in Thailand. However, if dry spells continue for a long time, the no-tillage system loses its advantages. High infiltration rate and favorable soil structure due to killed sod mulch under the no-tillage system could also minimize runoff and erosion hazards (Kubota *et al.*, 1979). The no-tillage system for soybean, kenaf, cassava was also investigated and similar results were obtained. In lowland soils, rice direct seeding culture under no-tillage and rice transplanting under common conventional tillage have recently been adopted in farmer's fields of northeastern Thailand. Soils at the experimental sites have a sandy-textured surface soil and loamy-textured subsoil. The results indicated that rice yield under the no-tillage system was considerably higher than under conventional tillage (Table 7). This difference in yield between both cultural practices was more pronounced when the fertilizer rate, especially nitrogen increased. This fact suggested that the no-tillage system required a fertile soil, otherwise a high rate of fertilizer, particularly nitrogen should be applied due to excessive leaching. However, as far as erosion control is concerned, this technique in addition to contour strip cropping is more suitable for a small farmer than the mechanical methods which require large input and adequate maintenance.

Table 7 Rice yield as affected by tillage management and fertilizer usage in farmer's fields at Sri Saket and Roi-et provinces of northeastern Thailand in 1986 (kg/ha)

$N-P_2O5-K_2O$	Sri Saket		Roi-et	
	Conventional tillage	No-tillage	Conventional tillage	No-tillage
0-0-0	1,600	—	1,544	1,400
0-6-6	1,850	2,163	—	—
4-6-6	2,969	3,131	—	—
8-6-6	2,450	4,331	1,956	2,744
16-6-6	3,125	4,150	—	—
Mean	2,599*	3,444	1,750	2,072

Source : Na Nagara *et al.* (unpublished).
*Mean of the last four excluding 0-0-0.

2 Mulch farming

Mulch farming for dry season crops in irrigated lowlands has been successfully developed for crop cultivation in the northern part of Thailand. Rice straw is the main source of mulching material. However, this technique cannot be applied for the main season crops due to the rapid decomposition of the crop residues unless a pre-season crop is grown. In addition, this practice which is laborious and time-consuming is limited. Extensive studies on this subject were carried out during the past decade (Kubota *et al.*, 1979 ; Ueno *et al.*, 1983 ; Inoue *et al.*, 1984 ; Uehara *et al.*, 1985 and Nakaya *et al.*, 1986). It is concluded that for mulch farming, mulching materials behave like a killed sod mulch in the no-tillage system for soil water conservation, but are less effective for erosion control than the no-tillage system, particularly for sloping land, due to the surface soil disturbance in mulch farming.

3 Organic matter recycling

Although, the recycling of organic matter has been practiced for centuries, only recently has basic information been collected. The effects of recycled organic materials on the soil physical properties were studied and reported by Nakaya *et al.* (1986). Na Nagara and Thawonmas (1988) had reviewed the process of organic matter recycling in Thailand and concluded that for sustainable crop production at low cost, *in situ* organic matter recycling, particularly the application of green manure is the best solution although farmers' acceptance is required. Under the FAO soil management program, a three-year experiment (1987-1989) which had been carried out by Na Nagara *et al.* (unpublished) indicated that a green manuring crop (*Sesbania speciosa*) could be used as a mulching material at the time of planting of maize crop under the no-tillage system instead of incorporation into the soil. This technique could effectively reduce the decomposition rate of the green manuring crop and weed infestation resulting in higher yield of maize when compared with other methods used in the experiment. In the same experiment, rotation of maize with a legume crop (soybean) also resulted in a considerable yield increase for maize because the system involved biological nitrogen fixation and, thus was another type of low-input technology for sustained crop production.

4 Living mulch

Under the present "clean weedless cultivation" system for cassava, it appears that annual soil loss with runoff water is large compared with that for other field crops. Intercropping which provides an opportunity to grow more than one crop within the same field at the same time is thus practiced to alleviate this problem. A long-term experiment has been conducted in a Warin soil, a low fertile soil of the northeastern region since 1986 (Verapattananirund *et* *al.,* 1988). *Stylosanthes hamata* (cv. Verano), a valuable pasture legume which is well-adapted to the northeastern region was used as intercrop. The experiment consisted of four management systems: 1) conventional plough and harrow system with three weedings (S1), 2) no-tillage system with one post-emergence herbicide prior to cassava planting and two weedings (S2), 3) no-tillage with Verano as a living mulch (S3), and 4) no-tillage with Verano as a living mulch and four cuttings of Verano at a height of 7-10cm above the ground surface during the growing season (S4). In practice, Verano needs to be planted only once in the first year, since it will be self-reestablished in the following years. Cassava was grown at a density of 10,000 plants per ha in the middle of the rainy season and harvested at the age of 11 months. The S1 and S2 treatments were planted at 1×1m spacing, while the S3 and S4 at 2×0.5m.

The results showed that the highest root yield of cassava which was 23.2tons per ha was obtained under the S4 treatment, while the S3 treatment recorded the lowest yield of only 14.1tons per ha. If we take the S1 treatment which is commonly practiced in farmers' fields as 100, root yields of the S2, S3 and S4 treatments were 121, 85 and 140, respectively (Table 8). The decrease in root yield under the S3 treatment was attributed to the competition between Verano and cassava for water and nutrients. On the other hand, in the S4 treatment, crop competition for water and nutrients was kept at its minimum by frequent cuttings of Verano. Also, the above-ground biomass of Verano in each cutting became a slow-release fertilizer source for the cassava crop which is the most effective source of fertilizer under the highly leached sandy soils of northeastern Thailand. If this practice is adopted, the current method of fertilization must be revised, since less fertilizer especially nitrogen is needed. Therefore, besides other advantages, this practice could reduce farm inputs, such as fertilizer, land preparation and weed control.

Table 8 Cassava production as affected by soil and crop management practices

Management practices	Fresh root t/ha	Production index
Conventional tillage (S1)	16.6	100
No-tillage (S2)	20.1	121
No-tillage/Verano intercrop (S3)	14.1	85
No-tillage/Verano intercrop/ 4 cuttings of Verano (S4)	23.2	140

Source: Verapattananirund *et al.* (1988).

Conclusions

There are many soil constraints on agricultural development in Thailand. The three major constraints are mineral stress, water stress and erosion hazard. These constraints are usually interrelated due to common causes, namely adverse climatic conditions and improper management of the land.

1 Mineral stress alone can usually be corrected by fertilization. However this method does not seem to be applicable under the Thailand conditions due to the socio-economic problems of the farmers and cropping risks under rainfed agriculture.

2 Water stress could also be corrected by supplemental irrigation. However since this practice is not applicable in Thailand, it is essential to maximize the use of rainwater and minimize the soil water loss through soil and water management. Varietal improvement for these adverse soil conditions is also an alternative.

3 Erosion hazard can often be corrected by terracing and contour bunding, but these mechanical methods require large capital input and adequate maintenance.

It is difficult to sustain crop production under such soil constraints when low inputs are used, especially mineral fertilizer. However, as far as low-input technology is concerned the following strategies, most of which can often be applied for more than one constraints are worth considering :

1) minimum tillage and/or no-tillage,
2) mulch farming,
3) organic matter recycling,
4) living mulch with leguminous species and proper management of the mulching crop,
5) crop rotation with leguminous species in the sequence,
6) contour strip cropping, and
7) combination of the above.

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Discussion

Woldeab Asnakew (Ethiopia) : To solve the problem of moisture stress, are your mulching data related to a short-term removal of moisture stress from one rain to the other or could this practice be effective over a long period of time?

Answer : Mulch farming and no-tillage system with a killed sod mulch can alleviate the detrimental effect on yield only for short dry spells and cannot offer a long-term solution, due to the low water-holding capacity of the soil.

Goh, K. M. (New Zealand) : The key to alleviate your soil constraints lies in the production and maintenance of organic matter. To achieve this objective which would enable to reduce erosion and improve the soil moisture regime, you could grow leguminous cover crops that fix nitrogen. However in acid soils with aluminum toxicity and low phosphorus content, it is essential to apply phosphatic fertilizers. Did you try to use cheaper sources of phosphatic fertilizers such as the new reactive phosphate rocks which can be applied directly to the soil?

Answer : Yes, for a good establishment of leguminous cover crops to increase the content of organic matter in soil, we applied rock phosphates.

Sekhon, G. S. (India) : You mentioned that mineral stress, water stress and erosion hazard are the three major soil constraints. In view of the experimental evidence regarding the benefits from removal of these constraints, what are the constraints on the ground on the adoption of ameliorative measures? What is the least cost option in forging ahead-the critical factor whose satisfactory solution can lead to the adoption of additional corrective steps?

Answer : The main constraint on the ground in the adoption of ameliorative measures such as the growth of pre-season crops for mulching or green manure crops which are not accompanided by financial gain is the inadequate extension program in soil management education for the farmers who are mainly subsistence farmers. The least cost option is *in situ* mulch farming and/or *in situ* organic matter recycling which can be implemented by growing a fast-growing pre-season leguminous crop for mulching material.

Khanna, S. S. (India) : Since rainfall is erratic and moisture stress is most limiting, have you tried to develop water harvesting devices to provide life-saving irrigation at the critical stages of growth of the plant in rainfed areas to promote nutrient response and improve the yield? Have you analysed the response of fertilizer and type of fertilizer based on soil test crop-response data?

Answer : So far we have not developed such a technology although only 20% of agriculture in Thailand is under irrigation. The rainfed harvesting technology developed by ICRISAT has not been successfully adopted by the farmers since the average farmholding in Thailand is small (4.5ha) and more than one farm must share a watershed. The response of fertilizer has been detected in most soils, particularly N and P. It was also observed that the application of fertilizers enables to increase the yield by 20-100%.