IMPROVEMENT OF THE MOISTURE REGIME OF UPLAND SOILS IN THAILAND BY SOIL MANAGEMENT

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Introduction

For a stable agricultural system it is necessary 1) that chemical nutrients removed by crops be replenished in the soil, 2) that suitable physical conditions of the soil or some humus levels in the soil be maintained, and 3) that soil erosion be controlled (Greenland, 1975). However, recent continuous cultivation of some commercial crops practiced in uplands in Thailand does not appear to satisfy these conditions. There, large-scale production of maize, cassava and other field crops has been carried out under extensive cultivation by clearing vast areas of forest land, for which there is concern about advancing soil deterioration.

Among the environmental factors affecting the stability of upland farming there, water availability is most important. Due to the unfavorable conditions of climate, topography and soil, water supply is insufficient. This limited water supply restricts the cropping period and the cropping systems under which fertility of soil may be restored. Furthermore, the worst is that in a vulnerable agriculture exposed to the risk of frequent drought damage most farmers do not take care of the soil, and thus proper management such as fertilization, liming or erosion control measures is sometimes hindered. In such a farming system soil water management implies not only improvement of soil water economy for higher yield but also protection measures against soil deterioration. Soil water management is also desirable for stabilizing agriculture.

The purpose of this paper is to present survey data on properties of upland soils in Thailand as related to soil water management, and to introduce some experimental results on the improvement of the soil moisture regime by soil management. These results were obtained from experiments carried out from 1976 to 1978 under the cooperative research program between the Tropical Agriculture Research Center, Japan, and the Department of Agriculture, Thailand.

Rainfall and cropping pattern

The largest part of Thailand has a climate characterized by Tropical Savanna "Aw" as defined by Koeppen. It has distinct rainy and dry seasons and average annual precipitation is in the range of 1100 – 1500 mm.

As an example, water balance at Phra Putthabat, Lop Buri, which is the major maize producing area in the Central Highlands, is shown in Table 1. Firstly, as seen in the Table, water supply is insufficient to secure annual field crop production. Water surplus in the rainy season from June to October is only 91 mm, whereas water deficit in the dry season from November to May amounts to as much as –492 mm. In most of the months of the rainy season precipitation is close to evapotranspiration, though exceeding it. Therefore annual crops like maize are likely to suffer from water stress if water loss by runoff occurs. Actually, runoff rates are fairly large as shown later.

Secondly, as in most tropical climates, rainfall distribution is unpredictable (Panichapong, 1974), and dry spells are sometimes prolonged in the rainy season so as to cause crop failure. Statistical analysis of rainfall reliability at Phra Putthabat indicated that every 6 years in August

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which is the most important month for farming, rainfall is likely to be below the critical value of 100 mm. Based on this assumption crop failure in maize due to drought was estimated to occur approximately every 4 years.

Under these climatic conditions cassava, kenaf, sorghum and sugar cane are able to grow. Maize which is susceptible to drought is also the main crop.

In addition to water availability, soil quality is important in determining successful cropping systems. Typical cropping systems nowadays practiced in Thailand are (1) monoculture of cassava on Gray Podzolic soil (low base status, good drainage), and (2) monoculture of maize or maize relayed by sorghum or beans on Reddish Brown Lateritic soil, Rendzina and Grumusol which are associated with limestone outcrops (low to high base status, deep soil). In addition, intensive cultivation of sugar cane predominates on Noncalcic Brown soil (high base status, some irrigation).

From the viewpoint of ecological adaptability of crops, these cropping systems seem rational and profitable. However, experimental results (Somsak, 1971) and the Agricultural Statistics Book (Div. of Agric. Economics, MAC, 1967/77) suggest that the yield of cassava has been decreasing year after year under continuous cultivation. Also it is believed, though quantitative data are lacking, that some low base status soils in the cornbelt show a decline in soil fertility under continuous maize cultivation presumably due to the decrease in nutrient-rich A horizon by quick decomposition of soil humus after cultivation, breakdown of soil aggregates, and consequent increase in runoff and soil erosion, as is often the case in tropical farming (Constantinesco, 1976; Aina, 1979).

Table 1 Water balance and precipitation in 1976, 1977 and 1978 at Phra Putthabat in the Central Highlands

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total (mm)
Normal precipitation	19	13	47	97	167	194	187	185	256	160	52	20	1397
Potential evapo-transpiration	116	135	168	172	179	167	168	162	149	145	128	109	1798
Soil water storage*	0	0	0	0	0	27	46	69	100	100	24	0	
Surplus water	0	0	0	0	0	0	0	0	76	15	0	0	91
Deficit water	97	122	121	75	12	0	0	0	0	0	0	65	492
1976 precipitation	0	5	13	71	240	179	143	300	240	173	20	0	1384
1977 precipitation	0	6	65	24	153	81	131	194	241	59	66	38	1059
1978 precipitation	5	51	0	134	320	83	410	152	434	55	0	0	1644

* for a soil with water storage capacity of 100 mm

Intake and retention capacity of rainwater by major upland soils in Thailand

For soil water management, information on soil physical properties and on farmer's cultural practices is required, though it is not always available if a new farming system has been recently introduced.

1 Dispersibility or erodibility of soil

In the humid tropics rainfall of high intensity is frequently recorded and intensity higher than 50 mm per hour occurs frequently under the Thai climate conditions. The impact of raindrops causes dispersion of soil particles and destruction of aggregates. The dispersed particles seal up pores in the soil surface or move downwards. This sealing lessens the intake of rainwater and promotes runoff. In our study this soil property was estimated by the Middleton's dispersibility measurement method (Committee of Soil Physical Properties Measurement, 1972).

Dispersibility of soil varied according to the Great Soil Groups in the Thai Soil Classification (Moormann and Rojanasoonthon, 1972) (Table 2). It was extremely high in Gray Podzolic and Red-Yellow Podzolic soils. It was also high in Noncalcic Brown soils. It is interesting to note

Table 2. Physical properties of major upland soils in Thailand

Great soil groups		Soil texture	Hydraulic conductivity (saturated K20) of subsurface layer (cm/sec)	Available moisture storage capacity of 1m deep soil (mm) **	Dispersibility of Ap soil to water (%) *
Regosol	(n=2)	S - LS	10^{-3} – 10^{-4}	58.2 ± 3.0	68.6 ± 32.3
Grumusol	(n=1)	HC	10^{-6}	107.2	6.8
Rendzina	(n=2)	HC	10^{-5}	111.0 ± 13.5	4.7 ± 4.0
Brown Forest soil	(n=1)	LiC	10^{-5}	83.7	23.7
Noncalcic Brown soil	(n=5)	CL - LiC	10^{-3} – 10^{-7}	106.2 ± 26.5	24.8 ± 2.0
Gray Podzolic soil (Southeast)	(n=6)	LS - SC	10^{-3} – 10^{-6}	71.8 ± 16.7	39.6 ± 34.1
Gray Podzolic soil (Northeast)	(n=10)	LS - SCL	10^{-3} – 10^{-4}	87.3 ± 12.9	50.1 ± 19.2
Red-Yellow Podzolic soil	(n=12)	LS - HC	10^{-3} – 10^{-6}	85.4 ± 19.2	28.5 ± 14.5
Reddish Brown Lateritic soil	(n=9)	CL - HC	10^{-3} – 10^{-5}	77.8 ± 17.3	17.0 ± 9.1
Reddish Brown Latosol	(n=2)	L, HC	10^{-3} – 10^{-4}	80.5 ± 39.4	10.8 ± 0.5
Red-Yellow Latosol	(n=2)	SCL	10^{-3} – 10^{-4}	106.1 ± 6.7	29.1 ± 11.6

*: Middleton's method.

**: Moisture retained at tensions between pF2.0 and pF4.0 was regarded as available moisture.

that all these Great Soil Groups have a "textural B horizon" in the soil profile (Moormann and Rojanasoonthon, 1972). In contrast, Reddish Brown Latosols, which lack the textural B horizon, exhibit a very low dispersibility.

Dispersibility of Grumusols and Rendzinas which are rich in humus and have high contents of active clay is extremely low whereas that of Reddish Brown Lateritic soils and Brown Forest soils is intermediate between that of the groups mentioned above.

Exposure of the soil surface during the rainy season should be avoided as much as possible especially in the case of the highly erodible Great Soil Groups. In a Reddish Brown Lateritic soil with a slope of 1%, soil loss during the maize growing period in a bare field was nearly twice that of the field where maize was being grown (Fig. 5). On Gray Podzolic soil cassava is generally planted widely apart, and it takes several months for the canopy to close the space. Intercropping with some field crops during this period is desirable. However, some experimental results (Faculty of Agric., Khon Kaen Univ., 1976) suggested unfavorable competition for soil water between both plants under scanty rainfall.

Soil crust impedes intake of rainwater. When preparing the seed bed, water melon growers in the Northeast region are used to do shallow cultivation repeatedly within a short period of time in the later part of the rainy season probably in order to store rainwater efficiently in sandy Gray Podzolic soils. Some farmers in the Central Highlands prepare the rough cloddy soil surface with a disc plow at the beginning of the rainy season for better intake of rainwater.

2 Infiltration

Infiltration can be affected to a great extent by the existence of a poorly water-permeable layer in the soil. Upland soils in Thailand are generally hard and densely packed. Use of high-power, heavy tractors is a common practice for tillage, which may induce formation of compacted subsurface layers. In our survey, a few soils were found to have been compressed to an unfavorable degree; 10^{-6} cm/sec or less by hydraulic conductivity of saturated soil. These were Noncalcic Brown soils under continuous sugar cane cultivation and some sandy clay Gray Podzolic soils under continuous cassava cultivation. For these soils attention should be paid to the possible mechanical deterioration of soil in future. However, as shown in Table 2, in most upland soils hydraulic conductivity of subsurface layer soil ranged around 10^{-4} cm/sec, which is suitable.

Subsoils of the Grumusol type were hardly permeable to water. Inundation and wet injury of maize seedlings is sometimes observed in this soil after heavy rain.

3 Available moisture storage capacity of soil

Available moisture storage capacity which is one of the most important soil properties in rainfed upland farming was 86.8 ± 19.3 mm per one meter depth on the average in the Thai upland soils, which is much lower compared with that of Japanese soils. Roughly speaking, under these conditions field crops of medium rooting depth such as maize cannot sustain normal growth for more than 16 days during the dry spells, assuming that evapo-transpiration is 5.5 mm per day*. Actually as soils under vegetation are not always storing moisture adequately, shorter periods of dry spells may cause severe damage to maize, at the tasseling stage of the plant.

Available moisture storage capacity was comparatively high in Grumusols, Rendzinas and Noncalcic Brown soils and low in Gray Podzolic soils, Reddish Brown Lateritic soils and Regosols. In the Central Highlands relay cropping of sorghum after maize is sometimes observed in Grumusols and Rendzinas whereas it is rare in Reddish Brown Lateritic soils. This variation may be attributable to the difference in the moisture storage capacity.

Characteristics of the moisture regime of soils under upland farming

Characteristics of the soil moisture regime under field crop cultivation should be determined for rational planning of soil water management. Seasonal changes in soil moisture are shown in Figs. 1-3 and Table 3, from which the following can be pointed out.

(1) Field crops function as a desiccator of soil, and various soil moisture conditions can be provided for the succeeding crop depending on the previous crop in the cropping pattern. In the survey made at the end of the dry season, no available water was found within a depth of 2 m in soil where cassava or kenaf had been grown. On the other hand, some available water was detectable within a depth of 1 m in soil where maize had been harvested, but it was less where maize had been relayed by mungbean cropping (Table 3).

(2) Solar energy in the dry season can lead to soil desiccation far beyond the wilting point. This occurred in a depth of 60 cm in the Reddish Brown Lateritic and Gray Podzolic soils surveyed. In this case the amount of vapor loss beyond the wilting point (pF4.2 in this case) was as much as 30 mm. It is highly probable that appreciable amounts of rainwater absorbed by soil in the early rainy season do not become available because of consumption as hygroscopic water of the soil. Therefore, not only the amount of available water but also the amount of moisture deficit to the wilting point should be taken into account.

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* Daily potential evapo-transpiration of approximately 5.5 mm was obtained by the Thornthwaite relationship (Agricultural Meteorology Handbook Committee, 1974) for most of the months of the rainy season in the Central Highlands. In another estimation, i.e. by the method of van den Eelaart (1973), it was about 3 mm, (0.6 x pan evaporation). According to Oldeman (1974), most upland crops in Southeast Asia need at least 100 mm water per month for evapo-transpiration except for the early growth and ripening stages.

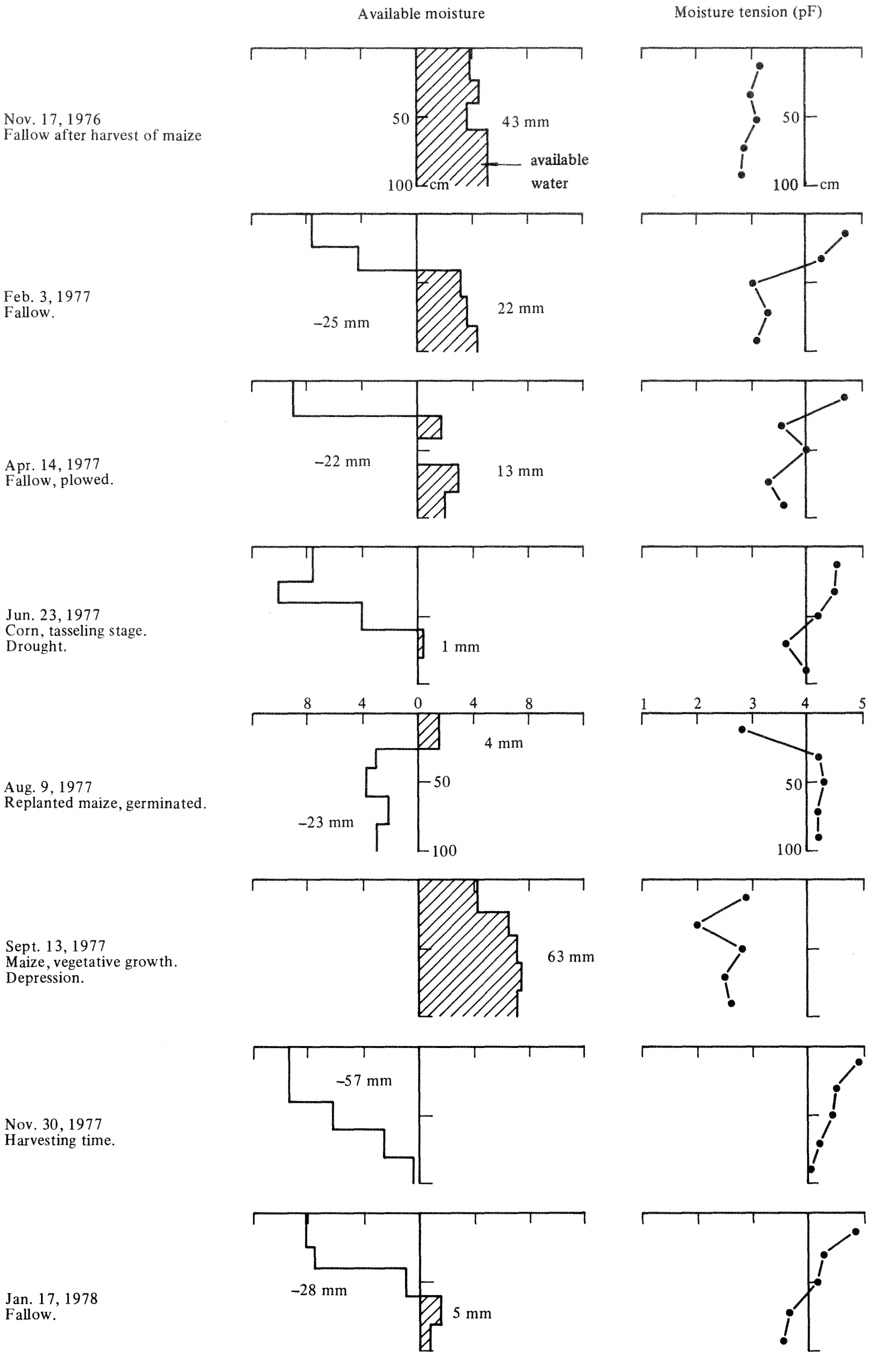

Fig. 1 Seasonal variation in soil moisture of a Reddish Brown Lateritic soil under maize farming, Lop Buri.

Fig. 2 Seasonal variation in soil moisture of Gray Podzolic soil under cassava farming, Chonburi.

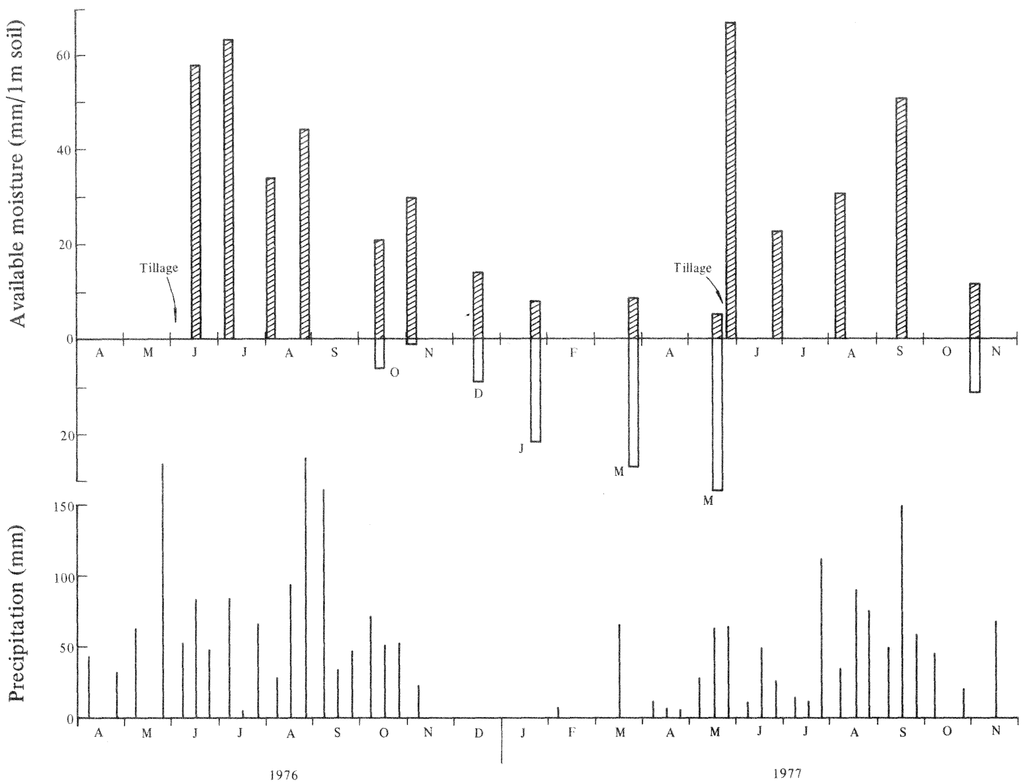

Fig. 3 **Seasonal variation in soil moisture of Reddish Brown Lateritic soil without vegetation, Lop Buri.**

Table 3. Soil moisture as affected by field crop cultivation

1. Red-Yellow Latosol, Khon Kaen, observed on April 24, 1978.

Soil depth	No crop in 1977 rainy season			Kenaf in 1977 rainy season		
	Moist. (wt.%)	Avail. * moist. (mm)	Tension by pF	Moist. (wt.%)	Avail. moist. (mm)	Tension by pF
0 – 20cm	5.8	-2.6	4	6.5	5.4	3.1
20 – 40	4.9	-2.7	4	4.9	-4.2	4
40 – 60	6.6	-2.9	4	5.4	-5.7	4
60 – 80	9.1	0.5	3.9	6.3	-6.1	4
80 – 100	8.6	2.1	3.5	5.7	-5.1	4
100 – 120				5.6	-2.9	4
120 – 140				5.9	-4.9	4
140 – 160				5.9	-4.8	4
160 – 180				5.8	-3.4	4
180 – 200				5.6	-4.0	4

2. Reddish Brown Lateritic soil, Lop Buri, observed on May 29, 1977.

Soil depth	Maize in 1976 rainy season			Maize & mungbean in 1976 rainy season		
	Moist. (wt.%)	Avail. moist. (mm)	Tension by pF	Moist. (wt.%)	Avail. moist. (mm)	Tension by pF
0 – 10cm	6.2	-5.9	4.7	6.3	-4.7	4
10 – 20	6.0	-6.8	4.8	5.6	-6.5	4
20 – 30	8.3	-6.6	4.5	7.8	-7.0	4
30 – 40	10.1	-4.2	4.4	10.0	-4.8	4
40 – 50	14.0	-2.5	4.3	10.6	-4.1	4
50 – 60	15.8	-1.8	4.2	11.4	-2.7	4
60 – 70	18.3	2.5	3.4	11.3	-1.7	4
70 – 80	17.9	1.5	3.7	12.3	-1.2	4
80 – 90	16.5	1.8	3.6	14.1	1.2	3.7
90 – 100	17.1	3.1	3.3	14.6	1.9	3.6

3. Gray Podzolic soil, Chonburi, observed on May 4.

Soil depth	Under fully grown cassava at harvesting time		
	Moisture wt.%	Available moist. (mm)	Tension by pF
0 – 20cm	12.5	18.5	2.7
20 – 40	6.7	- 4.1	4.3
40 – 60	6.7	-17.0	4.7
60 – 80	9.1	- 6.8	4.3
80 – 100	9.5	- 5.2	4.2
100 – 120	8.2	- 6.5	4
120 – 140	9.1	- 3.3	4
140 – 160	8.9	- 4.2	4
160 – 180	8.4	- 5.4	4
180 – 200	6.8	- 8.0	4

*: Available moisture is moisture retained at tensions between pF2.0 and pF4.0.

(3) In the seasonal changes of soil moisture, it was observed that soils were wet on the whole under depression in the late rainy season, as suspected in the water balance. Thus the main factors for soil water management seem 1) to depend on the ability to improve the soil moisture level during the middle part of the rainy season, and 2) to conserve the excess of soil water in the later part of the rainy season throughout the dry season.

Effects of soil management on soil moisture and growth of maize

Effects of mulching of crop residues, intertillage, and subsoiling on soil moisture retention and growth of maize were evaluated in a Reddish Brown Lateritic soil in the Central Highlands. The experiment was conducted for three years under different rainfall conditions; nearly normal in 1976, low in 1977 and high in 1978 (Table 1).

Experimental methods are briefly described below, and the main results are shown in Tables 4 – 5 and Figs. 4 – 8.

Experimental site Phra Putthabat Field Crop Experiment Stn., Lop Buri.

Soil Top soil with light clay texture had medium dispersibility and was fairly susceptible to splash and sheet erosion. Saturated hydraulic conductivity of the subsurface soil was 10^{-5} cm/sec, but the deeper subsoil was well drained. Available moisture storage capacity was 85 mm per 1 m of depth. The land inclination was approximately 1%.

Treatments for maize cultivation during the rainy season

A. Check plot .... The seedbed was prepared by a disc plow and a disc harrow.

B. Rice straw mulch .... The seedbed was covered with 4.5 ton/ha of rice straw.

C. Intertillage .... Furrows were cultivated superficially several times before the tasseling stage.

D. Subsoiling .... The field was chiseled at a depth of 50 cm and 80 cm apart before seedbed preparation.

Fertilizers were applied at the rate of 100-50-100 kg/ha for N-P_2O_5-K_2O, using ammonium sulfate, double superphosphate and muriate. Weeds were controlled by herbicides.

Treatment for fallow during the dry season

A. Check plot .... No treatment was applied to the maize-harvested field after removal of plant residues.

B. Cornstalk mulch .... A maize-harvested field was covered with 5 ton/ha of cornstalk in the late rainy season.

C. Cornstalk incorporation .... Cornstalk was incorporated by a disc plow to a maize-harvested field.

D. Shallow cultivation .... A maize-harvested field was cultivated superficially twice in the late rainy season.

Planting and harvesting time of maize

Maize (*Zea mays* L. Thai Composit 1) was planted in late May or early June, and was harvested in mid-September. The average growth period was 110 days.

Precipitation

Precipitation during the maize growing period was 782 mm in 1976, 475 mm in 1977 and 999 mm in 1978.

1 Effect of mulch of crop residues.

Function of mulch of crop residues in improving soil water economy is generally regarded as a means (1) to maintain infiltration at higher rates for longer periods by protecting the soil surface from slaking, and (2) to decrease evaporation. The first effect is consistently and widely recognized. However, according to the review of experimental results on mulch by McCalla and Army (1961), the role of mulch in reducing evaporation is variable. It is significant as long as the soil surface is wet or under frequent rains, but it is negligible if the rain is infrequent or during the fallow period.

In our study, mulch of rice straw at the rate of 4.5 ton/ha at planting time of maize maintained infiltration at high rates throughout the growing period. On the soil with mulch infiltration of rainwater amounted to 96% during torrential rains (90.7 mm per 2 hours). The soil covered with mulch could absorb rainwater as long as rainfall was less than 30 mm for 24-hour precipitation, whereas the check soil failed to do so even when the rainfall was only 10 mm (Fig. 4). Thus the runoff rate during the maize growing period was reduced by mulching to about one third of that of the check plot (Table 4) and soil loss by erosion was reduced by mulching at the same time (Fig. 5).

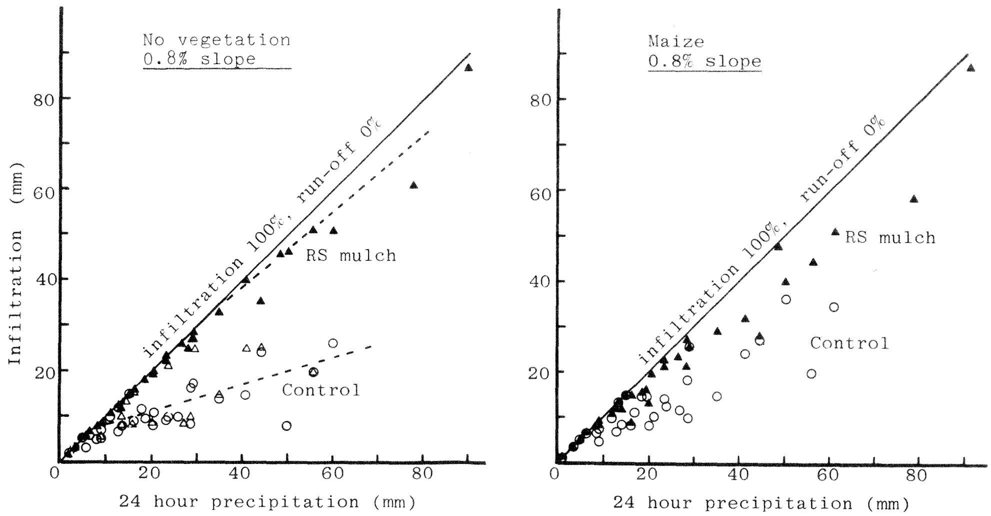

Fig. 4 **Effects of soil management on infiltration/runoff of rainwater during the maize growing period (1978).**

Table 4. Average runoff rate during the maize growing period on a Reddish Brown Lateritic soil with a slope of 0.8% (1978).

Soil management	No vegetation	Maize
Control	48.0%	38.0%
Intertillage	39.9	29.6
Subsoiling	44.9	38.3
Rice straw mulch	7.2	13.1

Table 5 **Maximum increase in available moisture due to soil management observed in plots without vegetation**

(per 1m deep soil)

Soil management	1976 (precip. 782 mm)	1977 (precip. 475 mm)	1978 (precip. 999 mm)
Intertillage	+ 6 mm	−17 – +22 mm	+33 mm
Subsoiling	+ 7 mm	−15 mm	+10 mm
Rice straw mulch	+61 mm	+30 mm	+46 mm

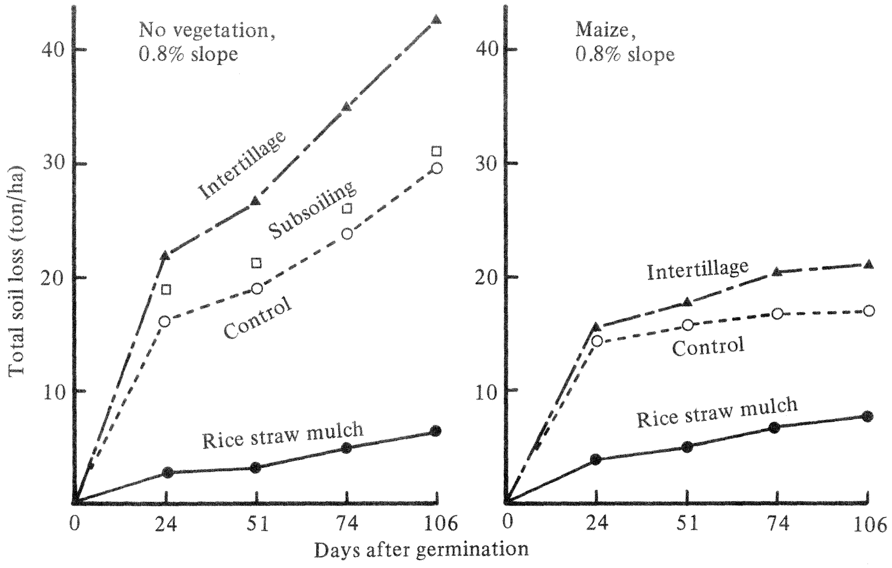

Fig. 5 **Effects of soil management on erosion control during the maize growing period (Reddish Brown Lateritic soil, 1978).**

Rice straw mulch improved soil moisture during the maize growing period to a great extent (Fig. 6), irrespective of the rainfall conditions (Table 5). The increase in available moisture by mulch which was observed in the plot without vegetation was 120% in 1976 with normal rainfall, 107% in 1977 with little rainfall and 57.8% in 1978 with high rainfall on the average compared with the check plot.

Rice straw mulch increased yield of maize significantly due to the improved soil moisture, except for the 1978 experiment conducted under abnormally high precipitation, in which the yield was decreased by 14% due to nitrogen deficiency (Fig. 8). The nitrogen deficiency was presumably due to high rates of water percolation under mulching and subsequent loss of applied nitrogen fertilizer (Thomas *et al.,* 1973). A lower rate of nitrification under mulching and nitrogen immobilization by the presence of fresh plant residues may have been involved to some extent.

Adverse effect of rice straw mulch was observed in 1977, a year with drought, as it promoted termite activity. In this year there was an outbreak of termite (*Microtermes obesi* Holmgren and *Macrotermes gilvus* Hagen) from the tasseling to the milking stage during the dry spells, and severe damage was observed especially in the mulch plot. However, nitrogen deficiency and the termite problem may be alleviated by proper management.

Soil management during the cultivation of the preceding crop or in the previous season sometimes has an appreciable influence on the succeeding crop. However, very little attention has been paid so far to management of fallow during the dry season. In the experiment shown in Fig. 7, it was found that mulching of cornstalk at the rate of 5 ton/ha in the field in fallow in the later part of the rainy season was very effective in absorbing and probably in preserving the soil water from residual rainfall, or erratic rainfall both during the middle of the dry season and in the early rainy season. Thus the net water reserves brought to the suceeding maize crop were higher in the plot with mulch than in the check plot (85 mm per 1 m soil). Due to the improved

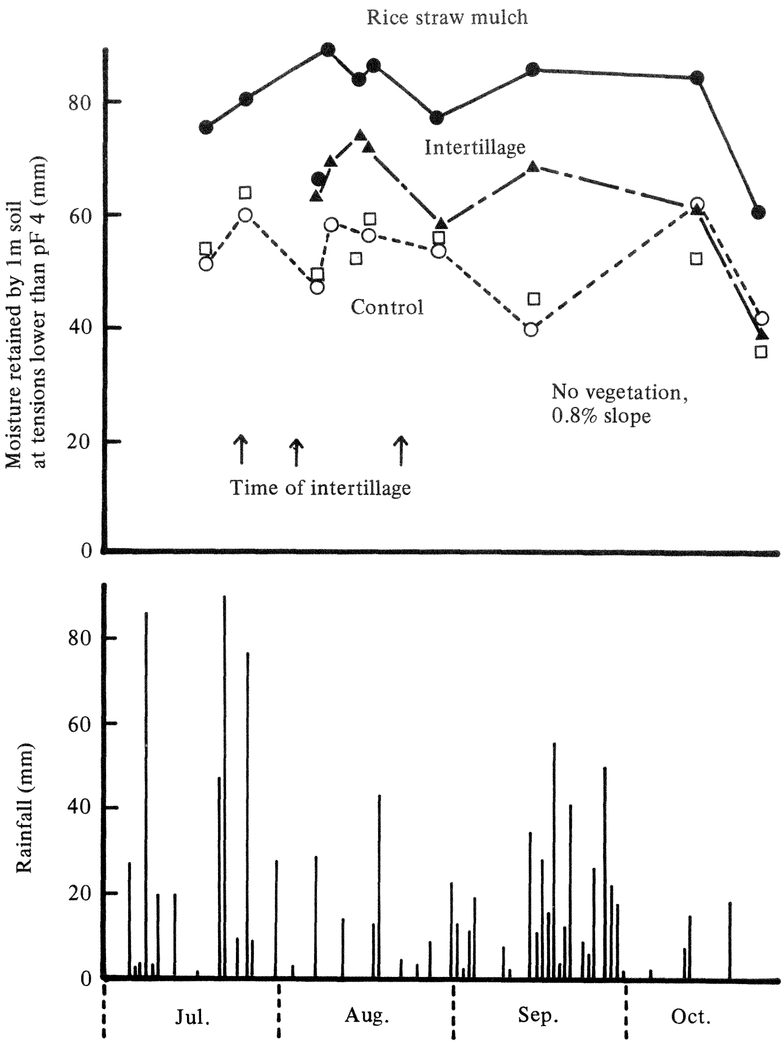

Fig. 6 **Effects of soil management on soil moisture during the maize growing period (Reddish Brown Lateritic soil, 1978).**

soil moisture vigorous growth of weeds in the field with mulch was observed at the time when maize was planted.

2 Effects of tillage, intertillage and subsoiling.

In a review of research on tillage in West Europe, Kuipers (Kuipers, 1970) pointed out that there have been two central themes, namely weed control and tilth (desirable physical and nutrition conditions of soil). In tropical agriculture, however, the concept of tillage or benefit of tillage seems obscure because of lack of basic information. Role of tillage probably varies with climatic and soil conditions.

In maize cultivation in Thailand, it is common for farmers to plow the land by tractors at least once before planting. This is probably done in order to obtain suitable seedbed condition and also in order to facilitate absorption of rainwater by soil. Then, about one month after planting, plowing is usually carried out mostly by hand hoe or buffalo in order to control weeds.

Disc plowing in the early rainy season facilitates rainwater absorption by soil as shown in Fig. 3. But when it is performed before dry weather, there may be a danger that the rough cloddy configuration of the soil surface accelerates loss of soil water by evaporation. The experimental results were as follows.

1) Intertillage and shallow cultivation

Intertillage (inter-row cultivation) increased infiltration to considerable extents (Table 4). It raised soil moisture levels slightly in a normal year, and somewhat conspicuously in a wet year (Table 5, Fig. 6). However, in a dry year the effect of intertillage was not consistent (Table 5). Loosening of the soil surface during dry weather seemed to promote evaporation. Thus it was uncertain whether intertillage exerted a sand mulch effect in maintaining soil moisture by cutting the capillary pores in the soil. As regards the detrimental effects, intertillage accelerated soil erosion as shown in Fig. 5.

Intertillage is beneficial and could contribute to preserve soil moisture as long as it is performed as weed control. But further positive effects in increasing soil moisture depend on the time of cultivation and the weather conditions. Considering the erosion loss and the magnitude of the effect, frequent intertillage is not recommended.

As for the yield of maize, intertillage increased it slightly in a normal year, but not in a wet year.

Shallow cultivation in the dry season fallow improved soil moisture to a small extent (Fig. 7).

2) Subsoiling

Subsoiling of Phra Putthabat Reddish Brown Lateritic soil failed to increase soil moisture on the whole (Table 5). It rather exerted a detrimental effect in increasing the loss of moisture from the subsoil when the soil was dry during the 1977 drought spells. The easy desiccation of the subsoil was also induced by subsoiling treatment during the dry weather in the experiment conducted on a sandy clay Gray Podzolic soil in the Southeast Region of Thailand. It was presumed that channels provided in soil might facilitate movement of vapor from the subsoil to the atmosphere. In connection with this, incorporation of bulky cornstalk in Reddish Brown Lateritic soil by using a disc plow increased the loss of water from the subsoil during the dry season, although it enhanced infiltration (Fig. 7).

To conclude, tillage is both beneficial and detrimental. Its effect on soil moisture very much depends on the weather conditions. Additional research under various soil and weather conditions is necessary to evaluate the effect of tillage more precisely and to develop suitable methods of cultivation.

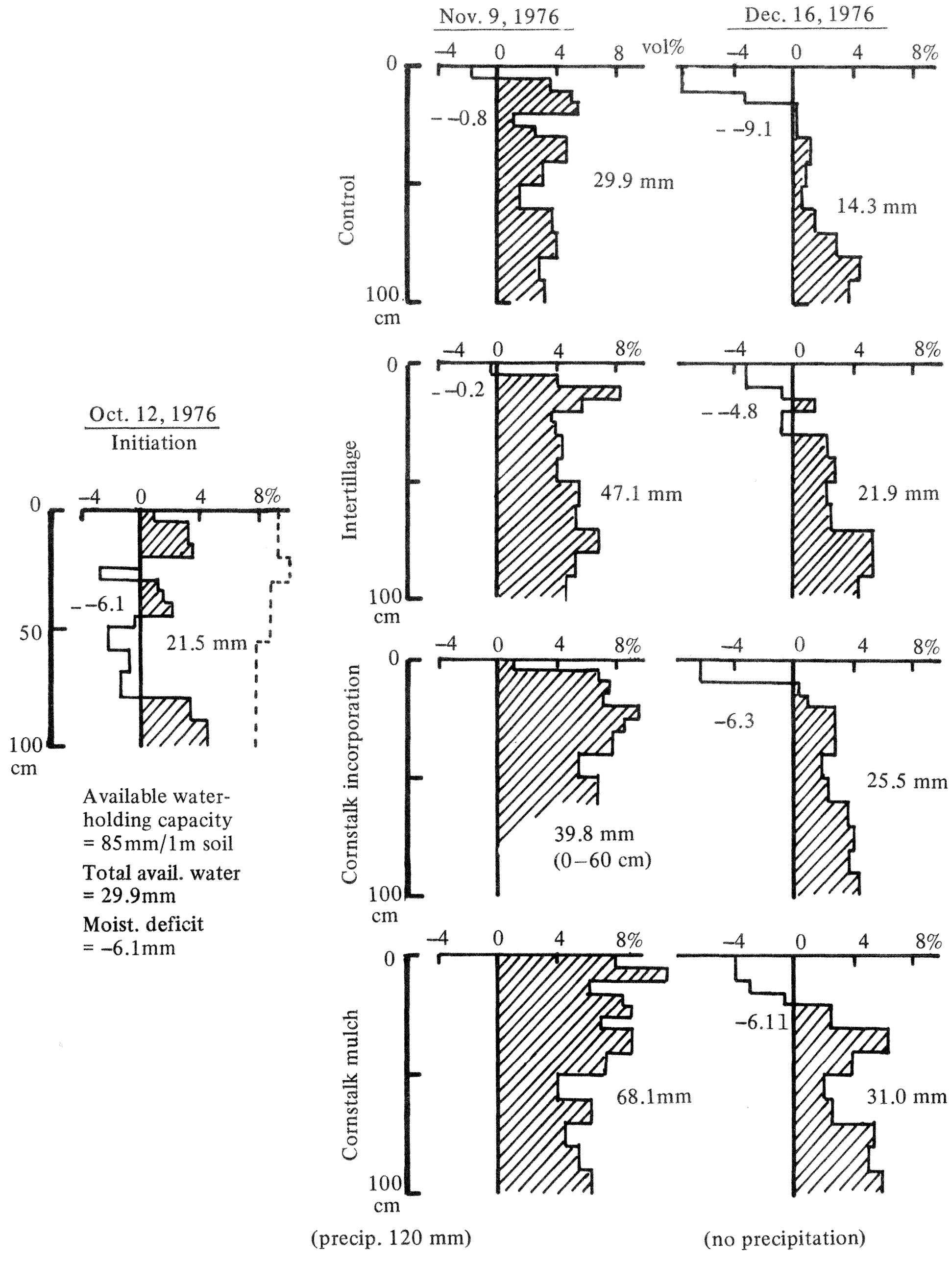

Fig. 7-1 **Amount and distribution of available water of the dry season fallow as affected by soil management (Reddish Brown Lateritic soil, 1976–1977).**

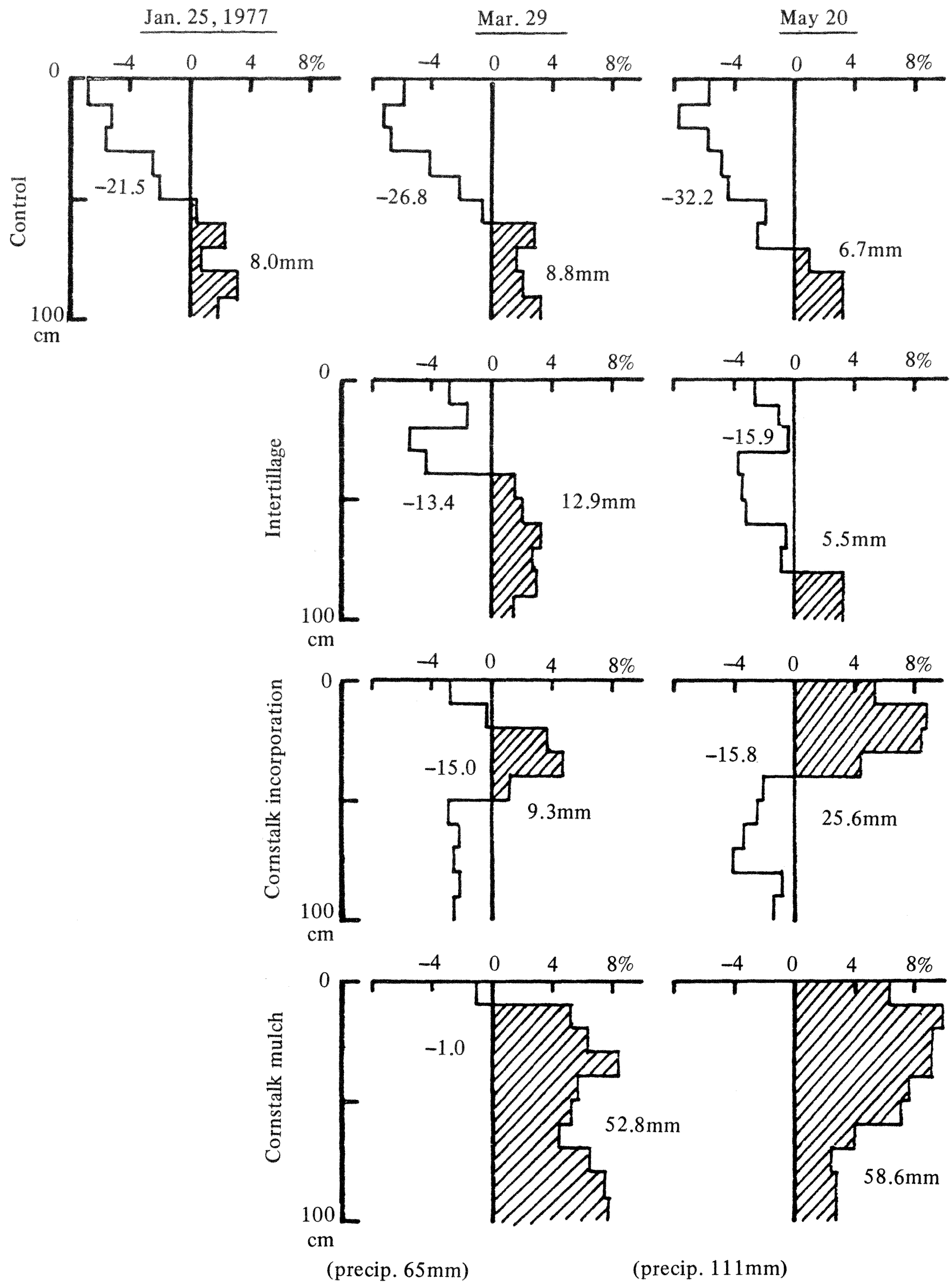

Fig. 7-2 Amount and distribution of available water of the dry season fallow as affected by soil management (Reddish Brown Lateritic soil, 1976–1977).

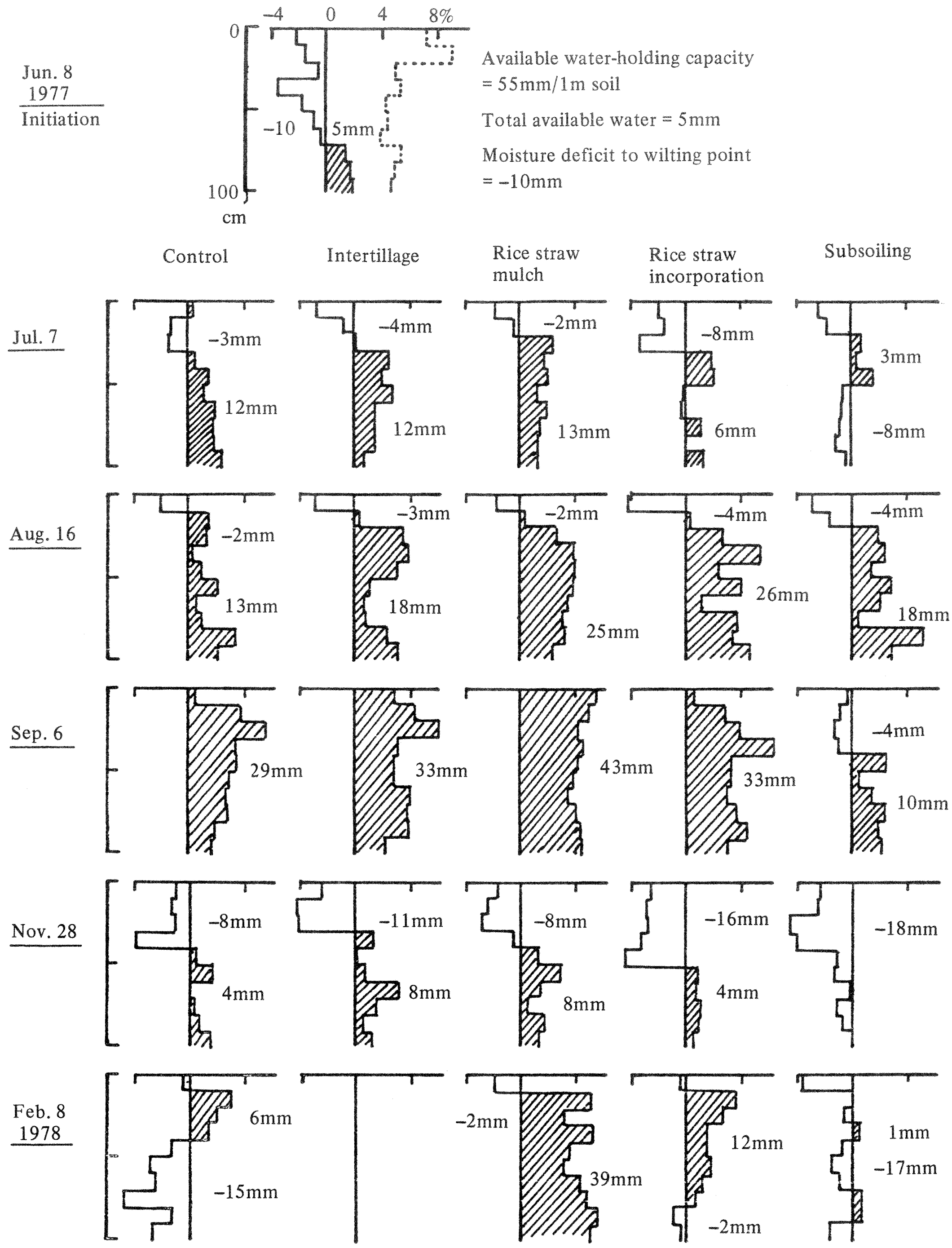

Fig. 7-3 Amount and distribution of soil available water as affected by soil management (Gray Podzolic soil).

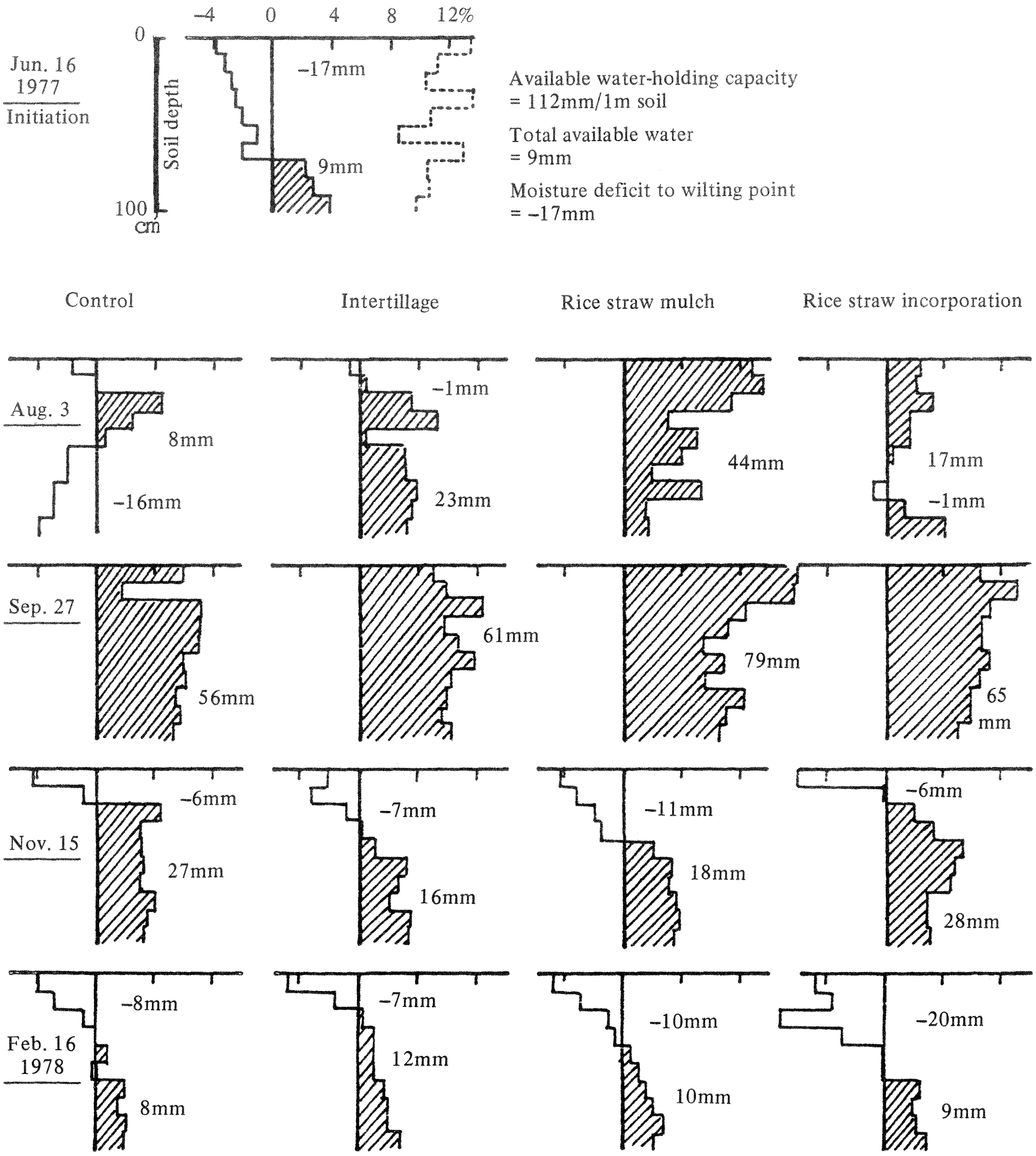

Fig. 7-4 Amount and distribution of soil available water as affected by soil management (Red-Yellow Latosol).

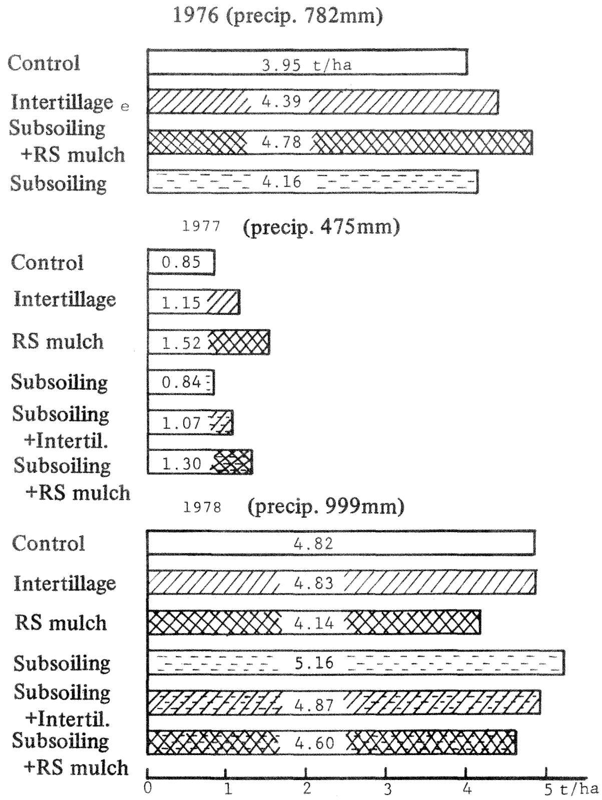

Fig. 8 Effects of soil management on grain yield of maize.

Effects of weed stubble mulch with minimum tillage

As described above, effects of mulch in improving soil moisture and in preventing runoff and soil erosion are very remarkable. And with normal or deficit rainfall in the Thai climate, one can expect considerably higher yields of maize from mulching. In order to bring mulching into practice, production of mulch materials on land and labor-saving methods are needed.

Recently no-tillage system for crop production has been investigated for its effectiveness in conserving soil and water and for its production potential (Triplett *et al.,* 1963; Triplett *et al.*, 1968; Chiba *et al.,* 1970). It has become an accepted practice for maize and soybean production in North America. Also some research has been carried out in Africa (Lal, 1976). In our study the possibility of using weed stubble mulch with minimum tillage was evaluated.

The experiment was initiated with the observation of the growth of weeds. As shown in Table 6, weeds grew well during the rainy season in the plot in which only disc plowing was performed at the beginning of the rainy season: as much as 4 ton/ha per dry matter weight was produced during the months of April and May 1978, although the soil moisture conditions during this period of the year were conducive to weed growth. With less rainfall, enough weed production for stubble mulch before the start of maize planting can be expected. Covering the land with cornstalk in the late rainy season of the previous year may produce good moisture conditions and lead to vigorous growth of weeds as observed in Fig. 7.

Table 6 Dry matter production of weeds during the rainy season and dominant species in the Central Highlands

Period	Plowed in late May and mid-September	Plowed in late May and mowed mid-September
1977 May 25 – Sep. 13	8.0 ton/ha	8.0 ton/ha
1977 Sep. 14 – Nov. 3	2.5	5.3
1978 April – May 24	4.3	3.8

1. *Eleusine indica* (Linn.) Gaertn.
2. *Echinochloa colonum* (Linn.) Link.
3. *Pennisetum polystachyon* (Linn.) Schult.
4. *Pennisetum pedicellatum* Trin.
5. *Commelina benghalensis* Linn.
6. *Trianthema portulacastrum* Linn.
7. *Arachne racemosa* (Heyne) Ohwi.

The relationship between the growth of maize and soil moisture was compared between two treatments. In the first treatment soil was conventionally plowed by use of a disc plow and maize was planted on June 12. In the other soil was sprayed with Grammoxone to kill the weeds and maize was planted by narrow band plowing with hoes to place the seed and fertilizers. These two plots were also compared with the conventional plot where maize had been continuously cultivated.

By disc plowing and harrowing, the available moisture level of soil was lowered from 70mm to 43 mm within a depth of 1 m in the conventional cultivation plot, and from 75 mm to 50 mm in the plot with continuous maize cultivation three weeks after disc plowing. This was caused by enhanced evaporation by plowing and decreased intake rates due to crust development. On the

Table 7 Effects of weed stubble mulch with minimum tillage on yield of maize

(ton/ha)

Treatment	Grain	Cornstalk	Cob
Continuous maize	4.86	5.61	0.91
Fallow, conventional cultivation	5.32	6.07	0.97
Fallow, minimum tillage	4.74	5.44	0.89

(LSD = 0.45)

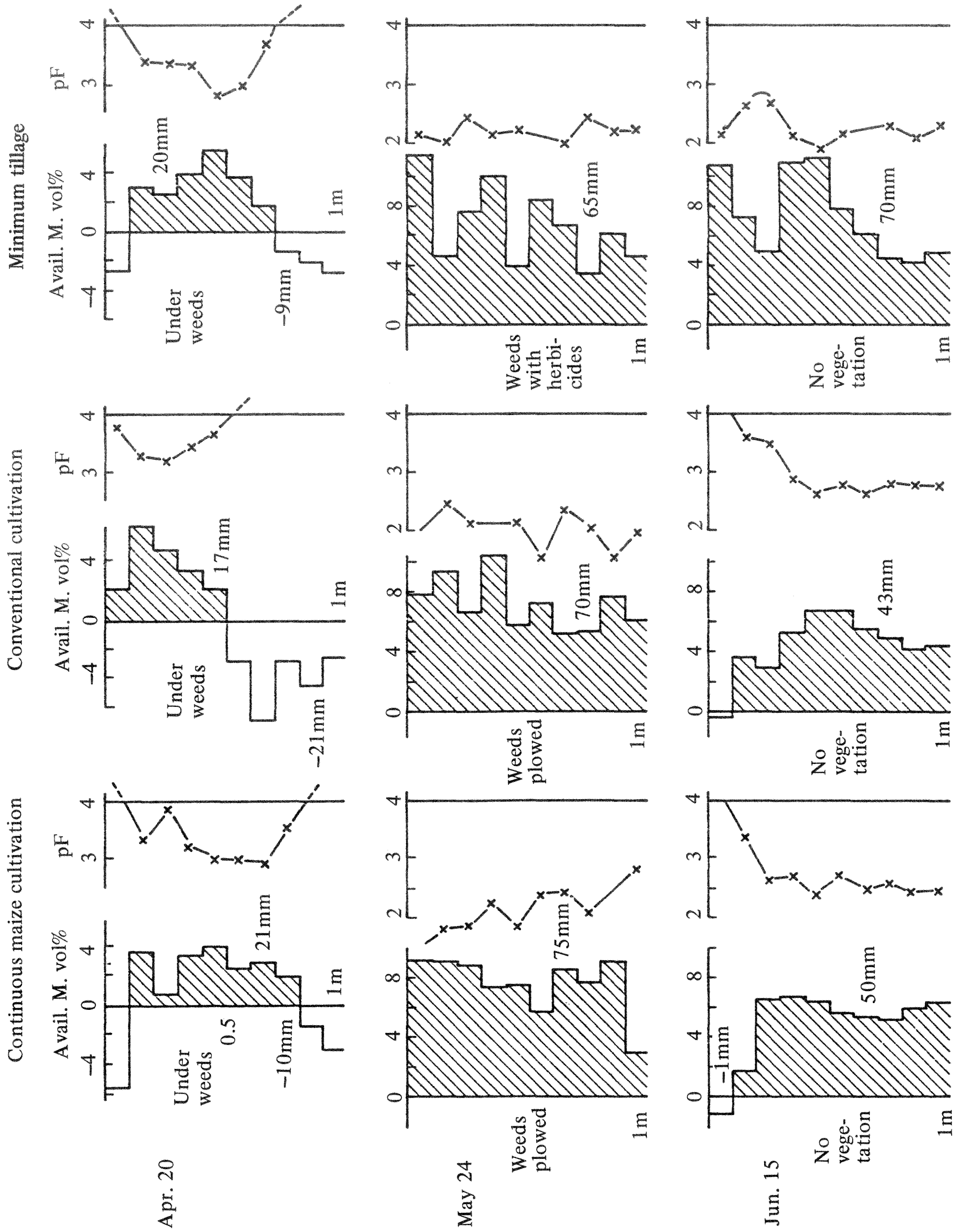

Fig. 9 Effects of weed stubble mulch with minimum tillage on soil moisture.

other hand, in the minimum tillage plot the level of soil moisture was maintained at 70 mm (Fig. 9). After this observation, there was high precipitation and all the plots were saturated with water. The amount of available moisture observed in the middle of July was 84 mm in the minimum tillage plot, 74 mm in the conventional one, and 76 mm in the plot with continuous maize cultivation.

Germination and early growth of maize plant in the minimum tillage plot were remarkably good, reflecting the improved soil moisture. However, high precipitation later reduced the growth difference between the plots, and induced nitrogen deficiency of the plant in the minimum tillage plot resulting in 10.6% decrease in grain yield below the conventional cultivation plot (Table 7). It must be emphasized that as a result of the abundant rainfall yield of maize in 1978 was considerably higher than that in a normal year (Fig. 8).

Although the results cover only one year, they indicate that adequate growth of maize can be obtained in fields with weed cover with minimum tillage.

Conclusion and recommendations

Most of the upland soils in Thailand are highly prone to crust formation and erosion, and are low in available moisture storage capacity. With unfavorable climatic conditions field crops are likely to suffer from water stress and agriculture thus becomes unstable.

As for soil management in order to improve soil moisture economy, much effect cannot be expected from tillage practices, though there still remain problems to be solved such as suitable time of cultivation, or cultural practices enabling to prevent soil moisture loss. On the other hand mulching with crop residues is considered beneficial. For maize farming in the Central Highlands mulching of cornstalk on the soil after harvest in the later part of the rainy season is recommended as a practical method. Weed stubble mulch with minimum tillage on soil covered with cornstalk is also considered beneficial and would be practical in future. The development of techniques enabling to minimize the use of herbicides, improve nitrogen fertilization and identify suitable grasses and legumes to replace weeds is highly desirable.

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Discussion

Hew, C.K. (Malaysia): In your table on the maximum increase in available moisture, you showed that in 1976 with 782 mm of precipitation the amount of available moisture under rice straw mulch was 61 mm but in 1978 with 999 mm of precipitation it was only 46 mm. What is the reason for such difference?

Answer: The field used in the 1976 experiment was different from that used in the 1977 and 1978 experiments. Also the soil texture was different.

Kyuma, K. (Japan): You mentioned that zero or minimum tillage was effective in conserving soil water. How about the effect of this practice from the standpoint of soil conservation, namely prevention of soil erosion?

Answer: Minimum tillage is effective in soil conservation. This method should be adopted before the fertile A horizon becomes irreversibly lost by erosion.

Ohno, Y. (Japan): 1) How did you define minimum tillage in your experiment? 2) At which precipitation threshold does mulching treatment become effective?

Answer: 1) In our experiment minimum tillage refers to the return of crop residues as mulch, the control of weeds by herbicides and tillage limited to narrow bands at a depth of 3 – 4 cm where seeds and fertilizers can be placed. 2) Effects of mulch on the increase of soil moisture especially through good infiltration could be recorded irrespective of the amount of rain water.