Soil Improvement in Corn Cropping by Long-Term Application of Organic Matter in Ultisols of Thailand

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ABSTRACT

Two long-term experiments on the effects of plant residue mulch and organic matter incorporation on the growth of corn and soil fertility were carried out in Ultisols (a Reddish Brown Lateritic Soil) of Central Thailand, starting from 1976 and 1981, respectively.

Plant residue mulch (5t/ha/year) combined with fertilizer application was remarkably effective in maintaining a high yield of corn throughout the experimental period. Without mulch application, the corn yield fluctuated to a great extent and decreased markedly in drought years even under chemical fertilizer application. The effect on the growth and yield was mainly ascribed to the maintenance of a suitable amount of soil moisture and the behavior of soil nitrogen.

The effect of compost application (20t/ha/year) on the yield was negligible in the first eight years. However, thereafter, gradually the yield increased compared with that in the absence of compost application. Organic carbon and total nitrogen contents in the soil increased. Soil biomass nitrogen and the content of available nitrogen (mineralizable nitrogen and inorganic nitrogen) increased with the decrease in the rate of nitrogen fertilizer application and increase in the amount of organic matter application. Soil bulk density, water permeability, plasticity, soil hardness, aggregate formation were improved by long-term incorporation of organic matter to the soil.

Though many technical problems still remain to be solved before the technology can be transferred, proper soil management consisting of the application of either plant residue mulch or compost would at least provide some economic answers to sustainable upland crop production under rainfed conditions in Thailand.

Introduction

For sustainable upland crop production in the sub-humid tropics, where there are distinct wet and dry seasons with annual rainfall ranging from 1,100 to 1,500mm, the soil should be well managed in such ways (1) that the soil nutrients removed by crops be replenished in soil, (2) that adequate organic matter levels and suitable soil physical conditions be maintained and (3) that soil erosion be controlled (Greenland, 1975). However recent continuous cultivation of some upland crops such as corn, sugarcane and cassava, does not appear to satisfy these conditions, hence the deterioration of upland soil productivity.

Soil analytical data obtained from a gentle slope area covered with Ultisols in Central Thailand showed that, after reclamation from forest, about 50% of soil fertility elements such as nitrogen, phosphorus, potassium as well as organic matter in the surface soil had been removed within 3 years, possibly due to rapid biodegradation, leaching and erosion losses (Inoue, 1986).

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In the case of Ultisols in Thailand, which is the major soil type, there is adequate information about the soil genesis and classification, as well as physical and chemical properties. Also, a large number of fertilizer trials have been carried out in order to increase grain corn yields for different soil types, and in order to introduce effective low-input fertilizer technology.

Several reports demonstrate the importance of the application of organic materials onto the tropical Ultisols for corn production,

However, research on the effect of long-term application of organic matter on the long-term yield response of corn, and on the soil physical and chemical properties is limited. This report deals briefly with a review of the experimental results which were obtained during these 15 years on the effect of long-term application of organic matter, either through plant residue mulch or compost incorporation, on the yield of corn and on the short-term and long-term changes in the soil properties that may limit the yields.

Soil constraints on corn production

(1) Soil moisture regime

Fig. 1 shows the 14 year's average annual precipitation pattern of the representative site

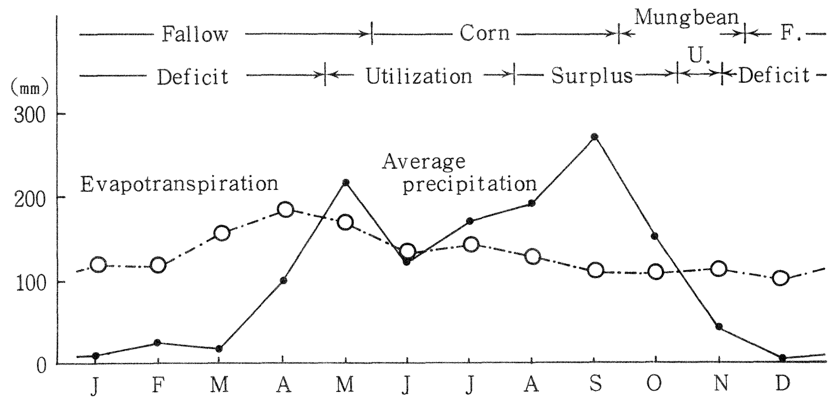


Fig. 1 Cropping system, soil moisture status and precipitation at the experimental sites.

in Central Thailand. Bimodal pattern of erratic precipitation with a short dry spell during June to July makes it difficult for the farmers to decide the timing of soil and fertilizer management for corn cultivation, particularly due to drought hazard. A statistical analysis for the prediction of drought hazard of corn showed that the soil moisture content decreases to below the critical level with a probability of once every 4-5 years in June, and once every 6-7 years in July. Assuming that 13 and 24% of the rainwater are lost by surface run-off, the probability of drought hazard was calculated to be once every 2 years and once every 3 years, respectively (Ueno, 1989).

(2) Soil nutrients

Soil used in the present long-term field experiment is classified as fine clayey, mixed/kaolinitic isohyperthermic typic Paleustult in the US Soil Taxonomy System, and as Reddish Brown Lateritic Soil in the Local Classification System. The predominant clay mineral is kaolinite with small amounts of vermiculite and chlorite. The fertility of the soil is extremely low and the soil is susceptible to biodegradation. Analytical data showed that the CEC was less than 7.0 meq/100g, pH was 5.0-5.5 in the surface horizon, organic carbon was less than 0.7% and available-P was 17ppm.

Long-term grain corn yield under plant residue mulch and compost incorporation

Five year averages of the grain corn yields with different organic matter treatments which were analysed at two sites are shown in Table 1 and Table 2. In site 1 (Table 1), a field

Table 1 Five year average of grain yield of corn at site 1

(t/ha)

Treatment		1981/1985	1983/1987	1985/1989	Average	Min.-Max.*
Nitrogen fertilizer	Organic matter					
N0	-	2.27	2.53	2.38	2.38	1.27-3.82
N0	CS	2.54	2.65	1.93	2.34	1.18-2.63
N0	MCS	2.33	2.44	2.22	2.19	1.50-3.07
N50	-	4.04	3.89	4.23	3.84	2.01-6.82
N50	CS	4.57	4.36	4.45	4.20	2.83-7.35
N50	MCS	4.78	4.94	4.97	4.56	3.42-7.75
N100	-	4.48	3.91	4.79	4.35	1.73-7.18
N100	CS	5.13	4.48	4.47	4.67	3.05-7.37
N100	MCS	5.71	5.16	5.59	5.40	4.76-7.90

* Data of 1987 are omitted due to very severe drought damage.

Fertilization (N-P205-K20kg/ha)
N0 : 0-100-50
N50 : 50-100-50
N100 : 100-100-50

Organic matter management
- : Control
CS : Corn stalk mulch
MCS : Corn stalk + Weed mulch

Plot size : 6 x 6m (36m^2) Spacing of corn : 75cm x 25cm, one plant/hill, 53,300 plant/ha

experiment was carried out with different levels of N-fertilizer and organic matter application. It was found that the application of N-fertilizer exerted a beneficial effect on the growth and yield of corn. The effect was more pronounced when the corn stalk residues of the previous year were incorporated into the soil. Additional application of organic matter as weed residue mulch (5t/ha) together with corn stalk incorporation gave the highest yield.

The same effect of fertilizer and organic matter application on yield was obtained in site 2 (Table 2). Continuous application of chemical fertilizer alone at first increased the yield but after more than 10 years, the yield decreased to a great extent whereas by the application of either rice straw mulch (4t/ha) or compost (20t/ha) the yield level remained high.

Fig. 2 shows the yield gains by fertilizer application, rice straw mulch and compost application. The application of chemical fertilizer alone was only effective in the first 10 years but thereafter depressed the yield. Plant residue mulch or compost application at first did not seem to enhance the yield considerably but after 8 years the yield increased gradually due to the cumulative residual effect of organic matter incorporation.

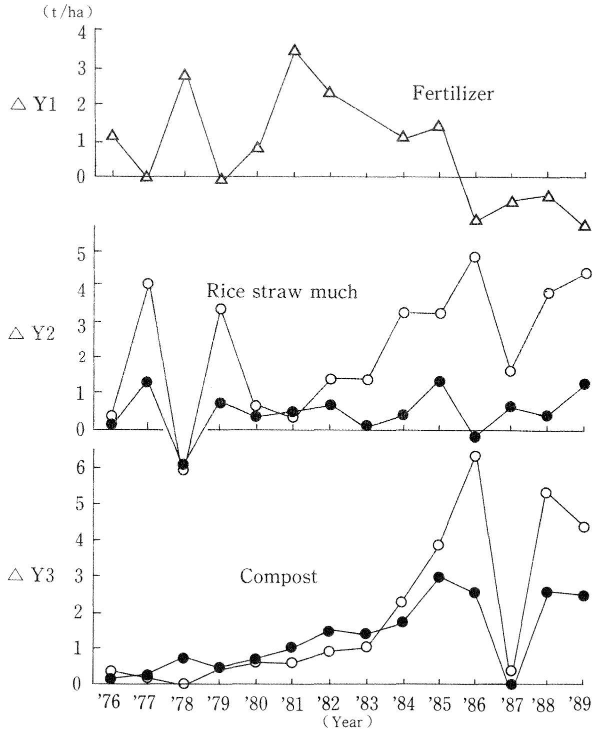
Table 2 Five year average of grain yield of corn at site 2

Treatment		Average grain yield (t/ha)				Min.-Max.
Fertilizer	Organic matter	1976/1980	1981/1985	1985/1989	Average	
−F	Control 1.84	1.82	1.82	1.64	1.76	0.39-3.10
−F	Rice straw	2.16	2.46	2.46	2.36	1.43-4.28
−F	Compost	2.34	2.45	3.79	2.58	0.68-5.88
+F	Control	2.72	3.46	1.23	2.44	0.22-5.55
+F	Rice straw	4.21	5.43	5.10	4.91	3.92-7.56
+F	Compost	3.05	5.28	4.19	4.17	1.02-8.24

Organic Matter Management
Control ; No organic matter application
Rice straw ; Rice straw mulch (4t/ha/year)
Compost ; Municipal compost (20t/ha/year)

Fertilizer (N-P_2O_5-K_2O kg/ha):
100-100-100 in 1976-1979, 63-63-0 in 1980-1989
−F: Without fertilizer
+F: With fertilizer

Plot size: 6 × 5.25m (31.5m^2) Spacing of corn: 75 × 75cm 3 plant/hill, 53,300 plant/ha



△Y1 ; Yield increment by chemical fertilizer
△Y2 ; Yield increment by rice straw much
△Y3 ; Yield increment by compost incorporation
1987: severe drought damage at cob-filling stage

Fig. 2 Grain yield gain by fertilizer application, plant residue mulch and compost application.

Short-term effect of organic matter application on the soil environment

(1) Soil erosion control

For sustainable upland crop production, fertile surface soil should be conserved by proper soil management. The effect of plant residue mulch on soil erosion under corn cropping is shown in Table 3. Soil mass erosion from a 50m slope length (1% slope) was 27t/ha/year under fallow and 17t/ha/year without mulch under corn cropping. When the soil was covered with plant residues, soil mass erosion was remarkably reduced to 3.4t/ha/year even in the field with a 5% slope.

(2) Control of surface runoff

Fig. 3 shows the effect of corn stalk mulch on surface runoff at the later stage of corn growth. In the absence of soil coverage with corn stalk, about 50% of the rainfall water was lost by surface run-off in the field under fallow, whereas practically no surface runoff of rain water occurred under corn cropping with corn stalk mulch.

(3) Soil moisture conservation

Table 3 Effect of soil management on soil erosion under corn cropping (Ueno *et al.*, 1989)

Treatment	Soil mass eroded (t/ha/year)	
	1% slope	5% slope
Control (no mulch)	17.4	36.5
Corn stalk mulch	3.4	3.4
Weed mulch	4.1	5.5
Fallow	27.2	98.3

1) Mulch : 5 ton dry matter per ha
2) Annual precipitation : 1,300mm
3) Slope length : 50m

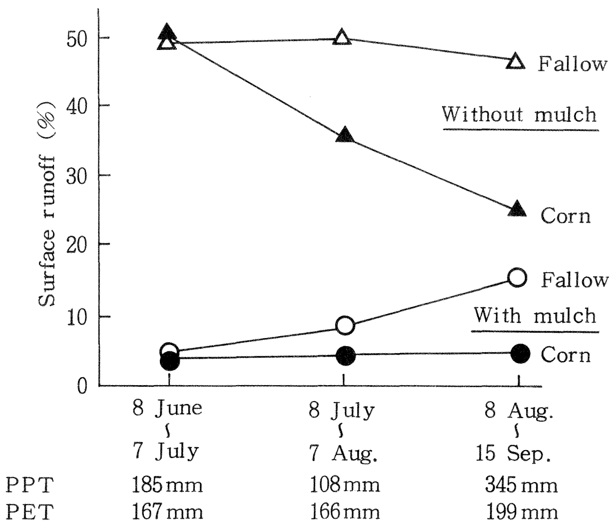


Fig. 3 Effect of corn stalk mulch on surface runoff under corn cropping and fallow (Ueno, 1989).

Soil moisture storage at a soil depth of 0-90cm was estimated from the moisture content and bulk density of the soil samples that were taken from every 15cm of the soil layer. As shown in Fig. 4, soil moisture storage was always higher in the field under plant residue mulch particularly in the growing season. However, the effect of the mulch on the moisture storage was not conspicuous during the dry season where the soil moisture content decreased below a level equivalent to the permanent wilting point (pF 4.0).

(4) Movement of soil nutrients

Fig. 5 shows the movement of nutrients in soil with and without plant residue mulch under fallow. The soil column experiment using an eslon tube 7cm in diameter revealed that almost all the ammonium nitrogen applied as ammonium sulfate was transformed into nitrate nitrogen and leached out from 21cm of the soil column within 2 months. The transformation and the mineralization of soil nitrogen were enhanced by the plant residue mulch. After 8 weeks during which the precipitation reached 250mm, a larger amount of nitrate nitrogen moved down below 21cm of the soil column in the tube with plant residue mulch compared with the tube without mulch. Although there was a remarkable increase in the content of potassium and phosphate in soil under plant residue mulch, no significant movement of potassium and phosphate was observed during the 8 week period.

Since the amount of exchangeable cations, particularly calcium decreased significantly after 8 weeks due to the downward movement of the cations associated with nitrate anion, the soil underwent a process of acidification. Split appplication of nitrogen fertilizer could contribute to the increase of the fertilizer efficiency and prevent soil acidification.

(5) Fate of applied nitrogen in corn cropping

A ^{15}N field experiment demonstrated that the presence of plant residue mulch under fallow enhanced the leaching loss of nitrogen through the downward movement of nitrate nitrogen, whereas under corn cropping it enhanced the uptake of nitrogen by the corn plant.

As shown in Table 4, 63% of the nitrogen applied as ammonium sulfate equivalent to 100kg N/ha was not recovered in the fallow field with the plant residue mulch. Under corn

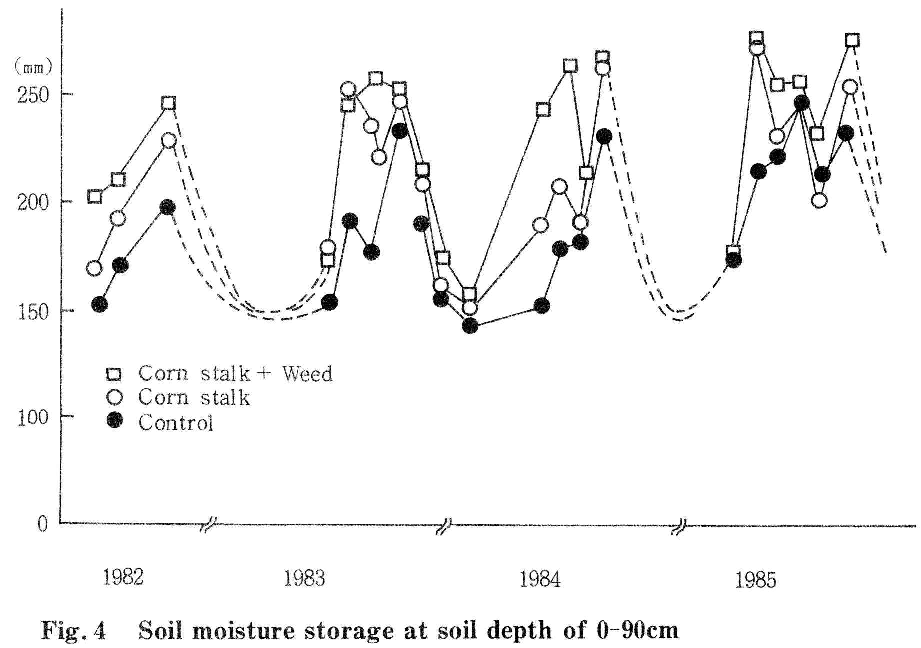


Fig. 4 Soil moisture storage at soil depth of 0-90cm
(Rearranged from Inoue*et al.*, 1984 and Nakaya *et al.*, 1986).

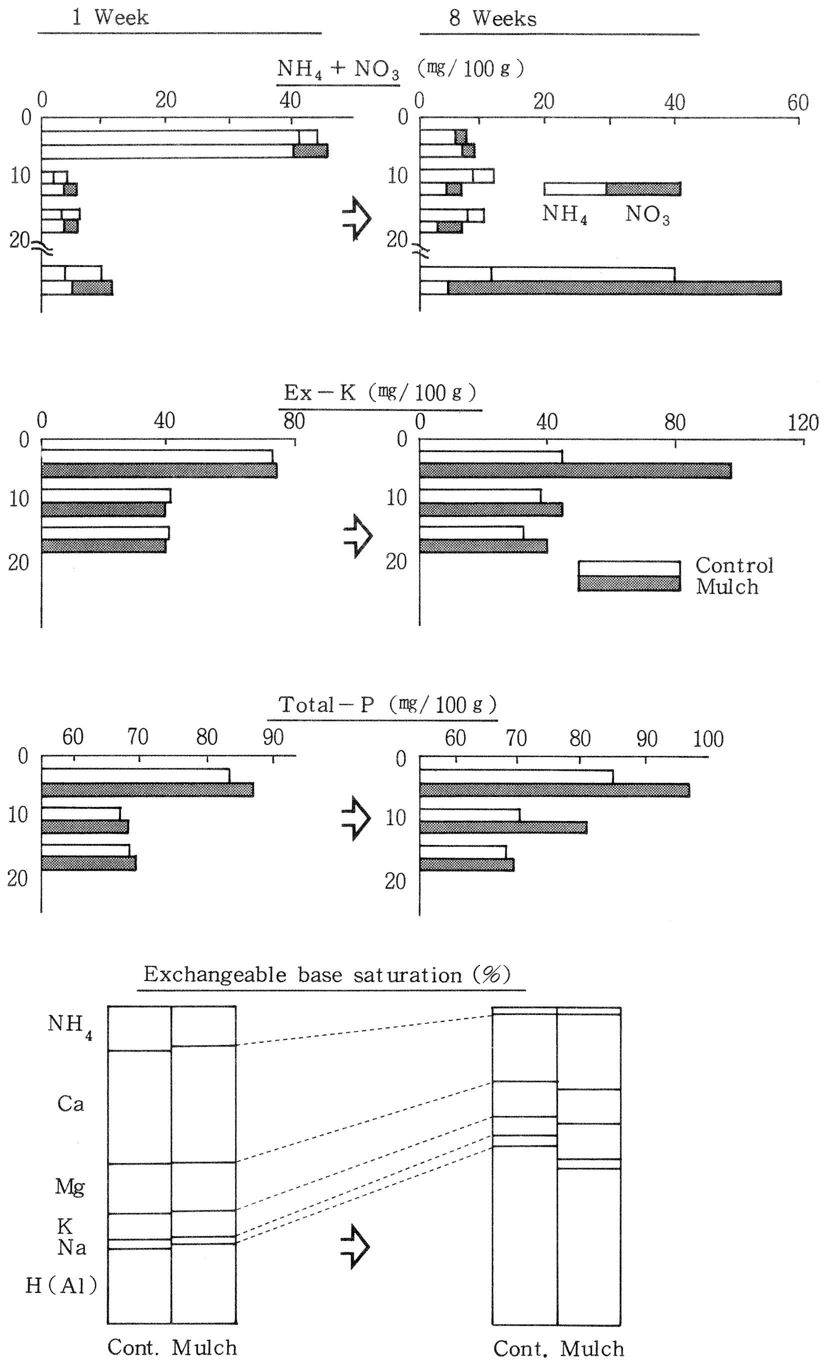


Fig. 5 Movement of nutrients in soil column with and without plant residue mulch under fallow (Inoue *et al*., 1984).

Table 4 Fate of applied nitrogen under corn cropping at harvesting stage (Uehara *et al.*, 1985)

Treatment	Recovery (%)				
	In soil (0-90cm)	In mulch	In crop	Sum	Unknwon
No crop, no mulch	83	-	-	83	17
No crop, mulch	36	1	-	37	63
Corn, no mulch	76	-	24	100	0
Corn, mulch	50	1	49	100	0

Mulch : corn stalk mulch (5t/ha)

cropping, the efficiency of nitrogen fertilizer uptake reached 49% by mulch practice, i.e. twice as much nitrogen was taken up by the corn plant compared with the treatment without mulch practice.

Long-term effect of organic matter application on the soil properties

(1) Changes in soil chemical properties

Table 5 shows the pH value, CEC and cation status of the surface soil under various levels of fertilizer and organic matter application in the long-term field experiments.

Table 5 PH value, CEC and cation saturation levels as affected by long-term application of organic matter at sites 1 and 2

Year Treatment		pH (H_2O)	CEC	Ca	Mg	K	Na	B.S (%)
			meq/100g					
1981					(Site 1)			
N0		5.9	6.85	2.60	0.90	0.32	0.15	58.0
1989								
N0		6.2	7.04	7.00	0.87	0.45	0.09	119.5
N0CS		5.9	6.08	5.00	0.96	0.29	0.09	104.3
N0MCS		6.5	7.04	6.50	0.99	0.88	0.09	120.2
N50		5.4	6.56	5.00	0.81	0.15	0.10	92.4
N50CS		5.4	6.64	5.50	0.75	0.21	0.09	98.6
N50MCS		6.2	7.04	6.50	0.94	0.77	0.17	119.0
N100		5.3	6.72	4.00	0.71	0.28	0.11	75.9
N100CS		5.0	6.48	4.00	0.67	0.18	0.09	76.2
N100MCS		5.5	6.88	5.50	0.92	0.56	0.11	88.5
1976					(Site 2)			
Control	−F	6.0	5.14	2.51	0.55	0.11	0.10	63.6
1989								
Control	−F	6.8	5.04	5.50	0.54	0.10	0.09	123.6
R. straw	−F	6.8	5.52	5.75	0.54	0.41	0.09	123.0
Compost	−F	8.1	6.48	14.00	0.96	0.29	0.11	237.0
Control	+F	5.7	5.20	4.00	0.60	0.12	0.09	92.5
R. straw	+F	6.1	5.12	4.50	0.62	0.29	0.09	107.4
Compost	+F	8.0	7.02	17.00	1.25	0.35	0.13	266.1

Compost ; calcareous municipal compost.
500 to 1,000kg of lime was annually applied in all the plots.

Nitrogenous fertilizer tended to decrease the soil pH, whereas continuous application of organic matter as plant residue mulch alleviated this tendency. Municipal compost increased the soil pH due to the high concentration of calcium in the compost. In site 2, a linear relation between the CEC and carbon content of the soil was observed: C(%)=0.308+0.100 CEC, r=0.582.

(2) Increase in soil organic matter content

Fig. 6 depicts the changes in the soil organic matter contents as affected by organic matter application. When compost was applied at the rate of 20t/ha, soil organic matter

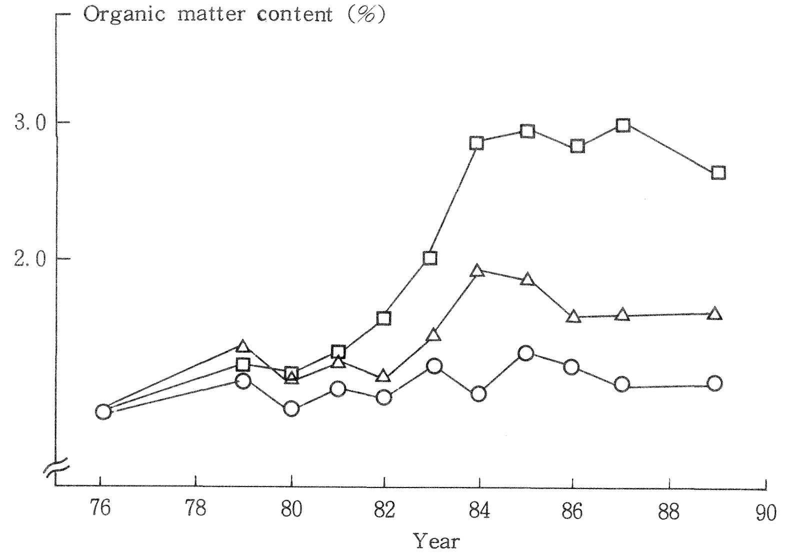


Fig. 6 Change of soil organic matter content as affected by long-term application of organic matter.

content at first did not increase significantly but after 8 years it started to increase remarkably to reach a value three times as high as that of the initial level. This increment is in agreement with the yield increment shown in Fig. 2.

Continuous application of plant residue mulch (4.0t/ha/year) also did not result in the increase of the organic matter content during the first 8 years, but thereafter the content rose from 1.0 to 1.5%.

(3) Increase in nitrogen fertility

As shown in Table 6, continuous application of rice straw and compost increased the total carbon and nitrogen content to a great extent. In the absence of chemical fertilizer, large amounts of inorganic nitrogen and biomass nitrogen remained in the soil.

The use of chemical fertilizer alone did not appear to increase the inorganic nitrogen content appreciably and it rather decreased the biomass nitrogen content significantly, which may result in the depression of the grain yield as a whole (Fig. 2).

(4) Changes in soil physical properties

Table 7 summarizes the effect of long-term application of organic matter on the soil physical properties. Continuous application of organic matter as long as 10 years markedly improved the soil physical properties such as bulk density and plasticity, and slightly improved the soil porosity, hydraulic conductivity, soil hardness and aggregate stability.

A five year application of organic matter even at a rate of 10t/ha/year did not appear

Table 6 Carbon and nitrogen content of surface soil after application of organic matter during 14 years (Watanabe *et al.*, 1989)

(March 1989)

Treatment		T-C (%)	T-N (%)	Inorg-N	Available N (mg/100g)	Biomass-N
Control	−F	0.74	0.055	0.29	3.08	3.16
Rice straw	−F	1.11	0.061	0.62	3.81	3.62
Compost	−F	1.54	0.112	0.27	3.88	2.08
Control	+F	0.74	0.053	0.50	3.93	1.39
Rice straw	+F	1.20	0.070	0.55	3.26	4.25
Compost	+F	2.08	0.128	0.76	5.11	3.16

Table 7 Effect of long-term applicatin of organic matter on soil physical properties

(Nakaya *et al.*, 1986)

Treatment	Rice straw (4t/ha)	Compost (20t/ha)	Weed+Corn stalk (10t/ha)
Year applied	10	10	5
Porosity	+	+	0
Bulk density	++	+	0
Hydraulic conductivity	+	+	0
Available moisture	0	0	0
Soil hardness	+	+	+
Plasticity	++	++	+
Aggregate stability	+	+	+

++ : improved significantly
+ : somewhat improved
0 : no improvement

to improve the soil physical properties yet, although some signs of improvement in soil hardness, plasticity and aggregate stability could be observed.

Technical problems and economic evaluation of organic matter application

Long-term experiment on corn yield under plant residue mulch and compost application revealed that the use of organic residues in corn cropping is a low input technology for increasing or stabilizing corn production in the rainfed areas of Thailand.

In practice, it is very difficult to introduce this technology directly to farms due to the cost of transportation and labour problems. This technology may induce the incidence of pests and diseases as well as of harmful insects and attract animals (snakes, rodents, birds, etc.), it may cause fire and may introduce some weed seeds into the fields. Plant residue mulch may disturb some farm practices such as fertilizer topdressing, hilling-up, and weeding. Leaching loss of nitrate nitrogen may be enhanced by plant residue mulch particularly in the years with high rainfall. Incorporation of organic matter with high C/N ratio may temporarily lead to nitrogen deficiency in corn through nitrogen competition between the roots and soil microbes.

However, as mentioned in this report, the plant residue mulch practice exerts a beneficial effect on corn yield. The effect can be divided into two kinds; a short-term effect and a long-term effect. The former includes soil erosion and run-off control, attenuation of soil temperature, soil moisture conservation and increase of fertilizer efficiency. The latter includes the improvement of the soil physical properties and the enhancement of the soil fertility level which become evident very slowly.

Table 8 shows an example of economic evaluation of the mulching practice. In the

Table 8 Estimation of net income in corn cropping with and without plant residue mulch

Treatment		1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Average	CV %
Control	(−F)	6,820	880	5,720	1,545	5,500	2,200	2,640	5,500	2,200	6,160	3,916	54
Control	(+F)	5,590	−2,990	8,010	−2,550	5,020	7,660	5,680	3,700	2,600	7,220	3,994	94
Mulch	(−F)	7,040	3,960	3,300	3,080	5,940	3,300	5,280	5,720	3,300	12,980	5,390	22
Mulch	(+F)	6,740	6,030	5,590	4,930	6,780	8,540	8,940	5,680	9,860	14,700	7,779	36

1) Net income in baht = (crude income) − (cost of fertilizer)
2) Crude income : 2,200 baht/ton of grain corn x yield ton/ha (1982)
3) Fertilizer cost : 19-13-9 baht/kg N-P205-K20 (1982)
4) LSD : 5% = 2,070 baht, 1% = 2,800 baht for net income

calculation, handling cost of mulching material was not taken into consideration. In drought years (1977 and 1979), the crude income derived by selling grain corn did not compensate the cost of fertilizer in the field without mulching practice. Net income under mulch practice did not fluctuate year by year. Highest average net income was attained by the mulch practice with fertilizer application, the average value being almost twice as high as that in the absence of plant residue mulch.

Though many technical problems still remain to be solved before the technology can be transferred, proper soil management consisting of either plant residue mulch or compost application would at least provide some economic answers to sustainable upland crop production under rainfed conditions in Thailand.

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