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Effects of Long-term Organic Material Amendments on Soil Properties and Corn Yield in Rainfed Area of Thailand

Prapit SANGTONG and Kunihiko KATOH*

JIRCAS Office, Soil Science Group, Department of Agriculture (Bangkok 10900, Thailand)

Abstract

A long-term field experiment on organic material application has been conducted since 1980 at Phraphuttabat Technical Service Center, Lop Buri Province, Thailand, to clarify the effectiveness of organic materials on chemical and physical properties of soil and yield of corn. Mimosa was the most effective crop for increasing organic matter content of soil. Total and Bray Ⅱ extractable phosphorus content markedly increased in city compost plots. Rice straw showed significant effect on increasing total and exchangeable potassium in soils. Total Ca, Mg, Cu, Zn, extractable Cu, Zn and exchangeable Ca contents distinctively increased in city compost plots. Extractable Fe content significantly increased in the mimosa plot. Average yield of corn with and without fertilizer from 2000 to 2005 showed that the use of crotalaria, mimosa, rice bean and city compost was beneficial to increase the production of corn yield for one, two, four and three years out of a six year experimental duration, respectively. The 5-year moving average of corn yield for 26 years showed the following trends. Corn yield in the mimosa plot without fertilizer increased but the increase was relatively low. The corn yields in the rice bean plot were relatively high during 1982-1986 and 1999-2003 in both fertilizer plots. The yield of corn in crotalaria plots with and without fertilizer was at a relatively low level from 1980 to 1988, and increased from 1989 to 2005. This long-term experiment suggests that application of green manure improved soil properties. Competition of green manure with corn resulted in a relatively low yield of corn and on the contrary, without the competition of green manure corn yields were relatively high. Rice straw mulch with fertilizer was effective in maintaining corn yield under critical rainfall years, while rice straw mulch without fertilizer did not increase the corn yield like that of the fertilizer plot under critical rainfall conditions. Although city compost application was effective in increasing corn yield, precautions against heavy metal contamination should be taken into consideration.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: crotalaria, mimosa, rice bean, rice straw

Introduction

Corn is one of the most important agricultural products in Thailand. The yield of corn has remained at low levels for the past 26 years. Inoue et al.[8] described the deterioration of chemical and physical properties of soil as the primary reason for low yields. The use of green manures such as mimosa, crotalaria and rice bean as well as organic matters such as rice straw and city compost were considered to be promising farm practices for improvement and maintenance of soil productivity.

There are a number of leguminous crops that can be utilized as green manure[3,10,13,22,24,27]. Crimson clover[24] and hairy vetch[10,27] were reported to be effective in increasing corn yield. Shahandeh et al.[22] showed that green manure, dolichos and sesbania had significantly increased millet grain yield in Mali. Mcdonagh et al.[13] demonstrated the residual benefit of the stover of groundnut to a subsequent corn crop in upland soil in northeast Thailand. These reports showed that the effect of the green manure on crop growth resulted primarily from their influence on soil N availability.

Long-term application of green manure, chemical fertilizer, rice straw and city compost may result in accumulation of nitrogen, phosphorus, potassium and heavy

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*Corresponding author: 404–8 Takaatsu, Nasushiobara, Tochigi 329–2813, Japan.
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metal. Richards et al.[19] showed that long-term addition of chemical fertilizer significantly increased total phosphorus. Pascual et al.[18] and Parat et al.[16] reported that sewage sludge addition increased heavy metal concentrations in the soil. Long-term experiments are effective to evaluate the change in soil properties[1,4,5,9,17,30].

Inoue et al.[8] described water shortage during the growing period of the crop as the reason for low corn production in a rainfed area of Thailand. The distribution of rainfall fluctuates year by year and month by month. Long-term experiments are indispensable to evaluate the effect of organic matter application on the soil properties and corn yield in rainfed areas [26].

A long-term field experiment has been carried out for 26 years (1980-2005) in Phraphuttabat, Lop Buri Province, Thailand. This experiment was initiated by Igarashi et al.[7] and has been continued by Inoue et al.[8], Uehara et al.[25], Nakaya et al.[14], Watanabe et al.[29], Ueno et al.[26], Fujimoto et al.[6], Suzuki et al.[23] and Prapit and Katoh. The objectives of this study were (1) to examine the long-term effects of green manure, rice straw, city compost and chemical fertilizer on the changes in nutrient contents of the soil and yield of corn and (2) to clarify the effect of rainfall on the yield of corn.

Method

A field experiment has been carried out to study the effect of long-term mulching and incorporation of organic materials on soil fertility and corn yield. The treatments of plots and growth season of plant are described in Table 1. Every year, corn was planted at about the last week of May, the early rainfall period, and harvested in early September. Mung bean was sown between the rows of corn at about 7-10 days before harvesting corn. Corn stalk was mulched between mung bean plants. Mimosa (*Mimosa invest*), crotalaria (*Crotalaria juncea*) and rice bean (*Vigna umbellate*) were intercropped between corn plants. Seeds of mimosa germinated from the remaining seeds of the previous year in the soil. Seeds of crotalaria were sown about 2 weeks after sowing corn. After about 45 days of growth, crotalaria was cut down and spread on the soil as mulch from 1980 to 1988. From 1989 to 2005, seeds of crotalaria were sown at about 80-85 days after corn planting. Seeds of rice bean were sown at about 50 days after seeding of corn. The residue of mimosa, crotalaria from 1989-2005 and rice bean was incorporated into the soil in the following year.

Corn variety and application rate of N-P-K, rice straw, city compost and lime are shown in Table 2. Corn (*Zea mays*) variety Suwan 1 was grown from 1980 to1988 and variety Nakhon sawan 1 was used from 1989 to 2005. From 1980 to 2005, ammonium sulfate and triple super phosphate were used at the rate of 62.5 kg N/ha and 62.5 kg P_20_5/ha, respectively. From 1990 to 2005, besides N and P fertilizer, K was applied at the rate of 62.5 kg K_20/ha. Rice straw was mulched at the rate of 4 tons/ha. City compost was incorporated at 20 tons/ha until 1988 and after that changed to 6.25 tons/ha. Application of city compost was stopped in 1996. In 1990, every treatment except the city compost plot was limed with dolomite at the rate of 0.5 ton/ha before planting corn.

The experimental design was a factorial in randomized complete block with three replications, and plot size was 5.25 m × 6.00 m. About one week before land preparation for planting, glyphosate was applied to eradicate weeds. Corn was grown with spacing of 75 × 25 cm. During cultivation, if there were any outbreaks of worms or pests, some pesticides such as alachor and azodrin were applied. This experiment was conducted under rainfed conditions.

The pH value of soil was determined with a glass electrode. Organic matter content was calculated from the organic carbon, which was determined by means of the Walkley-Black method[28]. Total nitrogen was determined by the semi-micro Kjeldahl method[2]. Total phosphorus was determined colorimetrically by means of the vanado-molybdo phosphoric yellow method[15]. Available phosphorus (Bray Ⅱ) was determined colorimetrically by the ascorbic acid blue method. Exchangeable cations (K, Ca, Mg) were extracted by the method of Shollenberger[20], and extractable Mn, Cu, Zn and Fe were extracted by DTPA[12]. K, Ca, Mg, Mn, Cu, Zn and Fe were determined by the atomic absorption method. The data obtained were subjected to analysis of Duncan's Multiple Range Test. For mean comparisons, significance was tested at $P < 0.05$.

Results

Average soil chemical properties with and without chemical fertilizer applications and soil chemical properties (T-P, T-Ca and T-Mn) are shown in Tables 3 and 4, respectively. The pH values ranged between 5.6 and 7.3. Soil pH in the city compost plot was high due to high cation concentration caused by application of city compost. Organic matter content in soil greatly increased in mimosa plots. Total nitrogen concentration increased in the mimosa plot. Total and Bray Ⅱ extractable phosphorus content markedly increased in city compost application plots. Rice straw showed a significant effect on increasing total and exchangeable potassium in soils.

Total Ca, Mg, Cu, Zn, extractable Cu, Zn and exchangeable Ca contents distinctively increased in city compost plots. Extractable Fe content significantly increased

Table 1. Treatments of plots and growing season of plants

	Treatment	Period		Apr–Dec
1	Control	1980-2005	a	corn
			b	mung bean
2	Crotalaria	1980-1988	a	corn
				crotalaria
			b,c	mung bean
		1989-2005	b,d	corn
			b	crotalaria
3	Mimosa	1980-2005	e	corn
				mimosa
4	Rice straw	1980-2005	a,f	corn
			b	mung bean
5	Rice bean	1980-2005	b,g	corn
				rice bean
6	City compost	1980-2005	a,h	corn
			b	mung bean
7	Control + F	1980-2005	a,i	corn
			b	mung bean
8	Crotalaria + F	1980-1988	a,i	corn
				crotalaria
			b,c	mung bean
		1989-2005	b,d,i	corn
			b	crotalaria
9	Mimosa + F	1980-2005	e,i	corn
				mimosa
10	Rice straw + F	1980-2005	a,f,i	corn
			b	mung bean
11	Rice bean + F	1980-2005	b,g,i	corn
				rice bean
12	City compost + F	1980-2005	a,h,i	corn
			b	mung bean

a : Residue of mung bean was incorporated.
b : Corn stalk was mulched.
c : Residue of Crotalaria was mulched.
d : Residue of Crotalaria was incorporated.
e : Residue of mimosa was incorporated.
f : Rice straw was mulched.
g : Residue of rice bean was incorporated.
h : City compost was incorporated.
i : Chemical fertilizer was applied.

in the mimosa plot.

Average corn yield with and without chemical fertilizer from the years 2000 to 2005 is shown in Table 5. The use of crotalaria, mimosa, rice bean and city compost increased the corn yield for one, two, four and three years out of a six year experimental duration, respectively. The 5-year moving average of corn yield for 26 years is shown in Fig. 1. Corn yield in the mimosa with no fertilizer plot increased but the increase was relatively low. The yields of rice bean plots were relatively high during the 1982-1986 and 1999-2003 in both fertilizer plots. The crotalaria plots with and without fertilizer resulted in relatively low

Table 2. Corn variety and application rate of N-P_2O_5-K_2O, rice straw, city compost, and lime

		1980-1988	1989	1990	1991-1995	1996-2005
Corn variety		Suwan 1	NS 1	NS 1	NS 1	NS 1
N-P_2O_5-K_2O	(kg/ha)	62.5-62.5-0	62.5-62.5-0	62.5-62.5-62.5	62.5-62.5-62.5	62.5-62.5-62.5
Rice straw	(ton/ha)	4	4	4	4	4
City compost	(ton/ha)	20	6.25	6.25	6.25	0
Lime	(ton/ha)	0	0	0.5	0	0

NS1: Nakhon Sawan 1.

Table 3. Soil chemical properties (2004-2005)

	pH		OM (%)		T-N (%)		Bray II-P (ppm)	
Treatments	2004	2005	2004	2005	2004	2005	2004	2005
Control	6.9 b	6 b	1.5 c	1.4 c	0.07 b	0.07 b	32 b	31 bc
Crotalaria	6.6 bc	6.1 b	1.7 bc	1.4 c	0.08 b	0.07 b	24 b	19 cd
Mimosa	6.4 c	5.6 c	2.2 a	2.1 a	0.11 a	0.1 a	34 b	38 b
Rice straw	6.9 b	6.3 b	1.7 bc	1.7 b	0.08 b	0.07 b	27 b	26 bcd
Rice bean	6.8 b	6.2 b	1.8 bc	1.3 c	0.08 b	0.07 b	26 b	14 d
City compost	7.3 a	7.2 a	1.8 b	1.7 b	0.1 a	0.08 b	203 a	163 a
	T-K (ppm)		T-Mg (ppm)		T-Fe (%)		T-Cu (ppm)	
Treatments	2004	2005	2004	2005	2004	2005	2004	2005
Control	474 bc	481 c	394 b	351 bc	2 b	1.8 b	12 cd	14 bc
Crotalaria	470 c	478 c	392 b	375 b	2 b	1.8 b	15 bc	16 bc
Mimosa	535 b	512 c	394 b	340 bc	1.9 b	1.7 b	16 b	16 b
Rice straw	700 a	656 a	374 b	334 c	1.9 b	1.7 b	12 d	13 c
Rice bean	435 c	457 c	392 b	355 bc	2 b	1.8 b	13 cd	15 bc
City compost	661 a	592 b	573 a	475 a	2.4 a	2 a	53 a	53 a
	T-Zn (ppm)		Exc-K (ppm)		Exc-Ca (ppm)		Exc-Mg (ppm)	
Treatments	2004	2005	2004	2005	2004	2005	2004	2005
Control	35 b	31 b	61 c	53 bc	544 b	-	68 b	-
Crotalaria	35 b	34 b	50 cd	35 d	506 b	-	73 ab	-
Mimosa	41 b	36 b	79 b	56 b	569 b	-	81 a	-
Rice straw	32 b	46 b	187 a	148 a	528 b	-	69 b	-
Rice bean	39 b	32 b	43 d	38 cd	526 b	-	77 ab	-
City compost	152 a	125 a	90 b	46 bcd	1036 a	-	84 a	-
	Ext-Fe (ppm)		Ext-Mn (ppm)		Ext-Cu (ppm)		Ext-Zn (ppm)	
Treatments	2004	2005	2004	2005	2004	2005	2004	2005
Control	12 c	10 c	29 c	16 a	1.4 c	1.4 b	2.2 c	1.9 b
Crotalaria	16 b	13 d	34 b	16 a	3.5 b	1.5 b	2.1 c	2 b
Mimosa	28 a	25 a	40 a	18 a	2.2 bc	1.4 b	4.9 b	4.3 b
Rice straw	13 bc	12 bc	30 bc	16 a	1.2 c	1.1 b	2.8 bc	2 b
Rice bean	13 bc	11 bc	33 bc	16 a	1.5 c	1.4 b	3.4 bc	2 b
City compost	8 d	7 d	15 d	13 a	12.1 a	11.1 a	29.4 a	22.9 a

Means in columns followed by the same letter are not significant at $P < 0.05$, using Duncan's Multiple Range Test.
Means of treatments include plots with and without chemical fertilizer.

Table 4. T-P, T-Ca and T-Mn of soil at 2004 or 2005

	T-P (ppm) 2004		T-Ca (ppm) 2004		T-Mn (ppm) 2005	
Treatments	F-	F+	F-	F+	F-	F+
Control	194 b	277 b	1820 b	1580 b	292 b	406 a
Crotalaria	186 b	277 b	1630 b	1620 b	321 ab	356 a
Mimosa	199 b	318 b	1780 b	1800 b	422 a	314 a
Rice straw	174 b	262 b	1690 b	1690 b	306 ab	320 a
Rice bean	194 b	274 b	1770 b	1610 b	335 ab	411 a
City compost	472 a	678 a	3010 a	4410 a	337 ab	342 a

Means in columns followed by the same letter are not significantly different at P < 0.05, using Duncan's Multiple Range Test.
F-: Plot without chemical fertilizer, F+: Plot with chemical fertilizer.

Table 5. Corn yield (2000-2005)

	Yield of corn (ton/ha)											
Treatments	2000		2001		2002		2003		2004		2005	
Control	1.9	ab	2.5	b	2.1	b	2.4	c	3.6	b	1.7	a
Crotalaria	2.7	ab	3	b	2.6	ab	3.7	ab	4.2	ab	2.1	a
Mimosa	2.9	a	1.2	c	2.2	ab	3.7	ab	5.1	a	2.6	a
Rice straw	1.9	b	2.3	b	2.1	b	3	bc	4.5	ab	2.5	a
Rice bean	2.6	ab	3.9	a	3.1	a	4.1	a	4.6	a	2.5	a
City compost	2.3	ab	2.5	b	3	a	3.5	ab	4.9	a	2.2	a

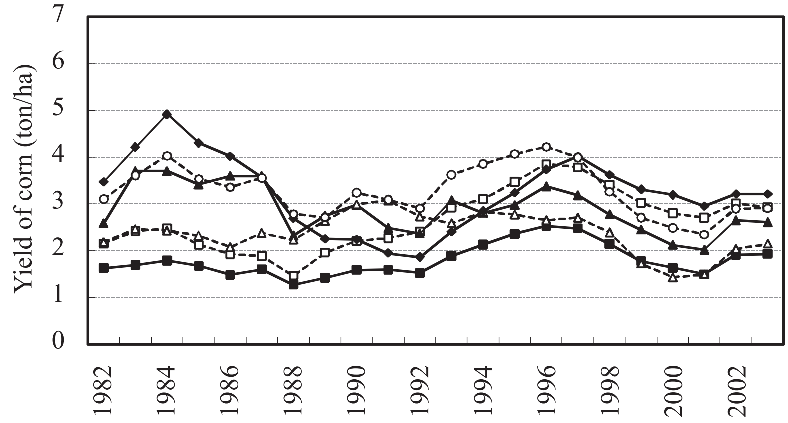
Means in columns followed by the same letter are not significantly different at P < 0.05, using Duncan's Multiple Range Test.
The values in [box] are higher than those of the control plot.
Means of treatments include plots with and without chemical fertilizer.

yields of corn from 1980 to 1988, and yields increased from 1989 to 2005. City compost application was effective in increasing corn yield.

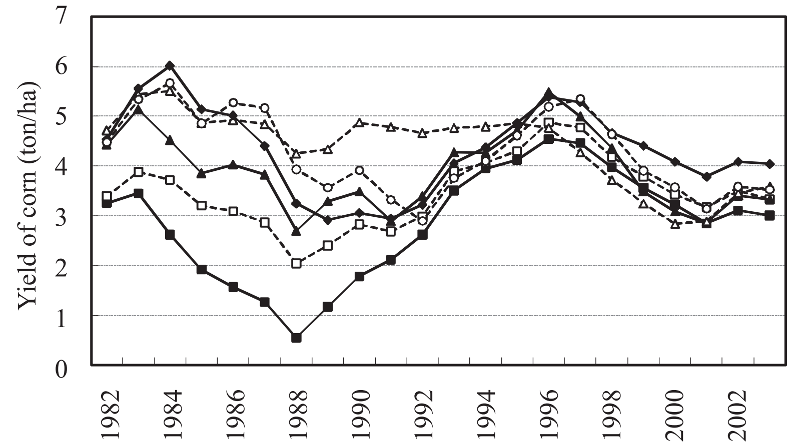
Monthly precipitation at Phraphuttabat center from 1980 to 2005 is shown in Table 6. Ueno et al.[26] calculated the critical amount of rainfall at Phraphuttabat center in June (91.3 mm), July (92.3 mm), August (81.7 mm) and September (63.5 mm). The calculation method for critical amount of rainfall is shown in Table 6. Rainfall lower than the critical amount are supposed to cause water stress in corn. According to Table 6 which shows the years of critical rainfall, there were 12 years of critical rainfall and 14 years of no critical rainfall years. In this report, critical rainfall years have been defined as the years with an amount of monthly rainfall below the critical amount of monthly rainfall for at least one month. Average corn yields for 12 years of critical rainfall and 14 years of no critical rainfall with and without fertilizer treatments are shown in Fig. 2. Figure 2 shows that under critical rainfall years, rice straw mulch with fertilizer was effective in maintaining corn yield. On the contrary, rice straw mulch without fertilizer did not increase corn yield like that of the fertilizer plot under critical rainfall.

Discussion

Table 3 suggests that nitrogen fixing activity of mimosa enriched the soil nitrogen fertility. Watanabe et al.[29] confirmed that inorganic N increased in the green manure applied soils in June. Incorporated organic matter of mimosa improved soil physical properties. Nakaya et al.[14] indicated that the use of mimosa improved the soil physical properties such as three phase distribution and moisture retention. However, mimosa seed that fell to soil in the



a Yield of corn (−Fertilizer)



b Yield of corn (+Fertilizer)

Fig. 1. Effect of soil management on the 5-year moving average of corn yield
Five year moving average of corn yield (Yn) was calculated using 5 year yield of corn ($X_{n-2,n-1,n,n+1,n+2}$) as follows: Yn = (Xn-2 + Xn-1 + Xn + Xn+1 + Xn+2)/5
—■— : Control, --□-- : Crotalaria, —▲— : Mimosa, --△-- : Rice straw, —◆— : Rice bean, --○-- : City compost.

previous year emerges in May or in June. Mimosa had a competition problem with corn for water and nitrogen use during water stress period in June, July and August. This competition of mimosa with corn might be the reason for the relatively low yield of corn in critical rainfall years (Fig. 2).

The yields of rice bean plots were relatively high during 1982-1986 and 1999-2003 in both fertilizer plots (Fig.1). Table 3 shows that T-N did not accumulate in the soil with application of rice bean residue. However, Watanabe et al.[29] showed an increase in inorganic N from residue of rice bean in soil of plots without fertilizer in June. Nakaya et al.[14] reported that incorporation of rice bean improved soil physical properties in the soil of fertilizer plots. These findings and no competition of rice bean with corn for water and nitrogen might be the reason for the relatively high yield of corn during 1982-1986 and 1999-2003.

From 1980 to 1988, the seeds of crotalaria were sown 2 weeks after corn sowing, and were grown for about 45 days, and then crotalaria plants were cut down to spread on the soil. Crotalaria had relatively low N uptake because of the short growth period. Crotalaria also had competition with corn. The low N uptake and competition of crotalaria with corn might be the reason for the relatively low yield of corn from 1980 to 1988. From 1989 to 2005, crotalaria seeds were sown at about 80-85 days after corn planting. The residues of crotalaria were incorporated into soil in the following year. The yield of corn from 1989 to 2005 increased due to the long growth period of crotalaria and no

Table 6. Precipitation at Phraphutthabat Center

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	0	15	28	41	170	232	128	234	233	85	54	0	1218
1981	0	120	25	147	133	83	249	160	353	78	131	0	1479
1982	0	0	38	72	204	174	118	170	291	113	57	0	1238
1983	3	0	0	0	213	106	80	325	352	334	63	0	1473
1984	0	74	33	76	139	56	154	216	198	95	6	0	1047
1985	2	15	0	98	261	136	222	132	217	194	25	0	1301
1986	0	0	0	185	237	54	246	203	210	127	0	0	1261
1987	0	0	21	16	54	113	167	36	334	229	64	0	1033
1988	3	48	0	130	337	221	157	188	221	208	0	0	1513
1989	21	7	0	29	187	57	177	256	200	78	19	0	1030
1990	0	0	10	13	274	156	151	40	308	414	28	0	1394
1991	17	0	1	110	100	117	114	244	155	60	0	23	942
1992	4	5	0	0	96	150	242	271	88	175	0	13	1044
1993	0	0	21	35	122	40	132	177	261	88	0	2	878
1994	24	0	169	79	189	240	28	410	115	106	9	0	1368
1995	0	0	34	136	64	123	340	304	359	109	0	0	1469
1996	0	31	2	225	244	145	132	86	225	216	160	0	1466
1997	0	0	8	28	92	89	151	139	375	163	4	0	1048
1998	0	18	39	86	394	157	243	117	223	161	18	0	1456
1999	41	2	0	261	240	127	109	180	195	233	48	1	1437
2000	0	24	8	214	329	169	222	341	167	193	1	0	1667
2001	12	11	134	54	189	94	96	77	214	91	23	29	1023
2002	4	0	60	63	271	133	44	308	167	88	54	19	1211
2003	0	24	243	129	68	221	207	112	188	76	0	0	1268
2004	1	32	0	66	24	92	161	171	216	30	0	0	792
2005	3	0	29	99	141	121	179	92	259	69	134	94	1220
Total	164	552	981	2775	5689	3863	4956	5720	7269	4089	983	219	37278
Mean	5.5	18.4	32.7	92.5	189.6	128.8	165.2	190.7	242.3	136.3	32.8	7.3	1242.6

Critical amount of rainfall was 91.3 mm (June), 92.3 mm (July), 81.7 mm (August), and 63.5 mm (September).
Critical amount of rainfall (CAR) was calculated using potential evapotranspiration (PET) and available soil water (ASW) as follows. CAR = PET - ASW, Monthly data on pan evaporation were used to determine the PET.
The numbers in □ are lower than those of critical amount of rainfall.

competition of crotalaria with corn. These findings suggest that application of green manure would improve soil properties. The competition of green manure with corn resulted in relatively low yields of corn; on the contrary, without that competition yields of corn were relatively high.

Under critical rainfall, rice straw mulching with fertilizer was effective in maintaining corn yield (Fig.2). Ueno et al.[26] described that the soil moisture level of a rice straw plot with fertilizer was higher than that of the other plots. The practice of mulching with rice straw has a favorable effect on crop yield through maintenance of soil moisture condition. Similar results were reported. Seneviratne et al.[21] recommended the use of leaves in order to increase the conservation of soil moisture in Sri Lanka. Latif et al.[11] reported that intercropped legumes significantly decreased dry bulk density and soil penetration resistance. Under critical rainfall, the yield of corn in the plot with rice straw mulch without fertilizer did not increase like that in the fertilizer plot. One of the reasons for this trend was due to low soil inorganic N content of the plot in June (Watanabe et al.[29]). Uehara et al.[25] described that under no fertilizer application, rice straw mulching was not effective due to nitrogen starvation of the corn plant.

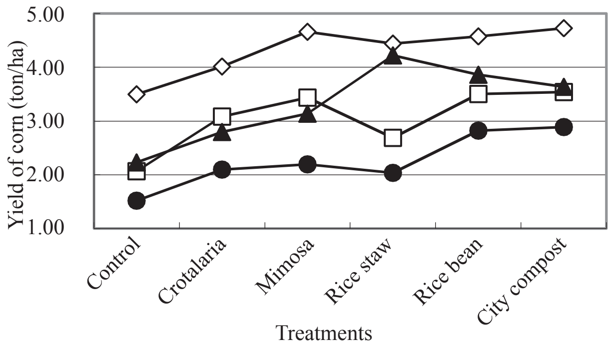


Fig. 2. Effect of soil management on the average corn yield under critical and no critical rainfall years

No critical + F : Average corn yield under no critical rainfall years in the fertilizer plots.
No critical : Average corn yield under no critical rainfall years in the no fertilizer plots.
Critical + F : Average corn yield under critical rainfall years in the fertilizer plots.
Critical : Average corn yield under critical rainfall years in the no fertilizer plots.
—◇— : No critical+F, —□— : No critical,
—▲— : Critical+F, —●— : Critical.

City compost application affected the increase in corn yield. This was caused by the high accumulation of plant nutrients especially P, K and Ca. Total Zn in the soil of the years 2004 and 2005 were 152 and 125 ppm, respectively. Long-term application of city compost to the soil caused Zn contamination. Parat et al.[16] found that long-term applications of sewage sludge resulted in accumulation of total Zn in the surface soil layer. Precautions against heavy metal contamination should be taken into consideration.

The yield of corn in the control treatment with fertilizer plot was 2.91 tons/ha (Fig. 1). This value was very low compared to the average corn yield in Thailand in 2003 (3.9 tons/ha). One of the reasons for this low value is due to the variety of corn, Suwan 1 and Nakhon sawan 1, which have low yield potential and are more sensitive to drought than other commercial varieties. Most farmers in Thailand are now growing hybrid corn, especially drought tolerant varieties. Hybrid and drought tolerant varieties are recommended for evaluating the effectiveness of organic materials on increasing corn yield.

Humus composition of soil was studied by Suzuki et al.[23]. He concluded that humus composition was changed clearly by the use of green manure as well as incorporation of city compost. Among green manures, mimosa showed a marked increase in free humic acid. Watanabe et al.[29] studied seasonal change of total biomass in the soil. Results showed that biomass-N and non biomass-N including microbial cell wall played an important role on soil productivities.

According to the results achieved from these experiments, it can be inevitably concluded that long-term experiment are indispensable for evaluating the effect of organic matter application on the soil properties and corn yield in rainfed area.

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