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Effects of long-term organic material applications and green manure crop cultivation on soil organic carbon in rain fed area of Thailand

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Abstract

A long-term field experiment on organic material application and crop rotation with green manure crops has been conducted since 1976 at Lopburi Agricultural Research and Development Center, Department of Agriculture, Lop Buri Province, Thailand, to clarify the effect of organic materials and green manure crop on soil organic carbon changes. The stock change factors that stand for the relative change of soil organic carbon on the carbon stock in a reference condition (native vegetation that is not degraded or improved). Stock change factor for input of organic matter (F_I), representing different levels of C input to soil such as organic material application, crop residue treatment and green manure crop cultivation, was computed with the present field experimental results. While the computed F_I of "High input with manure" was within the range of IPCC default F_I value, some of the computed F_I of "High input without manure" was much higher than the IPCC default though it was varied due to the biomass production and nutrient contents of the green manure crops planted as the second crops after corn. Therefore, the F_I computed by field experimental results can contribute to more accurate estimation of SOC changes in farm land especially in Southeast Asia because the default F_I mostly depends on the experimental data in temperate zones. Moreover, the field experiment has focused the effect of reduced tillage practices on SOC changes and corn yield since 2011. The results of the experiment will be used to compute Stock change factor for management regime (F_{MG}) which represents the effects of tillage operations.

Key Words: Soil organic carbon, Organic material application, Green manure crop

1 Introduction

Green House Gas (GHG) emissions from the agricultural sector is 26 per cent of the total GHG emission in developing regions (UNFCCC, 2005). Farm lands stock an enormous amount of carbon as soil organic matters. Farm and forest lands can serve as carbon sinks if they are managed appropriately so as to increase or maintain soil carbon. The change of soil carbon is determined by the balance of carbon (e. g. manure) application and decomposition of organic matter in soil. It is greatly affected by the farm land management such as manure application, and by crop residue management and tillage.

IPCC (2006) has proposed three Tiers to develop an inventory of soil organic carbon (SOC) stock changes

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for mineral soils. In Tier 1, SOC changes can be estimated using the equation:

$$SOC = SOC_{REF}\, F_{LU}\, F_{MG}\, F_{I} A \tag{1}$$

where SOC = soil organic carbon stock in the specific climate zone, soil type and management system, tons C; SOC_{REF} = the reference carbon stock, t C ha^{-1}; F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless; F_{MG} = stock change factor for management regime, dimensionless; F_I = stock change factor for input of organic matter, dimensionless; A = land area, ha.

The stock change factors express the relative change of soil organic carbon on the carbon stock in a reference condition (native vegetation that is not degraded or improved). In Tier 1, the SOC stock is computed from the default reference SOC stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I) proposed by IPCC. Tier 2 uses the same equation but country-specific information like stock change factors is incorporated. Tier 3 methods involve more detailed and country-specific models. Default stock change factors were computed using a global dataset of experimental results for tillage, input, set-aside, and land use. Most of the experiments were implemented in North America and Europe which are located in temperate zones and few are found in tropical zones especially in Southeast Asia (Fig. 1). Like other sources of GHG emissions in agriculture, decomposition / accumulation of soil organic matter is highly affected by environmental factors such as soil and climate. Therefore it is crucial to estimate the stock change factors using field experimental data in respective regions.

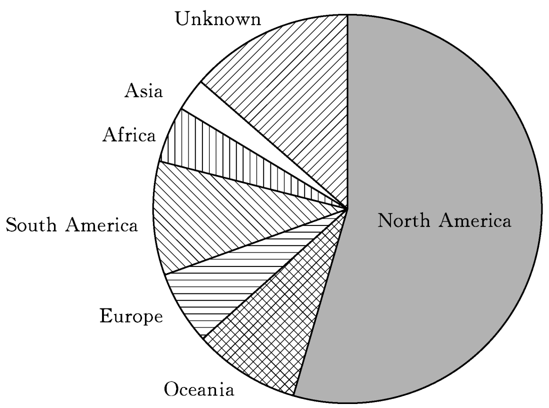

Fig. 1 Geographical distribution of field experiments cited for default stock change factors of IPCC
Source: By authors based on IPCC (IPCC, 2006).

Long-term experiments are effective to evaluate the change in soil properties (Böhme et al., 2004; Parham et al., 2002). Since 1976, the Japan International Research Center for Agricultural Sciences (JIRCAS), and the Thailand Department of Agriculture (DOA), Ministry of Agriculture and Cooperative have conducted a long-term field experiment at the Lopburi Agricultural Research and Development Center, DOA, Lop Buri Province, Thailand. The experimental results of earlier studies involving the long-term effects of green manure, organic material and chemical fertilizer application on soil nutrient contents and yield of corn, as well as the effect of other factors like soil moisture on corn yield have been reported (Sangtong & Katoh, 2010; Fujimoto et al., 1996). In this report the stock change factors for input (F_I) are estimated using field experimental data. The relevancy of the estimated factors is discussed by comparing them with the default factors of IPCC.

2 Research methodology

A field experiment was conducted to study the effect of long-term crop rotation with green manure crops and application of organic materials on SOC. The general properties of the soil in the experimental field are shown in Table 1. The soil is a Typic Paleustults, Ultisols in the USDA Taxonomy system. The treatments of plots are described in Table 2. Every year, corn was planted in May, the early rainfall period, and harvested in late August or early September. Mungbean (*Vigna radiata*) was used as the second crop after corn, and mimosa (*Mimosa invisa*), crotalaria (*Crotalaria juncea*) and ricebean (*Vigna umbellate*) were intercropped with corn from 1976 to 2005. Corn stalks were mulched between second crop planting except for Treatments 1 and 7 before 1980. After about 45 days of growth, crotalaria was cut and spread on the soil as mulch from 1980 to 1988. The residue of mimosa, crotalaria from1989 – 2005 and ricebean was incorporated into the soil the following year. Velvet bean (*Mucuna pruriens*), soybean (*Glycine max*) and sunflower (*Helianthus annuus*) were planted as the second crops after 2006.

Corn variety Suwan 1 was grown from 1980 to1988, variety Nakhon sawan 1 was used from 1989 to 2005 and variety Nakhon sawan 2 was used after 2006. Chemical fertilizers of the conventional dosage were applied to Treatment 7 – 12 (Chemical fertilizer applied: CF). No chemical fertilizers were applied to treatment 1 – 6 (No/Low chemical fertilizer applied: NF) from 1976 to 2005 and the reduced dosage was applied after 2006. The application rate is shown in Table 2. Rice straw was mulched. City compost was incorporated and terminated in 1996. In 1990, every treatment except Treatment 6 and 12 (city compost plot) was limed with dolomite (0.5 t ha^{-1}) before planting corn.

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

SOC was determined by means of the Walkley-Black method (Walkely & Black, 1934). Since some of the original data in the early stage of the experiment was missing, most of the data were obtained as an average of the three replications. However, if the original data was available, data obtained were subjected to analysis of Duncan's Multiple Range Test. For mean comparisons, significance was tested at $P < 0.05$.

Table 1 General properties of the soil in the experimental field (as of 2010)

Depth (cm)	% sand	% silt	% clay	Texture	pH	% OM
0 – 13	50.99	35.2	13.8	Loam	5.8	1.84
13 – 27	45.99	35.2	18.8	Loam	5.7	1.24
27 – 50	40.99	20.2	38.8	Clay loam	5.1	0.99
50 – 75	35.99	15.2	48.8	Clay	4.0	0.98

NH_4^+ (mg kg^{-1})	NO_3^- (mg kg^{-1})	% Total N	Avail. P (mg kg^{-1})	CEC (c mol kg^{-1})	B. D. * (g cm^{-3})
17.50	12.25	0.17	15	9.02	1.5
15.75	5.25	0.16	9	10.94	1.6
22.75	5.25	0.16	7	23.06	1.7
26.25	1.75	0.17	2	22.86	1.7

* B. D.: Bulk density.

Source: By authors.

Table 2 Treatments of plots

Treatments NF	CF		1976 – 1979		1980 – 1995		1996 – 2005		2006 – 2008	
1	7	Control	MZ-MG	L		M		M		M
2	8	Crotalaria	MZ-F, stalk inc	L	MZ-CR	H		H		H
3	9	Mimosa	MZ-F, stalk mul	L	MZ-MM	H		H	MZ-VB	H
4	10	Rice straw	MZ-MG, RS	O		O		O	MZ-MG, NT, RS	O
5	11	Ricebean	MZ-MG, vinyl	L	MZ-RB	H		H	MZ-SY	H
6	12	Compost	MZ-F, Comp	O		O	MZ-F	L	MZ-SF	M, H

MZ: corn, MG: mungbean, F: fallow, stalk inc: corn stalk incorporated, stalk mul: corn stalk mulch, CR: crotalaria, MM: mimosa, VB: velvet bean, RS: rice straw (4 t ha^{-1}), vinyl: vinyl mulch, RB: ricebean, SY: soybean, Comp: city compost (20 t ha^{-1} in 1976 – 1988, 6.25 t ha^{-1} in 1989 – 1995), SF: sunflower, NT: no-till.

L: Low input, M: Middle input, H: High input without manure, O: High input with manure; corresponding the input level proposed by IPCC (IPCC, 2006). See Table 4.

NF: No chemical fertilizer in 1976 – 2005 and N: P_2O_5 : K_2O = 41.5 kg ha^{-1} – 41.5 kg ha^{-1} – 41.5 kg ha^{-1} applied in 2006 –

CF: Chemical fertilizer applied (N : P_2O_5 : K_2O = 100 kg ha^{-1} – 100 kg ha^{-1} – 50 kg ha^{-1} in 1976 – 1979, 62.5 – 62.5 – 0 in 1980 – 1989, 62.5 – 62.5 – 62.5 in 1990 –).

3 Results and discussions

SOC trends during the experiment are shown in Table 3. As of 2005, SOC increase in soils ranged from 1.31 to 1.97 times of the initial SOC in 1976 with the highest increase observed in Treatment 3 of NF followed by Treatment 6 and Treatment 12 of CF followed by Treatment 9. These treatments planted mimosa as a green manure crop or applied city compost. The SOC increase of Treatment 6 and 12 which applied city compost during 1976 to 1995 showed the highest SOC in 1995. SOC of these treatments reduced or marginally increased after the compost application was terminated in 1996. Even Treatment 1, which didn't apply any fertilizers by 2005 but only incorporated crop residue of corn and mungbean after 1980, increased SOC significantly.

Values with the same letter (for 2008) in Treatments 1 – 6 and 7 – 12 respectively are not significantly different at $P<0.05$.

Values for 2008 are means followed by Standard Deviation.

F_I (stock change factor for input of organic matter): Relative SOC changes of 2005/1976 to that of Treatment 1 (for Treatments 2 – 6) and Treatment 7 (for Treatments 8 – 12).

Table 3 **SOC trends (% in 0 – 15 cm depth) and computed F_I**

		1976	1980	1995	2005	2008	2005/1976	F_I (1976 – 2005)
1	NF Control	0.64	0.48	0.75	0.84	0.88±0.11 a	1.31	1.00
2	NF Crotalaria	0.64	0.53	0.84	0.95	0.92±0.03 ab	1.48	1.13
3	NF Mimosa	0.64	0.61	0.91	1.25	1.08±0.14 ab	1.95	1.49
4	NF Rice straw	0.64	0.66	0.72	1.13	1.01±0.18 ab	1.77	1.35
5	NF Ricebean	0.64	0.51	0.62	1.00	0.89±0.07 a	1.56	1.19
6	NF Compost	0.64	0.66	1.29	1.22	1.21±0.03b	1.91	1.45
7	CF Control	0.64	0.52	0.66	0.85	0.89±0.02 a	1.33	1.00
8	CF Crotalaria	0.64	0.67	0.92	1.00	0.92±0.05 a	1.56	1.18
9	CF Mimosa	0.64	0.58	0.99	1.23	1.03±0.08 ab	1.93	1.45
10	CF Rice straw	0.64	0.61	0.73	1.16	1.18±0.08 b	1.81	1.37
11	CF Ricebean	0.64	0.61	0.89	1.08	0.96±0.09 a	1.69	1.27
12	CF Compost	0.64	0.67	1.24	1.26	1.16±0.05 b	1.97	1.48

An input factor (F_I) represents different levels of C input to soil. The default F_I is proposed by IPCC as SOC changes in soil surface (0 – 30 cm) over 20 years in the respective management practices on crop land relative to nominal ("medium") carbon input levels (IPCC, 2006). Table 3 shows F_I computed with the present field experimental results during 1976 to 2005. For the treatments of NF (Treatments 1 – 6), Treatment 1 (NF control) was used as the nominal carbon input levels while Treatment 7 (CF control) was used as the nominal carbon input levels for the treatments of CF (Treatments 7 – 12).

The description of input level proposed by IPCC (IPCC, 2006) is shown in Table 4. According to the description, Treatments 2, 3, 5 of NF and Treatments 8, 9, 11 of CF belong to "High input without manure" except an initial stage (1976 – 1979) of the experiment, when all these treatments belong to "Low input". Treatments 4, 6 of NF and 10, 12 of CF belong to "High input with manure" except Treatments 6 and 12 after 1996 when the compost application was terminated.

Table 4 **The description of input level proposed by IPCC**

Input level	Description
Low	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e. g., vegetables, tobacco, cotton), no mineral fertilization or Nfixing crops.
Middle	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e. g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
High without manure	Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
High with manure	Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.

Source: IPCC (IPCC, 2006).

Comparing IPCC default F_I (High input without manure: 1.11±10%, High input with manure: 1.44+ 14% (IPCC, 2006), the computed F_I was 1.13 – 1.49 (Treatments 2, 3, 5: High input without manure) and 1.35 – 1.45 (Treatments 4, 6: High input with manure) in NF, and 1.18 – 1.45 (Treatments 8, 9, 11: High input without manure) and 1.37 – 1.48 (Treatments 10, 12: High input with manure) in CF. While the computed F_I of High input with manure was within the range of IPCC default value, some of the computed F_I of High input without manure was much higher than the IPCC default. Due to the constraints of data availability, F_I was computed by SOC data in soil surface (0 – 15 cm) in the present study while IPCC default F_I is for 0 – 30 cm depth. The SOC change in surface soil is more active than subsoil (Yang & Wander, 1999). Therefore, the computed F_I might be overestimated since the F_I in subsoil (15 – 30 cm) could be lower than that of soil surface. All of the treatments implemented crop rotation with green manure crops namely, mungbean, mimosa, crotalaria and ricebean. There are a number of leguminous crops that can be used as green manure (McDonagh et al., 1993; Shahandeh et al., 2004; Torbert et al., 1996; Utomo et al., 1990) including the crops used in this experiment. However, the amount of biomass and nutrient components produced by the crops are widely varied. Table 5 shows the yield and nutrient content of selected green manure crops. Since mimosa provides a higher mass yield than traditional row crops (Huang et al., 2013), it will increase SOC more than the traditional row crops when it is used as a green manure crop. The carbon contents of organic matters by farmers are also varied resulting in a wide range of SOC changes according to the amount and raw material of manure applied.

It should also be noted that the amount of SOC increase or decrease is affected by the initial SOC. Some studies use SOC changes relative to initial SOC contents to avoid the influence of initial SOC values (Paul et al., 2002) when SOC change data with different initial SOC's should be compared. As discussed above, the default stock change factors of IPCC are used to estimate the SOC stock at the specific time as multiplying the reference carbon stock by these factors. Reference carbon stock is a soil organic carbon stock under native vegetation and the default value proposed by IPCC is 47 t C ha^{-1} in 0 – 30 cm depth (soils with low activity clay minerals, tropical moist) for the soil in the present experimental field (IPCC, 2006). The actual initial SOC in the present experimental field in 1976 was around 30 t C ha^{-1} in 0 – 30 cm depth, which was much lower than the IPCC default carbon stock. The higher computed F_I of "High input without manure" in some treatments than the IPCC default F_I means that the effects of green manure crops for SOC changes were more obvious in the present experiment because of the lower initial SOC. On the other hand, the initial SOC was little affected by the SOC changes in "High input with manure" treatments. This suggests that since manure application has a quicker and greater effect on SOC changes than green manure crops which must decompose before increasing SOC, manure application might cover the impacts from the lower initial SOC.

Table 5 **Yield and nutrient content of selected green manure crops**

	Stem + leaf weight ($t\ ha^{-1}$)		Nutrient content ($kg\ ha^{-1}$)		
	Fresh	Dry	N	P	K
Mungbean (U-Thong 1)	3.50	1.10	10	1	13
Soybean (SJ 5)	2.60	0.94	15	3	14
Mucuna sp. from CIAT	38.40	8.16	224	16	135
Crotalaria juncea	21.10	9.50	130	11	86
Mimosa sp	50.90	18.34	262	29	248

Note: The crops were grown at Rayong Field Crops Research Centre, Rayong, Thailand in 1987.
Source: (Howeler et al., 1998).

In the Tier 2 of IPCC to develop an inventory of SOC, each country can use country-specific stock change factors. Table 6 shows the results of SOC change estimation (assumption: annual cropland in tropical moist region with low input levels and full tillage converted to high input with/without manure managements for 25 years) both by using IPCC default F_I and computed F_I in the present study. All the estimated SOC changes of "High input without manure" during 1980 – 2005 using the computed F_I were greater than the estimated SOC changes using the default F_I. Though the actual SOC changes observed in the experimental field were still higher than the estimated SOC changes using the computed F_I, the use of F_I computed by field experimental data can contribute to a more accurate estimation of SOC changes.

Since the present experiments mostly investigated the effects of green manure crops and organic material application, little information is available for the effect of tillage management on SOC, which can be used to compute F_{MG}. Therefore, a part of the field experimental treatments were modified in 2011 and a no-tillage practice was introduced to investigate long term effects of reduced tillage practices on SOC and corn yield. It is anticipated that the results of the on-going experiment will contribute to the improved F_{MG} based on the field experimental data.

Table 6 Estimated SOC changes in 0 – 30 cm depth by default F_I and computed F_I in the present study

Treatment	F_I	SOC_{REF} ($t\ ha^{-1}$)	$SOC_{(0-t)}$ ($t\ ha^{-1}$)	SOC(0) ($t\ ha^{-1}$)	SOC changes [$SOC_{(0-t)} - SOC_{(0)}$] ($t\ ha^{-1}$)	Observed SOC changes ($t\ ha^{-1}$)
High input without manure (Default)	1.11	47	20.8	25.0	4.3	NA
NF Crotalaria	1.13	47	20.8	25.5	4.8	19.2
NF Mimosa	1.49	47	20.8	33.5	12.8	29.1
NF Ricebean	1.19	47	20.8	26.9	6.1	22.3
CF Crotalaria	1.18	47	20.8	26.5	5.8	15.0
CF Mimosa	1.45	47	20.8	32.8	12.0	29.8
CF Ricebean	1.27	47	20.8	28.7	8.0	21.5
High input with manure (Default)	1.44	47	20.8	32.5	11.7	NA
NF Rice straw	1.35	47	20.8	30.3	9.6	21.4
NF Compost	1.45	47	20.8	32.8	12.0	25.5
CF Rice straw	1.37	47	20.8	30.8	10.1	25.1
CF Compost	1.48	47	20.8	33.5	12.7	27.0

Note: Assumed that annual cropland in tropical moist region with low input levels and full tillage converted to high input with/without manure managements for 25 years.

SOC_{REF}: Native reference carbon stock for a tropical moist climate on Ultisol soils

$SOC_{(0-t)}$: SOC stock at the beginning of the inventory time period (annual cropland with low input levels and full tillage) = SOC_{REFD}×0.48 (default F_{LU} for long-term cultivated in tropical moist)&×1 (default F_{MG} for full tillage)×0.92 (default F_I for low input)

$SOC_{(0)}$: SOC stock in the last year of an inventory time period (annual cropland with high input with/without manure levels and full tillage) = SOC_{REFD}×0.48 (default F_{LU} for long-term cultivated in tropical moist)×1 (default F_{MG} for full tillage)×F_I

Observed SOC change: Actual SOC changes in the experimental field from 1980 to 2005

Source: By authors based on (IPCC, 2006) and the field experimental data.

4 Conclusions

Stock change factor for input of organic matter(F_I), representing different levels of C input to soil such as organic material application, crop residue treatment and green manure crop cultivation, was computed with the long-term field experimental data in Lopburi Agricultural Research and Development Center, DOA, Lop Buri Province, Thailand. While the computed F_I of "High input with manure" was within the range of IPCC default F_I value, some of the computed F_I of "High input without manure" was much higher than the IPCC default though it was varied due to the biomass production and nutrient contents of the green manure crops planted as the second crops after corn. The F_I computed by field experimental results can contribute to more accurate estimation of SOC changes in farm land especially in Southeast Asia because the default F_I mostly depends on the experimental data in temperate zones.

The long-term field experiment in the present study has been continued. Since 2011 the experiment has focused the effect of reduced tillage practices on SOC changes and corn yield. The results of the experiment will be used to compute F_{MG} which represents the effects of tillage operations.

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