On-farm assessment of long term effects of organic matter management on soil characteristics of paddy fields threatened by salinity in Northeast Thailand

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Keywords: Organic matter management, paddy, fertilizer, farmer management

Abstract

In Southeast Asia, the long-term effects of organic matter management (OMM) on the soil's attributes have seldom been studied in on-farm situations. Most studies are carried out in experimental plots where, except for OMM, all practices are kept similar. Therefore, their results need to be validated in the various crop management, soil and climatic conditions prevailing in the region. This paper develops an on-farm approach to diagnose some impacts of farmers' OMM practiced during the last five years at least, in Northeastern Thailand. Surveys and field measurements were carried out on a network of 53 rainfed paddy fields belonging to 50 farmers. The network was designed to be representative of three OMM (straw burned; straw buried; and straw buried + animal manure) whose effects on soil characteristics can be more or less variable depending on the interactions between two rice establishment methods, (transplanting and broadcasting), various levels of N fertilizer (N<20 kg ha^{-1} and 20<N<100 kg ha^{-1}) and two topographic positions of the fields (170 m<altitude<190 m and 190 m<alt<210 m). Whatever the method of sowing, the level of N fertilization and the field's elevation, straw incorporation was not associated with higher soil organic carbon, pH, exchangeable cations, or with lower bulk density or electrical conductivity (EC) as compared with straw burning. Applications of animal manure were usually less than 1 t ha^{-1} and had no significant effect on these soil parameters. So far, there is little evidence that the various OMM currently practiced by farmers of this region will make any difference regarding the soil fertility evolution.

Keywords: Organic matter management (OMM); On-farm research; interactions; total C; salinity; sandy soils

Introduction

The possibility of rapidly forecasting long-term effects of cropping systems on soil fertility is one of the main concerns of sustainable agriculture (Hansen, 1996). In the rainfed paddy systems of Northeastern Thailand, this question is very important since many farmers, in order to reduce the cost of land preparation, burn the rice straw remaining on the fields after harvest. Conversely, others go to much trouble to incorporate it, or even to add animal compost, being convinced that these practices will improve the fertility and prevent salinization of the soil (Grunberger, and Hartmann, 2004). A decrease in organic matter content of soils in the longterm could be very harmful since many farmers of this region are too poor to invest in mineral fertilizers. Hence, they often rely on the indigenous soil N supply to satisfy most of the rice crop's demand (Olk et al., 2000; Powlson and Olk, 2000).

One of the difficulties of the assessment of these OMM in Northeast Thailand is the need to take into account the interactions of various cropping practices existing over the region (Olk et al., 2000; Powlson and Olk, 2000). Indeed, due to the higher yields associated with the transplanting method of establishing rice compared to direct seeding (Pandey et al., 2002), a higher input of carbon to soils via the residues can be expected. Therefore, effects of burning the straw on soil carbon evolution might be greater in fields where transplanting is practiced than in direct-seeded fields. Likewise, the use of inorganic fertilizer could interact with OMM effects, not only via the increase of residue inputs to soils but also through the rate of carbon mineralization (Whitbread et al., 2003, Shirato et al., 2005). As different fields elevation could be associated with varied water dynamics and salinity levels (Arunin,

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1984, Bolomey 2002, Grunberger and Hartmann, 2004), the effects of this factor on inputs of carbon as well as loss of carbon by erosion and mineralization could also be expected. Considering all these interactions, and the lack of a carbon turnover model validated for these tropical cropping systems (Parton and Stanford, 1989), the assessment of OMM over the region could be investigated using an on-farm approach rather than by a long term “in station” experiment. This on-farm approach, based on comparison of fertility criteria over a network of farmers’ fields, requires that the current cropping systems have been practiced for at least five years, so that differences in the soil fertility components can be attributed to differences in the current cropping systems (Hasewaga et al., 2005). With such a network of fields, derivation of the parameters of a generic model of organic matter evolution could be carried out. However, as many fields have to be explored, basic or summary models using few parameters could be more successful than complex models.

Few data are available on the long-term effects of the OMM practiced by the farmers in Northeast Thailand. Experimental data sets exist for the cassava system developed in the uplands of the region, but not for the paddy system (Shirato et al., 2005). Tangtrakarnpong and Vityakon (2002), regarding the paddy system as relatively homogenous in comparison with other land use types existing in the region (forests, cassava, sugarcane), showed that carbon pools (labile and stable) of the paddy system ranked second behind forest systems, as total soil organic matter decreased from 5.5 in the forest to 4.2 g kg^{-1} in the paddy system, and microbial biomass, which corresponds to the pools of higher turnover rate, decreased from 116 in the forest to 78 mg kg^{-1} in the paddy system. Whitbread et al. (2003) examined the effects of the removal or otherwise of straw, and of leaf litter application on soil carbon in experimental plots. However, because it was mainly focused on the testing of new organic matter management, this study did not consider the possible interactions of the various current cropping practices and topography of fields at the level of the region. Moreover, the burning of straw was not assessed. Other studies pointed out the possible positive effect of organic matter on soil pH, due to increase of Fe reduction in the flooded soils (Maegth, 2003; Quantin et al., submitted). In accordance with this hypothesis, Enet (2003), by comparing two fields annually receiving (or not) animal compost amendments, showed positive effects of organic matter application on soil pH, measured during the cropping period. It was however likely that this effect of organic matter could be a short term effect, not noticeable during the following dry period.

The purpose of this paper was to assess briefly, using surveys and observations over a network of farmers’ fields, long-term effects on soil carbon, nutrient content, soil pH, salinity and bulk density of various OMM strategies encountered in the paddy systems of Northeast Thailand. Comparison of annual inputs of carbon as crop residues and manure with the measured post-harvest carbon content of soils was used to formulate hypotheses for the carbon dynamics of these sandy soils threatened by salinity.

Materials and Methods

Study area

The study was carried out during the dry season of December to April 2005 in Khon Kaen Province (16ºN 102ºE) in the Northeast of Thailand. The study area was chosen as representative of the natural conditions of the region. The landscape is a gently undulating plateau containing the villages of Ban Daeng, Ban Non Bo, Ban Kraduang and Ban Non Khlong (Figure 1). The soils are classified according to the USDA Soil Taxonomy mostly as Paleaquults, and sometimes Paleustult in the central area (Craig and Pisone, 1988). They are sandy loams with a low clay fraction, mostly kaolinitic, and a low pH due to considerable leaching. Because of the presence of shallow, saline groundwater, some parts of the area can have an electrical conductivity of the saturated extract in the soil surface as high as 7 mS cm^{-1}. The mean annual rainfall in this region in the 1990s was around 1,000 mm, with 90% of this falling between May and the end of October. Daily mean temperatures vary from 20 to 28ºC during the year. Temperature and rainfall recorded at the experimental site of IRD at Ban Daeng during the 2004 cropping season are representative of the region’s annual mean (Figure 2).

A preliminary study in this region showed that the farmers mainly grow rice. The rice is transplanted once a year during the rainy season, with nothing grown in the dry season. The soil preparation, consist of two plowings to 15 cm depth using a powered cultivator. The rice is either transplanted as month-old seedlings or directly sown by broadcasting just before the second plow. Direct seeding is not associated with the adoption of zero tillage in this region, probably because herbicides are not used. It is likely that the main difference between soil preparation for direct seeding and transplanting is the soil moisture during the second plow. In case of transplanting, soil moisture

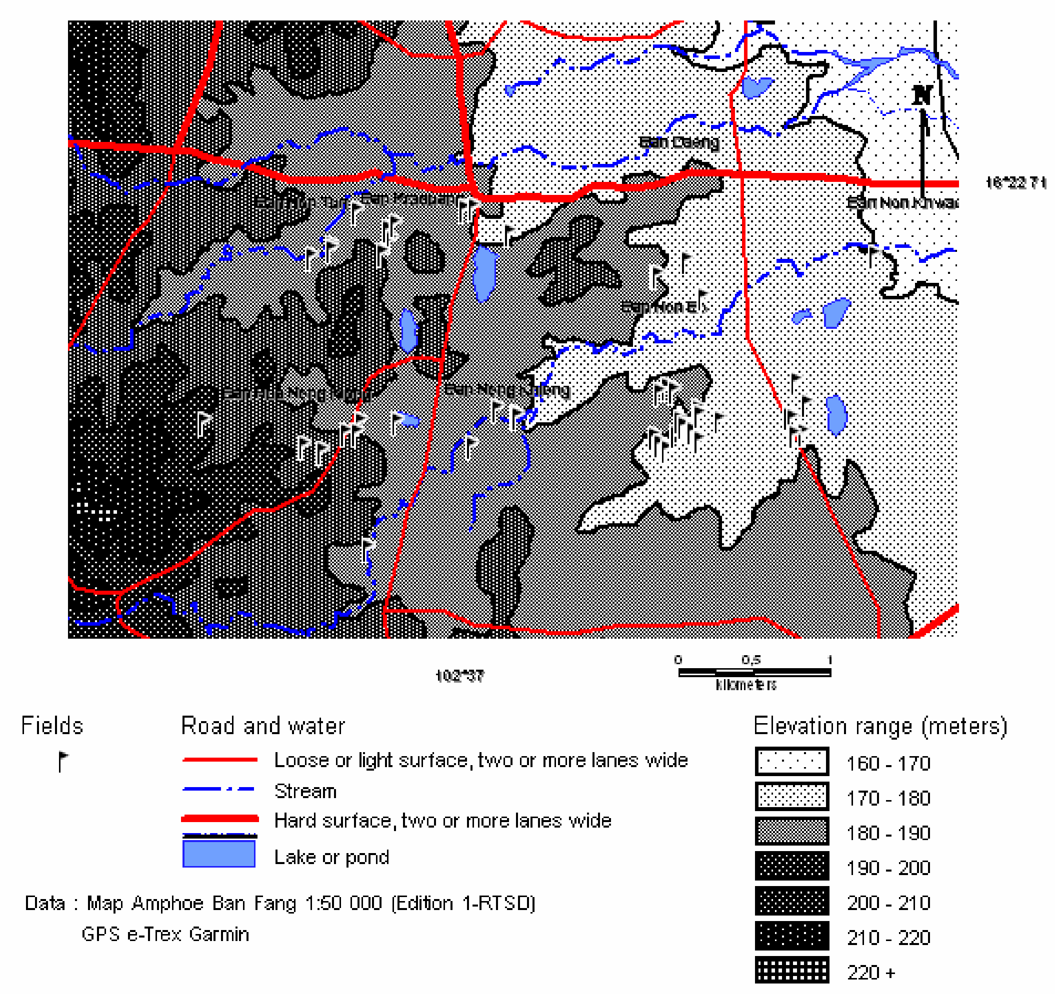

Figure 1. Map of the study area. Localisation of the paddy fields selected

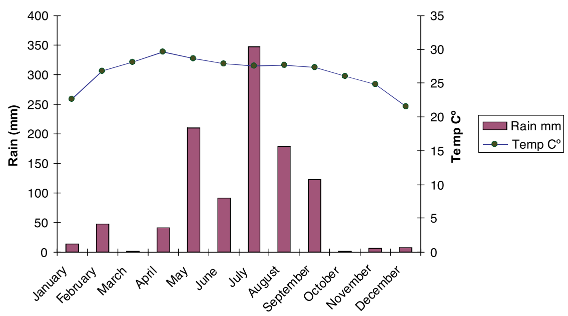

Figure 2. Monthly rainfall (bars) and average daily temperature (°) recorded in IRD site in Ban Daeng in 2004

should be very high so that the soil structure will look like a uniform mud after plowing. The most common rice variety (RD6) is glutinous, photoperiodic sensitive with a flowering period in mid-October and harvest in November. The sowing date depends on the rainfall and on the method of planting. Whereas transplanting has to be done into flooded soils, direct seeding can be done at the beginning of the rainy season when the rainfall is still light. Whatever the method of sowing, the rates of chemical fertilizers used are often less than 60, 25, 25 kg ha^{-1} of N P and K, respectively. Three main methods of organic matter management can be distinguished: 1) straw burning (SB), 2) straw incorporation (SI) or 3) straw incorporation and animal compost application (SI+C) before soil preparation. Application of animal compost is generally less than 1 t ha^{-1}.Potential yields in this area, estimated at 4 t ha^{-1} (Suzuki et al., 2003), are often not reached.

Surveys

A network of 53 plots, annually cropped with rice, were selected to represent the three main OMM methods, which were factorially combined with 2 topographic positions (lowlands, corresponding to altitudes from 170 m to 190 m, and uplands – altitudes between 191 m and 210 m), two methods of sowing (transplanting and direct seeding) and two fertilizer levels (low for applications of less than 20 kg N ha^{-1}, and high for applications from 20 to 60 kg N ha^{-1}). Applications of P and K are often combined with those of N. The structure of the network is presented

Table 1. Distribution of the fields according to organic matter management and altitude. Values in parenthesis indicate percentage of those fields using transplanting method for rice cropping

	Straw burned	Straw incorporated	Straw incorporated + animal compost
Lowland *(altitude <190 m)*	15 (60%)	14 (60%)	8 (66%)
Upland *(altitude = 190-210 m)*	6 (14%)	5 (37%)	5 (40%)
Total	**21**	**19**	**13**

in Table 1. Each plot corresponded to a set of practices stable over the last five years. The soil total N, C, cations content, pH and salinity level were considered in this study as output variables whose variations within the network could be explained by the various OMM methods interacting with various cropping practices. Within each plot, the following measurements and observations were made:

1) Soil analyses at the end of February (post-harvest period). At this time, the rice straw was still standing, as only the panicles were harvested by hand. No organic matter application or straw burning had yet been done. This period is probably the most appropriate to bring out long term effects of practices, as the short term effects of the crop management interventions are the least likely. Soil samples were made up of 5 cores collected from the 0-15 cm layer. Total organic carbon (C) was determined by the wet digestion method of Walkley and Black. Total N was determined by the Kjeldahl method. pH was determined in distilled water using 1:1 soil:solution ratio. Cation exchange capacity (CEC) was determined after a first exchange with 1M ammonium acetate at pH = 7, and a second exchange with 1 M NH_4Cl. Exchangeable (exch) Ca, Mg and K extracted with 1 M ammonium acetate at pH7 were determined by atomic absorption spectrophotometry and flame photometry. Available P was analysed using the Bray P nº2 method. Electrical conductivity (EC) was measured using a 1/5 soil water ratio.
2) Measurements of the amount of rice straw remaining on the fields after harvest (three replicates of 4 m^2).
3) Measurements of the amount of animal compost spread on the plots during the dry season, and records of farmers' estimates of the amount spread during the last five years
4) Bulk density of the 0-15 cm ploughed soil layer (three replications using a 100 cm^3 cylinder).

Data Analysis

Effects of position of the field in the landscape, OMM, method of sowing and N fertilizer level on soil contents of C, exchangeable cations and on soil pH, EC and bulk density were analysed by four-way analysis of variance using the GLM procedure and type III sum of squares of SAS 9.1 (2003). Interactions between cropping practices were also analysed statistically. The Student-Newman-Keuls test was used to compare the average values of the recorded variables.

The mineralization rate of the organic matter (K2), which is supposed to be very variable according to soil and climatic conditions and cropping systems (Mary and Guerif, 1994; Olk et al., 2000), was deduced according to the basic equation of Jenny (1941), which considers the soil carbon content as homogenous as regards its decomposition rate:

$$C_1 = C_0\, e^{-K2t} + m\, c_r\, K1(1 - e^{-K2t}) / K2$$

Assuming the soil carbon content was at equilibrium:

$$K\,2 = m\, c_r\, K1 / C_1$$

where m is the amount of annual organic dry matter supplied (mainly as straw residues), c_r the carbon content of the residues, and K1 the iso-humic coefficient which generally varies according to the composition of the amendment (Mary and Guerif, 1994). C_0 is the soil C content in the first year of the OMM application. C_1 is the total C content given by the soil analysis at the end of February 2004. As it has to be expressed in t ha^{-1} rather than mass (kg kg^{-1}), the data recorded for soil bulk density are used. The annual C supplied by straw residue humification (m* c_r *K1) was calculated assuming values of 15% for water content. K1 of rice straw was fixed at 0.15 (Mary and Guerif, 1994), and carbon content of the humus at 50%. According to the observation that the most lignin rich parts of the residues are not affected by the burning, this practice was assumed to reduce the annual C input of straw by only 50%. A specific contribution of the rice roots to the total input of carbon to soils was ignored. Carbon supplied by the compost was considered as negligible, as the fresh weights of these amendments were less than 1 t ha^{-1}.

Results

Relationships between different soil criteria

The mean values and standard deviations of each of the studied variables and their mutual correlations are presented in Table 2. Carbon content was significantly positively correlated with soil CEC. As well as CEC, carbon content was significant correlated with exch. K, Ca, and Mg. Total C and N were highly correlated, with a C/N ratio of 11 that was quite stable among fields (not shown). No significant correlations between carbon content and pH, bulk density or EC were found. EC was significantly correlated with Na and Mg.

Changes in soil characteristics according to practices

Whereas altitude had a highly significant effect on soil exch. K and Na, EC and pH, OMM had no significant long-term effect on any of the measured variables. Significant effects of method of sowing appeared on available P and bulk density. Available P was lower in direct sowing as opposed to transplanting. Exch. K and bulk density were lower and soil pH higher in fertilized than in unfertilized fields (Table 3).

Calculation of K2 assuming organic matter equilibrium

The dry weight of the straw incorporated in the SI and SI + C fields varied from 2 to 7 t ha^{-1}. This variation is significantly associated with the method of sowing, but not to the elevation of the fields or to the use of fertilizer (not shown). The dry weight of residues in the direct-seeded fields was 0.70 t ha^{-1} less than in the transplanted ones. The mean value of K2 allowing equality between annual incoming carbon and mineralized carbon was 3% in the SI fields. The same value might not apply to the SB fields under the equilibrium hypothesis: if it is assumed that about 50% of the carbon of the straw is lost due to burning, the mean K2 value of these situations should not be more than 2% (Figure 3).

Discussion

This on-farm survey was conducted to compare long-term effects of the various OMM of paddy fields existing in a region. These OMM are developed on sandy soils with a very low carbon content of 0.5% on average (Table 2). The C/N ratio of 11 suggests that the organic matter mineralizes readily in all these situations. About 20% of the CEC is due to the humus. Exch. K and Ca were very low, consistent with the low CEC. EC values were, at the time of the study, mostly below the level considered to pose a salinity problem for rice production (Dobermann and Fairhurst, 2000); however, these EC are significantly correlated with the Na content of the soils, revealing that they are due to the upward movement of saline groundwater. Due to the effects of farmers’ practices, variations in soil bulk density and pH were not significantly related to EC levels.

This study revealed that the observed differences in OMM did not result in differences in the soil C content, nor in pH, EC, exch. cations or bulk density. This non-significant effect on total C is consistent with results of Whitbread et al. (2003) who

Table 2. Average values, standard deviations of measured variables and correlations between them. Bold values mean that the correlation is significant at the 0,05 probability level

	Mean	**Root MSE**	**CEC CEC** *(cmol kg^{-1})*	**Total Carbon** *(%)*	**Exch K** *(cmol kg^{-1})*	**Exch Ca** *(cmol kg^{-1})*	**Exch Mg** *(cmol kg^{-1})*	**Exch Na** *(cmol kg^{-1})*	**EC** *(μS/cm)*	**pH H_2O**	**Bulk density** *(kg dcm^3)*	**P (Bray 2)** *(mg P kg sol^{-1})*
CEC *(cmol kg^{-1})*	4.067	2.009	–	0.61	0.44	0.81	0.67	0.05	0.12	0.02	0.07	0.14
Total Carbon (%)	0.47	0.12		–	0.48	0.68	0.45	0.07	0.00	0.14	-0.20	0.05
Exch K *(cmol kg^{-1})*	0.092	0.091			–	0.40	0.29	0.01	0.12	0.04	0.16	0.10
Exch Ca *(cmol kg^{-1})*	1.522	1.535				–	0.87	0.06	0.16	0.21	0.11	0.06
Exch Mg *(cmol kg^{-1})*	0.343	0.326					–	0.31	0.32	0.14	0.06	0.01
Exch Na *(cmol kg^{-1})*	1.341	1.414						–	0.66	0.17	0.06	0.04
EC 1:5 *(μS/cm)*	290	278							–	0.04	0.00	0.19
pH H_2O	5.770	0.835								–	0.12	0.01
Bulk density *(kg dcm^3)*	1.557	0.065									–	0.07
P (Bray 2) *(mg P kg sol^{-1})*	7.930	10.515									–	

Table 3. Soil chemical properties of 52 rainfed paddy fields of Khon Kaen as affected by altitude, organic matter management, crop establishment method and N fertilizer level

Factor	n	Organic C (g 100 g^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Na (cmol kg^{-1})	Bray-2 P (mg kg^{-1})	pH	EC 1:5 (µs/cm)	Bulk density (kg dcm^3)
Elevation										
Lowland (<190 m)	37	0.46	0.10 **a**	1.59	0.38	1.69 **a**	9.76	5.59 **b**	374 **a**	1.57
Upland (<=190 m)	16	0.48	0.06 **b**	1.36	0.25	0.53 **b**	3.68	6.18 **a**	96 **b**	1.53
Organic management										
Straw burned	21	0.46	0.09	1.77	0.41	1.36	7.43	5.82	283	1.56
Straw incorporated	19	0.49	0.10	1.47	0.32	1.66	8.79	5.90	364	1.55
Straw incorporated + OM	13	0.44	0.06	1.19	0.26	0.84	7.25	5.48	194	1.56
Crop establishment method										
Transplanting	31	0.49	0.09	1.67	1.37	1.59	10.71**a**	5.70	379	1.55 **b**
Direct seeding	22	0.44	0.08	1.31	1.29	0.98	4.01**b**	5.86	165	1.57 **a**
N fertilizer level										
Low (<20 kg ha^{-1})	26	0.47	0.10 **a**	1.49	0.31	0.98	7.83	5.66**b**	212	1.58 **a**
High (<=20 kg ha^{-1})	27	0.46	0.08 **b**	1.55	0.37	1.68	8.02	5.87**a**	365	1.53 **b**
Mean square										
Elevation	1[a]	0.00	0.03*	0.13	0.08	7.70*	294.53	6.59**	397,222 *	0.00
Organic management	2[a]	0.01	0.00	1.39	0.09	1.29	20.29	0.51	36,801	0.00
Establishment method	1[a]	0.09	0.00	1.39	0.04	0.65	403.9*	0.04	209,736	0.01*
N fertilizer	1[a]	0.00	0.03*	0.05	0.00	0.03	103.0	3.04*	63	0.03**

Asterisks (*, **, ***) mean significant at the 0.05, 0.01 and 0.001 probability level respectively. Numerals with different letters are significantly different at the 0.05 probability level using the Student-Newman-Keuls Test of SAS.

[a] Degrees of freedom (d.f.).

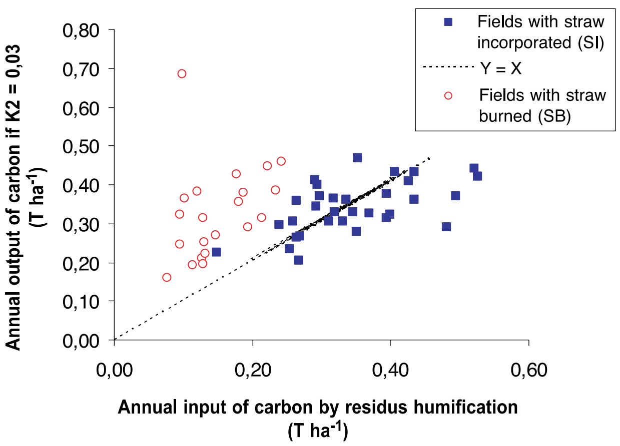

Figure 3. Values of annual output of carbon assuming mineralization rate of K2 = 3% for total soil C content

compared the removal and non-removal of rice straw during a six-year experiment. Unless the rice straw was returned in combination with the application of at least 50-14-14 kg N-P-K ha^{-1}, they did not find any significant difference in total C of soils among the treatments. Non-significant effects of the various OMM on exch. K and available P are in accord with the fact that most of the K and P contained in the fresh straw is still present in the ash. The non-significant effect of OMM on soil pH agrees the non-significant effect of OMM on the soil carbon content and the soil redox status, as the process of increasing pH found by Quantin et al., (submitted) and Maeght, (2003), was related to the increase of soil carbon content and the reducing conditions of flooded soils.

Comparison of the carbon inputs with the calculated outputs using the basic equation of Jenny (1941) at equilibrium (Figure 3), suggested that the non-significant effect of burning straw is due to a very low mineralization rate (K2) of the organic matter remaining in the soil after burning. Hence, the quality of this organic matter could be different from that of fields where the straw is incorporated every year. The average K2 of 3% is deduced for these situations, whereas the highest values mentioned in the literature for sandy soils in temperate zones reach 2% (Boiffin et al., 1986). Using the Jenny equation, this K2 value refers to the total organic matter content of the soils, with no distinction between more or less recalcitrant, or old or fresh organic materials. Therefore, it is certainly much lower than the mineralization rate that would be expected in such a tropical area for the incoming residues only (Shirato et al., 2005). It's clear that it would have been more accurate to distinguish two different pools in the total C amount: labile carbon, and less quickly mineralized carbon. The pool of labile carbon could be approached either by the microbial biomass (Alvarez et al., 1998), or following Blair et al.

(1995), by the KMnO4 extractable C fraction. Although Jenny's very basic model of carbon turnover is not the appropriate tool to accurately predict the qualitative evolution of organic status of soils, it had for this study the advantage of referring to an easily measurable carbon pool and to allow preliminary comparisons between different cropping practices.

The variation in exch. Na, EC and pH over the network of farmers' fields were mainly related to the position of the fields in the landscape. The higher values recorded for these variables in the lower lands were due to the proximity of the saline water table. The non-significant effect of topographic position on soil C content could mean that carbon movement by erosion is negligible. The effect of the method of sowing on available P (Table 3) could be due to a higher uptake of P by the recently harvested rice in the direct seeding method, whereas with transplanting most of the P would be fixed by the ferrous iron concentrated in the submerged soils during the cropping period. The lower soil bulk density in transplanted fields with fertilizer application could be due to the higher root volume developed by the recently harvested rice, or perhaps to a higher level of labile carbon in these soils. The lower exch. K in fertilized plots (Table 3) suggests that greater uptake of the initial soil K was possible by the rice crop. The higher pH recorded in fields receiving the higher fertilizer should be confirmed as acidification effect of urea application is more often observed.

Conclusion

Using a survey approach over a network of fields, it has been possible, within a short time, to examine some long-term effects of practices developed in paddy fields of Northeastern Thailand. More detailed data are in many cases still needed to draw definite conclusions. Future research should include assessment of labile carbon, as a more sensitive and early indicator of a change in the organic status of soils. Input of carbon by the roots, and leaching by drainage should be assessed for more accurate estimation of carbon budgets. Loss of carbon by the light burning practiced by the farmers should be measured. Estimation of nutrient uptake and root density of the rice with the various practices would allow our hypothesis to be used to explain variation in P and K availability and bulk density over the network. Besides the effects of farmers' practices on the soil chemical and physical attributes, changes in incidence of weeds, diseases and insects on the rice crop should be studied. The present preliminary results call into question farmers' assertions about the decrease in the extent of saline patches in their fields over time due to straw incorporation. Although the practice of burning straw should be avoided owing to air pollution, as regards soil fertility it does not seem to differ from the incorporation of straw. Therefore, positive short-term effects of straw incorporation on rice grain yield need to be large enough to persuade the farmer to accept its higher cost compared with burning.

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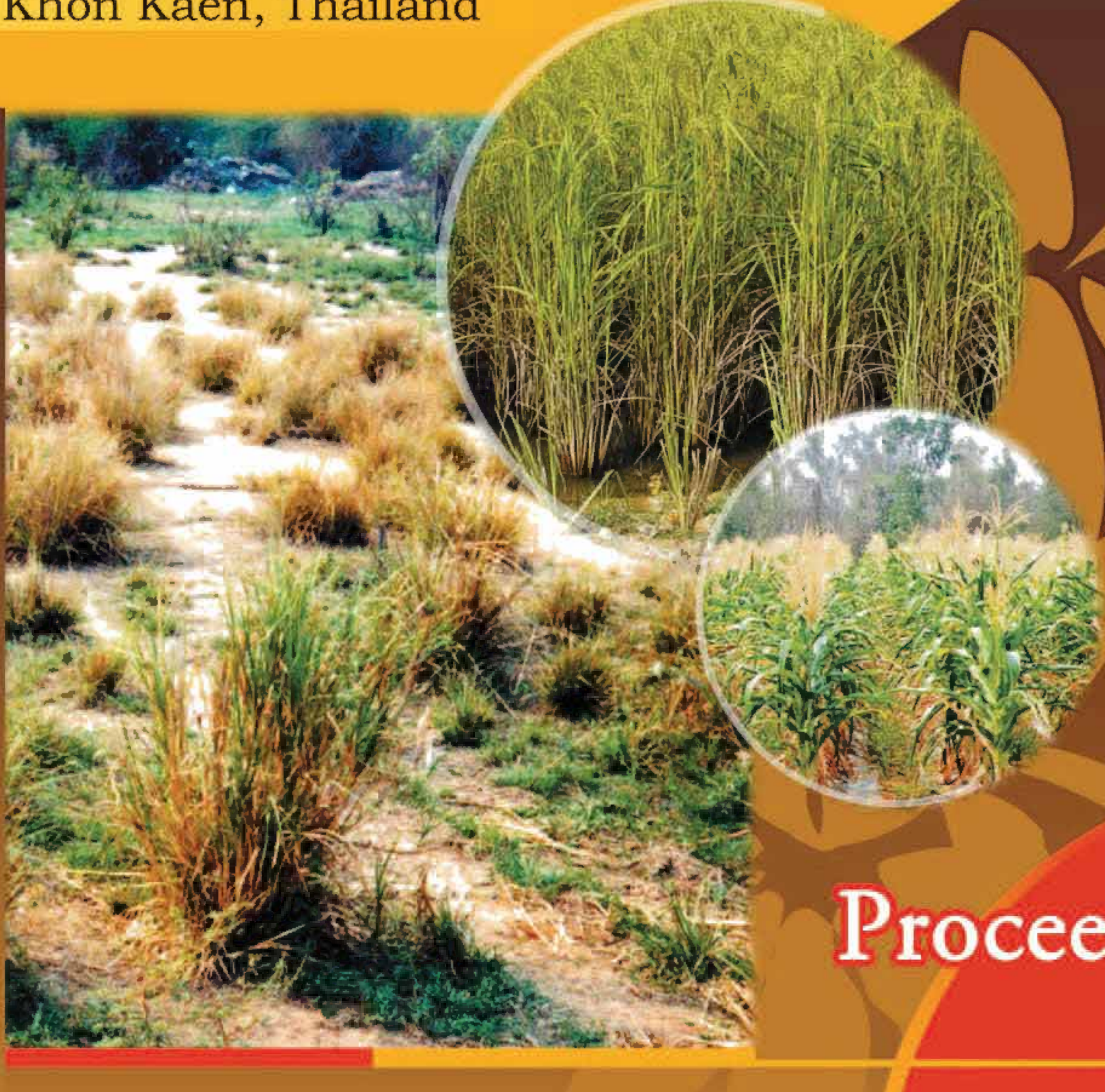

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