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The increased carbon storage changes with a decrease in phosphorus availability in the organic paddy soil

Suphathida Aumtong[1*], Chakrit Chotamonsak[2], and Bundit Somchit[1]

[1]Faculty of Agricultural Production, Maejo University
63 Sansai-Phrao Road, Sansai District, Chiang Mai 50290, Thailand
[2]Faculty of Social Science, Department of Geology, Chiang Mai University
Si Satchanalai 504 Alley, Tambon Su Thep, Mueang Chiang Mai District, Chiang Mai 50200, Thailand
*Corresponding author: aumtongsuphathida@gmail.com

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Abstract

This study aimed to investigate the effect of organic rice farming on the various forms of inorganic phosphorus, the concentration of dissolved organic carbon (DOC) and carbon storage, and the relationship between DOC and P fractions in organic rice farming (ORF). The soil samples were taken from 11 organic plots, and three pseudo-replicates were sampled from individuals of various soil depths. The P-fractions, the soil organic carbon (SOC), DOC, and other soil properties were analyzed by standard methods from soils. The data were analyzed using One-way and Two-way ANOVA and tested using the least significant difference. The results showed that ORF soils had less labile P than conventional rice farming, while ORF had a higher average of DOC, SOC, and C stock than conventional rice soil ($P<0.05$). Organic fertilizers such as animal manure application and rice straw retention were used for ten years in the ORF. The agricultural practices of ORF would convince the amount of amorphous Fe and Al on soil minerals significantly and would increase the adsorption capacity of the soil mineral surfaces by organic fertilization. The Fe-P fraction responded to the increased adsorption capacity in the ORF and shown along with the DOC and P which were less than in ORF. Both of them were more adsorbed on the surface mineral. Meanwhile, the lower P for nutrient cycling in ORF soil, the lesser the decomposition of DOC and SOC, which then affected the increase of soil C storage.

INTRODUCTION

The organic farming system uses only organic substances such as animal manure, compost, crop residues, and leguminous crops to increase soil fertility and productivity (FAO, 2021). In this way, there is a positive effect on the environment, i.e. increasing bio-diversity (Whittingham, 2011). Rice plantation in Asia needs more water than the original soil condition for water-logging (Kögel-Knabner et al., 2010). Soil managements include waterlog and drainage, tillage and puddles, chemical and organic fertilization (manure, straw, and other crop residues, often fermented with sediments taken from rivers or channels). The organic fertilization has been applied to rice cultivation for 16 years, increased the SOC, and might have created the soil aggregates, and has been the physical mechanism that contributed to holding in the structure by lignin (Tirol-Padre and Ladha, 2004). In paddy soils, the anaerobic conditions could induce the accumulation of organic matter in the upper soil, while the increased SOC in paddy soils is due to increased soil organic matter (SOM) inputs rather than the slow rate of decomposition of SOM under anaerobic conditions (Kögel-Knabner et al., 2010). Intensive application of organic fertilizers has been done for a long time which perhaps may induce the forming of the amorphous Al, Fe oxyhydroxide. This

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amorphous fraction could increase interaction with SOC and is called the amorphous organo-Al complex. This material also shows a high phosphorus adsorption capacity.

That would decrease the availability of P in organic paddy soil. Yan et al. (2017) showed that the addition of organic fertilizer (e.g. rice straw and swine manure) indicated a greater P sorption capacity than the addition of chemical fertilizer. The changes in surface electrochemical properties of soil minerals are induced by organic amendments and related to the changes in soil organic matter (SOM) levels. The long-term addition of P in paddy soil is in response to P transformation (Yan et al., 2017). Meanwhile, the amount of P fraction in soil relates to P adsorption capacity. The dissolved organic carbon (DOC) is a soil carbon fraction (Strahm et al., 2009) and can be as high as 50% of the total soil carbon (SOC) in some soils (Kalbitz and Kaiser, 2008). The DOC adsorbed/stabilized on the mineral surface results in reducing its usefulness to soil microorganisms (Guggenberger and Kaiser, 2003). The mechanism of adsorption of SOM on the surface of clay minerals protects organic compounds from decomposition by steric barriers and is a physical defense against enzymatic binding to compounds and catalyzing their decomposition. In this study, we emphasized our results in the ORF and indirectly figured out the reasons from the same lines of other studies. It was intended to find out the reason for more explanation of what was going on of our objectives. Therefore, the major aim was to present the effect of organic rice practice on the various forms of inorganic phosphorus, the content of DOC and organic carbon stock, and the relationship between DOC and P in organic paddy.

MATERIALS AND METHODS

Study area

The study site was organic rice farming (ORF) in Bann DonJiang, Mae-tang District, Chiang Mai province, northern Thailand. The physiological area was at 360–400 meters above mean sea level and was not different from topography within 22 farmer plots. This study was conducted in a survey of farmers' sites and by identifying organic farmers of 11 people. The agricultural practices of ORF were carried out during the rainy season and for the off-season; most farmers plant soybean in rotation every year (Figure 1). Soil samples were sampled from the 22 sites, which were organic farms (11 farmers), and were conventional rice farming (11 farmers), and were randomly sampled by three pseudo-replicates from each plot at 0–5, 5–10, 10–15, and 15–30 cm soil depth.

Soil P-fractions were subjected to sequence analysis (Guppy et al., 2000). The soil was first extracted for P-solutions using 1 M NH_4Cl, then the Al-P fraction was extracted using 0.5 M NH_4F (pH 8.2), Fe-P was extracted using 0.1 M NaOH as the extractor, the P-reductant was extracted using 0.3

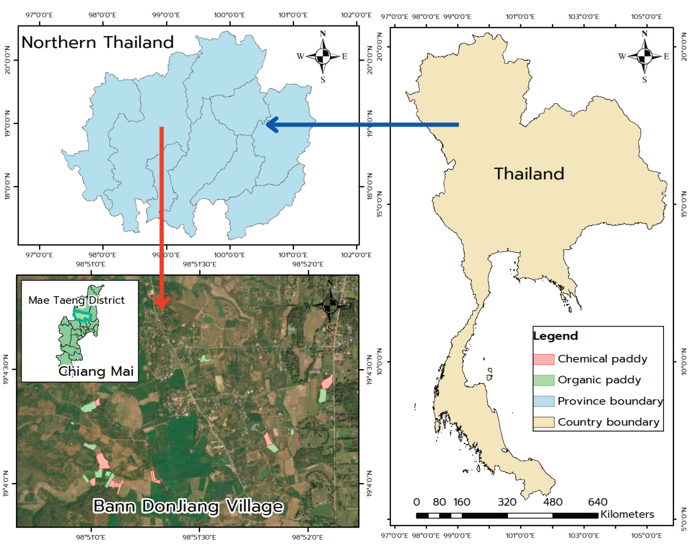

Figure 1. The aerial photography of the study site and the sampling sites (green boundary plots were organic paddy soils and the red boundary plots were conventional paddy soils).

M $Na_3C_6H_5O_7$ and 1 M $NaHCO_3$, and the Ca-P was extracted using 0.25 M H_2SO_4. Upon the completion of extraction, it was colored by the molybdenum blue method using ascorbic acid as a reducing agent (Murphy and Riley, 1962). The P content was analyzed by absorbing light with a visible wavelength spectrophotometer.

Calculating and data analysis

$$C = Cs \times Bd \times Sd$$

Note:

C = C strage ($g.m^{-2}$)

Cs = C in soil (%)

Bd = Bulk density ($g.cm^{-3}$)

Sd = The bulk density of individual soil depths of 0–5, 5–10,10–15, and 15–30 cm

The effect of land uses (i.e. ORF and CRF) and soil depth on the content of the various organic carbon was conducted using the One-way and Two-way ANOVA by mean comparison with the least significant difference at a confidence level of 95%. The relationship between carbon fractions and soil properties to SOC content and SOC storage was analyzed by Principle component analysis (PCA) on SPSS version 10.8.

RESULTS AND DISCUSSION

Effect of organic rice farming on C storage, soil carbon fractions, and Soil properties

This study found that the C storage, SOC, WSC, HWSC, DOM, and pH were significantly higher in ORF than CRF. However, POXC was lower in ORF than CRF (Table 2) ($P<0.05$), but phosphorus content (Avial. P) in CRF soil was higher than that of ORF soil ($P< 0.05$.) (Table 1). Kögel-Knabner et al. (2010) reviewed that the accumulation and stabilization of soil organic matter in paddy soil are characterized by high carbon accumulation through organic fertilizers and crop residues. According to our study, the SOC content was estimated at 39.1 and 25.5 $g.kg^{-1}$ from ORF and CRF, respectively. The SOC content in the topsoil of lowland rice soil ranged from 20 $g.kg^{-1}$ (tropical Asia) to 29 $g.kg^{-1}$ (Japan) and 27–41 $g.kg^{-1}$ (China's Yangtze River Valley). The decomposition rate of added organic matter was slow under anaerobic conditions. This reason induced a tendency to accumulate more SOC in anaerobic conditions (Kögel-Knabner et al., 2010). However, the degraded

Table 1. The methodology for carbon fractions and soil property analyses of soil samples

Carbon fractions/Soil property	Description
Total organic carbon (TOC)	The TOC is done with additional heat at 130°C and Cr_2O_7 solution and then left for 24 hours (Nelson and Sommer,1996).
Water soluble carbon (WSC)	The soil samples were added with deionized water, and then placed for 30 min on a shaker at 200 rounds per minute, and then centrifuged for 20 minutes, and all the supernatant from was filtered through membrane filter into Erlenmeyer flask for carbon measurement by Cr_2O_7 oxidation (Ghani et al. 2003).
Hot water soluble carbon (HWSC)	After WSC extraction, the same soil samples were repeated added 30 ml of deionized water, and left for 16 h in a hot-water bath at 80°C. The individual tube of soil suspension was then sedimentation for 20 min with centrifuge method and then was filtered with 0.45 µm membrane paper filters. The total carbon in the clear soil solution was tested by Cr_2O_7 oxidation.
Dissolved organic carbon (DOC)	calculated by WSC combined with HWSC.
Permanganate oxidized carbon (POXC)	3 g of air-dried soil and passed through the sieve 0.5 mm with 20 ml 0.02 M $KMnO_4$. (Weil et al., 2003)
Available P	Bray 2 method
Exchangeable Ca	1 N NH_4AO extraction
pH	by 1:1 H_2O method
Soil texture	done by weighing soil particles of 2 mm size and allowing soil particles to float in Calgon solution
Soil bulk density (Bd)	soil core method at each soil depth layer

Table 2. The means of carbon storage, soil organic carbon fractions, and some chemical properties were from organic rice farming and conventional rice farming

Farming systems	C storage ($kg.m^{-2}$)	SOC ($g.kg^{-1}$)	POXC ($g.kg^{-1}$)	WSC ($g.kg^{-1}$)	HWSC ($g.kg^{-1}$)	DOC ($g.kg^{-1}$)	Avai.P ($g.kg^{-1}$)	Ca ($cmol.kg^{-1}$)	pH (1:1 H_2O)
Organic rice farming	3.859 a	39.1 a	1.21 b	44.00 a	108.41 a	152.51 a	10.07 b	47.53 a	5.79 a
Conventional rice farming	2.624 b	25.5 b	1.68 a	30.46 b	88.64 b	118.33 b	29.11 a	13.31 b	4.02 b

Remarks: The different lowercase letters in the same column signify difference (P <5%). (means of the soil depth 0–30 cm), SOC= total soil organic carbon, POXC=permanganate oxidizable carbon ,WSC=water soluble carbon, HWSC=hot water soluble carbon, DOC= Dissolved organic carbon = (WSC+ HWSC) , Avai.P= Available phosphorus.

Table 3. The means of phosphorus fractions (mg kg-1) from organic (ORF) and conventional (CRF) paddy soils.

Soil	P-solution	Al-P	Fe-P	P-Red	Ca-P
			($mg.kg^{-1}$)		
Organic rice farming	35.80 a	106.91 a	76.25 a	66.58 a	35.22 a
Conventional rice farming	8.18 b	14.03 b	80.40 a	60.26 a	32.27 a

Remarks: The differences in the upper case letters mean the land uses differ significantly (P <0.05).

pattern of labeled rice straw was not different in permanently submerged rice soils compared to aerobic soils (Kögel-Knabner et al., 2010). The anaerobic condition is considered the main factor in regulating the rate of decomposition of SOC. From this study, the higher the SOC, the higher the C storage (0–30 cm.) in ORF, which could be accompanied by the formation of amorphous Fe and Al oxyhydroxides in organic paddy soil.

For P-fractions related/consequence from the P adsorption

The results showed that ORF soil had lower P-solution and Al-P content than CRF soil. Meanwhile, the Fe-P, P-Red, and Ca-P were not different from CRF at a depth of 0–5 cm, and the Al-P content in CRF soils was higher than ORF soils at soil depth of 0–5 and 10–15 cm (Table 3). In this study, when considering the P adsorption process in soil, the CRF in high Al-P (Table3) may be induced by exchanging carbon bound at the surface location of clay minerals or colloidal clays, thereby increasing the WSC and releasing HWSC. It is found that CRF soils had higher absorption of P in Al-P fraction than ORF soils, while Fe-P was found in the same amount in both ORF and CRF.

Therefore, this study showed low availability of P in ORF (Figure 2a) which could induce the P adsorption by amorphous of Al, Fe oxide on the surface soil mineral by organic fertilization. The organic fertilization of paddy soil could increase the negative charges of the soil surface from abundant negative electric charges of SOM. The consequence occurred significantly on the adsorption of P in soil by altering the sites used for co-adsorption and competition sorption. Therefore, negative charge increased affected the soil P adsorption capacity and DOC adsorption. This study found that involved soil depths; the Avia. P, under CRF soil, was higher than ORF soil (<0.05) at depths of 0–5, 5–10, and 10–15 cm, while soil pH and Ca in CRF were lower than ORF soils (<0.05) (Figure 2a–c). The pH in ORF was higher than CRF (Figure 2b), which was due to the significant dependence of the DOM sorption on pH in which there was the competition for binding sites between DOM with inorganic anions (phosphate and sulfate) and the release of OH- during the sorption. Thus, this process suggested the surface complexation of functional groups via ligand exchange (Oren and Chefetz, 2012), and was the important process in the sorption of OM on mineral soil (Kaiser and Guggenberger, 2000). Moreover, another result of organic fertilization by Audette et al. (2016) reported that manure application, especially animal manure such as a pig or poultry manure, has high calcium (Ca), phosphorus content, and organic matter. The resulting organic fertilizer application is a source of various forms of inorganic phosphorus, which can also be absorbed or fixed by the attached Ca. This is reason why the amount of P is low in organic soil (Figure 2c).

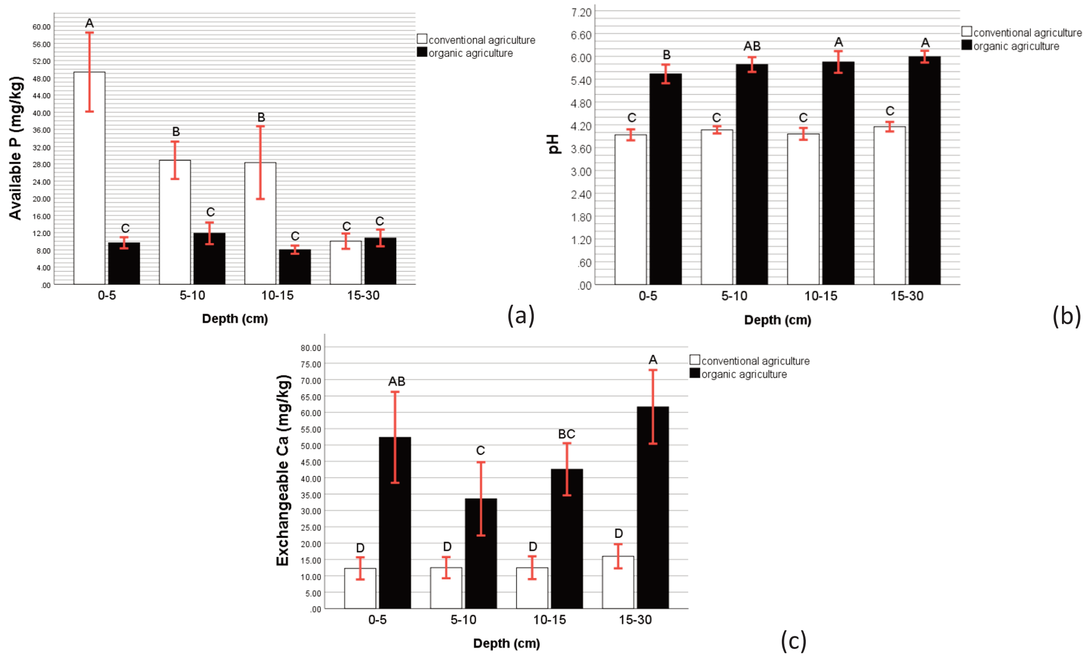

Figure 2. Some soil properties from the ORF vary the depths of soil, Note: (a) Availability of P (b) pH (c) Ca. The difference of letters means significantly (P <0.05) by the interaction between land uses and soil depth. Bar= standard error.

The alternation of the soil mineral surface affected P and C adsorption by organic fertilization

Yan et al. (2017) showed that organic fertilization of paddy soils such as swine manure for 33 years generally had a higher amorphous Fe and Al oxyhydroxides content than chemical fertilization. In support to that, Pizzeghello et al. (2014) also reported that organic fertilizers increased the Fe and Al oxyhydroxides and amorphous in soil according to profile 0–100 cm, and induced to adsorb DOC on the transformation of mineral surface. It contributed to the accumulation of SOC and C storage. Moreover, manure can contribute to higher amounts of dissolved organic matter (DOM). Therefore, the SOM and DOC were stabilized on the mineral surface by (dissolved and mineral-associated organic matter) through ion exchange and ion bridging (Yan et al,2013). However, the effect of Fe oxide anhydrous on SOC stabilization varies with clay minerals, and the stabilization of SOC depends on the type of anhydrous oxide also (Saidy et al., 2012).

Our study showed that DOC was higher in ORF than CRF (Figure 3a–d). Kaiser and Guggerbeger (2000) pointed out that related desorption of DOC adsorbed, and provided pieces of evidence from Kaiser and Zech (1999) who conducted an adsorption-desorption experiment on the soil layer and on the hydrous oxide twenty-four h after DOC adsorption, and showed that less than 3% of the adsorbed OC was released from goethite and $Al(OH)_3$ under the conditions of the solution which was similar to the conditions during the adsorption stage. The reversibility of OM adsorption was reduced with increasing rest time on the adsorbent (Kaiser and Zech, 1999; Saidy et al., 2012). This evidence could be some explanations of the accumulation of DOC and contributed to an accumulation of SOC in ORF.

This study clearly showed the ratio of DOC/P index from ORF, higher than of DOC (Figure 3a–d), and mean of microbial respiration in CRF soils increased due to the addition of phosphorus (P) (Spohn and Schleuss,2019). Moreover, the CRF soil could attribute to the resolve of microbial P limitation. Therefore, microbial activity and organic matter decomposition (Fisk et al., 2015) increased. The increased respiration rates and DOC concentrations in response to P addition might likely be caused by the desorption of organic carbon from mineral surfaces (Spohn and Schleuss, 2019) in CRF. Meanwhile, this study might be a P limitation that induced a decrease of decomposition of SOC and contributed to the accumulation of SOC and C storage in ORF.

Relations carbon fractions and soil properties increased SOC and C storage in ORF

PCA results showed that the relation carbon fractions

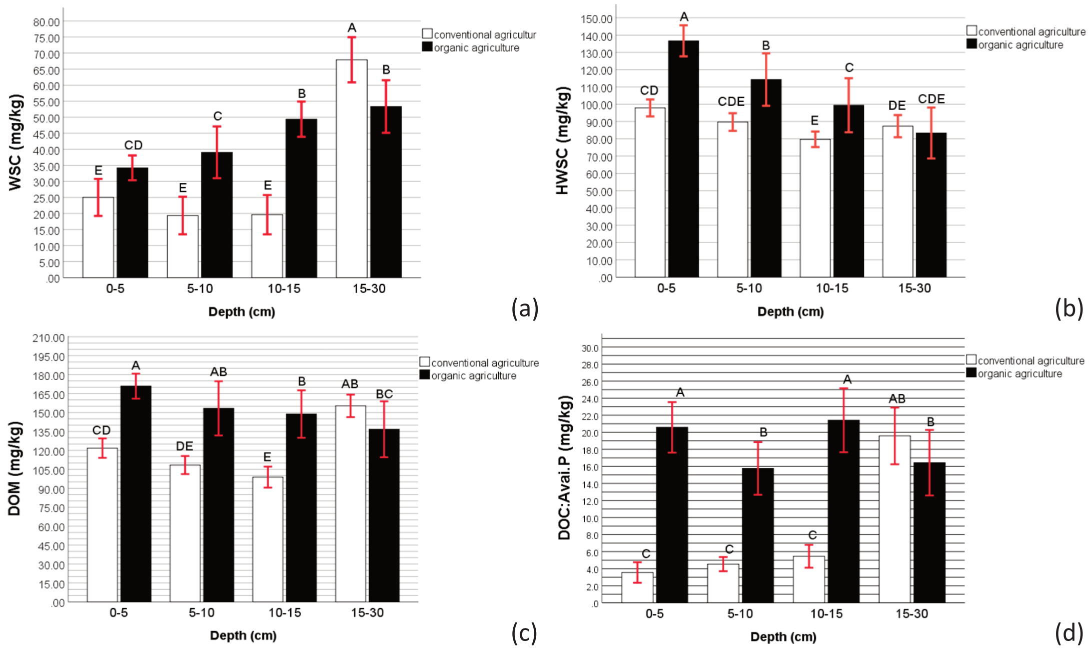

Figure 3. The effect of organic paddy soil and soil depths on some soil properties. (a) water-soluble carbon (WSC) (b) hot water-soluble carbon (HWSC) (c) Dissolved organic carbon (DOC) combined from WSC+ HWSC (d) ratio of DOC/P , Bar= standard error

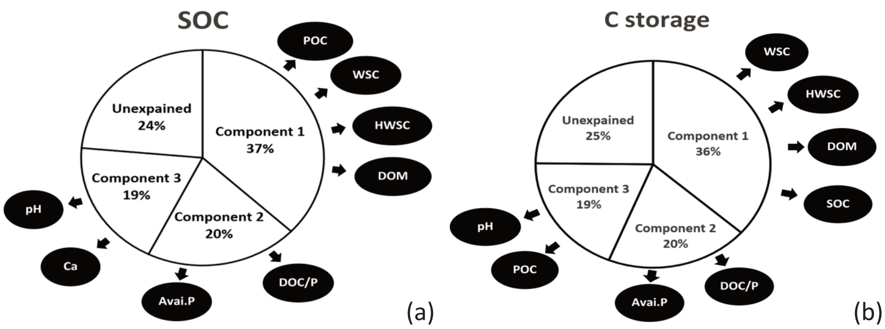

Figure 4. Principle component analysis (PCA) of carbon fractions and soil properties for (a) SOC content and (b) for C storage.

and soil properties affecting SOC content in organic paddy soil found that the first factor was DOM, POXC could explain the variance of 34.21%. Meanwhile, $H_2PO_4^-$P was the minor factor, and the other group consisted of pH and Ca, and explained the variance of 18.49% and 17.30%, respectively. All three groups could explain the 70% variability of SOC content in ORF (Figure 4a). The relations between carbon fractions and soil properties affecting C storage were categorized into three groups: the first group was DOC, WSC HWSC, SOC which described 36.98 % of variance, the second group was $H_2PO_4^-$P, and DOC/P, which explained 20.35% of variance. The third group was pH and POXC, which explained 19.11% of variance. All factors explained the variability of 76.45 % (Figure 4b). The PCA results would indicate that labile carbon fractions such as high DOC, low P content, and high DOC/P ratio, which were the moderator for the formation of SOC and accumulation of C storage in ORF. These consequently alternated the mineral surface by organic fertilization of paddy soil and would affect the formation of SOC and accumulation of C storage in ORF.

CONCLUSIONS

This study showed that in the C storage of ORF, SOC, WSC, HWSC, DOM, and pH were high. However, POXC and availability were low in the ORF. The P-fractions were related to P adsorption, which found that the ORF was mostly Fe-P fraction. The PCA results would indicate that labile carbon fractions such as high DOC, low P content, and high DOC/P ratio were the moderator for the formation of SOC and accumulation of C storage in the ORF.

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