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Potential of Agricultural Soil to Restore Carbon through Cultivation Practices and Plant Residues Managements

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Abstract. Agricultural soil is one of the most effective places for accumulating carbon in terrestrial ecosystems. Most of carbon in the soil is preserved in the form of soil organic carbon (SOC). The amount of accumulated SOC is therefore a function of inputs and decomposability of biomass, which in turn is determined by environmental factors and agricultural cultivation practices. The objective of this study is to investigate the effects of crop residues management and crop rotation on carbon stock of maize field is changed to upland rice. The experiment methods was conducted at Suwanwajokkasikit Field Corps Research Station, Nakornratchasrima province. The randomized completely block design (RCBD) with 3 replications of continuous maize cultivation(CM), continuous upland rice cultivation (CU), and upland rice rotated with maize(UM) plots was used. Plant residues were incorporated after harvest. Soil was sampled from the plough layer (0-10 cm) and analyzed for carbon (C) nitrogen (N) analysis. Soil organic carbon turnover was also studied by taking the advantage of the difference in carbon isotopic ratio between C_3 plant (rice) and C_4 plant (maize). The results found that after 3 cropping, soil carbon in the top layer of CM plot was changed when rotated with rice (CU plot); i.e. from 3.54±0.49 ton C ha^{-1} to1.46±0.17 ton C ha^{-1}. However, the carbon loss could be minimized when CM was rotated with UM (2.28±0.38 ton C ha^{-1}). The $\delta^{13}C$ values of rice and maize residues were-27.48±0.42‰ and -12.19±0.34‰, respectively. After three crops and when the cultivation system was changed from maize to upland rice, the$\delta^{13}C$ value of soil carbon shifted from -18.77 ‰to -20.27‰. Soil organic carbon turnover time was estimated to range from 3 to 6 years, and soil carbon in CM is turned over more rapidly than that in CU plots. From these data it was estimated that after changing the cultivation from maize to upland rice, there was about 29.78 % of soil organic carbon originated from rice plant

Keywords: soil carbon restoration, cultivation practices, maize, upland rice.

1. Introduction

Agricultural soil is one of the most effective places for accumulating carbon in terrestrial ecosystems. Most of carbon in the soil is preserved in the form of soil organic carbon (SOC). It is well known that SOC is very dynamic and makes up the important part of carbon cycling process which has direct effect to CO_2 in the atmosphere. Transferring carbon from the atmosphere to soil in fact starts when CO_2 in the atmosphere is assimilated to organic carbon in plant biomass by photosynthesis. Dead plant biomass is then decomposed by soil faunaand microbes, and parts of biomass carbon are incorporated into SOC. The amount of accumulated SOC is therefore a function of inputs and decomposability of biomass, which in turn is determined by environmental factors and agricultural cultivation practices.

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Past studies have indicated that some cultivation practices such as tillage and its intensity, and crop rotations can affect SOC by changing the soil physical and biological conditions and by changing the amounts and types of organic inputs to the soil [1].

As mentioned above, the amount of carbon storage in soil is to a great extent determined by the rate of organic matter input from the residues of plants growing in site from the previous native vegetation, and the other is the remains of the crop and the decomposition of its residues [2]. Increased primary production would result in an increased C storage, whereas increased decomposition (i.e., reduced C turnover time) would have an opposite effect. Other Factors such as erosion, leaching, and fire also affect soil C dynamics, generally in lesser and variable degrees [3]. SOC is an essential element of soil quality and increased SOC is generally associated with improved soil-tilth, improved water-holding capacity, improved storage and availability of plant nutrients, and reduced soil erosion [1]. The objective of this study is to investigate the effects of crop residues management and crop rotation on carbon stock of maize field when it is changed to upland rice.

2. Methodology

2.1. Experiment site and sampling

The field experiment was carried out at National Corn and Sorghum Research Center of Kasetsart University (Suwanwajokkasikit Field Corps Research Station), Nakornratchasrima province,Thailand. The duration was from December 2008 to April 2010, covering three crop cycles. The soil at the site has been grown with maize for approximately 20 years. The soil is classified as Pak Chong series, very fine, kaolinitic, isohyperthermic Rhodic kandiustox. The experiment layout is randomized complete block design, with 3 replications.

The experiments were composed of three cropping systems: (1) a continuous maize system (CM), (2) a continuous upland rice system (CU), and (3) an upland rice-maize-upland rice rotations (UM). For all the cropping systems, crop residues (maize or rice straw) at rate of 5 ton per hectare were added to soil 14 days before planting. Leaves, stems and roots of maize and rice from three crop cycles were ploughed into soil after harvested each crop cycles. Maize was grown with 4901 variety with plant spacing of 25 cm and row spacing of 75 cm. The chemical fertilizer was applied 2 times during cropping period, the first application being at planting time with 15-15-15 fertilizer at the rate of 312.50 kg per hectare and the second top dressing at 28 days after germination with 46-0-0 fertilizer at the rate of 156.25 kg per hectare. Upland rice was grown using SakonNakhon variety, a photo-insensitive variety by direct seeding method and plant spacing of 30 cm between row and 25 cm between hills. The fertilizer was applied 4 times. The first application was at 7 days after germination with 16-16-8 fertilizer at the rate of 187.50 kg per hectare. The second and the third times were top dressed with 46-0-0 fertilizer, applied at the rate of 62.5 kg per hectare at 24 and 40 days after germination. The fourth application was before ripening phase as top dressing with 46-0-0 fertilizer at the rate of 31.25 kg per hectare.

Soil samples were randomly taken at 0-10 cm depth from the soil surface. They were collected before the experiment was started and after the experiment was finished. Analysis of the total carbon and nitrogen contents in soil was done by completely combusted to CO_2 and N_2 and measured by using the CHN Elemental Analyzer (Flash EA 1112 series, Italy). Soil bulk density was determined using the core method.

The plant samples were taken from area of 1 × 1 m^2 after harvesting. Above ground (stem, leaf, panicleand spikelet) and below ground (root) parts were weighed, dried in oven at 80 ^oC until reaching the constant weight. Plant samples were grinded for organic carbon and total nitrogen analysis. Maize and rice yields were removed, but dry leaves, stems and roots were incorporated in the soil before the next crop cultivation starts.

2.2. Soil carbon turnover and soil carbon dynamics

Soil carbon turnover and soil carbon dynamics was studied by using stable isotope approach. The basis of this approach is that $\delta^{13}C$ values of C3 plants (e.g., rice) generally range from −33‰ to −22‰, whereas values for C4 vegetation (e.g., maize) range from −17‰ to −9‰ [4]. The change in plant cover from maize (C4) to upland rice (C3) in the experimental designs described above, therefore, will influence the isotopic composition of SOC and this is reflected in the $\delta^{13}C$ values of SOC itself. The isotope ratio ($^{13}C/^{12}C$) of organic carbon in soil and plant samples was determined at Goettingen University, Germany. Plant samples were ground to <2 mm in size before analysis. Results were expressed as $\delta^{13}C$ values in per mil (‰) units as follows;

$$\delta^{13}C = [(R_{sample} - R_{standard})/R_{standard}] * 1000 \quad (1)$$

whereR_{sample} = $^{13}C/^{12}C$ of the soil and plant samples; and $R_{standard}$ = $^{13}C/^{12}C$ of the PDB standard [5].The accuracy of individual sample measurements, when all possible errors associated with sampling, processing, and measurements are taken into account, was about ± 0.25‰.

The proportion(f) of carbon content derived from different source was calculated by the mass balance equation 2 and 3[6]:

$$\delta^{13}C_{new} = (\delta^{13}C_{mix})(f) + (\delta^{13}C_{old})(1-f) \quad (2)$$

$$f = \frac{\delta^{13}C_{new} - \delta^{13}C_{old}}{\delta^{13}C_{mix} - \delta^{13}C_{old}} \times 100\% \quad (3)$$

where $\delta^{13}C_{new}$ is the average $\delta^{13}C$ value of soil in the new plant community, $\delta^{13}C_{mix}$ is the $\delta^{13}C$ value of the plant material entering the soil, $\delta^{13}C_{old}$ is the average $\delta^{13}C$ value of soil in the old plant community, f is the proportion of carbon from new plant community, and $1-f$ is the proportion of carbon derived from old plant community.

3. Results and Discussion

3.1. Effects of cultivation practices on carbon content in soil

Studies in the past have indicated that cultivation practices have significant effects on the ability of soil to sequester carbon [1]. It is commonly known that soil disturbance has led to loss of SOC [1]. Some cultivation practices, such as conservation tillage, reduced tillage and organic material amendments have resulted in increased carbon sequestration in agricultural soils [7]. In the current study, we found that cultivation practices and incorporated crop residues into soil reduces soil bulk density to 1.08 g/cm^3 when compared with initial soil of 1.22 g/cm^3 (Figure 1).

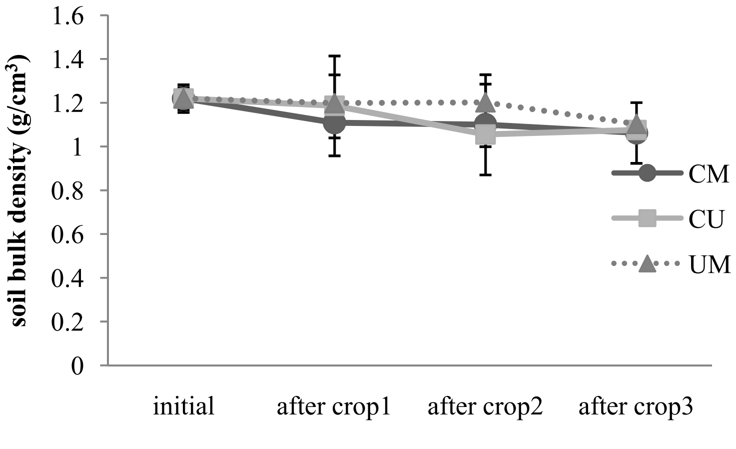

Fig. 1: Soil bulk density in three cropping systems in each crop of the experiment

The SOC content after 3 cropping under CM has increased from 17.53 to 21.07 ton C ha^{-1}, this is significantly increased ($p< 0.05$, Table 1). On the other hand, when upland rice was planted on the soil that has continuously grown with maize for more than 20 years, the SOC was decreased from 18.24 to 16.78 ton C ha^{-1}, a statistically significant decrease. However, when maize was rotated with upland rice (UM system), the SOC was also increased but with a lesser extends when compared with the CM systems. The increase SOC under CM system was probably due to the higher carbon input during crop 2 and 3 (11.7 ton C ha^{-1}) than CU system (4.42 ton C ha^{-1}).

Table 1: Soil organic carbon (SOC, ton C ha^{-1}) change in soil depth of 0-10 cm

Cropping systems	CM (maize)	CU (upland rice) (ton C ha^{-1})	UM (upland rice-maize-upland rice)
SOC, initial	17.53± 0.43^{a}	18.24 ± 0.09^{a}	18.14 ± 0.31^{a}
SOC, 3rd harvest	21.07 ± 0.43^{b}	16.78 ± 0.26^{c}	20.41 ± 0.61^{b}
Change in SOC	3.54 ± 0.49^{A}	-1.46 ± 0.17^{C}	2.28 ± 0.38^{B}
% Carbon change	+20.19	-8.00	+12.56

Values are mean (n = 3) with standard deviation. Different letters indicate significantly different values (LSD, P≤0.05).

3.2. Effect of cultivation practices on soil carbon turnover

The $\delta^{13}C$ values of maize (C4-pathway) and rice (C3-pathway) residues were -12.19±0.34‰ and -27.48±0.42‰, respectively. These values are in the ranges of those for C3 and C4 pathways [8].In Thailand $\delta^{13}C$ values of C3 plant leaves are -26.1 ‰ to -31.4 ‰ (average -28.9‰) and C4 plant leaves are -11.8 ‰ to -15.7 ‰ (average -13.6‰) [9]. In this study, after three crops and when the cultivation system was changed from maize to upland rice, the $\delta^{13}C$ value of soil carbon was shifted from -18.77 ‰ to -20.27‰ (UM system). The $\delta^{13}C$ value of soil carbon under CU system was -20.73 ‰. It can be said that the continuous incorporation of maize carbon into the soil has been resulted in less negative $\delta^{13}C$ values as compared to that of the $\delta^{13}C$ values under CU system. From these results, the was estimated that the average turnover time of SOC ranged from 3 to 6 years, and soil carbon in CM is turnover more rapidly (2.33 years) than in CU plots (5.93 years). In the same way in UM system turnover time of soil carbon was 3.89 years, reflecting that organic carbon input is a mixture of residue from maize and upland rice. It was calculated from the change in $\delta\ ^{13}C$ value that a fraction of the rice plant-derived SOC after changing the cultivation from maize to upland rice was about 29.78 % of total SOC, or for every cropping season 10% of SOC is derived from rice. The rest (70.22%) of organic carbon in top soil had their origins from maize residues. The small fraction of newly decomposed organic carbon that is incorporated into SOC pool was probably due to the lower input of carbon from rice straw incorporation. The rapid turnover of SOC has generally resulted in low SOC content in soil of this region. It is interesting to note that maize growing has resulted in faster turnover and higher accumulation of SOC. The higher input of maize residues may be the reason of this.

4. Conclusion

A cultivation practice of continuous maize with crop residues incorporation maintains higher carbon in soil when compared with changing it to upland rice cultivation. Our results also indicate that maize rotated with upland rice could help increase carbon stock when compared to cultivating upland rice alone. Soil organic carbon turnover time was declined from 6 to 3 years when cultivation was changed from continuous upland rice to rotate with maize. This result indicates that the way the land is used and cultivated has a significant influence on soil carbon dynamics. The magnitude of change and the capacity of agricultural land use system to sequester carbon vary. How such capacity/potential is related to detailed cultivation practices and environmental variables are being investigated

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