Research article

The Influence of Earthworm and Rice Stubble on Soil Aggregate, Carbon Sequestration and Soil Fertility in Sandy Loam Paddy Soil in Northeast Thailand

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Received 16 December 2012 Accepted 30 January 2013 (*Corresponding Author)

Abstract The objective of this study was to investigate the effect of epigeic earthworm (*Eudrillus eugeniae*) and rice stubble on soil aggregate, SOC, soil fertility and greenhouse gases (CO_2) emission in sandy loam paddy soils in Northeast Thailand. Experimental design was a completely randomized design. There were four treatments of incubation using Thai soil (Roi-et series) Sandy loam were: (I) soil control (no additions), (II) soil + rice stubble, (III) soil + earthworms (these added after 8 days incubation) and (IV) soil + rice stubble + earthworms (these added after 8 days' incubation), and then incubated for 20 days. During the experiment, soil respiration (CO_2), the aggregate size, SOC and soil fertility (N, P and K) were measured. The results suggest that the treatment with adding earthworms and rice stubble had significantly changed on soil aggregate than those without earthworm and added rice stubble only. Earthworm increased SOC and soil fertility (N, P and K) in paddy soil (sandy loam) than other treatment. The effect of earthworm on the decomposition of rice stubble in paddy sandy loam may influence the CO_2 emission from paddy soil.

Keywords sandy loam paddy soil, rice stubble, earthworm, carbon sequestration, soil fertility

INTRODUCTION

Earthworms, one of the most important macroinvertebrates in the terrestrial ecosystems of the temperate zone, exert important influences on soil functions (Fonte et al., 2007). Their activities play an important role in improving and changing the physical, biological, and chemical properties of soil (Coq et al., 2007). Earthworms improve the soil and increase water retention (Bossuyt et al., 2005). Additionally, the biomass and activity of soil microbial diversity (Doube and Beown, 1998) encourage earthworm activity, and allow fungi to perform better. Such activities are the main factors influencing the transformation of organic matter and are important for the dynamics of carbon in the soil. Thus, the experimental results of Don et al. (2008) reported that earthworms have a significant impact on the turnover of carbon in soil. They assist nutrient cycling in soil (Edwards and Bohlen, 1996).

Most of soil in Northeast Thailand is classified as sandy textured soil, which has relatively low fertility (Patama et al., 2004). The change of land use from forest to agriculture causes soil deterioration. Returning organic materials into the soil is one of the most effective approaches to restoring soil fertility (Patama et al., 2004). In Thailand, the main crop is rice. This contributes to a high amount of stubble and straw, while the rest of rice plant materials are retained in the paddy field. The rice residue produced is equal to 38.22 million tons/year (Rice Department, 2006). There are several beneficial uses of rice residue, such as incorporating the residue into soil, which may enhance soil fertility. Results of long-term research have shown that the carbon content of soil treated with rice residue was low, while simultaneously, CO_2 evolution increased (Samahadthai et al., 2010; Puttaso et al., 2011). There remains a critical need for research on the effects and interactions (soil carbon dynamics and nutrient turnover) of earthworms with rice residue in agro-ecosystems (paddy fields).

OBJECTIVES

The objectives of this study were to investigate the activities of earthworms and added rice stubble on soil properties; chemical, biological and physical; dynamics of organic carbon in soil and to improve the properties of soil and increase carbon sequestration in soil.

METHODOLOGY

Soil samples were collected (0-15 cm depth) from paddy fields in Khon Kaen province, Northeast Thailand. The soil textural class was sandy loam (62.40% sand, 36.60% silt, and 1% clay), organic C 4.55 g kg^{-1}, total N 0.28 g kg^{-1}, available P 6.29 mg kg^{-1} and exchangeable K 38.51 mg kg^{-1}. After collection, the soil was air-dried and sieved to pass 2 mm. Residue, stones, and sand larger than 2 mm. were discarded. Soil incubation consisted of 12 subsamples with four treatments, and three replicates each. Treatments consisted of four categories: 1) non rice stubble with no earthworms 2) soil with added rice stubble 3) soil with added earthworms and 4) soil with added rice stubble and earthworms. The earthworm species was *Eudrilus eugeniae*. The treatment added rice stubble 1.15 g (2-3 cm) was mixed in 200 g soil and put in glass jars with lids. Moisture levels in all treatments were appropriate (≈ 70%) and incubated at 30 ^{o}C. After seven days of incubation, eight adult earthworms were added in the designated earthworm treatments. Soil respirations were measured at days: 0, 3, 7, 10, 14 and 18. At 20 days; earthworms were removed from the jars, residues were discarded form soil, and the soil was air-dried. Soil was separated into two parts: one part aggregately measured (sieving shaker), another part chemically measured. Organic carbon was measured by the partial-oxidation method (Walkley and Black, 1934). Total nitrogen was measured by micro Kjeldahl method (Jackson, 1975). Extractable phosphorous was determined by following Olson's sodium bicarbonate extraction method (Olsen et al., 1954).

Exchangeable K was determined after extracting the sample using the ammonium acetate extractable method, and analyzed using the Perkin Elmer model 3110 double beam atomic absorption spectrophotometer (AAS) (Simard, 1993).

Analysis of variance pertaining to a complete random block design (CRD) and related statistical analysis were performed employing Statistics 8.0 (Analytical Software, 2003). Mean comparisons of different treatments were done by least significant difference (LSD) and standard error of the difference (SED).

RESULTS AND DISCUSSION

Soil aggregate formation

The results of short term experimentation show the influence of earthworm activity on soil aggregate formation in micro and macro aggregates (Table 1). The results clearly show that the earthworm significantly helped form new macroaggregates ($p<0.01$) on earthworm treatments compared with added earthworms and no earthworms, or added rice stubble only. On the other hand, activity of earthworm treatments decreased in the microaggregate. This is compatible with the hierarchical theory of aggregate formation (Samahadthai et al., 2010; Tisdall and Oades, 1982). In this experiment, added rice stubble had no effect on soil aggregate formation. Added earthworms had positive effects on soil aggregation. Earthworms contributed to soil aggregation mainly through cast production and burrowing activities. Earthworm gut transit involved contamination and mixing of soil, fragmentation of plant litter, and the addition of large amounts of water soluble mucus (Edwards and Bohlen, 1996).

Table 1 Chang of soil aggregate after 20 days of incubation with rice stubble and earthworm

Land use system	Microaggregate (<1 mm.)	Macroaggregate (≤ 2-1 mm.)
Control (soil)	89.86 a	9.63 c
Soil + Rice stubble	83.13 a	16.55 c
Soil + Earthworm	72.33 b	26.84 b
Soil + Rice stubble + Earthworm	57.31 c	41.82 a
f – test	**	**
CV %	5.41	16.43

Mean (n=3) in the same column followed by the same lower case letters are not significantly different at |p| ≤0.01 (LSD).

Carbon sequestration in soil

Carbon storage was increased in all soils compared to the initial, by about 2-27% in all treatments (Table 2). Concentrations of total C in soil between added rice stubble with earthworm and added rice stubble only were significantly ($p<0.01$) difference in soil organic C (SOC) than added earthworm only (Table 2). Newly added of rice stubble residues was improved SOC. This results were consistent with Naklang et al. (1999) which studied the management of chemical fertilizer and rice straw and leaves in rain fed paddy fields of Northeast Thailand (in both the dry and rainy season). They reported that in the first year's newly added residue (1994), the incorporation of rice stubble produced a higher level of organic carbon in soil (3.40 mg/g) than treatments without the incorporation of rice straw (3.10 mg/g). Interaction between earthworm activity and rice stubble increased SOC 27.22% higher than the control. Earthworm activities on macroaggregate dynamics are also important for C stabilization processes (Elliott, 1986; Six et al., 1998, 2002; Fonte et al., 2007). Due to rapid occlusion of organic materials, microbial communities associated with microaggregates within macroaggregates formed during or shortly after passage through the earthworm gut are relatively inactive, and therefore change relatively little over time compared to macro aggregate populations as a whole (Mummey et al., 2006). Earthworm gut mixing with soil was previously inaccessible as physically protected organic matter from microbial attack (Edwards and Bohlen, 1996).

Table 2 Quantities of carbon in soil after 20 days of incubation with rice stubble and earthworm

Treatment	Total C ($g\ kg^{-1}$)	Changes in quantities relative to the control (%)
Control (soil)	0.380 b	
Soil + Rice stubble	0.450 a	18.55
Soil + Earthworm	0.389 b	2.56
Soil + Rice stubble + Earthworm	0.483 a	27.22
f – test	**	
CV %	6.28	

Mean (n=3) in the same column followed by the same lower case letters are not significantly different at |p| ≤0.01 (LSD).

Soil respiration

In this study, CO_2 evolution was the highest in added rice stubble with earthworm treatment (Fig. 1). This demonstrates that rice stubble with earthworms could lead to a metabolically active microbial biomass efficient in utilizing carbon resources. A greater proportion of substrate carbon is lost in the form of CO_2 through respiratory activity (Pang et al., 2012). Rice residues were categorized as low quality organic material since they comprise a high content of carbon (367-423 g kg^{-1}) and cellulose (353-507 g kg^{-1}), and a low content of nitrogen (4.7–8.5 g kg^{-1}) and lignin (19-45 g kg^{-1}). Incorporated into soils with optimum conditions, rice residues rapidly decomposed (Samahadthai et al., 2010; Puttaso et al., 2011) and led to an increase in CO_2 evolution.

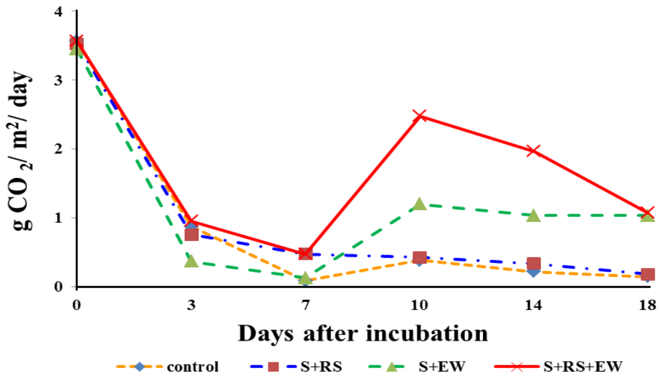

Fig. 1 Temporal pattern of CO_2 evolution (g CO_2 m^2 day) as affected by rice stubble and earthworm

Earthworm influence on N, P, K

In this experiment, the results have shown that the effect of earthworms and rice stubble increase soil nutrients such as N, P and K. Ponnamperuma (1984) reported that rice straw added to soil increases nitrogen, phosphorus, potassium and beneficial nutrients. Furthermore, rice straw helps increase the amount of organic matter and nitrogen in the soil (IRRI, 1976). Utilization of rice straw is possible through the incorporation of rice straw residue. Through cultivation into soil, rice straw proves to be an important source of plant nutrients and improves soil fertility (Azam, 1990).

Concentration of total N, though not significant, increased through earthworm treatments (Table 3). Earthworms increase nitrogen mineralization *via* the biological processes or physical changes they bring about in the environment (Costello and Lamberti, 2012). Earthworm feeding increases the rate at which organic N is mineralized into inorganic forms as earthworms primarily excrete NH_4^+ (Scheu, 1987; Whalen et al., 2000; Costello and Lamberti, 2012). Concentration of available P and exchangeable K were higher in rice stubble with earthworm treatment. Lui et al., (2005) reported that during 100-day incubation periods, earthworm inoculation combined with organic materials (rice straw, peanut residue and rape residue) increased significantly the content of soil available phosphorus. Basker et al., (1992) reported upon the incubation experiment of Tokomaru soil (silt loam) inoculated with the common pasture earthworm species *Aporrectodea caliginosa* for a period of 21 days. The resulting content of exchangeable K increased significantly due to earthworm activity.

Table 3 Chemical compositions of soil after 20 days incubation with rice stubble and earthworm

Treatment	Total N (mg kg^{-1})	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})
Control (soil)	0.28	6.83 c	42.39 d
Soil + Rice stubble	0.29	7.81 b	118.74 b
Soil + Earthworm	0.42	7.11 bc	69.55 c
Soil + Rice stubble + Earthworm	0.45	11.78 a	143.19 a
f – test	ns	**	**
CV %	51.62	4.67	2.46

*Mean (n=3) in the same column followed by the same lower case letters are not significantly different at |p| ≤*0.01 (LSD).

CONCLUSION

This study suggests that the effect of earthworm and rice stubble increase soil fertility N, P and K in paddy sandy loam. As, interaction between earthworm and rice stubble helped form new macroaggregate; they are increased carbon storage compared to the initial, by about 2-27%. And increase metabolically active microbial biomass and influence the CO_2 emission from paddy soil. Earthworms have an important in soil carbon sequestration. However, more studies need to be conduct to investigate other factors may influence such as type of earthworm, soil and rice stubble between agroclimatic zones.

ACKNOWLEDGEMENTS

This research was funding by Khon Kaen University Research fund, Integrate Water Resource Management Research and Development Center in Northeast Thailand, GWRC and the office of Higher Education Commission and Khon Kaen University under the research project “Agro-Industrial Waste Management and Utilization” and thanks to Prof. Dr. Machito MIHARA for kind support. Thanks to “Problem Soil Research Group” and research project “Using Soil Biota for Biological Monitoring and Ecological Zoning in the Salt-Affected Area in Northeast Thailand.

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