Research article

Soil Carbon Dynamics during the Amelioration of Salt-Affected Areas in Northeast Thailand

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Abstract An understanding of the effect of salinization on soil carbon (C) sequestration is important for environmental management. This study aimed to investigate the effect of salinity on soil organic carbon dynamics in salt-affected areas under a tree plantation, at Amphur Borabue, Mahasarakam province, Northeast Thailand. The study area has been established with tree plantation for three years and was divided into 3 zones based on the plant community found in each zone, correlated with the flooding situation and soil salinity. Soil samples were taken from three different zones and a fallow soil (control) at the same depth (0-20 cm) with three replications beginning from the rainy season of 2010 to the summer of 2011. The results from a three year old tree plantation showed decreasing EC_e and increasing soil organic carbon when compared with the fallow soil. Moreover, microbial activities were greater under the tree plantation soils when compared to the fallow soil. It could be concluded that soil organic carbon and biological properties were improved after establishment of a tree plantation in salt-affected soils. Therefore, it indicates that tree plantations are an effective strategy for carbon sequestration to reduce the buildup of carbon dioxide in the atmosphere.

Keywords salinity, carbon sequestration, microbial activity

INTRODUCTION

An understanding of the effect of salinization on soil carbon (C) sequestration is important for environmental management. Soils in Northeast Thailand are salt-affected due to the presence of salt bearing rocks (Land Development Department, 1991), particularly in Nakhon Ratchasima, Khon Kaen, Roi Et and Mahasarakham provinces (Department of Mineral Resources, 1982). Because of their age and the extent of weathering that has taken place in the past, soils in those areas are also relatively infertile. Levels of soil fertility are often strongly influenced by soil organic carbon (SOC), with low organic matter contents due to low biomass inputs and rapid turnover.

Since the amount of C present in the soil is dependent on C inputs and losses, increasing salinity levels have the potential to decrease C inputs into the soil through their effects on vegetation and impact on C dynamics. Not only high salinity directly impacts upon plant vigour through changes in osmotic potential, ion toxicities and ion deficiencies, but indirect effects on vegetation can result from altered soil conditions such as increased dispersion and decreased permeability. Changes in salinity affect soil physical (Boivin et al., 2004) and chemical properties (Sumner, 2000), which subsequently alter nutrient cycles, aggregation and biotic activity

(Zahran,97; Sardinha et al., 2003; Rietz and Haynes, 2003) and also influence on plant growth and yield (Marschner, 1995). Among them, changes in mineralization of C and N with increasing salinity have been observed (Nelson et al., 1996; Pathak and Rao, 1998). Despite the large area affected by salinity, both in Thailand and globally, data on the changes in soil C stocks in these degraded environments is scarce.

Carbon sequestration refers to the storage of atmospheric CO_2 in the plant biomass and soils of a particular ecosystem during a period of time. Tree-based plantation is a land management option that has C sequestration potential for two reasons. First, tree biomass contains more C than annual crops, leading to more C storage in tree plantation systems than conventional agricultural systems (Sharrow and Ismail, 2004; Peichl et al., 2006). Second, tree plantation systems are expected to have more SOC due to the greater annual C input from leaf litter, tree root turnover and tree root exudates, compared to agricultural crops. Organic residues from trees are lignin-rich and contain other resistant compounds (e.g., tannins) that are slowly decomposed and thus stabilized in the SOC pool (Montagnini and Nair, 2004). Garg (1998) also reported that salt-affected soils may be reclaimed by growing salt-tolerant tree species, which improve the physical and chemical properties as well as biological activity in the soil. Therefore, ecological management utilizing tree plantations in salt-affected areas has the potential to alleviate salinity stress and increase soil organic carbon. The objective of this study was to investigate the effect of salinity on soil organic carbon dynamics under tree plantations in salt-affected areas of Northeast Thailand.

MATERIALS AND METHODS

Study area

This study was carried out at Ak-Kasatsuntorn water reservoir, Tambon Borabue, Mahasarakam Province, Thailand at latitude of 16° 01' N and longitude of 103° 05' E, and at an elevation of 178 m from mean sea level. The study site has been established for three years with a tree plantation (2710 plants of 17 species). Woody plants such as common ironwood (*Casuarina equisetifalia* J.R. & C. Forst.) and fruit plants such as manila tamarind (*Pithecolobium dulce*) are growing in a salt-affected area with a covering of native grasses and weeds, i.e., torpedograss (*Panicum repens* L.). The study area was divided into 3 zones based on the plant type located in each area where they were correlated with the flooding situation and soil salinity. Zone 1 is more prone to flooding situation and high salinity, followed by Zone 2 and Zone 3.

Soil sampling and analysis

Soil samples were taken from three randomly selected locations at each zone and from a fallow soil near the experimental site (control) at a depth of 0–20 cm beginning from the rainy season of 2010 to the summer of 2011. Samples were analyzed to determine soil chemical and microbial properties in the laboratory at the Land Resources and Environment section, Faculty of Agriculture, Khon Kaen University. Electrical conductivity in saturated paste extracts (EC_e) was measured following the method described by the United States Department of Agriculture (USDA, 1954). Total soil organic carbon (SOC) was determined by the method of Walkley and Black.

Microbial biomass C and N were determined in field moist subsamples immediately after sampling by the chloroform fumigation extraction method. For microbial biomass C (MBC), 20 g of fumigated and unfumigated soil were extracted with 100 ml of 0.5 M K_2SO_4. MBC in the extracts was determined after oxidation with $K_2Cr_2O_7$. For microbial biomass N (MBN), 20 g of soil was extracted with 100 ml of 1 M KCl. Extracts were taken from non-fumigated samples immediately after sampling. MBN was determined by the ninhydrin-reactive N method (Amato and Ladd, 1988). MBC and MBN were calculated as the difference between fumigated and unfumigated values, using k_{EC} and k_{EN} factors of 0.33 (Sparling and West, 1988) and 3.1 (Amato and Ladd, 1988) to convert extracted organic C and N to microbial C and N, respectively. Microbial activity was studied by basal soil respiration using the titrimetric method (Zuberer, 1991). This method was based on the determination of CO_2 evolved from incubated soils. Field moist soil was placed in an airtight jar containing a vial with 15 ml of 1.0 M NaOH and incubated at 28°C. After one day of incubation, the NaOH vital was removed from the jar, 5 ml of excess 0.5 M $BaCl_2$ and 2-3 drops of phenolphthalein added to precipitate carbonate out from the NaOH solution as insoluble barium carbonate, and finally the excess NaOH was titrated with 0.5 M HCl. Soil respiration, i.e., evolved CO_2-C, was computed according to the Eq. (1) described by Anderson (1982).

$$CO_2\text{-C (mg)} = (B-V)\ NE \qquad (1)$$

where B is the volume (ml) of acid (HCl) used to titrate the alkali (NaOH) of a blank solution (not incubated with soil), V is the volume (ml) of acid used to titrate the alkali solution incubated with the soil sample, N is the normality of acid (HCl), and E is the equivalent weight of CO_2-C. The metabolic quotient qCO_2 (Anderson and Domsch, 1986) of each sampling period was calculated as in Eq. (2).

$$qCO_2 = CO_2\text{-C} / MBC \qquad (2)$$

where CO_2-C (mg kg^{-1} soil) is soil respiration and MBC (mg kg^{-1} soil) is microbial biomass C.

Statistical analysis: The data analysis was done using Statistix 8.0 (Analytical Software, 2003) to compare each zone at 5% probability level by using least significant different (LSD) method.

RESULTS AND DISCUSSION

The results from a three year old tree plantation with cover of native grasses showed significant effects on soil properties of this salt-affected soil. Soil texture of study area was sandy soil. There were significant differences in EC_e among the zones in all seasons (Table 1). The fallow soil (control) and zone 1 were saline soils (greater than 4 dS m^{-1}) while the others were non-saline (less than 4 dS m^{-1}), according to the classification of the USDA (1954). In the rainy season, the average EC_e was 9.02 dS m^{-1} and then decreased during the winter season (6.06 dS m^{-1}) and peaked in the summer season (12.22 dS m^{-1}), presumably due to salts in the groundwater moving up in the soil profile, accumulating on the soil surface, and consequently increasing the salinity in the summer season (Topark-Ngarm et al., 1990).

Table 1 Electrical conductivity (EC_e) and total soil organic carbon (SOC) in salt-affected soils after three years plantation

	EC_e (dS m^{-1})			SOC (g kg^{-1})		
	Rainy	Winter	Summer	Rainy	Winter	Summer
Control	17.83 a	14.20 a	26.87 a	1.80 b	2.80 c	1.71 c
Zone 1	15.54 a	9.41 b	17.39 b	3.51 ab	4.04 b	2.10 c
Zone 2	1.25 b	0.34 c	2.83 c	4.90 a	5.30 a	4.21 b
Zone 3	1.45 b	0.28 c	1.80 c	4.97 a	5.50 a	5.27 a
Mean	9.02	6.06	12.22	3.79	4.41	3.32
F-test	*	**	**	*	**	**
CV (%)	17	27	14	24	9	7

*Values in the same column followed by the same letter are not significantly different at the 5% level by the LSD test, ** significantly different at $P \le 0.01$, * significantly different at $P \le 0.05$*

Total soil organic carbon was significantly higher in the tree plantation zones than in the fallow soil (control) in all seasons, with the highest value being in zone 3 (Table 1). It might be due to the accumulation of humus from decomposition of leaf litter and root decay, which increased soil organic C. The results confirm the findings of Mishra et al. (2004). SOC contents of all zones were higher in the winter season, whereas values for the rainy and summer seasons were lower. It could be explained that the leftover leaf and root masses might have contributed to the increase OC content during the winter season.

The activity of MBC was greatly influenced by salinity (Table 2). It was significantly higher in the zone 2 and 3 when compared to the control in all seasons. It was not different between the zone 1 and control in the summer season, indicating that the zone 1 was still affected by salinity. In the rainy and winter seasons, there was significant difference between the zone 1 and control, probably due to high soil organic carbon in the zone 1 (Table 1). Among seasons, the highest average MBC was recorded in the rainy season. In contrast, the lowest was in summer when salinity was the highest, probably due to capillary rise of salty groundwater associated with evaporation (Topark-Ngarm et al., 1990). Soil salinity can decrease the microbial activity during summer season (Rietz and Haynes, 2003), and it is probably one of the environmental stresses for microbial growth and proliferation in soil. In this study, the values of MBC were higher in soils with higher SOC contents, as a similar result of Sparling, 1997. The values of MBN showed a similar pattern to those of MBC (Table 2). It was lowest in soil with highest EC_e.

Table 2 Soil microbial biomass carbon (C) and nitrogen (N) in salt-affected soils after three years plantation

Location	Microbial biomass C (mg kg^{-1})			Microbial biomass N (mg kg^{-1})		
	Rainy	Winter	Summer	Rainy	Winter	Summer
Control	99.4 c	60.1 c	43.8 c	15.6 b	8.1 c	7.3 c
Zone 1	164.4 b	135.7 b	45.3 c	17.6 b	11.4 c	9.0 c
Zone 2	176.0 b	175.9 ab	151.5 b	28.6 a	22.6 b	18.4 b
Zone 3	228.5 a	202.1 a	183.9 a	35.9 a	28.5 a	23.9 a
Mean	168.2	143.5	106.1	24.4	17.6	14.7
F-test	*	**	**	**	**	**
CV (%)	18	22	11	21	13	11

Values in the same column followed by the same letter are not significantly different at the 5% level by the LSD test,
*** significantly different at P≤0.01, * significantly different at P≤0.05*

Soil respiration, as a good index of the activity of microorganisms, was consistently lower in the control when compared to the tree plantation zones in all seasons (Table 3). It was highest in the zone 3 with highest SOC content that supports more CO_2 respiration. Variability in soil respiration mainly depends on weather variables (Kucera and Kirkham, 1971) and soil moisture (Gupta and Singh, 1981), along with the salt content of salt-affected soils (Garcia and Hernandez, 1996).

Table 3 Soil microbial basal respiration and metabolic quotient in salt-affected soils after three years plantation

Location	Soil microbial basal respiration (mg CO_2-C kg^{-1} day^{-1})			Metabolic quotient (qCO_2) (µg CO_2-C mg^{-1} MBC h^{-1})		
	Rainy	Winter	Summer	Rainy	Winter	Summer
Control	18.7 b	9.5 b	4.1 b	8.0 a	7.1 a	3.9 c
Zone 1	22.6 a	10.6 a	5.0 b	5.8 b	3.3 b	3.1 c
Zone 2	22.7 a	12.7 a	10.1 a	5.5 b	3.0 b	2.8 b
Zone 3	23.1 a	17.6 a	11.6 a	4.2 b	3.6 b	2.6 a
Mean	21.8	12.6	7.7	5.9	4.3	3.1
F-test	*	*	**	*	*	*
CV (%)	6	19	11	16	28	14

Values in the same column followed by the same letter are not significantly different at the 5% level by the LSD test,
*** significantly different at P≤0.01, * significantly different at P≤0.05*

The metabolic quotient (qCO_2) was higher in the control when compared to the tree plantation zones in all seasons. It was probably as a result of stress by salinity on soil microflora (Anderson and Domsch, 1993; Rasul et al., 2006), whereas it tended to lower in the tree plantation zones. A low metabolic quotient implies that the microbial populations were energetically efficient, i.e., allocating proportionally more carbon to growth (biosynthesis) than to maintenance (Zak et al., 1994). It was highest in the most saline soils, which may indicate low substrate quality (Smith, 1993) and low efficiency of organism functioning (Anderson and Domsch, 1990).

There were negative correlations between EC_e and SOC (r= -0.90, P≤0.01, n=36), between EC_e and MBC (r= -0.78, P≤0.01, n=36), between EC_e and MBN (r= -0.77, P≤0.01, n=36), between EC_e and soil respiration (r= -0.42, P≤0.01, n=36). These relationships revealed the detrimental effects that soil salinity had on the soil microbial activity. There was also a positive correlation between MBC and SOC (r= 0.83, P≤0.01, n=36), possibly because MBC is a part of SOC (Sparling, 1997). According to Rao and Pathak (1996), carbon is an important factor influencing microbial activity in salt-affected soils. Therefore, increased soil microbial activity might be due to the ameliorative effects of trees and consequently organic matter inputs.

CONCLUSION

The amelioration of salt-affected soil grown with tree species showed decreasing of EC_e and increasing of soil organic carbon. In addition, there were greater microbial activities in salt-affected soil under tree plantations. It could be concluded that soil chemical and biological properties were improved after establishment of a tree plantation in salt-affected soil. Therefore, it indicates that tree plantations are one of the most effective strategies for carbon sequestration to reduce the buildup of carbon dioxide in the atmosphere.

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