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Soil carbon sequestration and nutrient status of tropical rice based cropping systems: Rice-Rice, Rice-Soya, Rice-Onion and Rice-Tobacco in Sri Lanka

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ABSTRACT

Carbon sequestration increases soil fertility and reduces global warming by storing atmospheric carbon in soils. This study aimed to quantify and compare soil organic C fractions and C stocks in 4 different rice based cropping systems and investigate their variation as affected by crop rotation with upland crops. Soil nutrient availability and their relationship with chemical C fractions were also examined. Total organic C (TOC), microbial biomass C (MBC), water soluble C (WSC), $KMnO_4$ oxidizable C, pH and available macronutrients were analyzed at 0–15 and 15–30 cm depths in Rice-Rice[1] (RR), Rice-Soya (RS), Rice-Tobacco (RT) and Rice–Onion (RO) rotations on Alfisols of Sri Lanka. The data were analyzed by analysis of variance (ANOVA) on a completely randomized design (CRD) under 4 treatments with 6 replicates for each treatment. Results showed that carbon fractions and nutrient availability among different cropping systems varied significantly from one another. Under all cropping systems a higher content of all C fractions was observed in the 0–15 cm layer, except for WSC which was higher in the 15–30 cm layer because it moves to the deeper layers. The top soil layer also had a higher amount of MBC than the deeper layer, because the amount of microbial biomass and rate of microbial activity decline rapidly below the surface layer. Highest dry matter return to soil (147 g/m^2) in the RR system as paddy stubble accounted for highest amount of TOC in soil. RS system also had a higher TOC content due to the organic residues collected in soil as roots and leaf litter (67.7 g/m^2) as all dry leaves have fallen on to the soil at the time of harvesting of soyabean. However in RO system hardly any residues are added because the entire crop is removed at harvest and a significantly lower organic C content was recorded. Also the soil in RO and RT were tilled more than that used for soyabean during temporary bed preparation resulting in a relatively faster decomposition leaving significantly lower levels of C compared to RS. Change of cropping systems from RR to other annual crops such as RT and RO reduced the soil C sequestration to a significant level after 10 years of cultivation. However crop rotation change from RR to RS has maintained similar levels of C (65.18 t/ha) in RS and (63.48 t/ha) in RR. This indicated that C sequestration capacity is species specific and differences are mainly due to remaining crop residues and specific soil tillage practices used for upland crops. The study also showed that soil nutrient availability among the cropping systems varied significantly. Correlation analysis between chemical C fractions and major nutrient cations showed that there are significant correlations exist among them. The study confirmed that tropical rice based cropping systems have a great potential in storing and maintaining C in soils and thereby to facilitate nutrient availability.

1. Introduction

The potential of carbon sequestration by enhancing soil C stocks through sustainable land management has now been recognized for world agriculture (Smith et al., 2008). Crop rotations, soil tillage, fallow periods and water management are some management practices that could either reduce or increase soil C sequestration (Baker et al., 2007).

Paddy represents a large portion of global agriculture and is grown largely in South and East Asian countries as their staple food. Paddy fields are reported to have higher soil organic C storage (Pan et al., 2004) and sequestration with compared to drier croplands (Wissing et al., 2011). Organic carbon accumulation in paddy ecosystems was

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[1] RR; Rice-Rice, RS; Rice-Soya, RT; Rice-Tobacco, RO; Rice–Onion.

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faster and more pronounced than other arable ecosystems as organic matter decomposition is lessened in lowland rice fields (Wu, 2011) apparently due to excessively reduced conditions (Watanabe, 1984). Also the lack of oxygen for microbial activity under submerged conditions results in a decrease in the rate of decomposition (Jenkinson, 1988). Benbi and Brar (2009) reported that there is an incomplete decomposition of organic materials and decreased humification of organic matter under submerged conditions, resulting in net accumulation of organic matter in paddy soils as also reported by Sahrawat, 2004. In the long term, soil management controls the weathering and formation of minerals as well as accumulation of organic nitrogen in paddy soils (Kögel-Knabner et al., 2010). The mechanisms suggested for the accumulation of soil organic matter in paddy soils are identified as occlusion in aggregates, formation of organo-mineral associations, addition of pyrogenic organic matter and phyto-opal associated stabilization of organic C (Kögel-Knabner et al., 2010).

Information available on the C pools and stocks in tropical and subtropical paddy soils are restricted to some studies reported from China, India, Japan, Thailand, Indonesia and Vietnam. A study done in China reported that total SOC pool in China's paddy top soils is about 1.3 Pg, which is about 2% of the total storage in the topsoil of China (Pan et al., 2004). Wissing et al. (2011) reported an increase of topsoil organic C stocks from 2.5 to 4.4 kg m^{-2} during 50 to 2000 yrs of paddy soil management in China. Wissing et al. (2011) also reported that organic C accumulation in the bulk soil was dominated by the silt- and clay-sized fractions as also shown by Lal (2002). Nayak et al. (2012) reported that application of recommended dose of N–P–K either through organic fertilization or through inorganic fertilizer supplemented with farm yard manure or crop residues improved TOC, MBC, total SOC stocks and their sequestration rates in rice cropping systems in the Indo Gangetic Plains of India. They calculated that TOC stocks were about 6.8 g/kg in the surface 0–15 cm soil layer. Cheng et al. (2009) found higher C contents in a paddy soil chronosequence established for several hundred years in China under a rice/non-rice cropping system compared to upland soils in the same region. However their data did not include a comparison with rice alone.

Although anoxic conditions prevail during most of the time of rice growth, when the fields are drained few weeks before harvest, the redox potential increases (Jäckel et al., 2001). In addition paddy-specific water management creates a typical redox gradient in soil profiles. The highest potentials were consistently found at the surface of the roots presumably due to the influence of oxygenated water percolating into the top soil layer or due to atmospheric oxygen diffusion through shallow water (Doran et al., 2006; Schmidt et al., 2011). Oxic conditions are sustained over a longer period of time when upland crops are grown after paddy cultivation.

Management-induced change of oxic and anoxic conditions of paddy soil may affect the dynamics of organic and mineral soil constituents (Cheng et al., 2009). It is known that complexation of metals with soluble organic matter influence the solubility and mobility of metal ions in soil (Weng et al., 2002). However, Kögel-Knabner et al. (2010) reported that organic matter associated with minerals are still to be investigated for paddy soils.

Although it is known that submergence increases the quantity of soil organic matter, with long-term submergence results in the degradation of soil quality through the breakdown of stable aggregates and deterioration of soil organic matter (Mohanty and Painuli, 2004). Crop rotations are known to favour the build-up of soil organic carbon and improve soil nutrients contents in comparison with monocultures (Moore et al., 2000). Continuous monoculture will not be effective at sequestering C (Lal et al., 1998). This was further demonstrated by Campbell et al. (2007) using wheat-lentil crop rotations under upland conditions.

However crop rotations have not been studied for soil C fractions, C stocks, nutrient availability and their inter relationships in tropical paddy soils. The main objective of this study was to quantify and compare soil organic C fractions, C stocks, soil chemical and physical parameters in 4 different rice based cropping systems and to investigate their variation as affected by crop rotation with upland crops. The correlation between soil C fractions and soil nutrients were also established to understand the role of organic C fractions on nutrient availability in tropical paddy soils. We hypothesized that crop rotation changes from RR to rice with upland crops improves soil C fractions and C stocks and that C fractions affect nutrient availability in paddy soils. The information generated in this study could provide firsthand information vital to the establishment of a national carbon accounting system in the future and for maintaining sustainability of paddy soils in the tropics.

2. Materials and methods

2.1. Study area

This study was carried out on Alfisols in the North Central province of dry zone in Sri Lanka (5° 54′ N - 9° 52′ N latitude and 79° 39′ E - 81° 53′ E longitude). Four different cropping systems of paddy; Rice/Rice (RR), Rice/Soya (RS), Rice/Tobacco (RT) and Rice/Onion (RO) were selected. The sampling locations were scattered in the Divisional Secretariat Divisions of Dambulla, Awukana and Eppawala (Fig. 1). Descriptive information of the cropping systems is given in Table 1. The selected lands have maintained the same crop for >10 years. These lands were cultivated twice a year with rice in wet season while alternatively crops such as soya, onion or tobacco in dry season. The paddy fields selected were cultivated with inorganic fertilizers and no organic fertilizers were added. However the soil received a carbon input via paddy stubble during the wet season and via leaf litter and post-harvest residues of upland crops during the dry season. Inorganic fertilizer application rates are given in Table 2. Field preparation and harvesting methods are given in Table 3.

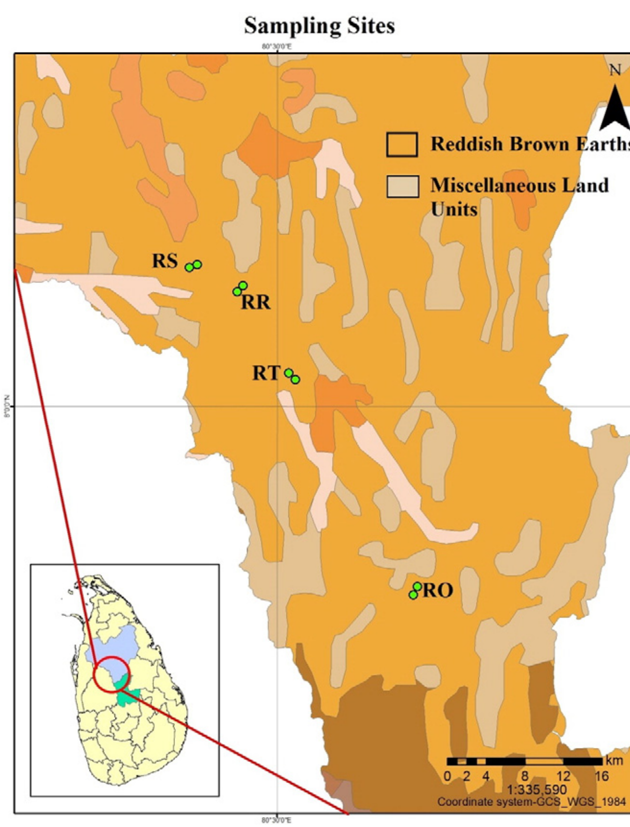

Fig. 1. Sampling locations of the study area in Sri Lanka.