Journal of Integrative Agriculture 2017, 16(1): 1–15

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Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems: A review

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Abstract

Soil organic carbon (SOC) sequestration is one of the major agricultural strategies to mitigate greenhouse gas (GHG) emissions, enhance food security, and improve agricultural sustainability. This paper synthesizes the much-needed state-of-knowledge on the effects of tillage, crop residue, and nutrient management practices on SOC sequestration and identifies potential research gap, opportunities, and challenges in studying SOC dynamics in rice (*Oryza sativa* L.)-based cropping systems in South Asia, mainly in Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. Improved management practices such as reduced- and no-tillage management, nitrogen (N) fertilizer and farmyard manure (FYM) application, and crop residue addition can improve SOC accumulation. Positive effects of no-tillage, crop residue addition, N addition through manure or compost application, and integration of organic and chemical fertilizers on SOC accumulation in rice-based cropping systems have been documented from South Asia. However, limited data and enormous discrepancies in SOC measurements across the region exist as the greatest challenge in increasing SOC sequestration and improving agricultural sustainability. More research on SOC as influenced by alternative tillage, crop residue, and nutrient management systems, and development of SOC monitoring system for existing long-term experiments will advance our understanding of the SOC dynamics in rice-based cropping systems and improve agricultural system sustainability in South Asia.

Keywords: carbon mapping, carbon sequestration, crop residue, no-tillage, rice-wheat system

1. Introduction

Agriculture faces significant challenges to meet the need of food production without significantly increasing the area under cultivation (Stevenson *et al.* 2013) and degrading the environment (Hobbs *et al.* 2008). In recent years, challenges in sustainable food production have remained in part due to climate change (Palm *et al.* 2013; Paudel *et al.* 2014a). Improved management practices such as reduced- or no-tillage management, crop residue addition, crop rotation, and

Received 16 October 2015 Accepted 4 March 2016
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doi: 10.1016/S2095-3119(16)61337-0

balanced nutrient application increases soil organic carbon (SOC) and improves agricultural sustainability (Six *et al.* 2002; West and Post 2002; VandenBygaart *et al.* 2003). Rice-based cropping systems in South and Southeast Asia that include irrigated continuous rice cropping, rice-wheat rotation, and rainfed rice-based mixed farming in upland areas feed more than 1.5 billion people (Cassman 1999). A typical rice-based system in South Asia follows traditional cultivation techniques that involve wet plowing (puddling), followed by transplanting rice seedlings grown in a seedbed in the summer (Hobbs *et al.* 2008). Wheat or other crops in a rotation are grown in the winter using traditional desi plow or moldboard plow tillage. There is a growing interest towards the use of conservation management systems, such as reduced-tillage, no-tillage, crop residue addition, and improved nutrient management practices in rice and other crops in rotation for sustainably increasing food production in South Asia (Carter 2002; Erenstein and Laxmi 2008; Johnston *et al.* 2009).

The conservation systems that reduce soil disturbance and retain residue at the soil surface can improve soil fertility status, soil aggregation, water infiltration, and nutrient availability (Lal 2004a, b). Improved SOC accumulation is associated with a greater microbial and root growth, nutrient and water supply, soil aggregation, and better pH and temperature regulation (Lal *et al.* 2007). However, information regarding effects of management practices on SOC accumulation in rice-based cropping systems in South Asia is very limited. Studies on SOC sequestration and sustainable crop production are primarily focused in the temperate region, where the rate of SOC decomposition is relatively slow (Halvorson *et al.* 2002). Therefore, recent interest in soil quality and sustainable crop production in South Asia warrants comprehensive analysis of the existing knowledge, research gap, and challenges in crop production in the region (Palm *et al.* 2013). Reduced- or no-tillage management and crop residue addition may benefit nutrient-depleted agroecosystems in South and Southeast Asia. This is because the response of the changes in management practices, such as crop residue addition and improved nutrient management, are observed more rapidly and in greater magnitude in highly depleted soils in the tropical than in the temperate region (Tirol-Padre *et al.* 2007). Improving agronomic and ecological benefits of greater SOC storage requires more information on management practices that increase C inputs and mitigate the loss of accrued benefits. This paper summarizes state-of-knowledge on the effects of tillage, nutrients, and residue management practices on SOC dynamics in rice-based cropping systems in South Asia. Our objectives were to (I) briefly discuss the status of rice-based cropping systems in South Asia, (II) compare the conventional and conservation practices, mainly tillage, residue and nutrient management to improve SOC accumulation, and (III) highlight the opportunities, challenges, and research gaps to increase sustainability of rice-based production systems in South Asia.

Agroecosystem of South Asia represents the area of humid to sub-humid tropical and sub-tropical climate with frequent extreme precipitation events during summer. The region spreads around 642 millon ha area and resides 1.6 billion people (FAO 2013). Precipitation ranges from 1 000 to 2 000 mm, approximately 70% of which occurs during the summer monsoon, and facilitates rice production (Yao *et al.* 2008; Ghimire *et al.* 2012). Continuous rice cultivation is commonly practiced in irrigated areas and lowland environments, where continuous embankment of water is possible, or water supply is assured throughout the year. Areas that do not have a year-round water supply are used for growing rice in rotation with other crops such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and vegetables. In South Asia, continuous rice cropping and rice-wheat rotation occupy approximately 26% of the cultivated land with additional 30% area under the rainfed mixed farming that includes upland rice production (FAO 2001). Upland rice is produced in areas with low precipitation and limited opportunities for irrigation.

We mapped SOC distribution at different soil depths in South Asian landscape and reviewed SOC accumulation as influenced by tillage, crop residue, and nutrient management practices in rice-based cropping systems. The SOC map was developed at the spatial resolution of 1 km using a SoilGrids1km — A global 3D soil information system using a spatial prediction function for some selected soil properties at six standard depths (Fig. 1). To our knowledge, this map is the first of its kind to demonstrate SOC distribution in South Asia. The spatial data delineating the rice production area are not available for the entire region. However, rice-based production system predominates the region and SOC mapping for the entire region provides a baseline for South Asia and serves as a good reference for comparing SOC in the future. In this map, field-based soil profile data and various covariate layers representing soil forming factors were used to predict SOC distribution. 2D and 3D regression and regression-kriging were combined with splines for numerical properties as implemented in the GSIF package of R. The regression was fitted using general linear models (GLMs) with a log-link function to predict SOC by using field-based measurements (Hengl *et al.* 2014; ISRIC 2015). Selection of spatial prediction models for making these maps was based on the iterative evaluation for each soil variable by assessing the success of cross-validation (Hengl *et al.* 2014). We also cross checked the mapped and measured SOC values in long-term experimental locations across the region, which revealed reasonable accuracy of kriging-based data to es-