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Effects of tillage and biomass on soil quality and productivity of lowland rice cultivation by small scale farmers in North Eastern India

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ABSTRACT

Intensive tillage-based production systems along with residue removal, grazing and/or burning of crop residues/biomass and poor nutrient replenishment through inadequate fertilizer and manure use are the major causes of soil degradation and unsustainable agriculture in hills of North Eastern India. Thus, a 4-year study (2003–07) was conducted during rainy (wet) seasons at Indian Council of Agricultural Research (ICAR) Research Complex for North Eastern Hill (NEH) Region, Umiam, India (950 m a.s.l.). Objective of the study was to assess the effect of different tillage systems (individual or combinations of spading, trampling and hand weeding) on rice (*Oryza sativa* L.) productivity and soil (*Typic Paleudalf*) quality under *in-situ* residue management in lowland conditions. Transplanting in manually weeded unpuddled field was termed no-till (NT). In comparison, individual or combinations of spading, trampling (one partial manual puddling to incorporate weeds) and weeding was termed minimum tillage (MT). Treatment involving the maximum tillage included 4 spading + 2 trampling + 2 weedings, and was termed the conventional tillage (CT). The latter is practiced widely by farmers' in the region. Nine tillage treatments were laid out in a Randomized Block Design (RBD) and replicated thrice in a fixed plot size of 5m × 5 m. Increasing tillage intensity (combinations of spading along with trampling and weeding) increased grain yields. Agronomic yields obtained with 2 spading + 1 trampling + 1 weeding (MT option) was statistically ($p = 0.05$) similar to that under CT. In general, the weed biomass was more under NT and MT than CT, and also contributed 2–4, 0.8–2 and 0.78–1.9 times more N, P and K, respectively, towards nutrient recycling than that under CT. However, the amount of N, P and K recycled through rice straw was more under CT than MT and NT. Weed biomass played a major role as a nutrient source in MT systems and contributed towards yield stabilization and improvement in soil quality. The soil organic carbon (25.2 g/kg), soil microbial biomass carbon (198.7 μg/g dry soil) and dehydrogenase activity (25.84 μg TPF/g dry soil) in NT were 11.5, 17 and 107%, respectively, more than those under CT. These parameters under MT systems were 6–13, 2–15 and 35–88%, respectively, more compared to those under CT. The bulk density (ρb) under CT (1.18 Mg/m^3) was significantly higher than those observed under MT systems of only one spading or one trampling (1.15 Mg/m^3). The net return was the highest with MT system comprising of 2 spading + 1 trampling + 2 weeding ($367.5/ha), and that was 25.5% higher than that with CT. The net return per dollar (NRP) invested decreased with increasing tillage intensity. *In-situ* rice residue retention along with weed biomass recycling (MT) for 4-years improved soil quality, reduced cost of production and stabilized productivity in a low-input marginal (marginal soil and small scale farmers) hill agriculture.

Abbreviations: a.s.l, above sea level; ρb, bulk density; CA, conservation agriculture; CT, conventional tillage; DAT, days after transplanting; DHA, dehydrogenase activity; FYM, farmyard manure; HI, harvest index; ICAR, Indian Council of Agricultural Research; IGPs, Indo-Gangetic Plains; LSD, least significant different; M ha, million hectare; Mg, mega gram; MT, minimum tillage; NEH, North Eastern Hill Region; NRP, net return per dollar; NT, no-till; OM, organic matter; PR, penetration resistance; RCTs, resource conservation technologies; RBD, Randomized Block Design; S, spading; SMBC, soil microbial biomass carbon; SOC, soil organic carbon; T, trampling; W, weeding.

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1. Introduction

Food security in Asian countries depends largely upon rice (*Oryza sativa* L.) and it is the main source of protein (15%) and energy (21%) for the population (Depar et al., 2011). The total area of rainfed lowland paddy rice in Asia is about 59 million ha (M ha), which accounts for approximately 44% of all the rice cultivated land (Maclean et al., 2002). However, rice productivity in rain fed lowland areas is low because of poor soil fertility (Das et al., 2008, 2013), unreliable water resources (Wade et al., 1999) and lack of resources and widespread poverty (Fujihara et al., 2013). Primary benefits of puddling are the creation of soft seedbed, reduction of water and nutrient losses and weed control (Sharma and De Datta, 1985; So et al., 2001). However, puddling can degrade soil structure (Cass et al., 1994; Bajpai and Tripathi, 2000) and may even decrease yield in long term (Utomo et al., 1985; Kirchhof et al., 2000). Excessive tillage destroys soil structure, disrupts continuity of soil pores, reduces the amount of residues on the soil surface, and degrades soil quality (Lal and Shukla, 2004; Osunbitan et al., 2005). Tillage influences soil quality and plant growth by altering the physical, chemical and biological properties (Sharma et al., 2004; Yaduvanshi and Sharma, 2008). Over a short time, mechanical tillage decreases soil bulk density (ρb) and penetration resistance (PR) and increases soil macro-porosity (Logsdon et al., 1999; Engin, 2009).

The short-term agronomic response to tillage may be either negative (Agboola, 1981; Lal, 1989) or positive (Kawakye and Bobo, 1995). In the long term, however, crop response may be neutral or negative because of the soil structural degradation (So et al., 2001). In general, excessive tillage reduces crop yield. Experiments on Alfisols in the semiarid tropics of India show that the benefits of tillage may be short-lived, and depend on weather during the growing season (Awadhwal and Smith, 1988). Long-term field experiments conducted at mid altitude (937 m a.s.l) on a silty-clay soil indicated some improvements in soil aggregation, higher micro-porosity and soil organic carbon (SOC) concentration under no-till (NT) compared to conventional tillage (CT) systems (Andrade et al., 2010; Almeida et al., 2005).

Excessive and inappropriate tillage in conventional agriculture is one of the most important drivers of soil degradation (Reichert and Norton, 1994; Papendick and Parr, 1997; Bertol et al., 2004). It leads to soil and nutrient depletion by water runoff along with strong financial and environmental impacts (Bertol et al., 2007) in high rainfall areas like North East India. Frequent tillage operations increase soil compaction and ρb due to human and vehicular traffic (Saxena et al., 1997; Lampurlanes and Cantero-Martinez, 2003). Continued and widespread use of tillage-based production systems along with removal, grazing and/or burning of crop residues would further exacerbate soil degradation and lead to unsustainable agriculture (Lumpkin and Sayre, 2009). Conservation tillage comprising of reduced tillage and residue recycling, is an appropriate strategy of conservation agriculture (CA) for rain fed production systems. Minimal soil movement by reduction in tillage intensity and retention of crop residues on the soil surface along with crop rotations to economically benefit the farmers are the key principles of CA (Lumpkin and Sayre, 2009). Tillage-induced soil degradation can strongly impair the productivity of rainfed agriculture because of erosion and other degradation processes (Lal, 1994). On the contrary, a system based on high crop residue addition in conjunction with NT can be a net sink of carbon (Reicosky et al., 1995). Adoption of the MT decreases risks of deterioration of soil physical properties, decreases the turn around time in a cropping sequence (Singh et al., 2004; Andrade et al., 2010), produces rice yield similar to that under conventional puddling, and reduces expenses in field preparation in the Indo Gangetic Plains (IGPs) (Bajpai and Tripathi, 2000). Significantly higher SOC concentration under NT (West and Post, 2002) and MT (Alvarez, 2005) compared to CT has been widely reported. Thus, conversion from CT to NT along with residue retention can sequester on average $48 \pm 13\,g\,C\,m^{-2}\,y^{-1}$ (West and Post, 2002). Therefore, MT systems are recommended as an alternative to CT because of their economic and environmental advantages (Al-Kaisi and Yin, 2004). However, yield reduction with MT or NT remains a major concern (Singh et al., 2011).

Recycling of residues and plant biomass in the soil is a promising option for replenishing soil fertility, improving physico-chemical properties, and enhancing/sustaining crop yield (Kayuki and Wortmann, 2001; Kolawole et al., 2004; Das et al., 2008; Bijay-Singh et al., 2008). Further crop residue retention is also important for sequestering SOC, and improving soil quality (Blanco-Canqui and Lal, 2007; Dolan et al., 2006; Wilhelm et al., 2004). The magnitude of the impact of residue management on soil quality is, however, site specific (Blanco-Canqui and Lal, 2007).

Lowland rice-based systems are important agro-ecosystems, and produce food for a large population in Asia. Along with grain yield, these systems also generate large amount of crop residues. Traditionally, crop residues have been removed from fields for livestock bedding and feed, fuel for cooking, and other off-field purposes including *in-situ* burning (Bijay-Singh et al., 2008; Das et al., 2008). An environmental concern of the field burning of straw include atmospheric pollution and volatilization of some essential nutrients. 1 Mg of crop residue on burning releases 1515 kg CO_2, 92 kg CO, 3.83 kg NO_x, 0.4 kg SO_2, 2.7 kg CH_4, and 15.7 kg nonmethane volatile organic compounds (Andreae and Merlet, 2001). In contrast, an effective management of residues, roots, stubbles and weed biomass can have a beneficial effect on soil fertility through addition of OM, plant nutrients and improvement in soil quality (Srivastava et al., 1988; Sidhu and Beri, 1989; Singh, 2003; Singh et al., 2003; Das et al., 2008; Bijay-Singh et al., 2008). Karchoo and Dixit (2005) reported that the incorporation of crop residues improved crop yield, increased nutrient uptake, and enhanced soil physico-chemical and biological properties. Retention of crop residues as mulch in combination with NT enhances resource-use efficiency (Sangar and Abrol, 2005; Ghosh et al., 2010). About 40% of N, 30–35% of P, 80–85% of K, and 40–50% of S absorbed by rice remains in the residues at maturity (Dobermann and Fairhurst, 2000). Typical amounts of nutrients in rice straw at harvest are 5–8 kg N, 0.7–1.2 kg P, 12–17 kg K, 0.5–1 kg S, 3–4 kg Ca, 1–3 kg Mg, and 40–70 kg Si/Mg of straw on a dry weight basis (Dobermann and Witt, 2000). Thus, residue removal exacerbates soil nutrient depletion. Residue retention also influences availability of micronutrients such as zinc, iron and silicon (Dobermann and Fairhurst, 2000, 2002).

Agriculture in the limited resource areas (e.g., North Eastern Hill region of India comprising about 18 M ha) are low-input subsistence in nature and based on manual labor and drought animals (Das et al., 2008). Rice is generally grown in a puddled soil. Puddling is unique to thr lowland rice cultivation in low-input cropping systems (So et al., 2001). Repeated tillage, planking and leveling are done to create a favorable soil conditions for transplanting. At least 3–4 spading (spade is an iron-made blade attached to a wooden handle used for turning soil manually) are given for preparing seedbed. Along with spading, manual trampling (practice of turning down the weeds into the field and softening the seed bed) and planking (a wooden or bamboo made plank pulled manually or by oxen) are also done for puddling and leveling the paddy field. Finally, a fine seedbed is prepared in CT practices. Hill farmers at mid altitude mostly use manual labor for field preparation for lowland paddy cultivation. Difficult terrain, small plot size (some time as small as $50\,m^2$) and poor economic conditions restrict the mechanization of farm operations (Das et al., 2008). Locally made tools and implements (*e.g.*, spade,