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Tillage and cropping sequence effect on physico-chemical and biological properties of soil in Eastern Himalayas, India

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ABSTRACT

Poor soil quality and low fertility are major limitations to agricultural intensification and increasing crop productivity under rainfed hill ecosystems of North Eastern Region (NER) of India. Intensive tillage and adoption of mono-cropping of rice (*Oryza sativa* L.) or maize (*Zea mays* L.) leads to depletion of soil fertility and crop productivity. A three year field experiment (2007–2010) was conducted at mid altitude of Meghalaya, India with eight cropping sequences [maize-rapeseed (*Brassica campestris* L. var. toria.), maize-pea (*Pisum sativum* L.), rice (*Oryza sativa* L.)- rapeseed, rice-pea, ricebean (*Vigna umbellate* Thunb.)-rapeseed, ricebean-pea, soybean (*Glycine max* L. Merr) – rapeseed and soybean-pea] under two tillage systems; conservation tillage (CST) and conventional tillage (CT). The objectives were to assess impact of tillage and cropping sequence(s) on soil quality and fertility after three years of the experiment. Soil moisture content and infiltration rate were significantly improved under CST relative to those under CT. The soil organic carbon (SOC) concentration was significantly higher under CST (23 g/kg) relative to that under CT (21.2 g/kg) at 0–15 cm soil depth. Available nitrogen (N), phosphorous and potassium, soil microbial biomass carbon (SMBC) and dehydrogenase activity (DHA) were also significantly higher in CST than those under CT. The cropping sequences did not affect the bulk density (ρ_b) and SOC significantly. However, available N, SMBC and DHA concentration were significantly higher under soybean-pea and soybean-rapeseed sequences as compared to others. During 2009–10, where rainfall received during the winter season was negligible, 4–70% higher yields of winter crops were observed under CST than those under CT. Thus, adoption of CST and soybean based cropping sequences offers an alternative to raise crops during the winter season on residual soil moisture and improve soil quality in eastern Himalayas.

1. Introduction

The Eastern Himalayan Region is highly susceptible to soil erosion due to undulating topography, very steep slopes and high precipitation (Mandal and Sharda, 2013). Lack of appropriate soil and water conservation measures in the terraced and sloping lands exacerbates soil erosion (46 Mg/ha/year) which depletes soil fertility and degrades the ecosystem of hilly areas (Lenka et al., 2012a) of the north eastern region (NER) of India. Conversion to conservation tillage (CST) practices can alleviate soil-related constraints (Lal, 2015) in achieving potential productivity and enhancing cropping intensity in such land forms. Improperly designed tillage practices can set-in-motion an array of degradation processes such as accelerated erosion (Ande and Senjobi, 2014), depletion of soil organic matter (SOM) and plant nutrients (Tolessa et al., 2014), deterioration in soil structure and disruption in water, carbon (C), nitrogen (N) and other nutrient cycles (Lenka et al., 2012b; Lal, 2015). Under upland and sloping lands, intensive tillage loosens the soil and breaks aggregates, while removal of residues and ploughing leaves the soil surface bare and unprotected against vagaries of harsh and increasingly uncertain climate (Ande and Senjobi, 2014;

Abbreviations: ANOVA, analysis of variance; AWC, available water holding capacity; ρb, bulk density; C, carbon; CST, conservation tillage; CT, conventional tillage; DAS, days after sowing; DHA, dehydrogenase activity; ICAR, Indian Council of Agricultural Research; IR, infiltration rate; K, potassium; KEC, K_2SO_4 extract efficiency; LSD, least significant difference; N, nitrogen; NER, North Eastern region; NS, not significant; NT, no-till; P, phosphorous; SEm ± , standard error from mean; SMBC, soil microbial biomass carbon; SMC, soil moisture content; SOC, soil organic carbon; TPF, triphenyl formazan

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Peng et al., 2016). Such practices exacerbate soils' susceptibility to erosion during the monsoon season (Lenka et al., 2012b) and evaporation loss during the winter season (Das et al., 2014). Further, soils of the NER are mostly light textured (sandy loam) with a low plant available water holding capacity (AWC) causing loss of about 10–13% of the rainfall through deep percolation (Lenka et al., 2012a,b). Merely 23–27% of rainwater is available for crop production as green water and the remainder is lost through runoff, percolation and evaporation (Saha et al., 2007). As much as 70–80% of the cultivated area remains fallow during the winter season with most of the cropping limited to the monsoon season (Kuotsu et al., 2014).

In general, CST improves the quality and productivity of soils (Page et al., 2013; Paul et al., 2013), by increasing biological activity through the presence of C substrate (Ghosh et al., 2010). The maintenance of SOM in the topsoil promotes biological activity (Dungait et al., 2012). Conversion of conventional tillage (CT) to CST with suitable cropping sequences can maintain soil quality and control erosion (Page et al., 2013). Proper maintenance of residue cover in surface under no-till (NT) is essential to optimize cropping system performance (Leys et al., 2010), minimize soil erosion (Lenka et al., 2012b), enhance retention of limited precipitation (Montenegro et al., 2013; Vermang et al., 2015) and improve soil quality (Thierfelder et al., 2013). Furthermore, soil structure also improves because of the cultivation of a second crop after the rainy season (Xuan et al., 2012), especially so when seeded with appropriate methods of seedbed preparation and seeding drill (Gangwar et al., 2006). There are very few studies on effect of cropping system on soil quality and the impact has not been understood well (Liebig et al., 2004). Instead of intensive cropping, diversified cropping is an alternative strategy to sustain soil fertility and crop productivity (Xuan et al., 2012). The crop rotation has positive impact on beneficial microbial population and their activity (Larkin and Honeycutt, 2006). Crop sequences modify the soil moisture content and water infiltration rate (Sasal et al., 2006). The quantity and quality of crop residues as well as the fallow time period are determined by the cropping sequence, which in turn modify the soil structure (Davis et al., 2012). Adoption of suitable cropping sequences and conservation tillage may positively affect the on soil organic carbon (SOC) concentration and improve the soil quality of degraded hilly soils (Das et al., 2014; Lal, 2015). Therefore, the present study was conducted with the objectives to assess the impact of cropping sequences and tillage on soil quality and fertility. The hypothesis tested was that CST will improve soil physical, chemical and biological properties owing to less/no soil disturbance and retention of crop/weed biomass and legume based cropping sequences will improve soil quality due to N-fixation and quality biomass retention over others.

2. Materials and methods

2.1. Experimental site

The experimental site was located in the Indian Council for Agricultural Research (ICAR) Research Complex for the North East Hill (NEH) Region, Umiam, Meghalaya, at a latitude of 25° 41′21″ N and longitude of 91° 55′25″ E and an elevation of 970 m above the mean sea level. The study site is a valley terraced land developed since 1990. Mono-cropping of maize and rice have been practiced over the years in the study site. At least two years prior to present study (ie., 2005 and 2006) exhaustive crop maize was grown under uniform management practices for fertility stabilization. The soil of the experimental site is a *Typic Paleudalf*, loam to sandy clay loam in the surface and silty loam to sandy clay in the sub-surface layer (Das et al., 2014). The climate of the NER as a whole is sub-tropical humid having hot summer and cool winter. Generally, the monsoon season starts from May and extends up to September, and the rainfall recedes from October. The long term average annual rainfall of the study site is 2450 mm. The annual rainfall received during present study period of 2007, 2008 and 2009 were with deviation of 21.8, −8.6 and −19.7% from the average annual rainfall. Thus, performance of the crops in 2007–2008 and 2008–2009 were normal. Whereas, 2009–2010 was a dry year and crop performance was adversely affected by drought stress. The mean maximum temperature was the highest during August 2009 (28.1 °C) and the lowest in December 2009 (21.5 °C).

2.2. Description of treatments

The experiment was laid out in a split plot design with 2 main-plots, 8 sub-plots and three replications. Two tillage treatments (*viz*., CT and CST) were laid out as main plots. The sub-plot treatments consisted of four crops (maize, rice, ricebean and soybean) during summer (rainy season), and two crops (rapeseed and pea) during winter (dry) season grown in eight sequences viz., maize (*Zea mays* L.)-rapeseed (*Brassica campestris* L. var. toria.) (CS_1), maize-pea (*Pisum sativum* L.) (CS_2), rice (*Oryza sativa* L.)-rapeseed (CS_3), rice-pea (CS_4), ricebean (*Vigna umbellata* Thunb.)-rapeseed (CS_5), ricebean- pea (CS_6), soybean (*Glycine* max L. Merr)-rapeseed (CS_7) and soybean- pea (CS_8). The dimensions of individual sub plots were 5.0 × 3.0 m leaving 0.5 m in between two subplots and 1.0 m in between two main plots as borders.

Under CT, the residues of weeds and above ground crop biomass were removed manually from the field using a sickle. For field preparation in CT systems, two manual spading followed by levelling were done to a depth of about 15 cm both during summer and winter seasons. Spading (a local made farm tool having a cast iron made thick blade of 15–20 cm width, 20–25 cm length, adequately sharpened and attached to a wooden/bamboo handle of 75–1 m long) is done for manual turning of soil that imitate a condition similar to that created by a primary tillage farm impalements under CT. Further, spading is the most common and possible tillage operation in the studied ecosystem due to small holdings and sloping land. Weeds were removed manually and retained on the soil as mulch under CST and completely removed in case of CT. The crop residues and weed biomass were chopped, spread on the soil surface and partially mixed with soil by one spading operation (5–7 cm depth) during field preparation for sowing the summer season crop under CST. However, for sowing the winter season crops under CST, residues of summer season crops were retained on the soil surface as in-situ mulch in between the two rows of a crop. Sowing under CST was done in narrow furrows made by a manual furrow opener (designed and fabricated by the Division of Agricultural Engineering, ICAR Research Complex for NEH region, Umiam, Meghalaya, India, costs about $ 16/piece) having two or three adjustable tines, can be pulled by one person in light soil, may need two person in compact soils) and primary tillage operations were completely avoided. Weeds were uprooted at each weeding operation and placed in between the crop rows as mulch under CST. Thus, under CST, minimum tillage (MT) during the summer season and NT during the winter season crops were practiced. The sowing operation under CT was also performed using a manual furrow opener in well pulverized field. Fertilizer dose (N:P:K kg/ha) used for different crops are described in Table 1. Urea (46% N), single super phosphate (7% P) and muriate of potash (49.8% K) were used as source of N:P:K, respectively. For leguminous crops like ricebean, soybean and pea, all the recommended dose of fertilizers (100% of N, P and K) were applied as basal. Whereas, for other crops like maize, rice and rapeseed, 50% N and 100% of P & K were applied as basal. The remaining 50% N was top dressed (application of fertilizers in the standing crop) in two splits as given in Table 1. The fertilizers were applied in furrow opened by using a manual furrow opener in well pulverized field under CT for both summer and winter crops. Whereas, in case of CST, furrows were opened using manual furrow opener in partially disturbed soil having partial incorporation of residues (one spading) in summer. Similarly, furrows were opened using manual furrow opener in between two lines of summer crops for sowing winter crops. The fertilizers were mixed with the soil before sowing and covering of seeds. Gap filling (re-