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Original Articles

Effects of fertilization on soil aggregation, carbon distribution and carbon management index of maize-wheat rotation in the north-western Indian Himalayas

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ABSTRACT

The impacts of the resource conservation practices can be evaluated in short-term through carbon management index (CMI) that conceptualizes the carbon lability and soil aggregation. To test this hypothesis, we investigated the labile organic carbon (LOC) pool and CMI in relation to runoff, soil loss and maize-wheat system productivity on 2% sloping crop lands of Indian Himalayan region in a study (2009–2014) where different nutrient management practices were adopted. Results showed that all integrated nutrient management (INM) practices (mineral fertilizers with different organic sources like farmyard manure (FYM), vermi-compost (VC), green manure (GM) and poultry manure (PM) enhanced soil aggregation compared with only mineral fertilization (NPK). Among all the treatments, the highest water-stable macroaggregates (+25%) in the 0–5 cm soil layer were recorded in 50% NPK + 50% FYM (7.5 t ha^{-1}) treatment. Aggregate size of > 2000, 250–2000, 53–250 and < 53 µm had ~18, 26, 34 and 18% higher soil aggregate-associated organic C in topsoil than 5–15 cm soil layer, respectively. Decreasing trend of soil aggregate-associated C was observed with decrease in size fraction from > 2000 to < 53 µm. Plots with fertilization of 50% NPK + 50% GM (1.8 t ha^{-1}) had significantly higher Walkley-Black carbon (WBC), total soil organic C (TOC), LOC, macroaggregate-associated C concentrations, and soil aggregation than other treatments. In the NPK + FYM treatment, LOC was ~16% significantly higher in topsoil than the sub-surface soil. CMI varied from ~17–48% to 15–41% among the nutrient management practices in the 0–5 and 5–15 cm soil layers, respectively. Significant positive correlation was found between CMI with maize yield ($r = 0.944$; $n = 28$; $p = 0.008$), wheat yield ($r = 0.942$; $n = 28$; $p = 0.005$), and negative correlation with runoff ($r = -0.818$; $n = 28$; $p = 0.042$) and soil loss ($r = -0.847$; $n = 28$; $p = 0.045$). FYM, GM, VC and PM with mineral fertilization decreased soil degradation compared to only mineral fertilization and unfertilized control plots, and FYM and GM sources were the best among all the organic sources. The highest wheat equivalent yield (WEY) was recorded with 50% NPK + 50% FYM (~6.0 t ha^{-1}) while similar WEY was recorded in rest of 50% organic sources. Relationships revealed that the single value CMI can be used for the assessment of soil degradation in the sloping crop lands.

1. Introduction

Soil aggregation is an important mechanism for stabilization of soil organic matter (SOM) (Lutzow et al., 2006; Kumar et al., 2013; Manna et al., 2013). Furthermore, it supports soil fertility as it reduces erosion and mediates soil aeration, water infiltration, water retention, and nutrient cycling (Li et al., 2015). Soil aggregation is caused by a variety of aggregate stabilizing compounds, which work simultaneously at different spatial scales and mineral particles that are bound together (Six et al., 2000). Soil erosion reduces soil aggregation, enhances soil degradation and reduces biomass production (Six et al., 2002; Ghosh et al., 2012). Crop yields in eroded soil can be drastically reduced even with application of high mineral fertilizer inputs. Erosion causes the breakdown of macro-aggregates into micro-aggregates and, possibly completes soil dispersion, exposing encapsulated different C pools (Monreal et al., 1997; Deressa, 2015). Soil organic carbon (SOC)

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sequestration under long-term management practices largely depends on C-stabilization of the management practices to mitigate climate change (INCCA, 2010). Declining SOC contents in agro-ecosystems are important in the global C budget (Ghosh et al., 2016). Agronomic practices, including tillage, nutrient management and crop rotation are crucial determinants of the quantity of C retained in the soil (Six et al., 1998; West and Post, 2002; Allmaras et al., 2004). Soil, an important medium of global C cycle, has twice the capacity to store C compared to the atmosphere (Kundu et al., 2007; Das et al., 2013). Dynamics of organic C storage in agricultural soils affects global climatic change and crop productivity (Lal, 1995; Li et al., 2007).

The C-sequestration potential is influenced by many factors, such as climate and soil conditions (Miller et al., 2004; Chabbi et al., 2009), cropping systems (Jagadamma and Lal, 2010), managements including tillage (Ogle et al., 2005) and fertilization (Bhattacharyya et al., 2012a). Maintenance of labile fraction of SOC is higher under the cooler climates where soils have more organic C, because of slower mineralization rates (Nianpeng et al., 2013: Ghosh et al., 2016). However, the SOC pools are lower in the tropical and sub-temperate hilly regions of India compared with temperate soils of the world, due to higher soil temperature and more soil erosion problems, respectively (Kumar et al., 2013; Manna et al., 2013; Nianpeng et al., 2013). Hence, there is need to identify and adopt the best management practices to maintain or improve SOC levels particularly in these regions where production systems are inherently low in soil fertility (Manna et al., 2013; Nianpeng et al., 2013). Carbon pools such as dissolved organic C, microbial biomass C and $KMnO_4$-oxidizable C have received considerable attention due to their sensitivity to agricultural management practices (Culman et al., 2012; Lucas and Weil, 2012). $KMnO_4$-oxidizable organic C or LOC and carbon concentrations within water-stable macro-aggregates and microaggregates are suggested to be more sensitive indicators than bulk SOC (Melero et al., 2009; Plaza-Bonilla et al., 2014). Soil aggregates are key elements of soil structure that play a major role in several soil processes including the accumulation and protection of SOM, the optimization of soil water and air regimes, and the storage and availability of plant nutrients (von Lutzow et al., 2006; Jha et al., 2012). Intra-aggregate properties strongly affect all these functions (Jasinska et al., 2006; Urbanek et al., 2007). Soil macro- and micro-aggregates are of particular importance for processes of soil C-sequestration (Six et al., 2004; Chenu and Plante, 2006; Ananyeva et al., 2013).

The C lability is the ratio of labile C to non-labile C. Blair et al. (1995) proposed labile C as oxidizable in 333 mM $KMnO_4$ solutions and carbon management index (CMI) which depends on C lability, has been commonly adopted in soil quality assessments. The CMI is a discerning tool for evaluating the impact of long-term management systems on the soil-plant-atmosphere equilibrium (Diekow et al., 2005). According to Su et al. (2006) integrated fertilization either maintained or improved SOC. The use of FYM/GM and incorporation of crop residues has been found to be even more beneficial (Singh et al., 2007).

Impacts of organic source addition on soil aggregation, its stability, and carbon sequestration, different pools (physical and chemical) are being studied in levelled lands, where soil erosion is very less. However, effects of INM in sloping crop lands on soil aggregation process and CMI has not been studied intensively. We hypothesized that INM in sloping crop lands would affect soil aggregation and carbon lability, thereby would improve crop productivity and reduce runoff and soil loss and there would be significant positive relationships between CMI and mean annual crop productivity and negative relationships between CMI and mean annual runoff and soil loss.

Keeping in view of the above hypothesis, the following objectives were derived for this study: (i) to determine the responses of long-term INM on SOC pools (physical) and soil aggregation under a maize-wheat rotation in a sandy clay loam soil of north-western Indian Himalayas, (ii) to find out and explain the relationship between CMI and crop productivity, and (iii) to know the best combination of organic manure with inorganic fertilizers in terms of improvement soil sustainability parameters.

2. Materials and methods

2.1. Study site

The fixed plot experiment was initiated from June 2009 at the experimental farm (fine mixed hyperthermic Typic Udorthent) of the ICAR-Indian Institute of Soil and Water Conservation (IISWC), Selakui, Dehradun, Uttarakhand, India (30° 20′ 40′ N, latitude; 77° 52′ 12′ E, longitude) at 516.5 m above mean sea level on a 2% land slope. The climate of the region is sub-temperate. The mean annual rainfall for the last 58 years (1956–2014) was ~1600 mm with nearly 80% occurring during the rainy season (June–September). The average daily maximum and minimum air temperatures ranged from 17.8 to 1.1 °C in January and 31.7 and 20.6 °C in June. Initial physic-chemical properties and fertility status of the experimental soil are presented in Singh et al. (2016).

2.2. Treatments' details

The field experiment was conducted with seven treatments [{T_1} control *i.e.* without any dose of fertilizer to both the crops, {T_2} 100% recommended dose of N, P_2O_5, and K_2O to both the crops (100-60-40 according to Singh et al., 2016) through inorganic fertilizers, {T_3} FYM (15 t ha^{-1}) to both the crops, {T_4} 50% N through inorganic fertilizers + 50% N through FYM to both the crops, {T_5} 50% N through inorganic fertilizers + 50% N through vermi-compost (VC) to both the crops, {T_6} 50% N through inorganic fertilizers + 50% N through poultry manure (PM) to both the crops, {T_7} 50% N through inorganic fertilizers + 50% N through *in-situ* sunnhemp (*Crotalaria juncea* L.) green manuring (GM) to both the crops] arranged in a randomized block design (RBD) with three replications during 2009–2014. After manures applications, remaining amounts of recommended P_2O_5 and K_2O were applied through inorganic fertilizers. The treatment details and mean input requirement are given in Singh et al. (2016). Nitrogen was applied through urea, phosphate through single super phosphate and potash through muriate of potash.

2.3. Tillage and crop management

After harvesting of wheat crop, secondary tillage operations were carried out in May month of every year to prepare seed bed and bury crop stubbles into soil. Maize composite 'Kanchan' was planted (90 cm × 20 cm) against the slope using maize planter by second fortnight of June to first fortnight of July during experimentation as per commencement of monsoon season rains and harvested in the second fortnight of September (Singh et al., 2016). After maize harvest, the field was ploughed within a week to incorporate surface applied mulch biomass for conserving moisture and nutrients for the succeeding wheat. Wheat cvs. 'PBW 343′ (2009–2010 to 2011–2012) and 'UP-2572′ (2012–13 to 2015–16) was sown against the slope by second fortnight of November using seed drill at 23 cm row spacing. From year 2012–13, wheat variety 'PBW-343′ was replaced with 'UP -2572′ due to yellow or stripe rust susceptibility of former variety; however, both the varieties have similar varietal characteristics (EXOWHEM, 2017). For weed control in maize, atrazine was applied as pre-emergence herbicide (1.5 kg ha^{-1}) in all the treatments except in GM plots, in which pendimethalin was applied (1.5 kg ha^{-1}) because of negative effect of atrazine on sunnhemp. One hand weeding was done between 30–35 days after sowing (DAS) of maize in all the treatments except GM plots. For weed control in wheat crop, tank mixture of 2, 4-D (1.0 kg ha^{-1}) and isoproturon (0.5 kg ha^{-1}) was sprayed after 35–40 DAS of wheat. Before sowing of both crops, chloropyrifos granules 10% (20 kg ha^{-1}) was applied at the time of sowing for control of termite

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