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Evaluating Fertilization Effects on Soil Physical Properties Using a Soil Quality Index in an Intensive Rice-Wheat Cropping System

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ABSTRACT

Soil quality assessment has been suggested as an effective tool for evaluating sustainability of soil and crop management practices. The objective of this study was to develop a sensitive soil quality index (SQI) based on bulk density (BD), water-holding capacity (WHC), water-stable aggregates (WSA), aggregate mean weight diameter (AMWD), total organic C (TOC) and C input to evaluate the important rice-wheat cropping system on an Inceptisol in India. A long-term experiment has been conducted for 18 years at the Indian Council of Agricultural Research-Indian Institute of Farming Systems Research, Modipuram, India. The treatments selected for this study were comprised of a no-fertilizer control and N, P and K fertilizers (NPK) combined with Zn and S fertilizers (NPK + Zn + S), farmyard manure (NPK + FYM), green gram residues (NPK + GR) and cereal residues (NPK + CR), laid out in a randomized complete block design with three replications. Soil samples were collected and analyzed for BD, WHC, WSA and TOC. Correlation analysis revealed that both rice and wheat yields significantly increased with the increases in AMWD, TOC and C input, but decreased with the increase in BD. The SQI values were then generated based on regression analysis of BD, WSA, AMWD, TOC and C input with rice and wheat yields for the 0–15 and 15–30 cm soil layers, respectively. Regression analyses between crop yields and SQI values showed a quadratic type of relation with the coefficient of determination (R^2) varying from 0.78 to 0.89. With regard to soil sustainability, applying crop residues to both rice and wheat could maintain soil quality for a longer period, whereas the highest yields of both the crops were recorded in the NPK + Zn + S treatment. The regression equations developed in this study could be used to monitor soil quality in a subhumid tropical rice-wheat cropping system.

Key Words: bulk density, C input, integrated nutrient management, total organic C, water-holding capacity, water-stable aggregates

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INTRODUCTION

Sustainability of rice-wheat (kharif-rabi) cropping system in the Indo-Gangetic Plains (IGP) of India has been in focus for its role in meeting the country's food demand, and also for its impact on global food security at large. Soil quality degradation has put this sustainability at risk, and decrease in yield has been reported. Continuous use of imbalanced fertilizers under intensive rice-wheat cultivation over the years has gradually degraded the soil structure, and the organic C and nutrient-supplying capacity of these soils have depleted. Yield sustainability of rice-wheat cropping system in the IGP can be ensured only through maintaining the soil physical quality and organic C status (Mandal *et al.*, 2007). Integrated nutrient management practices have come up as viable options in restoring the soil physical structure and chemical fertility, improving the organic matter in the soil (Rudrappa *et al.*, 2006; Nayak *et al.*, 2012), and sustaining the system productivity. Balanced application of fertilizers in combination with manures (farmyard manure and green manure), compost, industrial waste by-products and crop residues (particularly paddy straw) is one of the best ways to counteract organic matter depletion and rapid deterioration of soil physical properties, particularly soil structure (Haynes, 2000; Singh *et al.*, 2007).

Soil aggregation is the single most important parameter in soil health studies through its influence on most of the fundamental soil properties like structure, water retention and movement, organic matter stabilization and nutrient cycling (Ghildyal and Tripathi,

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1987; Jastrow, 1996; Grandy *et al.*, 2002; Shaver *et al.*, 2003). Better soil aggregation promotes adequate habitat and protection for soil microorganisms, supplies oxygen to roots and prevents soil erosion (Denef *et al.*, 2001; Franzluebbers, 2002). Germination, seedling emergence and root development are key factors of better crop productivity, which are guided by soil aggregation (Braunack and Dexter, 1989; de Freitas *et al.*, 1999). Moreover, aggregate stability is a factor controlling water erosion in most of the soils (Castro Filho *et al.*, 1991). It is also claimed that stability of large aggregates plays a crucial role in C sequestration in soils (Lal, 1997; Six *et al.*, 2000, Das *et al.*, 2014b), while structural degradation provokes soil organic matter loss (Six *et al.*, 1999).

Soil organic C (SOC), the most consistently reported soil property from long-term studies, is a key component of soil quality (Reeves, 1997), and its maintenance is vital for the productivity and long-term stability of agricultural systems (Carter, 2002). Addition of organic matter enhances SOC content, which directly or indirectly affects soil physical properties and processes like aggregation, water-holding capacity (WHC), hydraulic conductivity, bulk density (BD) and resistance of soil to water and wind erosion (Zebarth *et al.*, 1999; Franzluebbers, 2002; Celik *et al.*, 2004). As the source of C, different organic amendments may affect SOC distribution and its stabilization in aggregate fractions, indicating its physical protection of C in soil (Bandyopadhyay *et al.*, 2010).

While improvement in soil structural condition through the addition of C inputs has been profusely reported, a quantitative evaluation of soil physical properties under integrated nutrient management and their effect on crop yields is lacking. A study therefore has been conducted to investigate the impact of long-term nutrient management on selected soil physical properties, organic C and C input, and to quantify the effects of soil properties on sustainability of crop yields on a sandy loam soil under rice-wheat rotation.

MATERIALS AND METHODS

The study area (29°40′ N, 77°46′ E, 237 m above mean sea level) was located at the Indian Council of Agricultural Research-Indian Institute of Farming System Research (ICAR-IIFSR), Modipuram, Meerut, India with alluvium-derived soils (Mandal *et al.*, 1999). The climate is semi-arid and sub-tropical, characterized by hot summers and cold winters. The soil studied, an Inceptisol, is sandy loam, non-saline (electrical conductivity, 0.4 dS m^{-1}) but slightly alkaline (pH, 7.98). Selected soil properties (0–15 cm) were recorded at the start of the experiment as follows: Walkley-Black C of 4.1 g kg^{-1}, available P (extracted by 0.05 mol L^{-1} $NaHCO_3$) of 16.4 kg ha^{-1}, available K (extracted by 1 mol L^{-1} ammonium acetate) of 96 kg ha^{-1}, available S (extracted by 0.15% $CaCl_2$) of 14.5 kg ha^{-1} (PDFSR, 2009–2010), an average BD of 1.55 Mg m^{-3} and 0.42 cm^3 cm^{-3} WHC. Prior to the establishment of the experiment, the site was generally managed under sugarcane-ratoon-wheat cropping system, and rice (puddle transplanted)-wheat system was followed intermittently.

The experiment was initiated in 1993 with 11 treatments in a randomized block design, involving chemical fertilizers (NPK) alone or in combination with organic sources, *viz.* farmyard manure (FYM), green gram residues (GR) and cereal (rice and wheat) residues (CR); the treatment with no fertilizer was taken as a control. Five treatments, including the control and NPK amended with Zn and S fertilizers (NPK + Zn + S) or organic fertilizers of FYM (NPK + FYM), GR (NPK + GR) and CR (NPK + CR) with 3 replications, were selected for this study (Table I). The size of each plot was 8 m × 8 m.

Fertilizers were applied at recommended dose: 120 kg N ha^{-1} as urea, 26 kg P ha^{-1} as single super phosphate with additional supply of 45 kg S ha^{-1} and 33 kg K ha^{-1} as muriate of potash. Zinc was applied only to rice at 5 kg ha^{-1} as zinc sulphate. One-third of N and entire P, K, S and Zn were applied at the time of transplanting/sowing and remaining N was top-dressed in two equal splits at maximum tillering and panicle/ear emergence. The FYM and CR were incorporated in the soil one week and 15–20 d before transplanting/sowing of the crops, respectively. In the NPK + GR treatment, summer green gram was sown immediately after wheat harvest, and after pod-picking, the aboveground biomass was incorporated before puddling. Nearly 1 kg bulk soils were collected with a shovel in triplicate from 0–7.5, 7.5–15 and 15–30 cm soil layers in each plot at rice harvest in 2011 for the analyses.

Total organic C was determined by an automatic elemental analyser (Vario EL, Elementar Analysensysteme GmbH, Hanau, Germany). The amount of C returned to the soil through plant residues was estimated using C contents of stubbles, crop residues, roots of rice and wheat and green gram residues. The cumulative C inputs were calculated by multiplying total biomass of stubble, straw, roots and rhizodeposition with their respective mean C contents, and summing these together. Details of the C input calculation have been reported elsewhere (Das *et al.*, 2014a, b). For determination of BD, undisturbed soil cores (5-cm internal di-