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Long-term fertilization, manure and liming effects on soil organic matter and crop yields

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Abstract

Yield decline or stagnation and its relationship with soil organic matter fractions in soybean (*Glycine max* L.)–wheat (*Triticum aestivum* L.) cropping system under long-term fertilizer use are not well understood. To understand this phenomenon, soil organic matter fractions and soil aggregate size distribution were studied in an Alfisol (Typic Haplustalf) at a long-term experiment at Birsa Agricultural University, Ranchi, India. For 30 years, the following fertilizer treatments were compared with undisturbed fallow plots (without crop and fertilizer management): unfertilized (control), 100% recommended rate of N, NP, NPK, NPK+ farmyard manure (FYM) and NPK + lime. Yield declined with time for soybean in control (30 kg ha^{-1} yr^{-1}) and NP (21 kg ha^{-1} yr^{-1}) treatments and for wheat in control (46 kg ha^{-1} yr^{-1}) and N (25 kg ha^{-1} yr^{-1}) treatments. However, yield increased with time for NPK + FYM and NPK + lime treatments in wheat. At a depth of 0–15 cm, small macroaggregates (0.25–2 mm) dominated soil (43–61%) followed by microaggregates (0.053–0.25 mm) with 13–28%. Soil microbial biomass carbon (SMBC), nitrogen (SMBN) and acid hydrolysable carbohydrates (HCH) were greater in NPK + FYM and NPK + lime as compared to other treatments. With three decades of cultivation, C and N mineralization were greater in microaggregates than in small macroaggregates and relatively resistant mineral associated organic matter (silt + clay fraction). Particulate organic carbon (POC) and nitrogen (PON) decreased significantly in control, N and NP application over fallow. Results suggest that continuous use of NPK + FYM or NPK + lime would sustain yield in a soybean–wheat system without deteriorating soil quality.

Keywords: Soil aggregates; Soil organic C; Microbial biomass C; Particulate organic matter; Humic acid; Manure; Fertilizer

1. Introduction

Deterioration in soil quality, especially soil organic matter and its associated nutrient supply to soil, has been cited as one of the major factors for yield decline or stagnation under intensive rice (*Oryza sativa* L.) based cropping systems in most of the South-Asian countries (Dawe et al., 2000; Swarup et al., 2000). Such information for soybean (*Glycine max* L.) based cropping systems is limited. Soybean ranks first among oilseed crops with coverage of 69 Mha and production of 156 Tg in the world. It occupies an important place in Indian agriculture and oil economy. India is the fifth largest country in terms of area (5.8 Mha) and production 6.7 Tg (Tiwari et al., 1999). In India, soybean–wheat (*Triticum aestivum* L.) is a dominant cropping system under irrigated areas and soybean–chickpea (*Cicer aerietinum*

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L.) in rainfed areas. About 30% of India has laterite and various latosolic soils, i.e. ferruginous red soils, ferruginous gravelly red soils, mixed and yellow soils (Sehgal and Abrol, 1994).

Soil degradation occurs due to nutrient depletion, soil structure degradation, acidification and sub-optimal addition of organic and inorganic fertilizer to soil. Acidification of soil results in loss of exchangeable Ca^{2+} and Mg^{2+}, a decrease in effective cation exchange capacity, and an increase in exchangeable Al^{3+} (Graham et al., 2002). An adverse effect of acidification decreases water and nutrient retention capacity in soils and reduced biotic activity (Kinraide, 2003). Such adverse soil condition can lead to decline in soil quality and poor crop yields. Liming improves soil physical conditions and biological activities, although the mechanism is still unclear (Davies and Payne, 1988; Haynes and Naidu, 1998). Soon and Arshad (2005) found a significant increase in crop yield and soil labile N pools due to liming with zero tillage compared to liming with conventional tillage. Many reports have shown that long-term addition of organic matter improves crop yield, water holding capacity, porosity, and water stable aggregation and decreases bulk density and surface crusting (Edwards and Lofty, 1982; Schjonning and Christensen, 1994). The large organic matter returns with fertilizer addition can stimulate soil biological activity. After about 130 years on the Broadbalk experiment at Rothamsted, biomass C content had equilibrated to 128 μg C g^{-1} with unfertilized control and 189 μg C g^{-1} with annual application of N, P, K, Mg and Na (Sparling, 1985). Similar findings have been observed under pasture (Nauyen and Goh, 1990; Haynes and Williams, 1992). Changes in soil physical properties following addition of P fertilizer to soils have been documented (Haynes, 1984). The most likely explanation for such phenomenon is that addition of P to acid soils results in the precipitation of Al as insoluble Al phosphate.

Soil organic matter is an essential component with key multifunctional roles in soil quality and related to many physical and biological properties of soil (Smith et al., 2000). During the last few decades, researchers have identified specific soil organic matter fractions with functional significance in the turnover of soil (Janzen et al., 1992; Fortuna et al., 2003). Among these fractions, soil microbial biomass C and water-soluble C fractions are the most active and labile pools, which have short turnover times (Janzen et al., 1992). Moreover, particulate organic carbon (POC) can be used as an indicator of soil quality rather than total organic matter (Cambardella and Elliott, 1992; Chan, 2001). Organo-mineral fractions of specific particle size (<0.053 mm) can lead to development of stable microaggregates and slow decomposition rate within aggregates with respect to their composition and turnover (Sohi et al., 2001). An interrelationship between soil structure and soil organic C (SOC) is dynamic, where the level of decomposition of organic matter affects soil aggregation and aggregate stability. Soil C and N mineralization have also been related to microbial activity and soluble fractions of soil organic matter (Bonde et al., 1988). However, a relationship is needed to better predict yield sustainability from soil organic matter fractions under long-term liming, manure and fertilizer application.

The objectives of this study were (i) to evaluate the impact of fertilizer, manure and lime applications on yield and SOC with time and (ii) to assess soil C and N fractions and soil structure in an acid soil with 30 years of continuous cropping under soybean–wheat system.

2. Materials and methods

2.1. Site description

A long-term fertilizer experiment was initiated at Ranchi (1971–1972 to 2001–2002) under the All India Coordinated Research Project on Long-Term Fertilizer Experiments at the Birsa Agricultural University, India (23°30′N, 85°1′E, at 120 m above m.s.l.). Annual precipitation was 1450 mm yr^{-1}, with nearly all occurring between June and September. Average annual temperature was 23.1 °C with maximum of 34.5 °C during April and minimum of 6.8 °C in January.

The soils were red Typic Haplustalf with sandy clay loam texture containing 662 g kg^{-1} sand, 254 g kg^{-1} clay, and 84 g kg^{-1} silt at 0–15 cm depth. The dominant clay mineral fractions were kaolinite and illite. The surface (0–15 cm) soil pH (1:2: soil:water) was 5.3 at the initiation of this long-term experiment. Detailed initial physicochemical properties were reported elsewhere (Sarkar et al., 2000). The experimental site and fallow plots were never cultivated prior to 1970. During field experimentation, a fallow plot was maintained as a reference, which in turn helped in interpreting the results. Natural vegetation such as, weeds viz., *Lantana camara* L., *Melilotus alba* Medikus, *Phyllanthus niruri* L., *Convolvulus arvensis* L., *Paspalum scrobiculatum* L., *Cirsium arvense* (L.) Scop., *Commelina benghalensis* L. and grasses namely *Cyperus rotundus* L., *Cynodon dactylon* (L.) Pers and *Sachharum spontaneum* L. were present in the fallow plot. For treatment establishment, the experimental field was planted to wet