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SCIENCE DIRECT
Soil & Tillage Research 88 (2006) 180–192
Soil & Tillage Research
www.elsevier.com/locate/still

Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid sub-tropical India

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Received 30 November 2004; received in revised form 18 May 2005; accepted 27 May 2005

Abstract

Soil is a potential C sink and could offset rising atmospheric CO_2. The capacity of soils to store and sequester C will depend on the rate of C inputs from plant productivity relative to C exports controlled by microbial decomposition. Management practices, such as no-tillage and high intensity cropping sequences, have the potential to enhance C and N sequestration in agricultural soils. An investigation was carried out to study the influence of long-term applications of fertilizers and manures on different organic C fractions in a Typic Haplustept under intensive sequence of cropping with maize–wheat–cowpea in a semi-arid sub-tropic of India. In 0–15 cm, the bulk density was lowest (1.52 Mg m^{-3}) in plots treated with 100% NPK + FYM, while the control treatment showed the highest value (1.67 Mg m^{-3}). Balanced application of NPK (100% NPK) showed significantly lower bulk density (1.56 Mg m^{-3}) over either 100% N (1.67 Mg m^{-3}) or 100% NP (1.61 Mg m^{-3}) in surface soils. The application of super-optimal dose of NPK (150% NPK) showed higher total organic C (TOC) (12.9 g C kg^{-1}) over either 50% NPK (9.3 g C kg^{-1}) or 100% NPK (10.0 g C kg^{-1}) in 0–15 cm soil layer. There was an improvement in TOC in 100% NPK or 100% NP (9.3 g C kg^{-1}) over 100% N (8.7 g C kg^{-1}) in the same depth. The application of FYM with 100% NPK showed 15.2, 9.9 and 5.2 g C kg^{-1} in 0–15, 15–30 and 30–45 cm, respectively. Application of graded doses of NPK from 50 to 150% of recommendation NPK significantly enhanced other organic C fractions like, microbial biomass C (MBC), particulate organic C (POC) and $KMnO_4$ oxidizable C ($KMnO_4$–C) in all the three soil depths. The TOC in 0–45 cm soil depth in 150% NPK (63.5 Mg C ha^{-1}) was increased by 39% over that in 50% NPK treatment (51.5 Mg C ha^{-1}) and 29% over that in 100% NPK treatment (54.1 Mg C ha^{-1}). Integrated use of farmyard manure with 100% NPK (100% NPK + FYM) emerged as the most efficient management system in accumulating largest amount of organic C (72.1 Mg C ha^{-1}) in soil. Nevertheless, this treatment also sequestered highest amount of organic C (731 kg C ha^{-1} $year^{-1}$). Particulate organic carbon, a physically protected carbon pool in soil, could well be protected in sub-surface soil layers than in surface soil layer as a means of carbon aggradations. Microbial metabolic quotient (qCO_2) was significantly lower in 100% NPK + FYM over other treatments to indicate this to be the most efficient manuring practice to preserve organic carbon in soil where it facilitates aggradations of more recalcitrant

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0167-1987/$ – see front matter
doi:10.1016/j.still.2005.05.008

organic C in soil. As compared to POC, total TOC proved to be a better predictor of MBC as it strongly correlated with total carbon mineralized from soil.

Keywords: Bulk density; Carbon mineralized; Carbon sequestration; Long-term fertilizer experiment; Microbial biomass carbon; Particulate organic carbon; Total organic carbon

1. Introduction

Increasing importance has been placed on the use of agricultural soils for the mitigation of atmospheric CO_2 through sequestration of soil C. This may be achieved by adoption of best management practices, such as no-till and improved residue management. Changes in agricultural practices often influence both the quantity and quality of soil organic matter (SOM) and turnover rates. Impacts of tillage on SOM have been well documented, but results vary because of many factors such as soil type, cropping systems, residue management and climate (Reicosky et al., 1995). Cultivation reduces SOM and alters the distribution and stability of aggregates (Six et al., 1998). Soil acts both as sink as well as source for carbon. The loss of soil organic carbon (SOC) following conversion of native prairies to agricultural land was a major source of anthropogenic CO_2 and contributed to the historical rise in Global levels of atmosphere CO_2 (Wilson, 1978; Houghton et al., 1983; Flach et al., 1997). Therefore, the dynamics of carbon in terrestrial ecosystem has become a central question and there is much interest in potential of highly managed agricultural soils to store surplus atmospheric CO_2 as an amelioration measure.

Most of the studies relating to carbon sequestration are confined to no-till practices coupled with crop/residue management (Gebhart et al., 1994; Havlin et al., 1990; Robinson et al., 1996). However, it might be possible that manuring practices in highly managed multiple cropping systems could sequester C in soil as well. Manure amendment is a management practice that can improve the nutrient status of the soil and increase SOC levels (Rochette and Gregorich, 1998). Aoyama et al. (1999a) observed an increase in SOM with addition of manure and consequently the formation of slaking-resistant macroaggregates (250–1000 μm diameter). For more than 40 years, the effect of cultivation on soil aggregate disruption and SOM losses has been studied intensively (Low, 1954; Tisdall and Oades, 1982; Elliott, 1986; Cambardella and Elliott, 1993; Six et al., 2000). Recently, a few studies have been conducted to determine the effect of manure application on carbon sequestration (Aoyama et al., 1999a,b). However, it is unknown whether the effects of such reduced tillage and manure addition on the distribution of C and N among aggregates are additive.

Long-term fertilizer experiments (LTFE) running on a Typic Haplustept with maize (*Zea mays*)–wheat (*Triticum aestivum*)–cowpea (*Vigna unguiculata*) cropping sequence in Indian Agricultural Research Institute, New Delhi, since 1971 become a useful study material for C sequestration. Long-term fertilizer experiments in India were started during 1960s under the umbrella of Indian Council of Agricultural Research with the changing pattern in agricultural scenario adopting high yielding varieties of crops demanding much higher doses of fertilizer nutrients for higher crop yields. Only few studies have been conducted on soil organic matter dynamics and soil microbial activities in relation to application of balanced and imbalanced doses of inorganic fertilizers or organic amendments in LTFE experiments in India (Goyal et al., 1993, 1999). The soil organic matter fractions that are considered important include microbial biomass carbon (MBC), particulate organic carbon (POC), total organic carbon (TOC), labile carbon and mineralizable carbon. Long-term manuring in highly intensive cropping practices which would be expected to affect these fractions of soil organic matter.

The hypothesis set for our study was that the accumulation of different fractions of carbon might be influenced by the long-term applications of fertilizers alone and with manures to a maize–wheat–cowpea cropping system in a Typic Haplustept. The outcome of the project would help to make understand the accumulation pattern of different carbon fractions under different manuring practices that would