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Dynamics of Soil Organic Carbon Fractions and Aggregates in Vegetable Cropping Systems*[1]

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ABSTRACT

Fertilisers significantly affect crop production and crop biomass inputs to soil organic carbon (SOC). However, the long-term effects of fertilisers on C associated with aggregates are not yet fully understood. Based on soil aggregate and SOC fractionation analysis, this study investigated the long-term effects of organic manure and inorganic fertilisers on the accumulation and change in SOC and its fractions, including the C concentrations of free light fraction, intra-aggregate particulate organic matter (POM) and intra-aggregate mineral-associated organic matter (MOM). Long-term manure applications improved SOC and increased the concentrations of some C fractions. Manure also accelerated the decomposition of coarse POM (cPOM) into fine POM (fPOM) and facilitated the transformation of fPOM encrustation into intra-microaggregate POM within macroaggregates. However, the application of inorganic fertilisers was detrimental to the formation of fPOM and to the subsequent encrustation of fPOM with clay particles, thus inhibiting the formation of stable microaggregates within macroaggregates. No significant differences were observed among the inorganic fertiliser treatments in terms of C concentrations of MOM, intra-microaggregate MOM within macroaggregate (imMMOM) and intra-microaggregate MOM (imMOM). However, the long-term application of manure resulted in large increases in C concentrations of MOM (36.35%), imMMOM (456.31%) and imMOM (19.33%) compared with control treatment.

Key Words: long-term fertilization, physical fractionation, soil aggregates, soil organic matter

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INTRODUCTION

Soil organic carbon (SOC) has a profound effect on soil quality. It encourages aggregation, increases water retention, nutrient supply and soil organism activity and improves soil fertility and productivity (Karlen *et al*., 1997), thereby, ensuring the long-term sustainability of an agroecosystem. Soil can act as a sink for atmospheric CO_2, and the increased sequestration of C in agricultural soils can potentially mitigate the global increase in atmospheric greenhouse gases (Young, 2003).

Increasing C sequestration in agricultural soils and making soil a net sink for atmospheric C can be achieved by adopting the best management practices, such as conservation tillage, application of fertilisers and bio-solids or organic amendments, crop rotation and improved residue management (Lal, 2004). In particular, the benefits of a balanced application of inorganic fertilisers (*i.e.*, the combined application of N, P and K fertilisers) and organic manure in maintaining and increasing SOC levels in agricultural soils have been well documented (Rudrappa *et al*., 2006). Many long-term fertiliser experiments worldwide have proved that a balanced fertilisation using inorganic fertilisers and organic manure improves the nutrient status of the soil and maintains high crop yields and high levels of residues that can be returned to the soil to increase SOC concentration (Holeplass *et al*., 2004). In an experiment in north China, Meng *et al*. (2005) showed that a balanced application of N, P and K fertilisers and organic manure significantly increases SOC accumulation to averages of 0.1 and 1.01 Mg ha^{-1}, respectively, over a 13-year period. In studying organic C fractions, Yang *et al*. (2005) suggested that the continuous application of organic manure and inorganic fertilisers increases soil light fraction (LF) and C concentration of particulate organic matter (POM). Li *et al*. (2004) suggested that the long-term use of fertilisers enhances LF concentration and C concentration of

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POM in paddy soil in this order: NPK (inorganic fertilisers) + OM (organic manure) > 2NPK (double the NPK application rates) > NPK > control (no fertiliser). In addition, Zotarelli *et al.* (2007) reported that the combination of no-tillage and green manure application promotes the stabilisation of aggregate-associated C.

Six *et al.* (2002) revealed a physical fractionation method in SOC. In this method, SOC is divided into relatively homogeneous and differently functional fractions according to the protection extent of the soil aggregate. For example, SOC may be divided into LF, POM, and inter- and outer-aggregates of mineral-associated organic matter (MOM). The physical fractionation technique also elucidates soil processes and mechanisms involved in the storage of SOC. Aggregation is known to increase in less disturbed systems, and organic materials within soil aggregates (especially microaggregates) have lower decomposition rates than those located outside aggregates (Oades, 1984; Elliott and Coleman, 1988; Six *et al.*, 2000). Therefore, the present study aimed to determine the accumulation of SOC and the C concentration of different SOC fractions using the physical fractionation technique and to investigate the effect of inorganic fertilisers and farmyard manure on C changes in SOC fractions as applied in northeastern China in the long run.

MATERIALS AND METHODS

Site description and experimental design

A long-term fertiliser experiment was conducted at the College of Horticulture, Shenyang Agriculture University, Liaoning Province, China (latitude 41° 31′ N, longitude 123°24′ E). The soil was classified as Typic Fimi-Orthic Anthrosol (CRG-CST, 2001) and sandy loam (Soil Survey Staff, 1998). The experiment was initiated in 1988. Before this period, the field was an open vegetable plot. From 1988 to 1995, two field vegetable rotation cycles were completed. The crops sequentially cultivated in a two-crops-per-year manner consisted of Chinese cabbage, bean, carrot, onion, cucumber, potato, mustard leaf and pimento. The tillage depth was 20 cm. In 1996, the soil was moved from the study plot to the greenhouses for microfield experiments. The fertiliser treatments in the greenhouse experiment were identical to those in the long-term field study. Between 1997 and 2007, vegetable rotation was implemented in a one-crop-per-year manner. Specifically, eggplant was cultivated for two years, tomato for five years, cucumber for one year, and pimento for three years. After the pimento harvest in October 2007, soil samples were collected in the cultivated horizon (0–20 cm) of five random locations in each plot. The samples were mixed prior to analysis. The air-dried samples were passed through an 8 mm sieve, and the visible crop residue and roots were removed.

In 1997, the treatments were organised into a split plot within a randomised complete block design. Farmyard manure treatments were assigned to the main plots and inorganic fertiliser treatments to the subplots. The treatments consisted of 1) control (no fertiliser and manure), 2) IN (inorganic N fertiliser), 3) INPK (inorganic N, P and K fertilisers), 4) M (farmyard manure), 5) MN (farmyard manure with inorganic N fertiliser), and 6) MNPK (farmyard manure combined with inorganic N, P and K fertilisers). The farmyard manure used was horse dung. N, P and K were applied to the crops annually as urea (22.5 g N plot^{-1}), acid phosphate (720 g P plot^{-1}) and potassium sulphate (63.79 g K plot^{-1}) fertilisers. Farmyard manure was applied at a level of approximately 11.25 kg plot^{-1} each year. Each treatment was repeated thrice, and the size of each plot was 1.5 m^2. The plots were separated by ridges (0.3 m × 0.8 m). Farmyard manure, along with acid phosphate, potassium sulphate and urea, was applied annually prior to the cropping season.

Aggregate separation

The aggregate separation was conducted following the method of Elliott (1986), *i.e.*, the wet sieving of soil through a series of three sieves (2, 0.25, and 0.053 mm) to obtain four aggregate size classes (Fig. 1). A subsample of 100 g air-dried soil was submerged in deionised water on top of a 2 mm sieve for 5 min prior to sieving. The sieving was performed manually by moving the sieve up and down at a 3 cm level for 50 times in 2 min. Organic material floating on the water in the 2 mm sieve was removed after the 2 min cycle because this material is by definition not considered SOM. The fraction that remained on the 2 mm sieve was collected in an aluminium pan and oven dried. Water and soil sifted through the 2 mm sieve were poured onto the next sieve, and the sieving was repeated. All fractions were gently back-washed into an aluminium pan and dried overnight (50 °C). The next day, all fractions were weighed.

Free LF separation

The method of separating the free LF was adopted from the method of Dalal and Mayer (1986) (Fig. 1). Briefly, the free LF associated with different aggregate size classes was isolated through the density flotation method by bromoform of 2.0 g cm^{-3}. After the isola-