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# Soil fertility management: Impacts on soil macrofauna, soil aggregation and soil organic matter allocation

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## ABSTRACT

Maintenance of soil organic matter through integrated soil fertility management is important for soil quality and agricultural productivity, and for the persistence of soil faunal diversity and biomass. Little is known about the interactive effects of soil fertility management and soil macrofauna diversity on soil aggregation and SOM dynamics in tropical arable cropping systems. A study was conducted in a long-term trial at Kabete, Central Kenya, to investigate the effects of organic inputs (maize stover or manure) and inorganic fertilizers on soil macrofauna abundance, biomass and taxonomic diversity, water stable aggregation, whole soil and aggregate-associated organic C and N, as well as the relations between these variables. Differently managed arable systems were compared to a long-term green fallow system representing a relatively undisturbed reference.

Fallowing, and application of farm yard manure (FYM) in combination with fertilizer, significantly enhanced earthworm diversity and biomass as well as aggregate stability and C and N pools in the top 15 cm of the soil. Earthworm abundance significantly negatively correlated with the percentage of total macroaggregates and microaggregates within macroaggregates, but all earthworm parameters positively correlated with whole soil and aggregate associated C and N, unlike termite parameters. Factor analysis showed that 35.3% of the total sample variation in aggregation and C and N in total soil and aggregate fractions was explained by earthworm parameters, and 25.5% by termite parameters. Multiple regression analysis confirmed this outcome.

The negative correlation between earthworm abundance and total macroaggregates and microaggregates within macroaggregate could be linked to the presence of high numbers of *Nematogenia lacuum* in the arable treatments without organic amendments, an endogeic species that feeds on excrements of other larger epigeic worms and produces small excrements. Under the conditions studied, differences in earthworm abundance, biomass and diversity were more important drivers of management-induced changes in aggregate stability and soil C and N pools than differences in termite populations.

## 1. Introduction

In large parts of sub-Saharan Africa, the challenge of increasing crop yields to sustain the growing population is persistent. Decomposing plant residues are a major source of plant nutrients in soils with little inherent mineral fertility. In many cropping systems of Africa, organic matter is periodically returned to the soil either as litter, crop residues or as animal waste products, but the amounts and qualities differ (Karanja et al., 2006; Chivenge et al., 2009). Although such practices can enhance soil fertility or promote soil rehabilitation, organic resources alone often provide insufficient nutrients to build or maintain the long-term nutrient resource base for agriculture (Palm et al., 2001). Integrated soil fertility management (ISFM), widely advocated in sub-Saharan Africa, recognizes the benefits of combining organic and inorganic fertilizers for sustainable nutrient management (Chivenge et al., 2009; Gentile et al., 2009; Vanlauwe et al., 2010). The beneficial effect of soil organic matter (SOM) on soil productivity through supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and soil and water retention is well established (Swift and Woomer, 1992; Dudal and Deckers, 1993; Woomer et al., 1994). In addition, SOM supports various soil biological processes by being

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a substrate for decomposer organisms and ecosystem engineers, such as earthworms and termites, that play an important role in soil structure formation, organic matter decomposition and nutrient mineralization (Swift and Woomer, 1992; Dudal and Deckers, 1993).

Aggregate stability is a key factor for physical soil fertility and also affects SOM dynamics (Abiven et al., 2009; Six et al., 2000). Resistance of aggregates to physical stresses inversely relates to the soil's sensitivity to crusting and erosion (Le Bissonais, 1996; Blanchart et al., 1999), positively affects seed germination and rooting of crops (Angers and Caron, 1998) and water infiltration (Le Bissonais, 1996), and determines the ability of a soil to store SOM through physical protection against rapid decomposition (Bossuyt et al., 2005). Among the soil properties influencing aggregate stability are texture, clay mineralogy, cation content, aluminum and iron oxides, SOM and soil fauna (Amézketa, 1999; Six et al., 2004). Some of these factors (e.g. SOM and soil fauna) are affected by agricultural practices such as tillage, crop rotation, residue management and fertilization regimes (Shiran et al., 2002; Su et al., 2006). In several conceptual models, the increase of aggregate stability after organic additions to the soil has been related to the decomposition dynamics of the inputs (Abiven et al., 2009).

Earthworms are considered ecosystem engineers for their role in modifying the soil environment and availing resources for other organisms (Jouquet et al., 2006), through their impact on soil structure and soil organic matter (SOM) dynamics (Lavelle et al., 2001). Apart from speeding up initial breakdown of organic residues, they also incorporate organic matter in their casts and can thereby protect it against further rapid decomposition (Scullion and Malik, 2000; Bossuyt et al., 2005; Pulleman et al., 2005a,b). Crop performance can also be affected through the impact of worm-made aggregates and biopores on soil water dynamics and root growth. Termites also make channels in soil and influence soil aggregation by mixing organic matter with soil particles and thereby modify the physical properties of soil (Jouquet et al., 2002). Termites can form stable microaggregates by mixing soil with saliva for nest constructions or, in the case of soil-feeding termites, by excreting faecal pellets that are enriched in organic matter (Jungerius et al., 1999).

Soil aggregates, especially microaggregates (53–250 μm) formed within macroaggregates (≥250 μm), protect SOM against microbial decay (Tisdall and Oades, 1982; Six et al., 2000). Soil fertility and C stabilization are therefore mediated by the interactions between soil organic matter, soil structure and soil macrofaunal abundance and diversity, which depend on soil management (Six et al., 2004). For example, Pulleman et al. (2005a) showed that formation of stable and strongly organic C-enriched microaggregates was reduced under arable systems compared to permanent pasture, probably due to differences in earthworm abundance and/or species composition, the nature (i.e. quality) of organic matter input and mechanical disturbance.

Although stimulation of soil macrofauna activity and diversity through the provision of organic inputs can contribute to improved soil aggregation and C and N retention in soil (Lavelle et al., 2001), so far this role of the soil macrofauna has not been quantified in the context of ISFM. A considerable number of long-term experiments have been conducted in sub-Saharan Africa since the 1920s, giving insights in soil processes and management practices that control soil fertility (Vanlauwe et al., 2005). However, due to lack of resources, data collection is normally limited to crop yields (Kapkiyai et al., 1999; Kamoni et al., 2007), while little information is available on long-term effects of crop management on soil aggregation, C and N dynamics, and on soil macrofaunal abundance and diversity. It is also not known how different soils, such as tropical Nitisols that are high in iron and aluminum oxides, will respond to either organic or inorganic soil amendments, and how this will in turn affect soil aggregation and C and N dynamics compared to the much studied temperate soils (Elliott, 1986; Jastrow, 1996; Six et al., 1998, 2000). It has been shown that such soils are prone to high N losses due to leaching (Gentile et al., 2009). With recent considerable interest in (belowground) biodiversity conservation and ecosystem functioning (CBD, 2001; Clergue et al., 2005), an understanding of these specific interactions and the quantitative effects of each of those management factors in the long term are needed.

This study, therefore, investigates the linkage between management factors (fallowing, organic inputs, and inorganic inputs), soil biodiversity, soil structure and SOM (C and N) dynamics in a long-term (>60 growing seasons) field trial in Central Kenya. Specifically, the study seeked to:

(1) assess the effects of crop management on (i) soil aggregation and C and N dynamics and (ii) soil macrofauna parameters (earthworm and termite abundance, biomass and diversity);
(2) explore the relationships between soil aggregation, C and N dynamics, and soil macrofauna parameters.

## 2. Materials and methods

### 2.1. Study site

The study was conducted in a long-term trial based at the National Agricultural Research Laboratories (NARL) in Kabete, located about 7 km Northwest of Nairobi (latitude: 1°15′S; longitude: 36°41′E) at an altitude of 1740 m above sea level (Siderius and Muchena, 1977). The area receives a mean annual rainfall of 940 mm in two rainy seasons, the 'long rains' (March–May) and the 'short rains' (mid-October to December). The mean annual temperature ranges between 13 °C and 18 °C. The area falls under ecological zone III (dry sub-humid) with a precipitation to evaporation ratio ($P/E_0$) of about 56% (Siderius and Muchena, 1977; Jaetzold and Helmut, 1982). The area is underlain by the Limuru Quartz trachytes, an intermediate igneous rock dating back to the early Pleistocene period (Jaetzold and Helmut, 1982). The soil is classified as a Humic Nitisol (FAO) and locally referred to as Kikuyu red clay loam. The soils are well drained, deeply weathered, dark reddish brown to dark red, and with friable structure (Jaetzold and Helmut, 1982).

### 2.2. Experimental design

The long-term field trial was established in 1976. Different combinations of organic and mineral inputs are applied and their effects on arable crop production are compared. In our study, we compared soil properties of the arable treatments with those of a natural fallow. The cropping system consisted of a maize–bean rotation, with maize (*Zea mays* Hybrid 512) being grown during the long rains and beans (*Phaseolus vulgaris*, variety Rosecoco) during the short rains. The treatments selected for this study were:

(i) Control minus or plus mineral fertilizer (C – F/C + F). No organic inputs were applied.
(ii) Maize stover residues, minus or plus mineral fertilizer (R – F/R + F).
(iii) Farm yard manure, minus or plus mineral fertilizer (FYM – F/FYM + F).
(iv) Natural green fallow (NF).

Mineral fertilizer was applied at 120 kg N ha$^{-1}$ yr$^{-1}$ as calcium ammonium nitrate (CAN) and 52.6 kg P ha$^{-1}$ yr$^{-1}$ as triple superphosphate (TSP). Initially (from 1976 to 1980), a compound fertilizer 20:20:0 was used as a source of N and P, but this was