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Effect of fertilizer-N and organic resource management on soil aggregates formation and carbon cycling in the central highlands of Kenya

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Abstract. *Njoroge KS, Mugendi DN, Vanlauwe B. 2018. Effect of fertilizer-N and organic resource management on soil aggregates formation and carbon cycling in the central highlands of Kenya. Asian J Agric 2: 25-38.* The objective of this research was to inquire about the way the alteration of soils of various textures and fertility values with fertilizer-N and organic resources influence aggregate formation and subsequent carbon (C) cycling in aggregates. The experiment was carried out in the Embu and Machang'a regions of central Kenya and was rooted in a putrefaction tube experiment that was established in April 2005. This experiment was intended at completing long-term field experimentations initiated in 2002 to set up the impact of the application of various combinations of organic and mineral resources on soil nutrient status. The main variables were fertilizer-N and organic resources, with the sub-management being soil fertility values. Maize stover and urea fertilizer were mixed with 3.2 kg of soil and put in putrefaction tubes. The implementation rate was 4 tons and 120 kg per hectare, for the maize stover and fertilizer respectively. Four management techniques were tested, namely: control (no organic resources or fertilizer-N added), lone fertilizer-N, lone stover, and combined stover and fertilizer-N, with each management having three replicates. To decide the alterations in soil aggregates, dirt samples acquired from the putrefaction tubes were fractionated through wet sieving. SOM fractionation was also carried out to gain the various SOM fractions. All achieved aggregates and SOM fractions were then dried in the oven, ground, and analyzed for C. All collected data were examined with the PROC MIXED procedure of SAS and the means separated at $p < 0.05$. Bigger quantity of macroaggregates from Embu soils was studied than that from Machang'a soils. For both Embu and Machang'a soil, the alteration of soils with lone or combined fertilizer-N and organic resources had a notable impact ($p < 0.05$) on the portions of all aggregate class sizes. The alteration of soils of various fertility values with lone or combined fertilizer-N and organic resources also had a notable impact on the allocation of SOM fractions for both Embu and Machang soils. Remarkable discrepancies in whole soils, aggregates and SOM fractions percentage carbon values were also studied. Overall, the silt and clay fraction had higher C values than that in other aggregate size classes representing higher stabilization of C within this fraction. From the results of this research, it is concluded that the utilization of combined organic and mineral resources is preferred for the enhancement and the preservation of soil fertility in high fertility soils. In low fertility coarse-textured soils, the lone implementation of organic resources is suggested for the enhancement and preservation of soil fertility.

Keywords: Carbon cycling, fertilizer, Kenya, nitrogen, soil organic, soil aggregate

INTRODUCTION

Sustainable food manufacturing depends fervently on the keeping of adequate values of soil fertility. This can only be gained by keeping the equilibration of nutrient outputs and inputs (Kirchmann and Thorvaldsson 2000). In Sub-Saharan Africa (SSA), this equilibration is hardly reached since the input of nutrients both in the form of mineral fertilizers or organic are low. This is mostly caused by the sumptuous price of fertilizers due to the liberalization of fertilizer trade and the introduction of structural adjustment programs (SAP) (Ayuke et al. 2004) inflicting very low values of fertilizer utilization. Current estimations for fertilizer utilization in Africa are 9 kg ha-1 compared to 87 kg ha-1 in the developed countries (Bationo et al. 2004). As for organic inputs, their efficacious utilization in soil fertility increase is restricted by their low or disproportionate nutrient rate, poor quality, and the existence of other rival usages such as the utilization as livestock feed (Palm and Rowland 1997). With such low external input numbers, soil fertility decrease lasted bringing to low farm productivity and extensive famine in the continent. Newest statistics display that some 200 million people or 28% of Africa's inhabitants are chronically in need of food (Bationo et al. 2004).

The same circumstance has been detected in Kenya, where crop harvest in most parts of the country is low caused by a decrease in soil fertility. This is often a result of perpetual farming and no application of fertilizers by farmers. Low soil fertility has a tendency to decrease further as farmers remove many nutrient outputs in crops yield, crop residues and through losses such as leaching, and soil erosion processes (Kathuka et al. 2007). For example, in Embu district of Central Kenya as reported by Lesschen et al.(2003), nutrient equilibration of N, P and K were-55,-9 and-15 kg per hectare, respectively, in 1998 and in 2003, nutrient equilibration had reduced to-116.2,-22.1 and-31.7 per hectare for N, P and K, respectively. Therefore, there is an urgent need for the establishment of advantageous and inexpensive soil management methods that shall sufficiently overcome the issue of soil fertility reduction. One way to be done by smallholder farmers in

SSA to restore soil fertility in their farms is the application of methods of integrated soil fertility management (ISFM). These methods combine the organic and inorganic resources of fertility. These are reasonable methods since various nutrient resources are mostly obtainable for resource poor farmers but are utilized poorly due to the lack of knowledge or other limitation such as labor (Delve 2004). In these methods, fertilizers serve as a nutrient resource for plants and organic resources act as forerunner of soil organic matter (SOM) which keeps the physical and physicochemical components of soil fertility such as cation exchange capacity (CEC) and soil contexture (Vanlauwe et al. 2002). Organic resources also enhance soil contexture by increasing aggregate establishment, as they act as a resource of carbon compounds performing a major role in tying up individual soil particles into microaggregates, and subsequently tying up these microaggregates into macroaggregates (Blair et al. 2005). This is significant since soil accumulation governs the extent of soil properties such as aeration, water percolation, and drainage. These further govern plant development and accretion, while also supplying habitat for soil biota (Denef et al. 2002). Escalated soil aggregation also enhances rates of SOM as soil aggregates physically secure SOM within their structure, thereby decreasing its putrefaction rate (Alvarez et al. 1998). It further decreases the discharge of carbon (C) to the atmosphere, as soil aggregates in SOM establish temporary C pools by stabilizing C within their structure (Six et al. 2002).

For best use of organic and mineral resources in soil fertility enhancement, it is necessary to set their usage in agroecosystems that vary in terms of climate and soil texture. SSA is characterized by heterogeneity both in terms of climate and soil characteristics. One way to achieve it is by examining the putrefaction patterns of organic leftovers as it is through this process that nutrients kept in the remains are discharged into the soil (Palm 1995). Although the putrefaction number of organic leftovers is principally adjusted by the quality of the leftovers (Palm 1995), climatic circumstances and soil texture. The central plateaus of Kenya are marked by a high-density population that has created high pressure on the limited land resources. This has brought to the escalation of land fragmentation and perpetual cultivation with, frequently, minimal or no implementation of external nutrient inputs. This has created perpetual SOM and nutrient decimation in the soil leading to decreased crop harvests. Further, the capability of the land in sustaining other ecosystem services such as nutrient retention and liberation, water keeping and percolation, root breach among others have been compromised. The decrease in farm harvests has brought to the anxiousness for food availability and decreased farm earnings in this zone, leading to raised occurrences of starvation and penury. The attempts to restore soil fertility in these regions have mainly depended on the usage of organic and mineral inputs. The success of this has, however, been hindered by the decreased presence of the former and the high cost of the latter. There is, therefore, a requirement for the establishment of a more supportive and inexpensive method of soil fertility replacement.

The use of organic and mineral resources in combination is one method used by farmers in this region to manage decreased soil fertility. This is an achievable method because various organic and mineral resources in various quantities are available for farmers in the region. The prudent utilization of these two nutrient resources leads to the careful act of ameliorating plant nutrient provision while at the same time enhancing SOM values and the associated ecosystem services.

Even though, research has listed various advantages about the combined use of organic and mineral resources, little efforts have been done to specify the impact of soil fertility on the utilization of organic and mineral resources with consideration to the putrefaction of organic resources. This is significant, as the amount of organic resources putrefaction affects the establishment of SOM, aggregate establishment and hence the stabilization of carbon inside aggregates. Such research would be of great significance, as the central plateaus of Kenya are characterized by heterogeneity in relation to soil fertility degrees. In accordance with this, this research tries to specify the impact of organic and mineral alteration on aggregate establishment and C cycling to soils of different fertility extents in the central plateaus of Kenya.

The research aims to: (i) To specify the impact of the alteration of soils of various texture and fertility extents by fertilizer-N and organic resources on aggregate establishment. To specify the impact of the alteration of soils with various composition and fertility extents by fertilizer-N and organic resources on the allocation of obvious SOM fractions. (ii) To specify the impact of the alteration of soils with various composition and fertility extents by fertilizer-N and organic resources on C stabilization in soil aggregates.

MATERIALS AND METHODS

Experimental sites

This research was performed in two sites in central Kenya, namely, Embu and Machang'a. The two sites contrast in terms of rainfall, temperature and soil types as depicted below.

The Embu site is situated in Embu district (Central Kenya), at '0° 30' S, 37° 27' E and at an altitude of 1480 m above sea value. The area has a humid climate, with an average temperature of 20°C. Rainfall is bimodal with the long rains falling from March to May, and the short rains falling from mid-October to December. The average annual rainfall is about 1200 mm. The soil in Embu is a clay loam (sand 32%, silt 30%, and clay 38%) derived from basic volcanic rocks. The soil is classified as Humic Nitisols (FAO 1990) and has Kaolinite as the dominant clay mineral. Livelihoods of the population came from subsistence mixed farming consisting of the growing of cash and food crops and the keeping of dairy animals, which is the most important farming system in this area. The most important cash crop is coffee *(Coffea arabica)*, while the main food crop is maize (*Zea mays*).

The Machang'a site is situated in Mbeere district. It lies at '0˚47'S, 37 ˚40' E, and at an altitude of 1050 m above sea value. The area has a semi-arid climate, and the soil is a sandy clay loam consisting of 56.5%, 12.7% and 30.8% of sand, silt, and clay, respectively. It is classified as a Chromic Cambisol (Kamoni et al. 2007). The area has an average annual temperature of 26°C, while the average annual rainfall is 700mm. The common farming system in this area consists of subsistence mixed farming of food crops such as maize (*Zea mays*), beans *(Phaseolus lunatus)* and black peas *(Vigna unguiculata)* and cash crops such as coffee *(Coffea Arabica)*.

Experimental design

This research was based on a putrefaction tube experiment that was held in April 2005. The goal was to complete long-term field trials with the aim of establishing the impact of implementation of various compositions of organic plus mineral resources on soil nutrient status.

Materials and procedure

The putrefaction tubes were made of polyvinyl chloride (PVC) as shown in Figure 1.A, with a diameter of 10 cm and a length of 35 cm. All the tubes had an iron mesh at bottom to prevent soil from falling out from tubes. The tubes were also covered with an iron mesh at the top to prevent the entry of any substances such as litter, etc. The organic and inorganic resources were mixed with 3.2 kg of soil and placed into the putrefaction tubes which were then placed in holes measuring 15 cm in diameter and 30 cm in depth. The organic resources were in the form of maize stover applied at a rate of 4 tons per hectare, while the mineral resources were in the form of urea applied at a rate of 120 kg per hectare (Table 1). The organic resources were mixed by hand while the fertilizer was mixed in liquid form during the arrangement of the experiment.

Design of the experiment

The experiment was arranged as a randomized complete block design. Soils of various fertility values; low, medium, and high fertility were acquired from farms around the experimental locations, mixed with sole or combined organic and mineral resources, and arranged in putrefaction tubes in the respective sites as shown in Figure 1.B. The experiment consisted of four management techniques namely, control (no stover or fertilizer-N is applied), sole stover, sole fertilizer, and stover plus fertilizer. Each management had three replicates, amounting to a total of 36 tubes per site.

Soil sampling

Soil sampling for the baseline study was performed at the onset of the experiment in 2005. Soil samples were gathered from farms near each of the two locations, and the chemical and physical soil characterization was performed. Based on the results of the soil characterization, soils were categorized as low, medium, and high fertility. The physical and chemical characteristics of these soils are shown in Table 2.

Soil sampling from the putrefaction tubes was performed in December 2006. The soil was sieved through an 8 mm sieve, and subsamples of approximately 2 kg were acquired for SOM fractionation. The soil was then packed, air-dried and stored at room temperature in readiness for physical fractionation through wet sieving.

Table 1. Management structure for Embu and Machang'a tube experiments managements.

Management	Quantity of organic resources applied (t ha^{-1})	Quantity of inorganic resources applied (kg ha^{-1})
Control	0	0
Fertilizer-N	0	120
Maize stover	4	0
Fertilizer-N plus maize stover	4	120

A B

Figure 1.A. A putrefaction tube set up in the field. B. A section of the field layout shows the set-up of putrefaction tubes.

Table 2. Chemical and physical characteristics of soils sampled in Machang'a and Embu, Kenya in April 2005.

Site	Fertility	% C	% N	C: N	P ppm	pH	EX K (cmol/kg)	EX Ca (cmol/kg)	EX Mg (cmol/kg)	EX Na (cmol/kg)	CEC (cmol/kg)	Sand %	Silt %	Clay %
Machang'a	Low	0.33	0.03	11: 1	4.0	6.60	0.90	8.01	2.25	0.12	13.5	75.1	10.0	14.9
	Medium	0.44	0.04	11: 1	4.5	5.84	2.44	12.85	3.51	0.25	25.5	75.1	14.9	10.9
	High	0.92	0.08	12: 1	56.5	7.12	2.02	18.13	4.44	0.12	26.0	81.1	10.0	8.9
Embu	Low	1.58	0.17	9: 1	1.0	6.48	0.37	2.09	0.70	0.83	4.0	17.2	30.0	52.8
	Medium	2.77	0.26	11: 1	4.5	6.92	0.68	6.01	1.03	0.59	8.5	17.1	16.0	66.9
	High	3.41	0.33	11: 1	3.0	6.50	0.92	8.28	2.63	0.11	14.0	15.2	16.0	68.8

Laboratory analysis

Aggregate formation and carbon cycling

To specify the impact influence of fertilizer-N and organic resources combination on aggregate formation and C cycling. Soil samples taken from the field and from the putrefaction tubes were examined using physical fractionation methods (Elliot 1986) into the various fractions.

Aggregate division

Soil samples were divided into four aggregate size fractions through wet sieving into large macroaggregates (>2000 µm), small macroaggregates (250 µm-2000 µm), microaggregates (53-250 µm), and silt + clay associated particles (<53 µm) (Elliot 1986). An 80 g subsample of soil was evenly spread over a 2 mm sieve submerged in 1cm of deionized water for 5 minutes. The soil was subsequently sieved by manually moving the sieve up and down 50 times during a 2-minute period. Soil remaining on the sieve was backwashed into a pre-weighed beaker for drying, while the soil and water that passed through the sieve were transferred to a 250 µm sieve and the sieving procedure was repeated. Using the 53 µm sieve, the procedure was repeated. To subsample the silt and clay fraction, a bottle-based method was used to obtain a 250 ml subsample. The four aggregate fractions were oven-dried at 105°C and weighed. All fractions were then pulverized and analyzed for C.

Soil organic matter fractionation

Following the method described by Six et al. (2000b), subsamples from the small and large macroaggregates were taken to isolate the microaggregates held within macroaggregates, to acquire the SOM fractions. A micro aggregate isolator, (Figure 2) was used to entirely break up macroaggregates while minimizing the breakdown of microaggregates. This method was applied to each soil to allow for total dispersion of the macroaggregates without disrupting the microaggregates within macroaggregates.

For Embu soils, 5 g subsamples were immersed in 50 ml of deionized water for one night. The following day, the subsamples were submerged in deionized water on top of a 250 µm mesh screen and gently shaken on a reciprocal shaker with 50 glass beads (4 mm diameter) for 5 minutes at 250 rpm. A perpetual and constant stream of water through the device was kept on, making certain that microaggregates were immediately flushed into a 53 µm sieve and not further disrupted by the glass beads. Microaggregates collected on the 53 µm sieve were further sieved according to Elliot (1986) to make certain that the collected microaggregates were water stable.

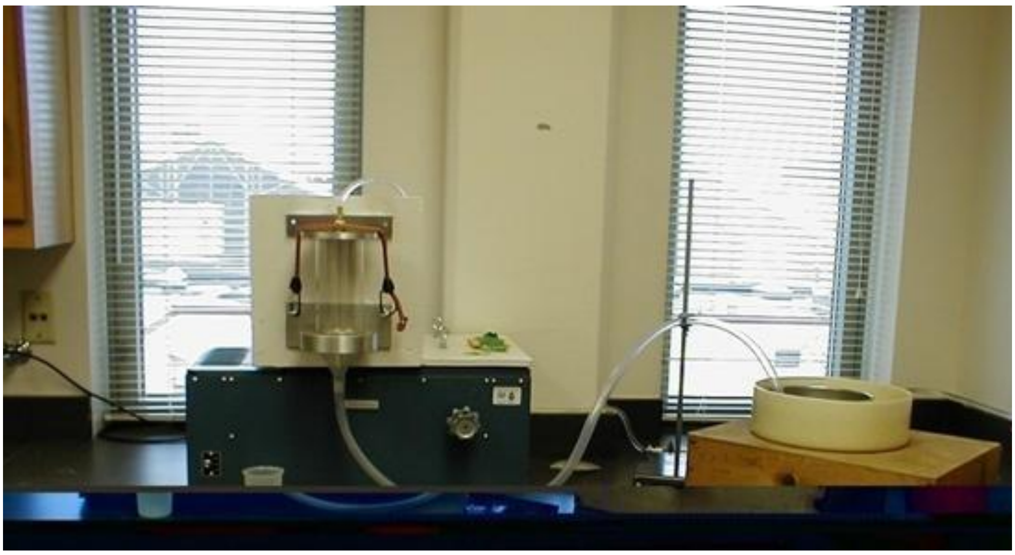

Figure 2. A microaggregate isolator set up on a reciprocal shaker

Three fractions were achieved: coarse particulate organic matter (> 250 µm), microaggregates within macroaggregates (53-250 µm), and silt and clay (< 53 µm). The fractions were then oven dried at 105°C, weighed, pulverized, and analyzed for C.

For the Machang'a samples, a different procedure was utilized since macroaggregates from sandy soils are less stable. A 15 g sub-sample of macroaggregates was applied for the isolation process. These sub-samples were immersed in deionized water for 20 minutes and then shaken for 3 minutes at 150 rpm.

Statistical analyses

The collected data was studied using the SAS PROC MIXED procedure. The means were then separated at p <0.05 and the standard error of difference (SED) of the means was utilized to compare the responses between sole and combined application of fertilizer-N and organic resources.

RESULTS AND DISCUSSION

General overview

This chapter presents the results of the study. It is divided into three sub-sections. The first section reviews the impact of the alteration of soils with fertilizer-N and organic resources on soil aggregates proportions. The second section reviews the impact of these alterations on the distribution of distinct SOM fractions within macroaggregates. Finally, the third and last sub-section reviews the impact of these alterations on the carbon contents of whole soils (unsieved soil), aggregates, and SOM fractions.

Effect of alteration of soils of various texture and fertility values with fertilizer-N and organic resources on aggregate proportions

Soil aggregates play an essential part in soil fertility which is caused by their many vital functions. For this study, soils were divided into four aggregate size classes namely large macroaggregates (>2000 µm), small macroaggregates (250-2000 µm) microaggregates (53-250 µm), and silt and clay (<53 µm) through wet sieving. In the Embu site (Table 3), higher proportions of small macroaggregates (250-2000 µm) were examined in all alterations compared to the other aggregate size classes. For the Machang'a site (Table 4), the highest proportion of aggregates was examined in the microaggregates (53-250 µm) size class.

In the Embu site (Table 3), the proportions of large macroaggregates (>2000 µm) for all alterations of low fertility soils with fertilizer-N and organic resources were significantly different (p<0.05) to the proportion examined in the control. This was in the order, sole fertilizer-N> stover plus fertilizer-N> sole stover. For the alterations including medium-fertility soil, only the combined stover and fertilizer-N management had an important impact (p<0.05) on proportions of large macroaggregates regarding the control. Proportions of large macroaggregates for all alterations of high fertility soils with fertilizer-N and organic resources were significantly different (p<0.05) to the control. For these managements, the sole fertilizer-N management had the highest proportion (16.46%) of large macroaggregates.

Table 3. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on proportions of soil aggregates in Embu soils, Kenya.

	Aggregate size class proportions (%)											
	>2000 µm			250-2000 µm			53-250 µm			<53 µm		
Managements	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	6.62	5.04	12.10	64.71	59.88	63.00	21.55	26.31	17.11	3.69	3.98	2.09
Fertilizer N	9.50	4.23	16.46	62.00	61.56	61.00	20.35	25.71	15.21	3.36	4.47	1.79
Stover	7.57	4.90	13.67	61.90	61.08	64.23	23.74	25.41	15.57	3.70	3.05	2.14
Stover + Fert N	8.40	7.25	13.41	67.16	63.47	64.09	18.29	21.44	15.60	3.10	3.25	2.01
SED	0.77*	0.77*	0.77*	1.23*	1.23*	1.23*	0.89*	0.89	0.89	0.28	0.28*	0.28

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at p<0.05

Table 4. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on proportions of soil aggregates in Machang'a soils, Kenya.

	Aggregate size class proportions (%)											
	>2000 µm			250-2000 µm			53-250 µm			<53 µm		
Managements	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	0.90	1.27	15.34	36.19	20.21	30.27	56.45	70.99	44.41	5.03	6.86	4.73
Fertilizer N	2.39	1.02	15.11	36.80	19.78	32.19	52.80	70.34	45.45	5.72	7.49	5.74
Stover	4.57	2.94	16.65	34.33	19.26	33.80	54.95	66.99	43.72	4.80	8.57	3.89
Stover + Fertilizer N	1.18	3.01	16.51	35.22	19.43	30.88	57.35	69.40	45.84	5.05	6.77	5.13
SED	0.56*	0.56*	0.56*	0.83	0.83	0.83*	1.00*	1.00	1.00*	0.40*	0.40*	0.40*

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at p<0.05

In the Machang'a site (Table 4), the alteration of low fertility soil with sole fertilizer and sole stover had important impacts ($p<0.05$) on the proportions of large macroaggregates as compared to the control management. overall, for these alterations, the sole stover management had the highest proportion (4.57%) of large macroaggregates. For the medium fertility soils, the sole stover and combined stover and fertilizer-N managements had important impacts on the proportions of large macroaggregates, compared to the control management. For these managements, the combined stover and fertilizer-N management had the highest proportion (3.01%) of large macroaggregates. A similar trend was examined in the high fertility soil where the proportions of large macroaggregates, in both the sole stover and combined stover and fertilizer-N managements, were significantly different from those of the control. For these managements, the sole stover management had the highest proportion (16.65%) of large macroaggregates.

In the small macroaggregates size class (250-2000 µm), the alteration of low fertility soil in the Embu site with combined stover and fertilizer-N had an important impact on the proportions of small macroaggregates (Table 3) regarding the control management. This management accounted for the highest proportion of small macroaggregates (67.16%). Regarding the medium-fertility soil, both the sole fertilizer-N and combined stover and fertilizer-N managements had important impacts on the proportions of small macroaggregates. For these alterations, the combined stover and fertilizer-N management had the highest proportion (63.37%) of small macroaggregates. For the management including high fertility soil, only the sole stover management had an important impact on the proportion of small macroaggregates. In the Machang'a site, the impact of alteration of low fertility soil with fertilizer-N and organic resources on proportions of small macroaggregates was only significant for the sole fertilizer-N management. This management accounted for the highest (36.80%) proportion of small macroaggregates. For the alterations including medium-fertility soil, no management technique was significantly different from the control. Regarding high fertility soil, both the sole stover and the sole fertilizer-N managements had important impacts on the proportions of small macroaggregates as compared to the control management. Overall, for these managements, the sole stover management had the highest proportion (33.80%) of small macroaggregates.

In the microaggregates size class (53-250 µm), the alteration of low fertility soils in Embu with sole fertilizer-N and combined stover and fertilizer-N had an important negative impact in that it resulted in lower values of microaggregates compared to the control management (Table 3). In the medium-fertility Embu soils, all alterations including fertilizer-N and organic resources resulted in reduced values of microaggregates. A similar trend was examined in the high fertility soils. For the Machang'a site, all alterations of soils with sole stover had an important negative impact on proportions of microaggregates.

The dissimilarities in aggregate composition between the Embu and Machang'a soils could be caused by a higher clay content in the Embu soils than that of Machang'a (Table 4). Several studies have shown that soil texture affects aggregation (Chaney and Swift 1984; Plante et al. 2006) such that raised clay contents are correlated with raised aggregation or aggregate stability. Bartoli et al. (1992) claimed that water-stable aggregates were associated with aggregate strength that was well associated with clay content. More recently, a study by De Gryze et al. (2005) found that the amount of water stable aggregates >2000 µm in a natural ecosystem declined respectively as follows: silty clay loam > silt loam > sandy loam. This is also in accordance with a study by Barthes and Roose (2002), who reported that an increase in coarse sands caused simultaneous declines in clay plus fine silts and aggregate fractions.

The higher proportions of large macroaggregates examined in the sole fertilizer-N or combined stover and fertilizer-N alterations in the Embu soils (Table 3) indicated raised macroaggregate formation upon the alteration of these soils with fertilizer-N. This could be caused by raised N values, which resulted in an escalation in microbial activity as N limiting conditions have been found to be low value in microbial activity (Harris et al. 1996). Studies have also shown the addition of mineral N with raised microbial activity and the subsequent release of C-rich binding compounds resulting in higher formation of large macroaggregates (Six et al. 2000a; Dutta et al. 2003). This is supported by a study performed by Kavoo (2008) who stated that a higher initial formation of large macroaggregates upon the alteration of sawdust with mineral N fertilizer for soils in Embu was found.

For the Machang'a site (Table 4), the important impacts examined with the alterations including sole stover and combined stover and fertilizer-N on the proportions of large macroaggregates indicate raised macroaggregate formation. This could be caused by the addition of maize stover as the addition of organic matter such as crop residues and other organic substances to soil which has been found to usually raise aggregation (Bipfubusa et al. 2007). This is supported by a study by Sodhi et al. (2009) who reported an escalation in the proportions of macro-aggregates and a subsequent decline in the proportions of microaggregates upon the alteration of soil with rice compost. Bronick and Lal (2005) also reported raised aggregation and aggregate stability upon alterations of soils with corn residues. Studies have also presented that the large macroaggregates fractions are highly responsive to organic residue addition in soil (Bipfubusa et al. 2007). Escalated formation of macroaggregates upon the addition of organic resources has been attributed to the organic resources serving as nucleation sites for the growth of fungi and bacteria (Jastrow 1996; Puget et al. 1996; De Gryze et al. 2005). The fungal hyphae then initiate macroaggregate formation by enmeshing fine particles into macro-aggregates (Tisdall and Oades 1982). With time, the microbial (fungal and bacteria) exudates, were produced because of putrefaction of plant residues to form binding agents that further stabilize macroaggregates (Six et al.

2002). The formation of macroaggregates around organic residues has further been confirmed by studies using ^{13}C natural abundance in fields.

These studies have consistently shown that macroaggregates are formed around newly incorporated organic residues (Puget et al. 1996; Six et al. 1998). De Gryze et al. (2005) also reported a linear increase in aggregate formation with increasing amounts of the added low-quality residues (low in N but high in lignin).

The important negative impact on the proportions of microaggregates for all alterations, including high fertility soils in the Embu site, could be caused by raised binding of microaggregates into macroaggregates upon alteration of soils with fertilizer-N and organic resources. According to the hierarchical concept of aggregate formation, macroaggregates are formed by the binding together of smaller aggregates such as stable microaggregates (Tisdall and Oades 1982; Balesdent et al. 2000). Six et al. (1999) suggested that the addition of new residues in a no-till management system promoted organic matter stabilization through the binding of primary soil particles and old microaggregates into new macroaggregates. Further, fragmented crop residue (particulate organic matter) has been found to form the nuclei for new microaggregates that can be bound together by transient and labile organic matter to form new macroaggregates (Golchin et al. 1994; Olchin et al. 2008). This causes an increase in proportions of macroaggregates, followed by a subsequent decrease in macroaggregate proportions. The results indicate that macroaggregate formation and stabilization was higher in higher fertility soils and is in line with the higher proportions of macroaggregates examined in the Embu high fertility soils.

Effect of alteration of soils of various texture and fertility values with fertilizer-N and organic resources on distribution of distinct SOM fractions

The proportions of functional soil organic matter fractions, i.e., coarse particulate organic matter (cPOM), microaggregates within macroaggregates (mM) and silt and clay (s+c) were determined through isolation from macroaggregates. For the Embu site (Table 5), higher proportions of microaggregates within macroaggregates were examined in all alterations than that of other SOM fractions. The scenario was different for the Machang'a site (Table 6), where higher proportions of cPOM fractions were examined in all alterations than that of other SOM fractions.

In the Embu site, all alterations of low fertility soil with sole and combined application of fertilizer-N and organic resources had an important impact on the distribution of cPOM fractions compared to the control (Table 5). The sole fertilizer-N management accounted for the highest proportion of cPOM fractions (9%). Alteration of medium fertility soils with fertilizer-N and organic resources had no important impact on the distribution of cPOM fractions. A resemblant trend was examined in the high fertility soil. Overall, cPOM fractions ranged between 2.60% and 9.00%, 0.73% and 1.00%, and 0.73% and 1.33% for the low, medium, and high fertility soils respectively.

In the Machang'a low fertility soils, the proportion of cPOM fractions in the combined stover and fertilizer-N management was significantly different to that of the control (Table 6).

Table 5. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage (%) distribution of distinct SOM fractions within macroaggregates in Embu soils, Kenya.

	% Distribution of SOM fractions								
	cPOM			**mM**			**S&C**		
Management	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	2.60	1.00	1.00	65.46	63.73	60.33	23.83	25.74	30.81
Fertilizer N	9.00	0.93	0.86	61.73	66.86	68.20	23.73	21.45	21.41
Stover	7.00	0.93	0.73	61.33	60.46	55.93	19.74	24.74	39.76
Stover + Fert. N	4.93	0.73	1.33	63.40	65.53	58.26	27.44	25.21	36.94
SED	0.45*	0.45	0.45	1.96	1.96*	1.96*	2.85*	2.85	2.85*

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at p<0.05

Table 6. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage (%) distribution of distinct SOM fractions within macroaggregates in Machang'a soils

	% Distribution of SOM fractions								
	cPOM			**mM**			**S&C**		
Management	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	69.76	68.11	71.54	23.85	25.85	21.80	3.27	6.83	3.80
Fertilizer N	67.61	65.50	70.70	26.97	28.81	22.88	2.95	4.12	4.39
Stover	68.60	71.89	71.30	25.34	22.35	21.12	4.24	3.56	5.70
Stover + Fert. N	74.51	67.67	68.83	19.26	23.80	22.23	4.75	6.36	7.08
SED	2.25*	2.25*	2.25	1.99*	1.99*	1.99	0.6*	0.6	0.6*

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at p<0.05

This management accounted for the highest proportion (74.51%) of cPOM fractions among all alterations. For the medium-fertility soil, only the sole stover management had an important impact on the proportions of cPOM fractions about the control. A similar trend was examined in the high fertility soil. Overall, cPOM fractions ranged between 67.61% and 74.51%, 65.50% and 71.89%, and 68.83% and 71.54% for the management including low, medium, and high fertility soil values respectively.

The higher proportions of cPOM fractions examined in the Machang'a soils, as compared to the Embu ones, could be due to dissimilarities in texture. Studies have shown that the proportion of mass associated with the course (>250 µm) sand plus POM fractions decreases with increasing clay content (Plante et al. 2006). Regarding the mM fractions, the higher proportions examined in the Embu soils indicate that formation and stabilization of macro-aggregates in these soils is higher than in the Machang'a soils. Studies have shown that it is through the formation and subsequent stabilization of macroaggregates that microaggregates are formed within macroaggregates (Puget et al. 1996; Six et al. 2004). During macroaggregate stabilization, the intra-aggregate particulate organic matter POM (i.e., fresh plant material that was incorporated in the macroaggregates during "biological" aggregate formation) is further decomposed by microorganisms and fragments into finer POM. This fine POM then becomes increasingly encapsulated with minerals and microbial products forming new microaggregates within the macroaggregates (Six et al. 1998). These microaggregates are later released upon the breakdown of macroaggregates and may be subsequently reincorporated into new aggregates. This is corroborated by the higher proportions of macroaggregates examined in the Embu soils as compared to the Machang'a soils (Tables 5 and 6).

The lower formation and stabilization rates of macroaggregates in the Machang'a soils compared to the Embu soils can be attributed to dissimilarities in texture as this influences the turnover rate of organic matter (Six et al. 2002), It is known that in coarse-textured soils of arid and semi-arid regions such as those of Machang'a, there exists a rapid turnover of organic matter (Quiroga et al. 1999; Hevia et al. 2003), and that only a low amount of fresh organic residues will contribute to humified soil organic matter which is essential for soil aggregation. Under these conditions, most plant and animal residues incorporated in the soil will be mineralized (Gregorich et al. 1994).

The higher proportions of cPOM fractions examined in the low fertility soils compared to higher fertility soils at the Embu site could mean that there was an accumulation of POM. This could probably be due to slow putrefaction rate in these soils as this has been found to cause decreases in POM size (Guggenberger et al. 1999). The low putrefaction rate exhibited in this soil could be due to the low microbial activity usually associated with low fertility soils (Kolbl et al. 2006). In their studies, Scolter et al. (2003) and Sehy et al. (2003) reported a direct relationship between soil fertility and the putrefaction of organic residues.

The important impact on mM proportions for the alteration of low fertility soil with sole fertilizer-N, and alteration of medium and high fertility soils with sole fertilizer-N and combined stover and fertilizer-N in the Embu site indicates raised macroaggregate formation and stability. This can be attributed to the addition of fertilizer-N which raised soil N values resulting in a subsequent rise in microbial activity and hence improved aggregate formation and stabilization, and the subsequent formation of microaggregates within macroaggregates (Harris et al. 1996; Six et al. 2000a). The formation of microaggregates within macroaggregates upon the stabilization of macro-aggregates has been found to be crucial for the long-term sequestration of C (Six et al. 2002), as microaggregates have a greater capacity to protect C from putrefaction as compared to macroaggregates (Balesdent et al. 1993).

In the following subsections, the carbon content of whole soil, aggregate size fractions and SOM fractions isolated from macroaggregates are presented and discussed.

Effect of alteration of soils of various texture and fertility values with fertilizer-N and organic resources on carbon content of whole soils

The incorporation of fertilizer-N and organic resources in soils resulted in changes in soil C status of whole soils in both Embu and Machang'a (Tables 5 and 6). At both sites, C% values of soils were raised with increased fertility. Overall, soils at the Embu site had higher C% values compared to those for Machang'a. At the Embu site, no management had an important impact on C% values of whole soils for all soil fertility values (Table 7). However, for all fertility values, the combined stover and fertilizer-N managements had the highest C% values.

In the Machang'a site (Table 8), alteration of low fertility soils with sole stover had an important ($p<0.05$) impact on the C% value of whole soil compared to the control management. For the medium fertility soils, whole soil C% values of both the sole fertilizer-N and sole stover management were significantly different from that of the control. For these managements, the sole stover management had the highest whole soil C value (0.31%). For the high fertility soils, whole soil C% values of both the sole fertilizer-N and the combined stover and fertilizer-N managements were significantly different from that of the control. For these managements, the combined stover and fertilizer-N management had the highest whole soil C value (0.66%).

Table 7. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of whole soils in Embu, Kenya

Management	C%		
	Low	**Medium**	**High**
Control	1.71	2.89	3.13
Fertilizer N	1.59	2.94	3.16
Stover	1.73	2.87	3.13
Stover + Fert. N	1.74	2.96	3.20
SED	0.14	0.14	0.14

Note: SED = Standard error of difference of means

Table 8. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of whole soils in Machang'a, Kenya.

Management	% C		
	Low	**Medium**	**High**
Control	0.26	0.27	0.61
Fertilizer N	0.17	0.30	0.64
Stover	0.28	0.31	0.62
Stover + Fert. N	0.24	0.22	0.66
SED	0.02*	0.02*	0.02*

Note: SED = Standard error of difference of means; SED* = Difference between managements is statistically significant at $p<0.05$

The higher whole soil C values examined in the Embu soils as compared to the Machang'a ones could be due to the higher proportions of clay content examined in the Embu soils compared to the Machang'a ones (Table 2). Studies have shown that soil texture is a key variable affecting soil C, because of electrostatic binding between negatively charged clay surfaces and organic colloids via cation bridges (Paustian et al. 2003; Barthes and Roose 2002). Comparing similar tropical soils with different clay mineralogy, Wattel-Koekkoek and Burman (2004) found that the effective cation capacity of the clays can explain dissimilarities in the mean residence of OM. In a study over a range of tropical soils, Feller and Tessier (1996) also confirmed that due to the sorption of fine organic constituents to fine mineral particles, C amount in the fine fraction increases with the proportion of fine primary particles. The relationship between clay concentration and SOC content is sufficiently strong that SOM models such as Century (Parton 1996) and RothC (Jenkinson 1990) assume that SOM putrefaction decreases as clay concentration increases, such that if all factors are equal, SOC accumulates faster as soil clay content increases (McLauchlan 2006).

The lower whole soil C values examined in the Machang'a soils also explain the lower proportions of macroaggregates examined in these soils. A study by Castro et al. (2002) reported that a soil that is low in organic carbon will be poorly aggregated since the weight and the content of organic carbon in the >2000 µm size class is lower than the weight and the content of organic carbon of other aggregate size classes.

The higher whole soil C values examined in all Embu soils with combined stover, and fertilizer-N alterations as compared to the sole application of stover is in line with a study by Kavoo (2008). This study reported that the combined application of tithonia and mineral fertilizer-N had a higher concentration of C (35.8 g C kg^{-1} whole soil) compared to the sole application of tithonia (31.8 g C kg^{-1} whole soil) for soils in Embu. Hati et al. (2006) also reported an important impact of fertilizer-N and organic manure application on the soil organic carbon values up to a depth of 0.30 m, with the SOC content in the 0-0.15 m layer being the highest (6.5 g kg^{-1}) in the fertilizer-N plus manure management.

These higher values of percent C could be because of raised rate of putrefaction of maize stover and the subsequent release of carbon compounds in the presence of mineral fertilizer. Studies have shown that addition of mineral-N increases the putrefaction rate of organic resources. Jenkinson and Rayner (1985) reported that the addition of mineral-N raised the putrefaction rate of wheat straw by satisfying the N requirements of microorganisms. Berg and Matzner (1997) also reported that in the early stages of plant putrefaction, mineral-N inputs stimulate hydrolysis of soluble C compounds and nonlignified holocellulose. During the putrefaction of organic resources, plant material fragments or particulate organic matter (POM) gradually become encrusted with clay particles and microbial products to form the core of stable microaggregates (Six et al. 2004), resulting in an increase in whole soil C. The formation of microaggregates has been found to be crucial for the storage and stabilization of soil C in the long term through the incorporation of new C into microaggregates (Jastrow and Miller 1998; Six et al. 1998; Gale et al. 2000). This incorporation of new C into free microaggregates is an important factor contributing to C sequestration (Skjemstad et al. 1990) since C contained in free microaggregates has a slower turnover than C in macroaggregates (Jastrow 1996). These results indicate potential changes in soil C storage that could become more important over time, because small short-term dissimilarities in putrefaction with mineral-N input can add up to large dissimilarities in the long-term storage of SOM (Agren et al. 2001).

The important impact of the alteration of low and medium fertility Machang'a soil with sole stover on whole soil C, could be due to a buildup of SOC upon the application of stover. This is in line with findings by Angela et al. (2007), who reported that the amount of SOC sequestered in an organic system (5.70 Mg SOC ha^{-1}) was greater than the SOC sequestered by conventional and low input systems (570 and-340 kg SOC ha^{-1}, respectively). Harris et al. (1996) also suggested that the addition of class III organic resources leads to intermediate aggregate formation and breakdown resulting in C accumulation. Studies by Paustian et al. (2000) and Waswa et al. (2007), further reported that increases in soil carbon inputs are one of the ways through which soil C stocks can be raised. The addition of organic matter to soils results in higher soil C values through their occlusion within soil aggregates when new aggregates form around the organic matter. Increased occlusion increases C sequestration because of the decrease in mineralization in the occluded state due to raised interaction of the organic matter with reactive surfaces (Plante and Mcgill 2002).

Effect of alteration of soils of various texture and fertility values with fertilizer-N and organic resources on carbon content of soil aggregates

The alteration of soils with fertilizer-N and organic resources had various impacts on the carbon content of soil aggregates (Tables 7 and 8). Overall, soil aggregates from the Embu soils had higher C% values compared to those from the Machang'a soils. In the large macroaggregates achieved from Embu soils (Table 9), only the alteration of low fertility soil with sole stover management had an important impact on C% values of large macroaggregates as compared to the control management. For the large macroaggregates achieved from Machang'a soils (Table 10), only the alteration of medium fertility soil with sole stover had an important impact on the C% values of large macroaggregates compared to the control management. For this soil, this alteration was considered as the highest C% (1.67) value of macroaggregates.

In the small macroaggregates (250-2000 µm) size class, alterations of Embu soils with fertilizer-N and organic resources had no important impact influence on C% values. For the Machang'a site, alterations of low fertility soil with fertilizer-N and organic resources had no important influence impact on C% values of small macroaggregates. However, in the medium-fertility soil, the C% value of small macroaggregates in the sole stover management was significantly different ($p<0.05$) to that of the control. In the high fertility Machang'a soils, only the sole fertilizer-N management had an important impact on the C% values of small macroaggregates.

In the Embu low fertility soil (Table 9), the C% value of microaggregates (53-250 µm) in the combined stover and fertilizer-N management was significantly different ($p<0.05$) from that of the control management. For the medium fertility soils, only the sole fertilizer-N management had an important impact on the C% value of microaggregates. Alteration of high fertility soil with fertilizer-N and organic resources had no important impact on the C% value of microaggregates. For the Machang'a soils (Table 10), only the alteration of high fertility soil with sole fertilizer-N had an important impact on the C% value of microaggregates as compared to the control management. For both Embu and Machang'a soils, the silt and clay size class had the highest C% value compared to the other size classes. On average for all soil fertility values, the silt and clay size class (<53 µm) had higher C% contents compared to the other aggregates size classes for both the Embu and Machang'a sites.

The important impact of the stover management on the C% values of large macroaggregates in Embu and Machang'a, and the small macroaggregates in Machang'a indicates a C build up in macroaggregates upon organic residue application. This could be due to higher formation of macroaggregates upon the application of stover, as the putrefaction of organic residues has been shown to increase aggregation and aggregate stability (Tisdall and Oades 1982; Bronick and Lal 2005). This is in accordance with a study by Bipfubusa et al. (2007), who reported an increase in the C content of large and small macroaggregates upon the alteration of soils with both paper mill sludge and paper mill sludge compost. Studies elsewhere have also suggested that macroaggregates are stabilized mainly by carbohydrate-rich root or plant debris occluded within aggregates (Golchin et al. 1994). A study by Angers and Giroux (1996) provided further evidence that state resistant macroaggregates are stabilized by recently deposited residues, while Jastrow (1996) suggested that the intra-macroaggregate particulate organic matter (POM) is an important agent that facilitates the binding of microaggregates into macroaggregates. Increased aggregation results in an increase in the C value of macroaggregates, as aggregates are known to physically protect C (Jastrow et al. 1996 and Puget et al. 1996).

Table 9. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of soil aggregates in Embu soils, Kenya.

	C%											
	>2000 µm			250-2000 µm			53-250 µm			<53 µm		
Management	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	1.2	3.04	3.12	1.61	2.52	3.21	1.61	2.83	3.03	2.52	3.72	4.03
Fertilizer N	1.02	2.83	3.18	1.53	2.84	2.93	1.56	3.33	3.01	2.57	3.29	3.02
Stover	1.53	2.93	2.97	1.62	2.71	3.44	1.59	2.85	3.03	1.69	4.25	4.03
Stover+Fert. N	1.19	2.99	3.01	1.56	2.95	2.96	1.96	2.79	3.09	3.06	3.59	4.13
SED	0.24*	0.24	0.24	0.61	0.61	0.61	0.23*	0.23*	0.23	0.29*	0.29*	0.29

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at $p<0.05$

Table 10. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of soil aggregates in Machang'a soils, Kenya.

	C%											
	>2000 µm			250-2000 µm			53-250 µm			<53 µm		
Managements	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	0.45	0.35	0.25	0.28	0.35	0.64	0.23	0.19	0.59	0.83	0.92	2.23
Fertilizer N	0.55	0.47	0.25	0.25	0.20	0.72	0.32	0.19	1.32	1.17	0.85	2.05
Stover	0.52	1.67	0.22	0.23	0.54	0.63	0.25	0.16	0.59	0.89	0.81	2.57
Stover+Fert. N	0.52	0.34	0.31	0.29	0.21	0.41	0.23	0.13	0.42	1.14	0.85	1.65
SED	0.37	0.37*	0.37	0.08	0.08	0.08*	0.16	0.16	0.16*	0.24	0.24	0.24

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at $p<0.05$

Studies have shown that aggregates contain labile C that is physically protected from microbial putrefaction (Amelung and Zech 1999; McLauchlan 2006). The protection of C in macroaggregates contributes to C retention in soils by slowing its mineralization rate, resulting in a net gain in soil C (Mikha and Rice 2004).

The important impact on C% values of microaggregates examined in the alteration of both medium fertility Embu soil and high fertility Machang’a soil with sole fertilizer-N could be due to raised turnover of macroaggregates and the subsequent release of microaggregates. This increase in turnover rate could be because of raised putrefaction of C compounds binding macroaggregates upon the addition of sole fertilizer-N. Upon the application of fertilizer-N without a C source, microorganisms have been found to decompose the C-rich binding agents, resulting in C losses (Angela et al. 2007). As the binding agents in macroaggregates degrade, macroaggregate stability is lost resulting in the release of stable microaggregates (Six et al. 2000b). This causes a transfer of carbon from macro-aggregates into microaggregates upon the breakdown of the macroaggregates (Jastrow 1996, Six et al. 1998, Gale et al. 2000), resulting in raised C values of microaggregates.

The higher C% values examined in the silt and clay size class (53-250 µm) as compared to the other aggregate size classes for both the Embu and Machang’a soils could be caused by the transfer of carbon compounds into this fraction. This is in line with findings by Jastrow (1996) and Kavoo (2008). Their findings indicated that there occurs a direct transfer of some plant compounds into the silt and clay fractions, primarily through breakdown, leaching, communication and selective microbial degradation (Mikutta et al. 2006). Other studies have also shown that the silt and clay fractions can biochemically and chemically protect organic C bound to them, thereby protecting it from microbial putrefaction (Sleutel et al. 2006; Fonte et al. 2007). It has also been reported that the silt and clay fractions have a higher C stabilization capacity compared to other fractions. The stabilization of C by association with silt and clay particles has been found to be one of the ways through which organic C is preserved (Six et al. 2002). A study by Balabane and Plante (2004) hypothesized that silt-size aggregates are sites where physically protected OM can mature and interact with specific adsorption sites on mineral surfaces. Data by Virto et al. (2008) showed that almost half of the total soil organic C was stored in these aggregates. The higher stabilization of C in silt and clay particles could be due to the greater biological activity associated with clay-sized particles which are reflected in the larger content of microbially derived products in clay than in >2 µm separates (Christensen 1992). Clay also maintains the largest concentrations of OM, suggesting that the microbial activity provides more microbial metabolites and residues (including cell wall materials) that become stabilized and accumulate in clay (Hedges and Oades 1997; Kaiser et al. 1998). Stabilization of C in the silt and clay fraction plays an important role in the development of soil carbon as it is one of the main ways to preserve organic C (Six et al. 2002; McLauchan, 2006).

Effect of alteration of soils of various texture and fertility values with fertilizer-N and organic resources on carbon content of distinct SOM fractions

The following section shows the results of carbon contents analysis of SOM fractions [(coarse particulate organic matter (cPOM), microaggregates within macroaggregates (mM) and silt and clay (s+c)]. For the Embu soils, the cPOM fractions had generally higher C% values than the other SOM fractions (Table 11), whereas for the Machang’a soils, the silt and clay fractions had the highest C% values compared to other SOM fractions (Table 12).

In the Embu site, the implementation of fertilizer-N and organic resources into the low fertility of Embu soils gave no remarkable influence ($p<0.05$) on the C% value of cPOM fractions in relation to the control (Table 11). An identical trend was detected for both the medium and high fertility soils. Generally, a prevalent raise in cPOM C% values with the raising of soil fertility was detected in this area. No remarkable influences on cPOM C% values were detected for the implementation of fertilizer-N and organic resources in Machang'a soils. However, as detected in the Embu soils, C% values of cPOM fractions raised by raising soil fertility. Overall, cPOM fractions from the Embu soils ranged between 0.68% and 11.26% and were greater than those from the Machang’a site which ranged between 0.13% and 0.29%.

Regarding microaggregates within macroaggregates fractions, it was detected that for the alterations including low fertility Embu soil (Table 11), only the lone stover management had a remarkable influence ($p<0.05$) on C% values. For the medium-fertility soil, all alterations including fertilizer-N and organic resources had a remarkable influence on C% values of mM fractions in comparison to the control management. For these managements, the influence on C% values of mM fractions was in the order lone fertilizer-N > lone stover > stover plus fertilizer-N > control. Implementation of lone or combined organic and mineral resources in Embu high fertility soils had no remarkable influence on C% values of mM fractions.

For the Machang’a low fertility soils (Table 12) the carbon contents of mM fractions showed that only the lone fertilizer-N management had a remarkable influence on the C% values of mM fractions. Whereas with medium fertility soil, no management had a remarkable influence on C% values of mM fractions about the control. For the management including high fertility soils, only the lone stover management had remarkable on C% values of mM fractions. Overall, the C% values of mM fractions for Embu soils were at greater value than from those of Machang’a soils.

Table 11. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of distinct SOM fractions in Embu soils, Kenya.

	C%								
	cPOM			mM			S&C		
Management	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	1.27	8.25	10.47	1.25	2.01	3.06	2.62	4.18	3.99
Fertilizer N	0.78	5.78	11.26	1.19	3.05	3.18	1.75	4.54	3.85
Stover	0.78	5.62	7.56	2.05	2.92	2.87	3.03	4.64	3.96
Stover + Fert N	0.68	5.59	6.58	1.42	2.85	3.07	2.15	3.57	3.70
SED	1.48	1.48	1.48	0.37*	0.37*	0.37	0.51	0.51	0.51

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically significant at $p<0.05$

Table 12. Effect of alteration of soils of various fertility values with fertilizer-N and organic resources on percentage carbon content of distinct SOM fractions in Machang'a soils, Kenya.

	C%								
	cPOM			mM			S&C		
Managements	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Control	0.21	0.20	0.27	0.50	0.11	0.56	1.01	0.52	1.81
Fertilizer N	0.17	0.21	0.23	0.63	0.17	0.62	1.85	0.64	1.57
Stover	0.15	0.21	0.26	0.14	0.18	1.52	0.55	0.68	1.44
Stover + Fert. N	0.13	0.16	0.29	0.11	0.15	0.45	0.49	0.56	1.23
SED	0.30	0.30	0.30	0.32	0.32	0.32*	0.32*	0.32	0.32

Note: SED = Standard error of difference of means; SED*=Difference between managements is statistically. significant at $p<0.05$

The greater C% value of cPOM fractions for Embu soils in comparison to Machang'a soils showed raised macroaggregates formation for these soils. Studies have shown that macroaggregates form around POM (Six et al. 1998; Olchin et al. 2006). This leads to a rise in cPOM C, as intra aggregate POM is less vulnerable to putrefaction than free POM in the soil matrix (Six et al. 1999; Olchin et al. 2006). This is due in part to the physical and chemical protection provided by aggregates. This is in accordance with the greater proportions of macroaggregates detected for the Embu soils in comparison to the Machang'a ones.

The remarkable influence on C% values of mM fractions detected for the lone stover management in the low and high fertility Embu soils shows a transfer of C from macroaggregates into the mM fraction. This could be due to the putrefaction of organic residues from maize stover input. This has been shown to result in macroaggregate stabilization, which is associated with the formation of microaggregates within macroaggregates resulting in subsequent C transfer (Denef et al. 2002; Jiao et al. 2006). In relation to C isolation, this is significant as microaggregates have a greater capability to protect C than that of macroaggregates.

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