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Changes in Soil Organic Matter as Influenced by Organic Residue Management Regimes in Selected Experiments in Kenya

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Abstract

The failure to understand the dynamics of soil organic matter (SOM) is a major limitation to the sustainability of smallholder production systems that predominantly relied on organic resources for the maintenance of soil fertility. This study evaluated the influence of organic resource management on SOM in three selected experiments in central and western highlands of Kenya. Results showed that soil carbon (C), nitrogen (N) and carbon-13 (^{13}C) values in the three experiments were depending on the amounts of the organic residues applied as well as the duration of application indicating that organic residue management practices have a profound impact on the final contribution to the SOM pools. Kabete experiment had the narrowest C, N and ^{13}C values pointing to its young age as well as the low quantity of the organic residues applied. On the other hand, Embu experiment had soil C values above the critical level of 2.0% indicating a positive effect of continued application of organic residues. In all the three sites, aggregate mineral fraction (MF) size distribution were dominated by macroaggregates (250–500 μm and >500 μm) which on average accounted for about 72%, 65% and 69% of the dry soil weight for Maseno, Kabete and Embu experiments, respectively. Similarly higher proportions of aggregate light fractions (LF) C and N were observed in macroaggregate fractions for the three experiments with organic treatments having higher proportions. The ^{13}C signatures of the LF in the macroaggregates (>250 μm) were more negative as compared to the ^{13}C values in the microaggregate (53–250 μm) LF suggesting a more C contribution from C3 vegetation to the most recently incorporated SOM pool

Key words: Soil organic matter, organic resources, fractionation

Introduction

Soil organic matter (SOM) plays an important role in mitigating major constraints to crop production as well as essential environmental services and hence its decline with cropping is of concern (Vanlauwe, 2004). Studies indicate that soil physical, chemical and biological properties can sustainably be improved through the improvement of SOM (Woomer et al., 1994; Buyanovzky et al., 1994; Parton et al., 1989). Practices such as alley cropping and biomass transfer offer the potential of improving SOM through the cycling of organic matter back to the soil. The major obstacle hindering the efficacy of these strategies is the lack of adequate understanding of the effects of the different organic resource qualities on the nature of the resultant SOM. Soil organic carbon analyses carried out on whole soil (WS) samples do not give a clear impression of the status of the soil since this is obscured by the high background carbon levels (Blair et al., 1995). This therefore calls for the need to explore the SOM fractions. Considering that information on the active pools of the SOM is still scanty, it is difficult to optimize decisions on the use of the qualities of SOM that contribute to higher nutrient recovery. This study therefore sought to increase understanding of the

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effects of organic resources on the nature of the SOM formed and to identify the roles played by the various components of SOM in nutrient supply as well as other soil properties.

Materials and methods

This study was conducted in three experimental sites run by Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT) and Kenya Agricultural Research Institute (KARI):

1) **Kabete experiment** is located in Central Kenya at the National Agriculture Research Laboratory (NARL) which lies at 36° 46' E and 01° 15' S and an altitude of 1650 m (Kimetu, 2002). The site is located in the semi-humid climatic zone with a total bimodal rainfall of over 970 mm per annum. The soils are derived from quartz trachyte geological material, and are typical Humic Nitosols inherently fertile, with moderate amounts of organic carbon, Ca, Mg, K but low in available P, clay 40%, sand 23% and silt 37%. The experiment was established in 1999 and involved seasonal application of Tithonia diversifolia, Calliandra calothyrsus, and Senna spectabilis at the rates of 1.3, 1.8 and 1.9 t ha^{-1} respectively.
2) **Maseno experiment,** located on Msinde Farm in western Kenya was established in 1995 as a Randomized Complete Block Design (RCBD) with four replicates (Nziguheba et al., 2000). The site is located at an altitude of 1420 m, a latitude of 0° 06′ N and a longitude of 34° 34′ E. The mean annual rainfall is 1800 mm distributed between two rainy seasons: the long rainy season from March to August and the short rainy season from September to January. The soil is a nitosol (FAO, 1990) with 42% clay, 25% silt and 33% sand. Msinde farm had been under mixed native vegetation involving grasses and shrubs. The experiment involved application of Calliandra calothyrsus, Tithonia diversifolia and Senna spectabilis organic resources at the rate of 5 t ha^{-1} for 6 consecutive seasons (Short rains 1995 – Long rains 1999) after which the experiment had been under residual phase.
3) **Embu experiment** is situated in eastern Kenya, Central highlands at the Embu Regional Research Centre in Eastern Kenya (Mugendi et al., 1999). The centre lies at 0° 30′ S, 37° 30′ E and an altitude of 1480 m. The soils are mainly Typic Palehumult (Humic Nitosols according to FAO-UNESCO) derived from basic volcanic rocks. The soils are deep, well weathered with friable clay texture and moderate to high inherent fertility. The site has clay, silt and sand contents of 38%, 30% and 32%, respectively. Total annual average rainfall ranges between 1200 mm and 1500 mm received in two distinct rainy seasons: the long rain (LR) from mid March to June and the short rains (SR) from October to December. The average monthly maximum temperature is 25° C and the minimum 14° C. The experiment was established in 1992 and involved application of Calliandra calothyrsus and Leucaena leucocephala organic resources at the rate of about 2.3 t ha^{-1}.

The choice of these three experiments was based on the different rates of organic resources applied, the experiment lifespan as well as their unique ecological locations that characterize most smallholder farming areas in Kenya.

Table 1 presents the quality parameters of the organic resources applied in Kabete, Maseno and Embu experiments. Calliandra, with the highest polyphenol content,

Table 1. Chemical properties for the organic materials used in Kabete, Maseno and Embu experiment

Experiment	Organic Resource	% N	% P	% PP	% Lignin
Kabete	Tithonia	4.35	0.45	2.2	7.25
	Senna	3.4	0.15	2.6	10.8
	Calliandra	2.7	0.1	7.65	15.95
Maseno	Tithonia	3.66	0.28	3.71	12.0
	Senna	3.61	0.23	2.17	13.2
	Calliandra	3.5	0.16	7.91	12.1
Embu	Calliandra	3.95	–	11.75	11.6
	Leucaena	3.95	–	3.3	6.85

PP – Polyphenol, P – Phosphorus, N – Nitrogen (Source: Mugendi et al., 1999a; Kimetu, 2002 and Nziguheba, 2001).

was considered as of lower quality compared to the other organic resources. Senna was intermediate while tithonia and leucaena were of the highest quality due to their high nitrogen contents but relatively lower lignin and polyphenol contents. Preliminary carbon-13 (^{13}C) values on the organic resources showed senna to have a delta ^{13}C of −24.17‰, calliandra −21.62‰ and tithonia −22.40‰.

Soil sampling and analysis

Soil samples were collected from the selected experiments before the onset of the long rains (LR) 2002. Soil was collected from the 0–10 cm layer, as this is where most impact of added organic matter is felt. A proportion of the soil samples was finely ground (pulverized) using a pestle and mortar and analyzed for total carbon (C), nitrogen (N) and carbon 13 (^{13}C) on an automated nitrogen and carbon (ANCA) mass spectrometer (Diels et al., 2001). Carbon isotope composition was expressed in delta-13 (^{13}C) units using the international Pee De Belemnite (PDB) reference standard:

$$\delta^{13}C‰ = [^{13}R_{\text{sample}} - 1] \times 1000^{13}R_{\text{standard}}$$

Where: $^{13}R = ^{13}C^{12}C$

SOM fractionation was done following a modification to the method of Six et al. (2000). Soil fractionation was done on a sample of 100 g dry weight. Prior to fractionation the soil was capillary wetted overnight for 18 hours at 4° C. The soil was then sieved through a series of four sieves (500 μm, 250 μm, 53 μm and 20 μm). To ensure minimal aggregate disruption the sample was submerged in water on top of each successive sieve and the aggregates separated by moving the sieve in a bucket of water up and down 3 cm for about 2 minutes. After the washing the stable aggregates were then washed into a moisture beaker. As observed by Sollins et al. (1984) studies of SOM require distinguishing mineral-associated from free particulate organic matter. Most free SOM is usually undecomposed debris that floats on heavy liquids and is referred to as light fraction (LF). As such LF from each aggregate class was separated by gently swirling the aggregates to suspend and decanting any material floating on water. Silt and clay were separated at room temperature (25°C) following the sedimentation process. Silt and clay were isolated from the <20 μm aggregate fraction following the aliquot method. In brief, the total soil plus water passing through the 20 μm sieve was weighed, thoroughly mixed and a subsample (1:5) collected for subsequent sedimentation cycle. The subsample collected was placed in a 1 litre-measuring cylinder and made to the mark with water. The aliquot was then mixed by tumble inverting the cylinder 20 times and left to settle for 2 h 10 min. The top 20 cm fraction was then siphoned from the top. This represented the clay fraction (0–5 μm). Material that settled after this time is considered to be silt (5–20 μm). The siphoning process was repeated (at least 4 times) until the water in the cylinder became clear, an indication that the entire clay fraction had been removed. The two fractions were then flocculated using hydrochloric acid (HCl) dried and weighed prior to C and N analysis. The aggregates plus the LF were then oven dried at between 55° and 60° C, weighed and analysed for C, N and ^{13}C.

Whole soil and SOM fractions C, N and ^{13}C were analyzed using an automated carbon, nitrogen mass spectrometer (ANC analyzer) and the eventual proportions expressed on soil weight basis. Data was subjected to analysis of variance (ANOVA) and means separated at $P \leq 5\%$.

Results

Whole soil total carbon, nitrogen and carbon-13 in Kabete, Maseno and Embu experiments

Kabete experiment had the narrowest contents of C, N and carbon-13 contents compared to Maseno and Embu experiments (Table 2). This could be attributed to the short period of organic residue application in Kabete experiment compared to the other experiments. Despite this, all treatments receiving organic residues had higher C and N content compared to fertilizer and the control treatments. Soil carbon-13 signature for the whole soil (WS) from Kabete was not significantly different and indicated a delta ^{13}C signature closer to that of C4 vegetation. Values ranged from −11.92% to −12.18% (Table 2). These signatures tended to be closer to the C4 ^{13}C signature of maize residues of about −12.00% (Schwartz et al., 1986). This indicates that despite the application of the C3 organic resources (calliandra, senna and tithonia) in this experiment, a minimal shift in the WS carbon-13 had occurred. Reasons for the narrow ranges of C, N and ^{13}C in Kabete may be the rapid mineralization of the organic residues due to increased aeration as a result of tillage, higher soil temperatures leading to

Table 2. Whole soil total carbon, nitrogen and carbon-13 of Kabete, Embu and Maseno experiments as at March 2002

Experiment	Treatment	% C	%N	^{13}C (PDB)
Kabete	Control	1.81	0.14	−11.92
	Fertilizer	1.78	0.14	−11.96
	Tithonia	1.84	0.14	−12.18
	Senna	1.86	0.14	−11.95
	Calliandra	1.81	0.14	−12.15
	SED	**0.044**	**0.002**	**0.275**
Embu	Control	2.35	0.19	−15.65
	Fertilizer	2.47	0.20	−16.07
	Calliandra	2.48	0.21	−16.69
	Leucaena	2.52	0.21	−16.32
	SED	**0.132**	**0.009**	**0.250**
Maseno	Control	1.59	0.14	−17.46
	Tithonia	1.80	0.15	−17.82
	Calliandra	1.83	0.16	−18.09
	Senna	1.86	0.16	−18.10
	SED	**0.047**	**0.004**	**0.173**

higher decomposition rates, smaller quantities of litter inputs and the shorter duration of organic residue application in this experiment (Nandwa, 2001). The delta carbon-13 (δ^{13}C) of SOM is comparable to that of the source plant material (Schwartz et al., 1986) and thus every change in vegetation between C3 and C4 plants or the application of organic residues to the soil as organic manure result in a corresponding change in the δ^{13}C value of the SOM (Lefroy et al., 1995). As observed by Paustian et al. (2000) gains in soil C can be enhanced if proper management is maintained and that increases in soil C stocks require increasing C inputs and/or reducing soil heterotrophic respiration.

Total C values for Embu treatments were higher than the recommended critical value for soil carbon of 2.0% (Table 2) for Kenya as reported by FURP (1987). Such a favourable SOC content in Embu experiment could be attributed to the continued application of the organic resources to the soil. Leucaena treatment had soil C content of 2.52% while calliandra, fertilizer and the control had C content of 2.48%, 2.47% and 2.35% respectively. Higher soil carbon content in the calliandra treatment could be due to the low decomposition as explained by its higher polyphenol and lignin contents (Palm and Sanchez, 1990; Mafongoya et al., 1998). Soil total N in Embu treatments was significantly different and was of the order leucaena = calliandra = fertilizer > control. As with the soil carbon, continued mineralization of leucaena and calliandra organic residues may have resulted in the build up of soil organic matter N pool. Whole soil carbon-13 values were significantly different for the treatments in Embu experiment. This was as a result of the less negative δ^{13}C signature observed in the control (–15.65‰) treatment as compared to the highest δ^{13}C of –16.07‰ observed in the calliandra treatment. The great shift observed in the ^{13}C signature between the treatments receiving organic residues and the control indicate a greater contribution to the soil C from the continued application of the leucaena and calliandra residues. This study did not consider the contribution to the ^{13}C signatures of weeds. As observed by Ong et al. (1996), C4-weeds tend to lose their competitive advantage in terms of higher light–use efficiency at light saturation as shading by a growing maize crop increases. Weeds can significantly result in an input of carbon-13 into the cropping system Diels et al. (2001).

Whole soil (WS) total carbon for Maseno experiment was significantly different ($P \leq 0.05$) among the treatments (Table 2) and was of the order senna = calliandra = tithonia > control. Senna treatment recorded WS C content of 1.86%, calliandra 1.83%, tithonia 1.80%, while the control recorded WSC content of 1.59%. The high C contents in senna and calliandra treatments compared to the tithonia treatment could be attributed to the lower quality of these two organic resources, which results in lower rates of mineralization leading to C build-up. As with C, total N across the treatments was significantly different ($P = 0.05$) and was highest in all treatments receiving organic resources compared to the control treatment (Table 2). This indicates that application of organic resources can help increase the soil N contents. Further lower quality organic resources such as calliandra and senna will result in larger build up of soil N pools as compared to high quality resources such as tithonia (Gachengo et al., 1999). Carbon-13 signature for Maseno was more negative compared to Embu and Kabete experiments indicating a greater shift in the type of soil C towards a C3 signature contributed by the application of C3 organic materials (senna, tithonia and calliandra). Further, the greater C3 labelling observed here could be due to the larger quantities of the organic residues applied (5 t dry matter per season) and the stabilization of the decomposing organic residues applied in Maseno experiment.

Soil organic matter fractionation

Aggregate mineral fraction

Aggregate MF proportions for Maseno were not significantly different for aggregate classes >500 μm, 20–53 μm, silt and clay classes (Table 3). For the 250–500 μm fraction, calliandra had the highest aggregate MF proportion (21.10%) followed by tithonia (19.69%) then the control (17.58%). In Kabete experiment, significant differences in aggregate MF was observed in the silt fraction, where aggregate MF proportions were in the order tithonia > calliandra = control (Table 3). There was no significant difference among the treatments in Embu experiment across all aggregate size classes (Table 3). This may be explained by the relatively high and uniform soil carbon contents in both the organic and the control treatments.

Despite the above observations, there were higher proportions of macroaggregates across the three sites. Large proportions of macroaggregates imply an elevated soil C concentrations resulting from the binding effects from fungal mycelia (Elliott, 1986). The well defined aggregate proportion in Maseno experiment could be attributed to improved SOM resulting from the large application of organic residues (OR). Kabete soils indicated a substantial decrease in small macroaggregates (250–500 μm) concomitant with an increase in microaggregate MF. As observed by Six et al. (2000) and Paustian et al. (1997), increasing cultivation intensity could lead to a loss in macroaggregates and an increase in microaggregates, silt and clay contents.

Proportions of aggregate free light fraction

Higher aggregate light fractions (LF) were observed in macroaggregate fractions of Maseno experiment with calliandra treatment having the highest proportions followed by tithonia and the control (Table 4). There was significant difference in the >500 μm fraction where the proportion of the LF in the calliandra treatment was 0.059 g/100 g soil while that of tithonia and the control were 0.050 and 0.036 g/100 g soil respectively. Higher LF in calliandra treatment could be attributed to slow decomposition which results in the persistence of calliandra residues in the soil. There was a generally higher microaggregate LF

Table 3. Proportion of aggregate mineral fraction for Kabete, Embu and Maseno experiments

	>500 μm	250–500 μm	53–250 μm	20–53 μm	Silt	Clay
Kabete Experiment						
Calliandra	32.72	20.53	23.40	4.70	2.74	1.29
Control	35.29	18.58	21.98	4.22	2.68	1.08
Tithonia	29.32	19.99	26.29	5.23	3.36	1.50
SED	**4.06**	**1.088**	**2.85**	**0.448**	**0.206**	**0.1577**
Embu Experiment						
Calliandra	32.82	23.59	24.62	2.61	1.54	0.68
Control	34.95	22.14	24.21	2.42	1.46	0.59
Leucaena	37.17	21.72	22.78	2.32	1.43	0.62
SED	**3.810**	**1.578**	**3.210**	**0.508**	**0.269**	**0.0964**
Maseno Experiment						
Calliandra	28.38	21.10	15.13	2.70	1.55	0.82
Control	31.27	17.58	12.97	2.32	1.17	0.59
Tithonia	28.99	19.69	14.87	2.59	1.48	0.73
SED	**2.123**	**0.518**	**0.77**	**0.264**	**0.1263**	**0.1051**

Table 4. Proportion of aggregate light fraction for Kabete, Embu and Maseno experiments

Treatment	>500 μm	250–500 μm	53–250 μm
Kabete Experiment			
Calliandra	0.08	0.05	0.06
Control	0.07	0.03	0.05
Tithonia	0.052	0.04	0.07
SED	**0.015**	**0.008**	**0.013**
Embu Experiment			
Calliandra	0.29	0.08	0.11
Control	0.16	0.05	0.07
Leucaena	0.19	0.06	0.07
SED	**0.054**	**0.009**	**0.029**
Maseno Experiment			
Calliandra	0.06	0.04	0.04
Control	0.04	0.03	0.04
Tithonia	0.05	0.03	0.04
SED	**0.005**	**0.004**	**0.005**

compared to the small macroaggregate (250–500 μm) fractions. This is an indication of increased mineralization of organics from the large macroaggregate LF to the microaggregate fraction. In Kabete, there was no significant difference in the three aggregate LFs although there was a build up in the microaggregate (53–250 μm) LF relative to the small macroaggregate (250–500 μm). LFs were highest in calliandra followed by control and lastly tithonia (Table 4). In Embu experiment, calliandra had the highest LF proportions in the 250–500 μm class with a recorded LF proportion of 0.085 g/100 g soil compared to tithonia with 0.057 and the control with 0.052 g/100 g soil (Table 4).

Of the three experiments, Embu experiment had higher aggregate LF proportions thus indicating the beneficial effects of continued organic residue application in this experiment. Further, the difference in the free light fraction across the sites indicates that the quantity of free light fraction in any soil is mostly affected by differences in residue management regimes (Paustian et al., 1997). As observed by Six et al. (1999) coarse free LF is probably less chemically recalcitrant than the fine free LF (53–250 μm) due to the less advanced stage of decomposition of the coarse free LF. The LF consists of recognizable plant debris with high C:N ratio and low specific weight, and is easily decomposable (Christensen, 1992). Further, the C:N ratio in the LF generally decreases with the decreasing particle size separates indicating an increasing degree of humification. It further implies that this macro-organic matter is much more susceptible to mineralization, and contributes significantly to the soil available nutrient pool (Tiessen and Stewart, 1983). Decreased LF in Maseno that was under residual at the time of sampling need for continued application of organic residues to sustain the losses in organic matter resulting from increased oxidation as a result of cultivation.

Aggregate mineral fraction carbon and nitrogen in Kabete Experiment

The aggregate MF total organic carbon (TOC) in Kabete was dominant in the macroaggregates compared to the micro-aggregates (Figure 1). TOC averaged 11.12 g kg^{-1} soil in the macroaggregates soil and 4.93 g kg^{-1} soil in the microaggregate fractions. Significant differences in the aggregate MF C were only observed in the silt fraction where tithonia recorded a C content of 0.79 g C kg^{-1} soil followed by the control (0.61 g C kg^{-1} soil) and calliandra (0.57 g C kg^{-1} soil). As the case with aggregate C, significant differences in aggregate MF N were only observed in the silt fraction where tithonia recorded aggregate N content of 0.06 g N kg^{-1} soil followed by the control (0.05 g N kg^{-1} soil) and calliandra (0.04 g N kg^{-1} soil) treatment (Figure 2). The bulk of the aggregate MF N was observed in the macroaggregates (>250 μm) in the three treatments. This is an indication that most of the readily available

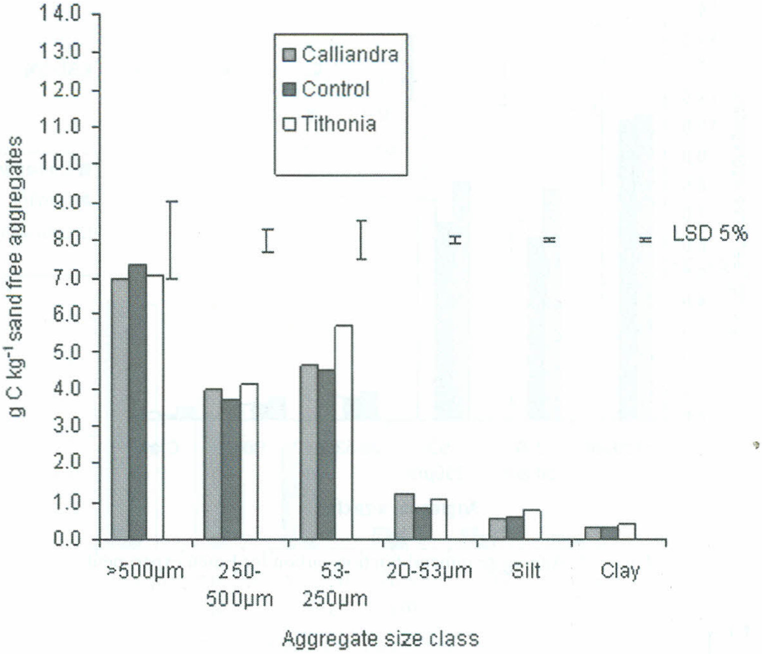

Figure 1. Aggregate mineral fraction carbon for Kabete experiment.

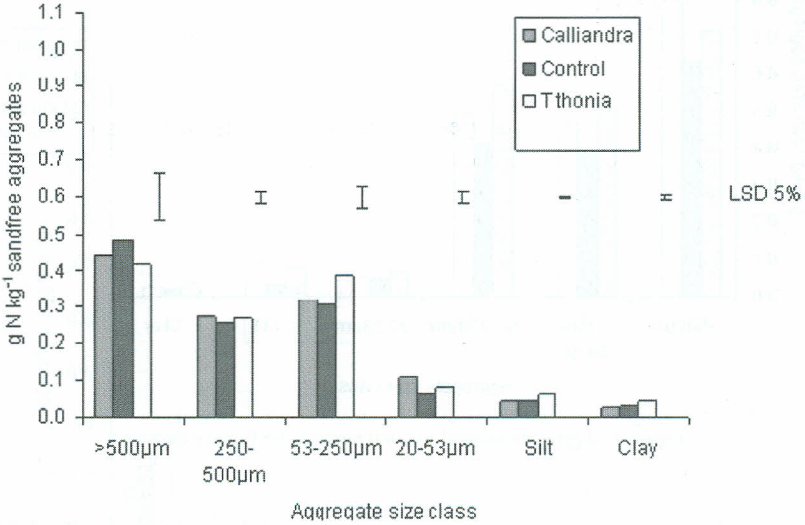

Figure 2. Aggregate mineral fraction nitrogen for Kabete experiment.

SOM-N is stored in the recently incorporated organic residues that have a faster turnover rate. Lower N in the >500 µm fraction for tithonia was compensated by a higher total organic nitrogen (TON) in the 53–250 µm fraction indicating that decomposition of tithonia was faster and tended to shift towards the finer aggregate classes.

Aggregate mineral fraction carbon and nitrogen in Embu Experiment

There were no significant differences in the aggregate MF C and N for the treatments in Embu experiment (Figures 3, 4). However as with the Kabete experiment, most of the aggregate MF C and N was dominant

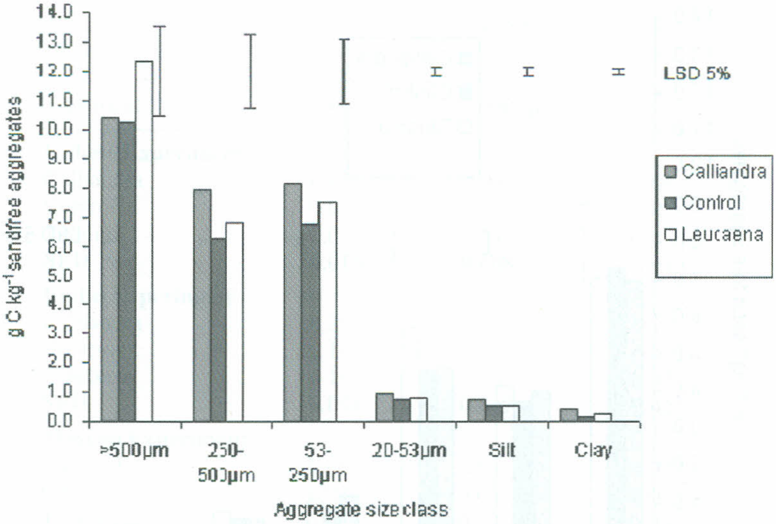

Figure 3. Aggregate mineral fraction carbon for Embu experiment.

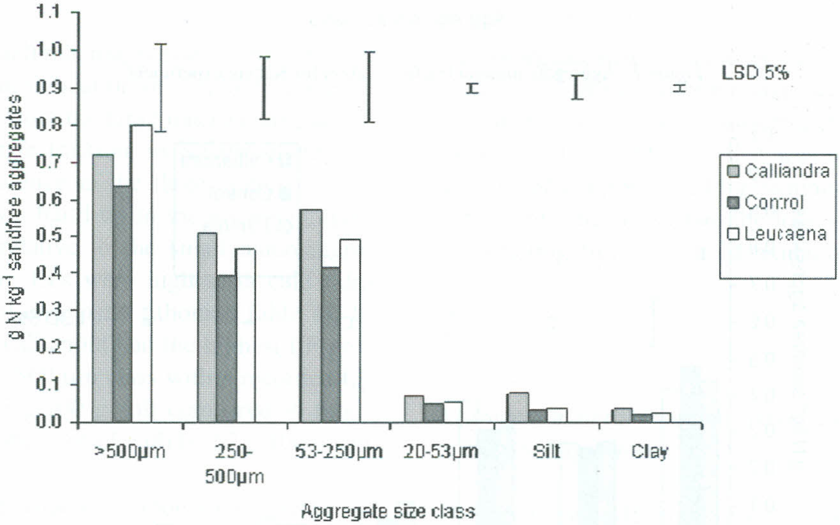

Figure 4. Aggregate mineral fraction nitrogen for Embu experiment.

in the macroaggregates relative to the microaggregate fractions.

Aggregate mineral fraction carbon and nitrogen in Maseno Experiment

Figure 5 indicates aggregate MF carbon for Maseno experiment. There was significant difference in the aggregate MF C of the 250–500 µm, 53–250 µm and silt aggregate size classes. In the 250–500 µm class calliandra recorded the highest C content of 3.97 g C kg^{-1} soil and was followed by tithonia (3.73 g C kg^{-1} soil) then the control (2.99 g C kg^{-1} soil). A similar trend was observed in the 53–250 µm and the silt where the order was calliandra > tithonia > control. The persistence of the calliandra derived organic residues could be attributed to its higher polyphenol and lignin contents compared to tithonia which has lower polyphenol and lignin contents. There was a general decrease in the amount of carbon across all the aggregate size classes suggesting a stabilization of the SOM with continued mineralization without addition of external organic residues. Soil aggregate nitrogen was more

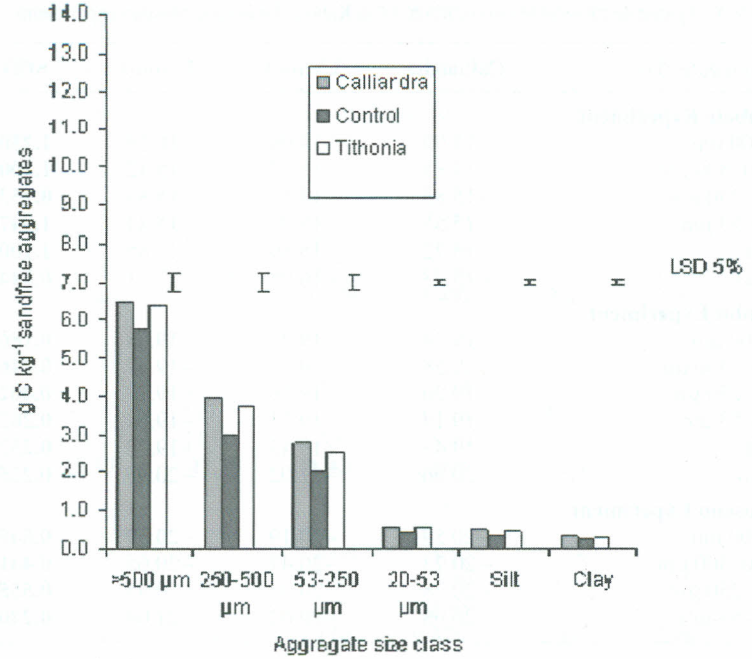

Figure 5. Aggregate mineral fraction carbon for Maseno experiment.

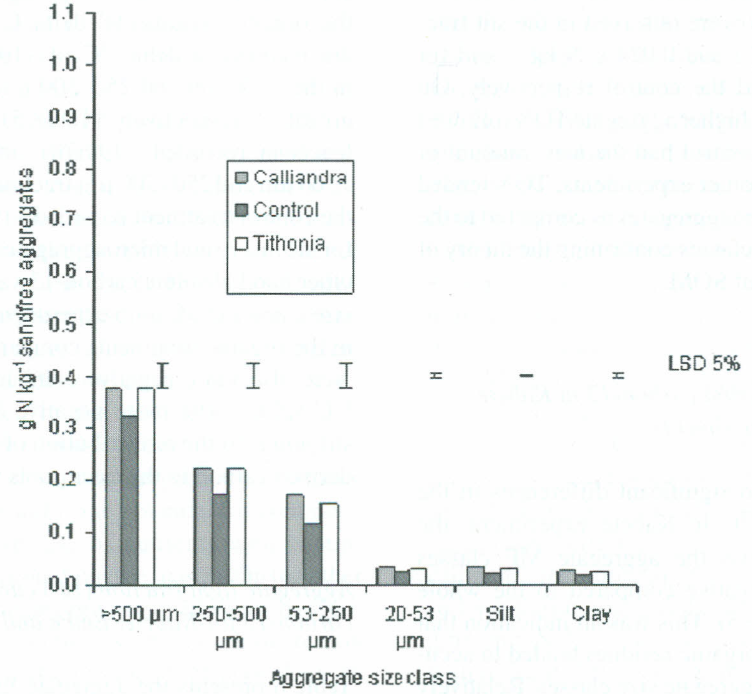

Figure 6. Aggregate mineral fraction nitrogen for Maseno experiment.

Table 5. Aggregate mineral fraction carbon-13 in Kabete, Embu and Maseno experiments

Aggregate class	Calliandra	Control	Tithonia	SED
Kabete Experiment				
>500 µm	−15.90	−14.98	−16.29	**1.250**
250–500 µm	−14.85	−15.12	−15.42	**1.200**
53–250 µm	−15.83	−15.42	−15.83	**0.753**
20–53 µm	−15.55	−15.05	−15.44	**1.047**
Silt	−15.72	−15.59	−15.85	**1.100**
Clay	−15.93	−16.98	−17.31	**0.744**
Embu Experiment				
>500 µm	−19.34	−19.23	−19.68	**0.186**
250–500 µm	−19.58	−19.13	−19.47	**0.246**
53–250 µm	−19.26	−19.16	−19.77	**0.402**
20–53 µm	−19.14	−19.33	−19.64	**0.262**
Silt	−19.43	−19.43	−19.72	**0.252**
Clay	−20.96	−21.02	−20.93	**0.225**
Maseno Experiment				
>500 µm	−20.59	−20.19	−20.59	**0.545**
250–500 µm	−20.73	−20.47	−20.65	**0.441**
53–250 µm	−20.78	−20.93	−20.95	**0.555**
20–53 µm	−20.98	−20.62	−21.04	**0.240**

defined in Maseno experiment compared to Embu and Kabete experiments (Figure 6). Significant differences in the aggregate MF N were observed in the silt fraction where 0.036, 0.033 and 0.024 g N kg^{-1} soil for calliandra, tithonia and the control respectively. On average, calliandra had higher aggregate TON followed by tithonia while the control had the least amount of N. As observed in the other experiments, TON tended to dominate in the macroaggregates as compared to the smaller aggregate size classes confirming the theory of hierarchy distribution of SOM.

Aggregate mineral fraction carbon-13 in Kabete, Embu and Maseno Experiments

Despite there being no significant differences in the aggregate MF delta ^{13}C in Kabete experiment, the carbon-13 values across the aggregate MF classes tended to be more negative compared to the whole soil δ^{13}C values (Table 5). This was an indication that recently incorporated organic residues tended to accumulate in the various aggregate size classes. Relatively less negative δ^{13}C values in the control compared to the organic treatments indicates a lesser labelling effect of the SOM pools in the control treatment. With increased organic matter mineralization, the organic C tends to be distributed to the finer aggregate classes hence the more negative delta values in the clay and silt fractions. In Embu there was no significant difference in the organic treatments' delta C signatures. Calliandra recorded a delta ^{13}C of −19.34‰ and −19.58‰ in the >500 µm and 250–500 µm fractions (macroaggregates), respectively (Table 5). On the other hand, leucaena recorded −19.67‰ and −19.47‰ for the >500 µm and 250–500 µm fractions, respectively while the control treatment recorded −19.23‰ and −19.13‰ for the macro and microaggregates, respectively. On the other hand absolute carbon-13 values in the aggregate size classes in Maseno experiment were more negative in the organic treatments compared to the control and were also more negative compared to the whole soil ^{13}C values. The more negative δ^{13}C in the clay and silt points to the redistribution of the older organically derived carbon to the finer pools where it is fixed.

Aggregate light fraction (LF) carbon, nitrogen and carbon-13 for Kabete, Embu and Maseno experiments

Table 6 presents the aggregate light fraction TOC for Kabete, Embu and Maseno experiments. There were only slight differences in the aggregate LF C in aggregate classes 250–500 µm and 53–250 µm. On the other hand aggregate LF N was not significantly different for the three classes. The delta carbon-13 signatures

Table 6. Aggregate light fraction total carbon, nitrogen and carbon-13 in Kabete, Embu and Maseno experiments

Treatment	Total Carbon (mg kg^{-1} soil)			Total Nitrogen (mg kg^{-1} soil)			*Delta* ^{13}*C (‰)*		
	>500 μm	250–500 μm	53–250 μm	>500 μm	250–500 μm	53–250 μm	>500 μm	250–500 μm	53–250 μm
Kabete Experiment									
Calliandra	252.0	112.3	117.0	12.59	6.94	12.80	−25.23	−19.66	−18.28
Tithonia	143.0	93.9	144.2	6.98	5.59	10.47	−17.70	−17.36	−18.85
Control	204.0	60.6	96.1	9.71	3.30	6.35	−15.21	−16.33	−17.27
SED	**42.00**	**16.46**	**14.20**	**1.975**	**1.492**	**2.417**	**2.305**	**1.150**	**0.316**
Embu Experiment									
Calliandra	774.0	202.6	230.0	50.1	15.58	18.9	−22.78	−21.46	−20.32
Leucaena	350.0	119.5	117.0	29.7	10.14	10.1	−21.28	−19.85	−19.42
Control	333.0	104.5	115.0	22.1	8.09	10.0	−20.35	−19.29	−19.12
SED	**101.00**	**15.59**	**49.70**	**11.43**	**1.680**	**4.28**	**1.302**	**0.422**	**0.546**
Maseno Experiment									
Calliandra	115.8	88.3	117.0	8.08	5.52	12.80	−22.40	−18.46	−18.28
Tithonia	118.0	77.9	144.2	7.91	4.39	10.47	−16.90	−17.20	−18.85
Control	94.3	72.5	96.1	4.72	3.68	6.35	−17.10	−16.71	−17.27
SED	**21.72**	**7.46**	**14.20**	**1.170**	**0.376**	**2.417**	**2.46**	**0.661**	**0.316**

of the LF in this experiment indicated that calliandra treatments had more of its residues persisting in the soil long after the cropping season. This was evident from the more negative δ^{13}C of the >500 μm (-25.23‰), 250–500 μm (-19.66‰) and 53–250 μm (-18.09‰) (Table 6). Tithonia treatments tended to have its LF signatures closer to that of the control; an indication that being of higher quality, most of the tithonia decomposed during the cropping season and hence little persisted in the soil as LF. In Embu experiment, calliandra had the highest TOC in the all the aggregate size classes and these were significantly different for the >500 μm and 250–500 μm fraction (Table 6). This is best explained by the persistence of the calliandra due to its lower quality residues (Palm et al., 2001). One benefit of such large particulate organic matter (POM) in the soil is the potential for continued mineralization and release of nutrients with continued decomposition throughout the season. On the other hand rapidly decomposing organic residues such as leucaena will persist less in the soil and hence the reason for their lower contribution to the POM pool. As with the C in the LF, TON was also higher in calliandra treatment compared to the leucaena and control treatments (Table 6). Light fraction N was significantly different ($P<0.05$) for the 250–500 μm fraction and was of the order calliandra > leucaena > control.

The carbon-13 signature of the LF were significantly different for the 250–500 μm LF with calliandra recording a delta carbon value of –21.46‰ and was followed by leucaena then the control with delta ^{13}C of –19.85‰ and –19.29‰ respectively (Table 6). The above results point out that calliandra contributed more to the SOM pool compared to leucaena and the control. In general, aggregate LFC and N contents were higher in Embu experiment compared to Kabete experiment and this may be attributed to the longer-term application of organic residues which resulted in the accumulation of organic residues in the soil.

In Maseno experiment aggregate LF C was significant for the aggregate class 53–250 μm where tithonia recorded LF C content of 144 mg kg^{-1} and was followed by calliandra (117 mg kg^{-1}) and the control (96.1 mg kg^{-1}) (Table 6). Aggregate LF N was significantly different for the 250–500 μm class with calliandra recording an N content of 5.52 mg N kg^{-1} soil while tithonia and the control recorded 4.39 and 3.68 mg N kg^{-1} soil respectively. There was also a significant difference in the ^{13}C signatures for the 53–250 μm LF class with tithonia having the highest delta ^{13}C followed by calliandra then the control. In general Embu experiment had more aggregate LF C and N followed by Kabete then Maseno experiment.

Conclusion

The results of this study indicated that SOM tended to vary with organic residue management practices. Secondly, favourable soil C and N can be managed by continued application of organic residues as evident in the Embu experiment. The results also indicated that the ^{13}C signature can be used to evaluate the contribution of the organic residue applied on the whole soil C. By assessing the shifts in the $\delta^{13}C$ signature between treatments receiving organic residues and the control, predictions can be made on the contribution of the organics to the SOM pools. Complimenting $\delta^{13}C$ method with SOM fractionation methods can enhance the use of this technique in SOM studies. Soil organic matter fractionation revealed large differences in the SOM mineral and light fractions, a testimony that management regimes of different organic residues will contribute differently to the SOM pools.

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