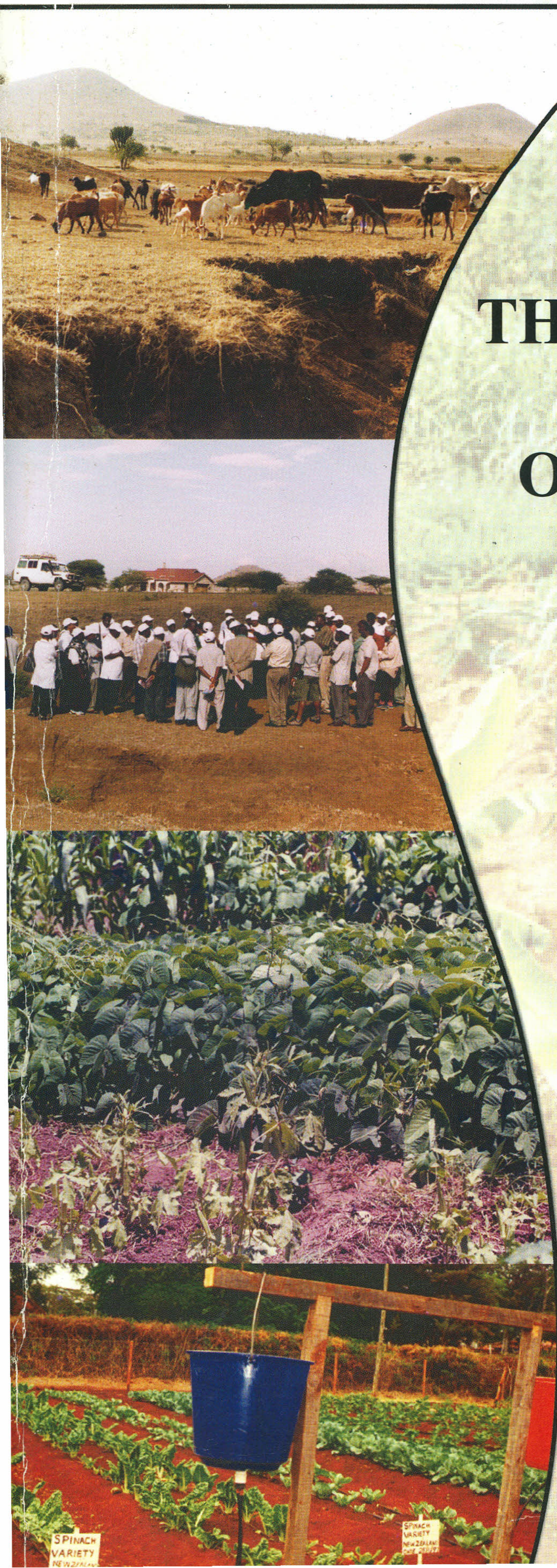

THE SOIL SCIENCE SOCIETY OF EAST AFRICA

PROCEEDINGS OF THE 21ST ANNUAL CONFERENCE
1st – 5th December, 2003,
Eldoret, Kenya

THEME:
Capacity Building for Land Resource Management to Meet the Challenges of Food Security in Africa

Editors:
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ORGANIC RESIDUE EFFECTS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES IN KENYA

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ABSTRACT

This study was designed to evaluate the influence of organic resource management on selected soil chemical properties in central and western highlands of Kenya. Three ongoing experiments (Kabete, Maseno and Embu) involving the integration of organic and inorganic resources as nutrient sources were selected. The choice of these experiments was based on the different organic resources applied, their lifespan as well as their unique ecological locations that characterize most smallholder farming areas in Kenya. These experiments involved the application of *Tithonia diversifolia*, *Senna spectabilis, Leucaena leucocephala* and *Calliandra calothyrsus* as organic nutrient sources to a maize crop which were compared to fertilizer and control treatments. Soils were sampled from these experiments and analysed for inorganic nitrogen, total carbon, nitrogen, bulk density and potassium permanganate oxidizable carbon. In addition, SOM aggregate and size fractionation was used to determine the quantity of the various SOM fractions formed. Soil C, N and ^{13}C and $KMnO_4$-C values in the three experiments varied among sites depending on the amounts of the organic residues applied as well as the duration for application indicating that organic residue management practices indicating that organics have a profound impact on the final SOM pools. Kabete experiment had the narrowest C, N and ^{13}C values pointing to the young age of this experiment 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 the effect of continued application of organic residues. Using the ^{13}C labelling technique revealed greater shifts in C signatures to a C3 carbon type between the organic and the control treatments in Embu and Maseno experiments which indicated greater labelling effect from the organic residues applied.

Key words: Soil organic matter, soil fertility

INTRODUCTION

The fertility of any soil is central to the sustainability of both natural and managed ecosystems because it is the medium from which terrestrial production emanates (Scholes et al., 1994). Soil organic matter (SOM) plays an important role in maintaining soil structure, water-holding capacity, the microbial biomass and soil fauna, and in nutrient cycling. The decline of SOM with cropping is a major factor affecting sustainability of cropping systems (Buyanovzky et al., 1994). Nutrient have gradually been depleted by crop harvest removals, leaching and soil erosion to the extent to which soil fertility replenishment has been recommended as a necessary investment in natural resource capital (Izac, 1997). Studies indicate that soil physical, chemical and biological properties can sustainably be improved through the improvement of SOM (Paul, 1984). Practices such as alley cropping and biomass transfer offer the potential of doing this through the cycling of organic matter back to the soil. The major obstacle hindering the efficacy of using organic residues is the lack of adequate understanding on the effects of the different organic resource qualities on the nature of the resultant SOM and soil properties. The objective of the study was therefore to evaluate changes in selected soil physical and chemical properties as influenced by organic residue management in selected experiments in Kenya.

MATERIALS AND METHODS

Site description

Kabete experiment (Nitrogen management - N1 Kabete experiment) located at the National Agriculture Research Laboratory (NARL) Kabete Kenya was established in 1999 as a randomized complete block design (RCBD) with ten treatments replicated four times (Kimetu, 2002). The mean annual rainfall is 1800 mm distributed into two rainy seasons: the long rainy season from March to August and the short rainy season from September to January. The soil is a nitisol (FAO, 1990) with 42% clay, 25% silt and 33% sand. This study considered only five of the ten treatments: *Tithonia diversifolia* (tithonia), *Calliandra calothyrsus* (calliandra) and *Senna spectabilis* (senna), fertilizer and the control. The soils are mainly nitisols and the area receives about 970 mm rainfall annually. Both the organic and inorganic N sources were applied at a rate to supply 60 kg N ha^{-1}. The organic residues were applied at the rate of 1.3, 1.8 and 1.9 Mg ha^{-1} on dry matter basis for tithonia, senna and calliandra respectively.

Maseno experiment (Phosphorus Management - PM1 Maseno experiment) was established in the highlands of western Kenya, on Msinde farm in Vihiga District in 1995 as a randomized complete block design (RCBD) with four replicates and 7 by 7.5 m plot sizes (Nziguheba et al., 2000). The mean annual rainfall is 1800 mm distributed into two rainy seasons: the long rainy season from March to August and the short rainy season from September to January. The soil is a nitisol (FAO, 1990) with 42% clay, 25% silt and 33% sand. This study considered the control and three (calliandra, senna and tithonia) out of the original six organic residue treatments. Each season, fresh leaves of each of the organic materials were broadcast and incorporated by hand hoes into the top 0.15 m, at 5 Mg ha^{-1} on dry matter basis, for 6 consecutive maize growing seasons that is the short rains 1995 to long rains 1998 (SR95-LR98), two per season. After this, organic residue application was terminated and the experiment left under residual effect.

The Embu experiment (Hedgerow Intercropping – HI Embu experiment) was located at the Embu Regional Research Centre (RRC), Eastern Province, Kenya (Mugendi et al., 2000). 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 soils are mainly Typic Palehumult (Humic Nitisols according to FAO-UNESCO) derived from basic volcanic rocks. The site has clay content of 38%, 30% silt and 32% sand contents. The experiment was set up in 1992 to evaluate the influence of soil-incorporated leaf biomass of agroforestry trees on soil fertility and maize yield. Only four (*Calliandra calothyrsus*, *Leucaena leucocephala*, fertilizer and control) out of the ten treatments were considered.

Soil sampling and analysis

Soils were collected to a depth of 10 cm in March 2001 from the three experiments. A portion of the field moist soil was immediately used for inorganic nitrogen determination while the rest was air-dried, sieved to pass 2 mm and used for subsequent physical and chemical analyses as well as for SOM fractionation.

Soil inorganic nitrogen that is nitrate-N (NO_3^--N) and ammonium-N (NH_4^+-N) were measured after extraction in 2 N KCl, with ammonium determination after Anderson and Ingram (1993). Nitrate was measured by the cadmium (Cd) reduction method followed by colorimetric determination of nitrite. Potassium permanganate oxidizable carbon ($KMnO_4$-C) was determined according to Blair et al., (1997), with the exception that readings were taken after 24 hr instead of 1 hr reaction time. Total organic C, N and carbon-13 were determined on pulverized (finely ground) soil samples by dry combustion using an automated carbon and nitrogen analyzer (ACN- analyzer) mass spectrometer. Carbon isotope composition was expressed in delta-13 ($\delta^{13}C$) units using the international Pee Dee Belemnite (PDB) reference standard:

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

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

SOM fractionation was done following the soil fractionation method as described by Six et al., (2000). The light fraction (LF) fraction from each aggregate class was separated by gentle swirling the aggregates to suspend and decanting any light fraction flotation on water. Silt and clay were separated by the sedimentation-decantation process. All fractions obtained were dried at between 55-60° C before weighing.

Data was subjected to analysis of variance (ANOVA) using Genstat for Windows Version 6.1.

RESULTS AND DISCUSSION

Soil available nitrogen in Kabete, Embu and Maseno experiments

Table 1 shows the soil available N for soils from Kabete, Embu and Maseno experiments before the short rain season of 2001. In Kabete experiment, mineral N was highest in all treatments receiving organic resources as compared to the fertilizer and the control treatments. Senna treatment recorded the highest inorganic N content (26.1 mg N kg^{-1} of soil) followed by tithonia (24.1 mg N kg^{-1}), calliandra (21.0 mg N kg^{-1}), fertilizer (19.0 mg N kg^{-1}) while the control had the lowest inorganic N content of 16 mg N kg^{-1} of soil. Higher mineral N contents in the organic treatments points to the continued mineralization of the N held in the SOM pools even after the end of the previous cropping season. Such nitrogen held within the SOM pools can be utilized during the subsequent cropping seasons.

Available soil N content in the treatments of Embu experiment were significantly different with the fertilizer treatment recording the highest mineral N content of 72 mg N kg^{-1} of soil (Table 1). Other treatments were in the order leucaena > calliandra > control. Highest N contents in fertilizer treatment can be attributed to the readily soluble inorganic fertilizer. On the other hand lower mineral N contents in leucaena and calliandra treatments suggest mineral N immobilization and storage in the less labile SOM pools (Mafongoya et al., 1997).

Available soil N content from Maseno experiment were lower than those observed in Kabete and Embu experiments (Table 1). Senna treatment had the highest mineral N content (8.6 mg N kg^{-1}) and was followed by calliandra, tithonia and the control in decreasing order. Lower mineral N contents in the Maseno experiment could be attributed to the residual nature of the experiment and suggest the need for continued application of both organic and/or inorganic nutrient sources if higher nutrient supply and crop yields are to be maintained.

Table 1: Soil available nitrogen, bulk density, percent carbon and nitrogen, carbon-13 and potassium permanganate oxidizable carbon in Kabete, Embu and Maseno experiments as at March 2001

Site	Treatments	Available N (mg kg^{-1} soil)	Bulk density (g cm^{-3})	Percent Carbon	Percent Nitrogen	Carbon-13 (δ PDB)	$KMnO_4$-C (mg C kg^{-1} soil)
Kabete	Senna	26.1 a	0.99a	1.86a	0.14a	-11.95a	751.7a
	Tithonia	24.1 ab	1.06a	1.84a	0.14a	-12.18a	753.5a
	Calliandra	21.0 bc	1.05a	1.81a	0.14a	-12.15a	752.6a
	Fertilizer	18.9 cd	1.00a	1.78a	0.14a	-11.96a	742.0a
	Control	16.0 d	1.03a	1.79a	0.14a	-11.92a	709.0b
	SED	1.54	0.038	0.044	0.002	0.275	12.16
Embu	Fertilizer	71.9 a	0.89a	2.47a	0.20a	-16.07bc	1003.4b
	Leucaena	52.1 b	0.92a	2.52a	0.21a	-16.32ab	1081.0a
	Calliandra	47.3 bc	0.88a	2.48a	0.21a	-16.69a	1034.9ab
	Control	40.1 c	0.87a	2.35a	0.19a	-15.65c	1009.0b
	SED	5.90	0.021	0.132	0.009	0.250	27.63
Maseno	Senna	8.6 a	1.09a	1.86a	0.16a	-18.10a	815.5a
	Calliandra	8.5 a	1.07a	1.83a	0.16a	-18.09a	824.8a
	Tithonia	8.0 a	1.11a	1.80a	0.15b	-17.82a	800.5a
	Control	7.4 a	1.12a	1.59b	0.14c	-17.46b	739.4b
	SED	0.90	0.038	0.047	0.004	0.173	17.44

Values followed by the same letter are not significantly different
SED- Standard error of differences of means

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

Soil bulk density was not significantly affected by organic residue management regimes at any of the sites (Table 1). However, the narrow ranges of bulk density in the three sites justified the comparison of other soil physical and chemical properties across the sites. Kabete experiment had narrowest C, N and carbon-13 contents (Table 1) as compared to Maseno and Embu experiments. In general, all treatments receiving organic residues had higher C and N contents compared to fertilizer and the control treatments.

Carbon-13 signature for the soils from Kabete indicated a delta ^{13}C signature closer to that of C4 vegetation. Values ranged from -11.92‰ to -12.18‰ (Table 1). 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 higher decomposition rates, lower litter inputs and the shorter duration of organic residue application in this experiment (Nandwa, 2001).

Total C values for Embu treatments were higher than the recommended critical value for soil carbon of 2.0% for Kenya as reported by FURP (1987). Such a favourable soil organic carbon (SOC) content in Embu experiment could be attributed to the continued application of the organic resources to the soil. Higher soil carbon content in the leucaena and calliandra treatment could be due to their low decomposition as explained by their higher polyphenol and lignin contents (Mafongoya et al., 1998). Such slow decomposing organic residues can have a greater contribution to the stored soil C pool. Soil total N in Embu treatments was not significantly different. However, like soil C, leucaena recorded the highest N content followed by calliandra, fertilizer while the control treatment had the least N content. Whole soil carbon-13 values were significantly different for the treatments in Embu experiment. This was as a result of the less negative $\delta^{13}C$ signature observed in the control (-15.65‰) treatment as compared to the more negative $\delta^{13}C$ 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 organic residues.

In Maseno experiment, whole soil (WS) total carbon was significantly different. Senna treatment had the highest WS C content (1.86%) followed by calliandra (1.83%), tithonia (1.80%), and the control (1.59%). The high C contents in senna and calliandra treatments compared to the tithonia treatment could be attributed to the low quality of these two organic resources, which result in C immobilization hence less mineralization of the C in the soil. Total N was highest in all treatments receiving organic resources as compared to the control treatment (Table 1). 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 signatures for Maseno experiment soils were more negative as 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). In relation to the control, senna treatment had the largest shift in delta ^{13}C signature followed by calliandra and tithonia. The greater C3 labelling observed here could be due to the larger quantities of the organic residues applied (5 t dry matter per season) as well as the longer duration of organic residue application as compared to the Kabete experiment.

Potassium permanganate oxidizable carbon ($KMnO_4$-C) in Maseno, Embu and Kabete experiments

Potassium permanganate oxidizable carbon ($KMnO_4$-C) contents in Maseno were significantly different with calliandra treatment recording the highest soluble carbon content of 824.8 mg C kg^{-1} (Table 1). This was followed by senna, tithonia and the control respectively. In Kabete experiment, like Maseno, $KMnO_4$-C was significantly different at 5% with tithonia recording the highest $KMnO_4$-C content (753.5 mg C kg^{-1}) while the control had the least content of 709.0 mg C kg^{-1} (Table 1). Of the three experiments, Embu had the highest $KMnO_4$-C contents. In this experiment, leucaena recorded a $KMnO_4$-C content of 1081.0, followed by calliandra (1034.9 mg C kg^{-1}), control (1009.0 mg C kg^{-1}) while the fertilizer treatment recorded $KMnO_4$-C content of 1003.4 mg C kg^{-1} (Table 1) The variations observed in the three experiments concur with the observation made by Blair et al. (1997) that the labile carbon as estimated by the $KMnO_4$ oxidation technique is extremely sensitive to soil management. The above results are within the ranges observed by Wang et al. (2003) in a study on Australian soils who observed $KMnO_4$-C contents of between 852-8104 mg C kg^{-1}.

Soil fractionation

Aggregate mineral fraction

Fig 1a, b and c present the proportions of aggregates in Maseno, Kabete and Embu experiments. In all the sites, aggregate size distribution were dominated by macro-aggregates 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. Higher aggregate proportion in Maseno experiment could be attributed to improved SOM resulting from the large application of organic residues. On the other hand, lower macro-aggregate proportion in Kabete experiment could be due to the short duration of organic residue application in this experiment. On the other hand, the micro-aggregates (53-250 µm) mineral fraction accounted for 23% in Maseno, and 26% in Embu and 27% in Kabete experiment. Kabete soils indicated a substantial decrease in small macro-aggregates (250-500 µm) concomitant with an increase in micro-aggregate MF (Six et al., 2000). Increasing cultivation intensity could lead to a loss in macro-aggregates and an increase in micro-aggregates, silt and clay contents (Six et al., 2000 and Paustian et al (1997).

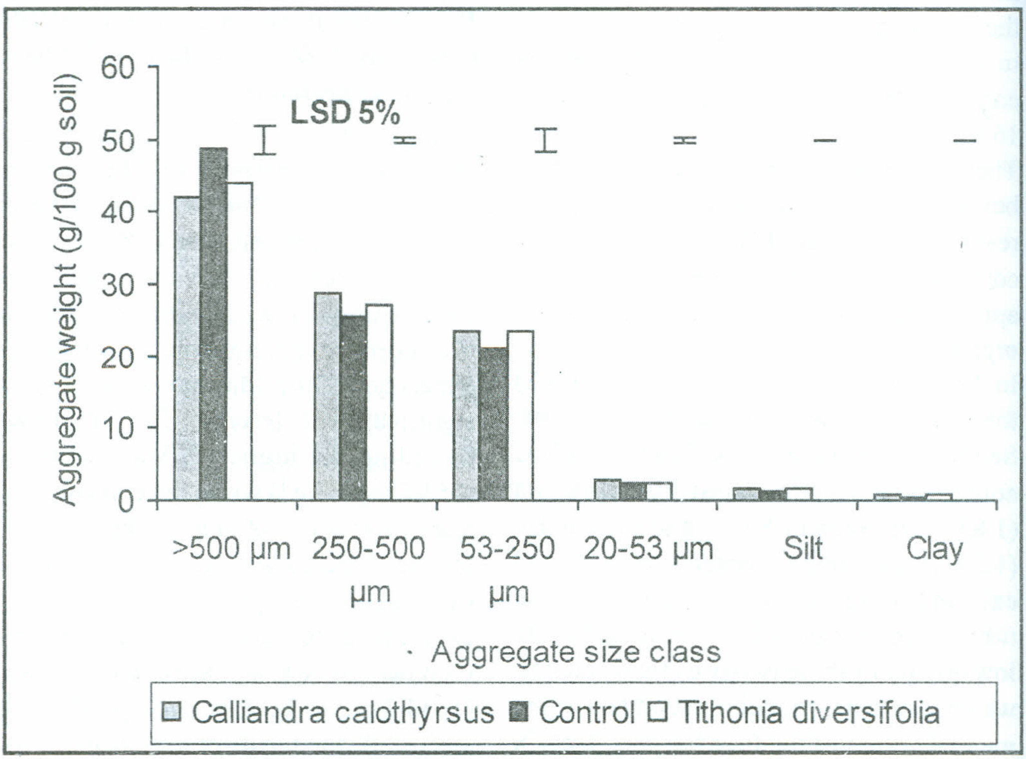

Fig 1a: Proportion of the aggregate mineral fraction for Maseno experiment

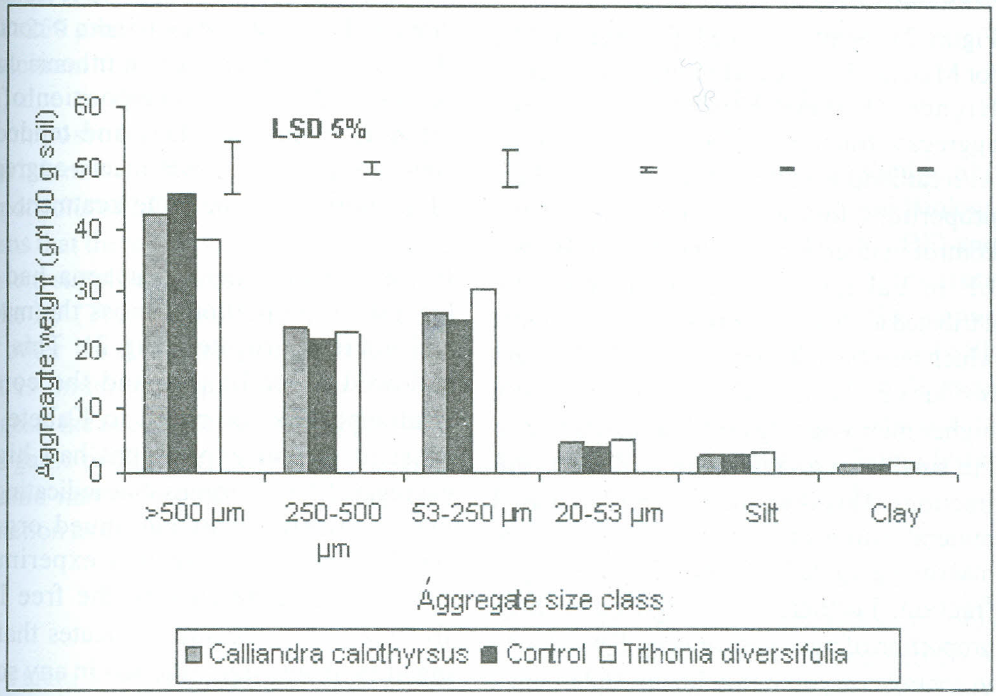

Fig 1b: Proportion of aggregate mineral fraction for Kabete experiment

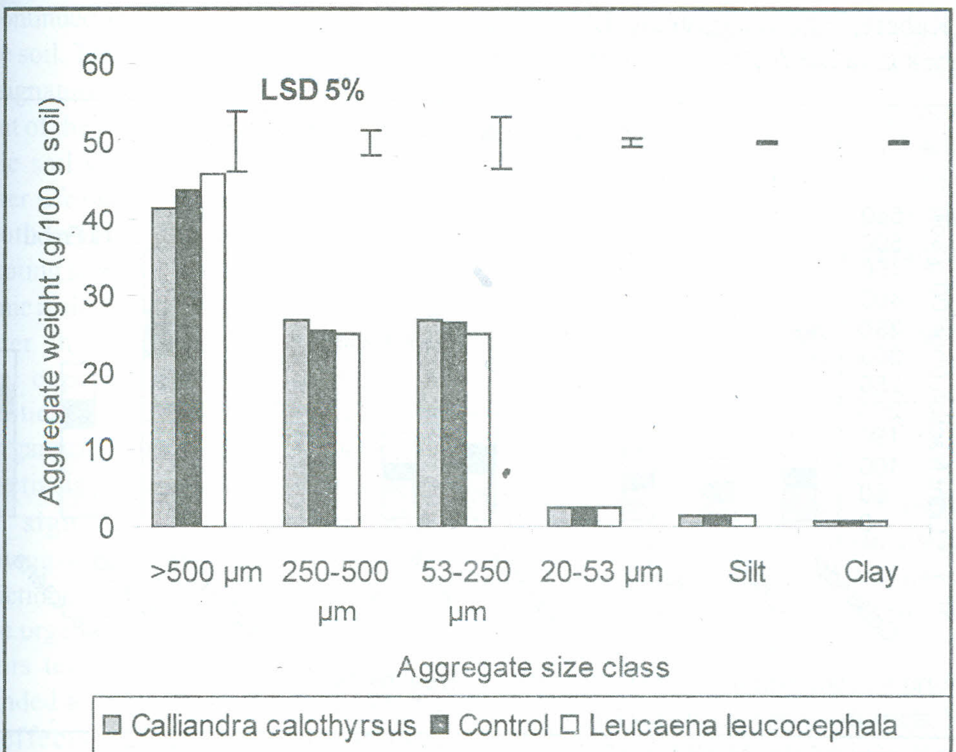

Fig 1c: Proportion of aggregate mineral fraction for Embu experiment

Free light fraction

Figure 2 presents the free light fraction (LF) for Maseno, Kabete and Embu experiments. Higher LF were observed in macro-aggregate fractions of Maseno experiment with calliandra treatment having the highest proportions followed by tithonia and the control in decreasing order (Fig 2). Higher LF in calliandra treatment could be attributed to slow decomposition of calliandra which results in the persistence of calliandra residues in the soil. There was a generally higher micro-aggregate LF as compared to the small macro-aggregate (250-500 μm) fractions. This is an indication if increased mineralization of organics from the large macro-aggregate LF to the micro-aggregate fraction. Further, a non-significant high proportion of micro-aggregate LF was found in control compared to calliadra and tithonia treatments.

In Kabete, macro-aggregate LF's were highest in calliandra followed by the control tithonia (Fig 2). Micro-aggregate LF were in the order tithonia > calliandra > control. High micro-aggregate LF in tithonia could be due to the rapid decomposition of the tithonia organic residues and tended to compensate for the lower macro-aggregate LF proportions in the same treatment.

In Embu experiment, leucaena had the highest LF proportions across the macro- and micro-aggregates (Fig 2). This was followed by calliandra and the control treatments. As compared to Kabete and Maseno, 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).

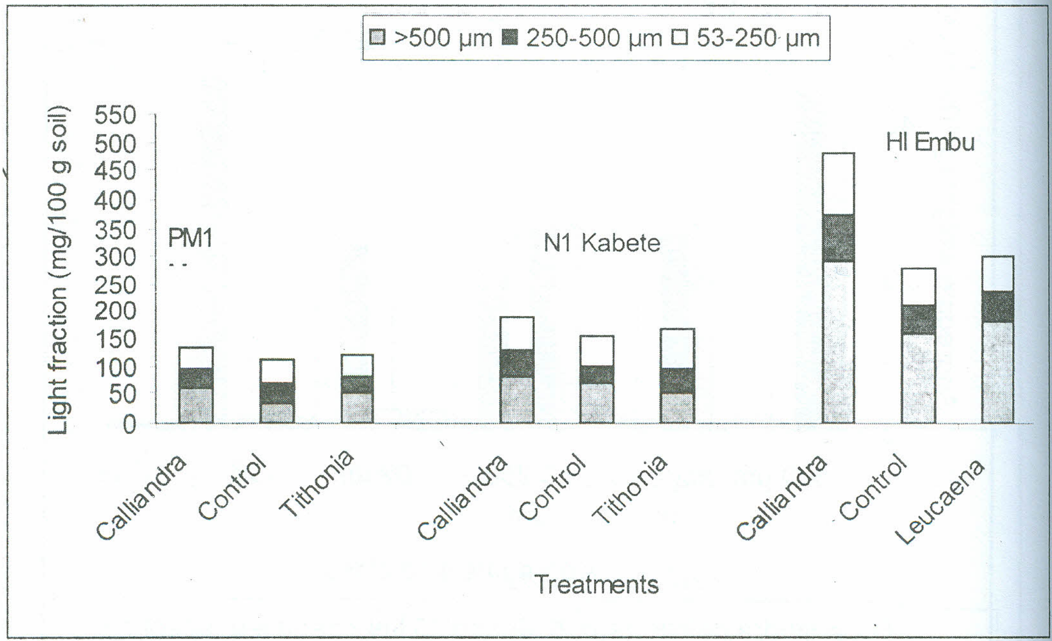

Fig 2: Aggregate light fraction in Maseno, Kabete and Embu experiments

As observed by Six et al. (1999) coarse free LF (>250 µm) 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 (Christensen, 1992). By having high proportions of LF in the Embu experiment means that there is a potential for increased nutrient supply as a result of mineralization of the LF (Tiessen and Stewart 1983). On the other hand, decreased LF in Maseno that is under residual for over 7 years suggests the need for continued application of organic residues to sustain the losses in organic matter resulting from increased oxidation as a result of cultivation.

CONCLUSION

For a significant change in the SOC and N hence the quality and quantity of the resultant SOM to be achieved, there is need for continued application of organic residues to the soil. The results also indicate that the ^{13}C signature can be used to evaluate the extent of the organic residue applied on the whole soil C. Kabete experiment with a shorter lifespan had narrower $\delta^{13}C$ values in both organic and control treatments indicating minimal labelling effect from the organic residues applied. On the other hand, greater shifts observed in Maseno and Embu experiments, point to the large quantities and the continued application of the organic residues in the two experiments respectively. 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. The use of this technique should therefore be expanded to other field such as assessing the effects of deforestation or land intensification on the soil organic matter quality. Complimenting it with SOM fractionation methods can enhance the use of this technique in SOM studies.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support given by the Tropical Soil Biology and Fertility Institute if CIAT (TSBF) and Kenya Agricultural Research Institute (KARI) in management of the above experiments. Gratitude also goes to TSBF and Katholieke University, Leuven Belgium laboratory staff for assisting in analysis. In addition, gratitude goes to Rockefeller Foundation for funding the study.

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