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Borlaug LEAP Paper

Effects of Organic and Inorganic Fertilizers on the Soil Carbon Sequestration Influence of Mavuno and Manure Fertilization on Soil Carbon Fractions

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Abstract

A soil's ability to resist erosion and maintain high levels of carbon (C) and nitrogen (N), rests in the distribution of soil fractions. Human soil management practices, such as tillage practices, alter the fraction distribution and subsequently the ability to sequester soil C and resist erosion. The objective of this study was to look at the influence of organic farm yard manure (FYM) and inorganic fertilizer (mavuno) on C fractions in soils from two counties in Kenya. The treatments applied were Imazapyr Resistant (IR) Maize (control), manure, and mavuno+ manure. Soils were wet sieved to separate into fractions and subsequently analyze the fractions for C content. Results indicate that there were significant differences in carbon content amongst the fractions with the largest carbon c in the silt and clay fractions There were however no significant differences in the proportions of the large macro-aggregates (LM), small-macro-aggregates (sM), micro-aggregates (m) and silt and clay (s+c) in different sites, treatments and fertility gradients. Elemental combustion was carried out and significant differences in C and N fractions were observed with the highest being 2.05% C and 0.18% N in the silt and clay fraction. A combined application of both manure and mavuno, increased overall N and C in fractions. The treatments, fertility gradients and sites had no effect on the carbon fraction distribution.

Key words: soils, carbon sequestration, organic carbon fractions, mavuno, farm-yard manure ajfand SCHOLARLY, PEER REVIEWED AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT Volume 19 No. 1 January 2019 PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST ISSN 1684 5374

Introduction

Soil organic carbon is the carbon stored within soil and is part of the soil organic matter (SOM). Soil organic carbon is composed of fractions and the knowledge of the type of organic carbon fraction present, is important as this greatly impacts soil productivity. Baldock (2010), identifies four biologically significant fractions of soil organic carbon as crop residues, particulate organic carbon, humus and recalcitrant organic carbon. Particulate organic carbon are individual pieces of plant debris that are less than 2mm but larger than 0.053mm. Humus are less than 0.053mm and are dominated by molecules stuck to soil minerals. Recalcitrant organic carbon is carbon which is biologically stable and typically in the form of charcoal.

The fractions do not only differ in size but also in material compositions and have different chemical and physical properties and decomposition rates (Yang *et al*., 2005). Soil organic carbon fractions have different functions depending on the fractions' relative stability and biological availability. The amount of each carbon fraction varies significantly across soil types and some fractions can be altered by management practices such as tillage, mulching and minimum tillage(Six, Elliott, *et al*., 2000).

Farmers in Siaya and Vihiga manage their maize fields by application of mavuno, a locally blended inorganic fertilizer composed of NPK, 10:26:10 ratio, plus trace elements specific for crops such as maize, and FYM (N:1.35 kg/t, P:1.20kg/t and K: 6.0kg/t) as these are cheap and readily available methods. The farmers also use Imazapyr Resistant (IR) maize to control the occurrence of *Striga hermonthica* (Del.) Benth, a weed that attacks cereal crops mainly maize, rice and sorghum. It is commonly referred to as the "witch weed" by local dwellers as the plant is known to debilitate plants it invades thereby greatly reducing crop yields. *S. hermonthica*, is an out-crossing species with purple flowers that produces massive amounts of seed estimated at between 58,000 and 200,000 per plant (Hassan *et al*., 1994).

There is, however, preferential application of these fertilizers resulting in the formation of fertility gradients within one farm. Soil fertility gradients are gradients of decreasing soil fertility found with increasing distance from the homestead within smallholder African farms, due to differential resource allocation (Tittonell *et al*., 2005). It is, therefore, important to analyze the effects of these fertilizers on carbon fraction distribution so as to make informed decisions on the potential for the soils in the study area to sequester carbon or resist erosion based on the different sites, the fertility gradients and the treatments applied. The study, therefore, grouped the carbon fractions identified by Baldock (2010) into large macro-aggregates (LM) >2000 µm; small macro aggregates (sM) 250 – 2000 µm; micro-aggregates, 53-250 µm; and silt and clay (S+C) < 53µm(Six, 2011).

It is important to differentiate aggregate size classes within the soil as this gives a measure of the soils stability and, therefore, differentiates a more resistant soil from one that is prone to soil erosion (Stewart *et al*., 2009). A soil that has more macro-aggregates means it has a better soil structure and therefore offers more resistance to soil erosion. The soil matrix affects microbial activity, nutrient cycling and carbon sequestration and in this regard macro- aggregates are not important in C sequestration

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because they are less stable and therefore more dynamic when compared to micro aggregates. They are, however, important as a temporary nutrient sink and source, thus are critical for soil fertility (Six *et al.*, 2000). Micro aggregates on the other hand, are more stable and less dynamic and form an ideal microenvironment for microorganisms. In micro-aggregates, a bit of carbon is stabilized creating a long-term pool of carbon. The silt and clay fractions are a non-aggregated fraction containing a lot of older carbon that is stabilized within the silt particles (Six *et al.*, 2000).

Materials and Methods

Site Description and farmer selection

Fertility trials were conducted on-farm in 3 locations, Nyalgunga and Nyabeda in Siaya County and Emusutswi in Vihiga County, all in Western Kenya. Table 1 below shows the location of the experimental sites in Western Kenya.

Table 1: Location of Experimental Sites

District	Farm	Site	Northing	Easting	Elevation(m)
Vihiga	1	Emusutswi	0º07’39.1”	34º40’17.2”	1,528
Vihiga	2	Emusutswi	0º07’23.2”	34º40’26.0”	1,503
Vihiga	3	Emusutswi	0º07’30.0”	34º40’11.9”	1,470
Vihiga	4	Emusutswi	0º07’36.2”	34º40’46.2”	1,510
Siaya	5	Nyalgunga	0º04’42.6”	34º18’19.1”	1,335
Siaya	6	Nyalgunga	0º04’50.1”	34º18’21.8”	1,300
Siaya	7	Nyalgunga	0º05’05.4”	34º17’53.3”	1,310
Siaya	8	Nyalgunga	0º04’56.9”	34º13’17.5”	1,312
Siaya	9	Nyabeda	0º07’42.9”	34º24’29.5”	1,323
Siaya	10	Nyabeda	0º07’50.5”	34º24’10.8”	1,333
Siaya	11	Nyabeda	0º08’02.8”	34º24’29.5”	1,360
Siaya	12	Nyabeda	0º08’01.2”	34º24’17.5”	1,347

The area receives rainfall averaging over 2000mm per annum and temperatures are as high as 35oC (Cheserem, 2012b). The two main soil types in Emusutswi are humic nitosols and ferralsols and Nyabeda and Nyalgunga have ferralsols and acrisols (Gachene and Kimaru, 2003). Humic nitosols are developed from volcanic rocks and have better chemical and physical properties than other tropical soils: Most are acidic (pH < 5.5) due to the leaching of soluble bases but are the best agricultural soils found in the region (Gachene and Kimaru, 2003).

Ferralsols occur on gently undulating to undulating topography such as that in Siaya district. The ferralsols are made up of acidic parent rocks and have high quartz amount. They are very old, highly weathered and leached soils, and therefore with a poor fertility, which is restricted to the top soil, as the subsoil has a low cation exchange capacity. Ferralsols are rich in Aluminium (Al) and Iron (Fe) but Phosphorous (P) and Nitrogen (N) are always deficient (Okalebo *et al.*, 2005). Acrisols on the other hand occur on undulating to hilly topography. They show an increase of clay content in the sub-soil (B-Horizon) often resulting in a low porosity sub soil hence impeding root

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penetration. In wet areas, Acrisols have a low pH (acid), Al and Mn toxicities and low levels of nutrients and nutrient reserves. The above soil types all require organic and inorganic fertilizers to improve crop production. The soils respond well to fertilizers (especially N, P and K) and to the use of soil organic matter (Gachene and Kimaru, 2003).From the three sites, 12 farmers were selected, four from each site, using Y frame sampling procedure (Tittonell *et al*., 2010). Farms were demarcated into fertility gradients as perceived by farm owners. Fields classified as having low fertility had sparser crops, approximately 30% less plants per square meter, and higher weed infestation levels than those fields classified as high fertility fields.

Experimental Design and treatments
A randomized complete block design with a split plot arrangement, replicated 4 times (with each farmer acting as a replicate) was used to test the effect of fertilizer application on soil carbon fractions. The main plots were the fertility gradients (high and low) and the subplots were the fertilizer treatments; control, FYM and FYM+ mavuno. IR maize was used as the test crop and mavuno was applied at a rate of 20kg P per ha whilst FYM was applied as a projection of 2 tons/ha. IR maize was planted at a spacing of 30 cm x 75cm in a plot of size 6m x 4m, weeded twice and top dressed with mavuno. The experiment was conducted during the long rains of 2011 and 2012 seasons.

Soil sampling and analysis
Soil samples were collected using a soil auger at a depth of 0-20 cm at 5 points using W-sampling procedure as described by Peters *et al*. (2008). The soil was composited, and then divided into four equal parts and a 200g sample obtained and placed in labeled plastic containers. The soils were then passed through an 8mm sieve to homogenize the sample and break apart other larger soil particles. The method for separating soil into different stable aggregates used was adopted from Six (2011). The procedure has four parts (Figure 1) but for this experiment only one part, Part A, was of interest, which is the wet sieving of the soil. After wet sieving, the soil aggregates were further analyzed using the Costech ECS 4010 elemental combustion system to analyze the amount of C and N in the different soil fractions.

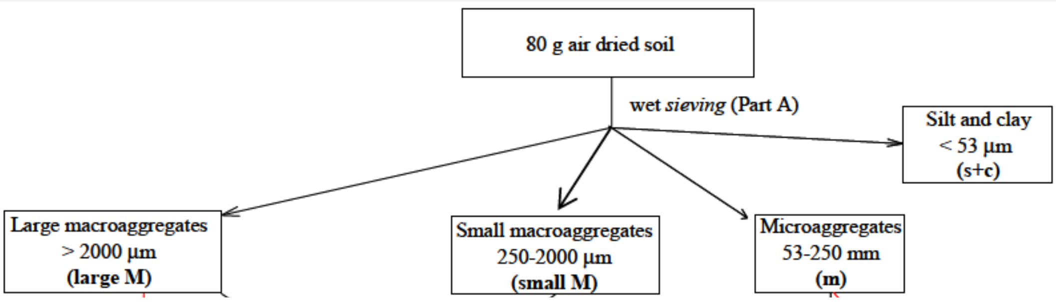

Figure 1: Procedure for Soil Organic Carbon Fractionation as adopted from Six (2011)

Wet-sieving of whole soil
About 80 g of a sub-sample from air-dried whole soil was weighed using a digital balance. A white 30cm diameter and 8cm deep basin was filled with water and a

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2000μm sieve-mesh placed into it. The soil sub-sample was sprayed evenly on the sieve and allowed to soak for 5 minutes. The soil was then sieved through the mesh for 2minutes by moving the sieve 50 times up and down with a slight angle ensuring that water and small particles went through the mesh. The>2000 μm aggregates, that is large macro-aggregates were backwashed into a pre-weighed small drying pan. Floating litter was also decanted into a drying pan. The sieving procedure was repeated using 250 μm mesh (small macro aggregates), 53 μm mesh (micro aggregates), and the aggregates were all placed in pre-weighed drying pans. The remaining particles < 53 μm particles (silt + clay) were also transferred into a drying pan.

The experiment aims to separate the soil into different water stable aggregate size fractions in order to look at the stability of the soils as well as the carbon and nitrogen stabilized in the fractions as affected by organic and inorganic fertilizers. When the soil sample soaks for five minutes, it mimics the slaking process occurring in the field upon rainfall. The water goes into the aggregate from the outside and pressure builds up within the aggregate. For an unstable aggregate, when the pressure becomes too much, the aggregate breaks unless if that aggregate is stable enough to withstand the pressure and so does not break up. It is, therefore, basically the process of slaking and pressure build up that determine if an aggregate is stable versus an aggregate that is not stable (Six, 2011). The study hypothesizes that organic and inorganic amendments influence soil stability by affecting the quantity and quality of organic fractions. At the end of the wet sieving of each sub-sample, there were 5 drying pans each with soil fractions. All the drying pans with soil fractions were then transferred into a 60oC forced air-dry oven. After the soil samples in the pans had dried, the pans were re-weighed and the soil weight was calculated as follows:

$$SoilWeight=(Pan+soilweight)-\ emptypanweight$$

Elemental Combustion
The different soil fractions collected from the wet sieving, silt+clay (S+C), micro aggregates (m) and macro-aggregates (sM+ LM) were passed through the elemental combustion system. A sample of between 19- 20mg soil was weighed using a micro-balance and placed in aluminum weigh tins. The soil samples were then transferred into the Costech ECS4010 elemental combustion system that was responsible for detecting N and C levels of the different fractions.

Data Analysis
Analysis of variance to assess the site effect, treatment effect, fertility gradient effect and their interactions on soil carbon fractions and the C and N content of the fractions was conducted using GENSTAT 14th edition. The Least Significant Difference (LSD 5%) was used to separate means of significant differences.

Results and Discussion
Soil Organic Carbon Fraction Proportions
There were no significant differences in the weight of LM, sM, m and S+C fraction proportions (P>0.001) across sites, treatments and fertility gradients (Figure 2). The transportation, storage and handling of soil samples may have resulted in breakage of

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the aggregates and hence, affecting their proportions in the soil across treatments, sites and fertility gradients. Farmer fields in the study area are heavily infested with Striga weed. Thus, the continuous soil turnover during the growing season in order to control weeds may also have contributed to the breakdown of soil aggregates. This, however, is in contrast to the findings of Lee *et al*. (2009), who reported a significant difference in the carbon fraction proportions in long term fertilized fields. The differences could be attributed to the long-term aspect in Lee *et al*. (2009)'s experiment compared to the above study.

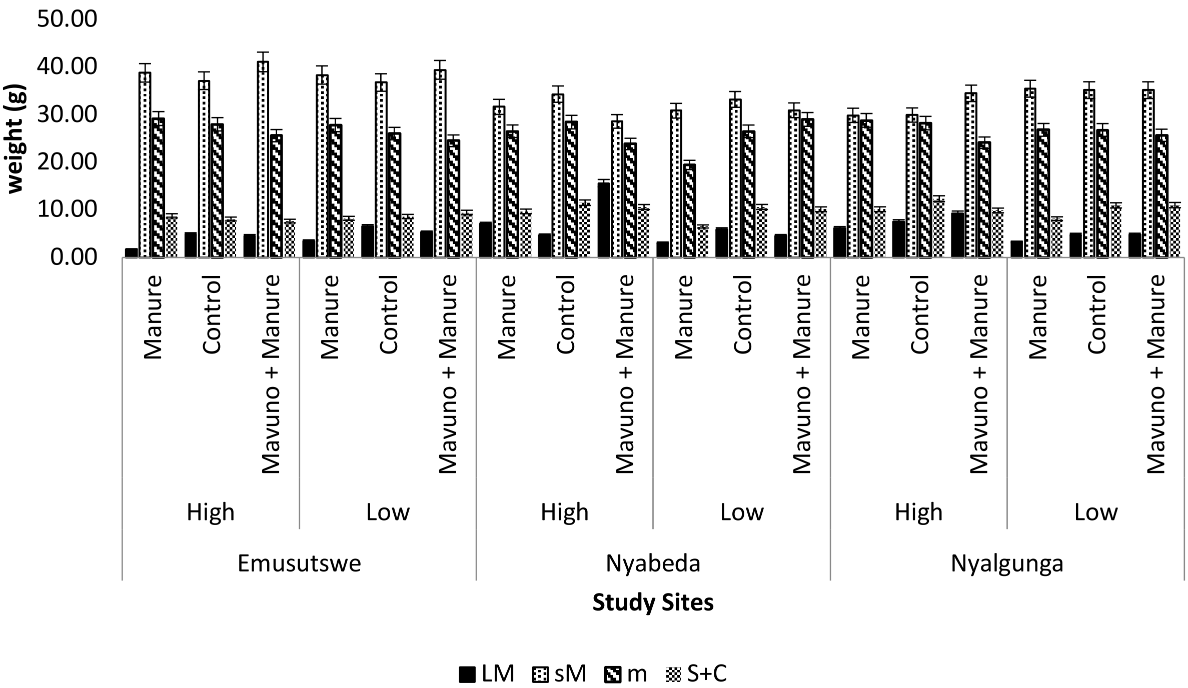

Figure 2: Proportions of soil fractions in different fertilizer treatment

The large proportion of sM can also be attributed to the breakdown of the LM (>2000 µm) during soil sampling, handling and transportation. This is similar to the findings of Six *et al*. (2000) that the proportion of macro aggregates (LM and sM) accounted for 85% of the dry soil weight and was similar across management treatments.

Low proportions (<10%) of the LM (>2000 µm) fraction in all treatments were also observed. This can be attributed to high decomposition rates of organic materials by microbes in the farmer fields as a result of high temperatures and available organic material on the soil surface. On the other hand, fraction breakup during sampling and storage cannot be entirely ruled out. These findings are in line with those of Lee *et al*. (2009) who found the SOC proportion of LM fractions to be less than 3% in compost only fields.

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C and N composition in organic fractions

Significant differences (P<0.001) were observed in the %C composition in the macro-aggregates (M), micro-aggregates (m) and the silt and clay (s+c) fractions across sites but not across treatments or fertility gradients (Fig. 3).

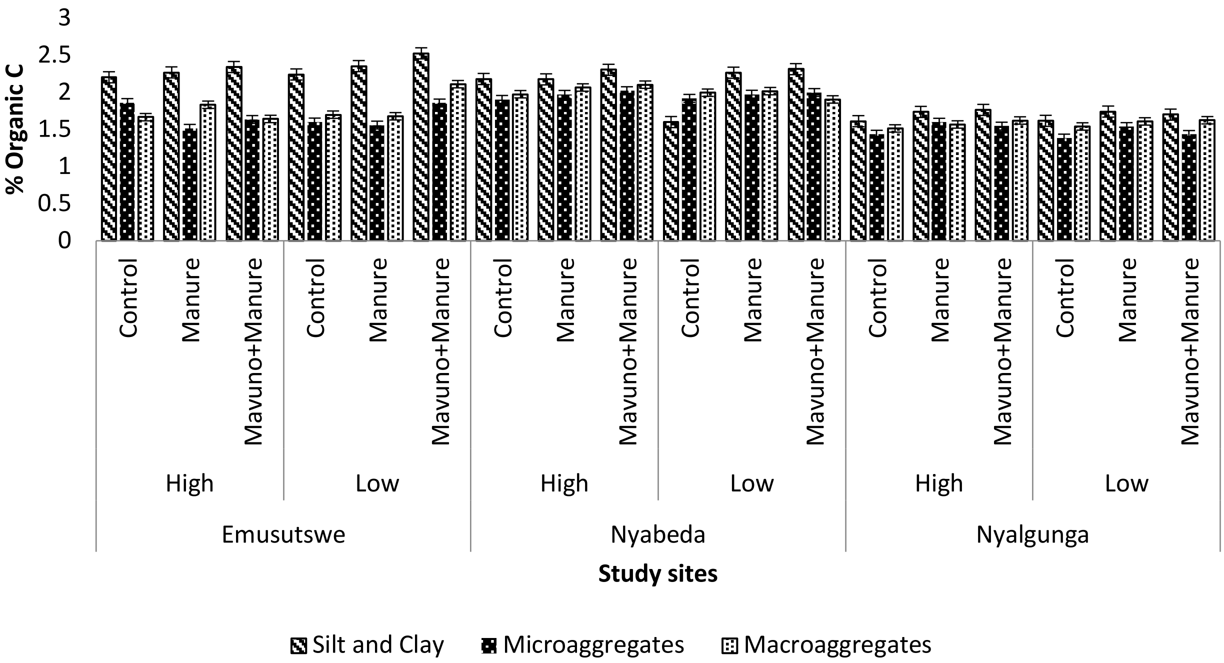

Figure 3: % carbon in different soil fractions

SOM added to the soil in the form of FYM contributes to the quality of carbon fractions formed. The FYM added to the farmers' fields was specific to the sites and dependent on the quantity of organic residues and cattle manure the farmers had within their locality. This therefore may have resulted in the formation of SOM of different quality. The FYM added resulted in an increase in microbial populations in the soil that enhanced breakdown of organic material and hence resulted in significant differences in %OC in the aggregates formed across sites. The addition of mavuno did not influence the soil's physical properties but the chemical properties hence no treatment effect observed. After crop harvest, farmers in the study sites would leave crop residues in the field thus also causing no significant differences between the fertilizer amended plots and the control plots. This is supported by the findings of Lee *et al*. (2009) who reported that total SOC concentration was significantly increased by continuous addition of compost, but continually decreased with the chemical (NPK) and no fertilization (the control). In the NPK and control treatments, most of the SOC was supplied through the plant root biomass, because the aboveground part was removed at the harvesting stage.

Most of the SOC was accumulated in the particulate organic carbon (53 µm <sM<2000 µm) fraction which occupied over 75% of the total SOC in the control, manure and mavuno+manure treatments. This was the largest proportion of SOC because at harvest farmers leave crop residues in the plots forming a conducive microclimate for

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microbial activities. Microbes quickly act on the organic substrates and breakdown the crop residues into individual plant debris forming the particulate organic carbon. The highest OC (2.53%) was recorded in the silt and clay fraction. The silt and clay fraction is composed of decomposed materials that are dominated by molecules stuck to soil minerals. It also has recalcitrant organic carbon which is biologically stable thus resulting in all the carbon broken down from the macro and micro-aggregates, stabilized in the silt and clay fraction hence the highest OC recorded thereof. This is in line with Lee *et al*. (2009) who reported that after continuous addition of NPK fertilizers, NPK + compost and compost only to the soil and testing for organic carbon in the various fraction, most of the SOC was accumulated with the organo-mineral fraction (<0.053 µm) which occupied 83%, 84%, 73% and 78% of the total SOC in the control, NPK, NPK + Compost, and Compost, respectively. The stability of the OC in the silt and clay fraction makes the silt and clay fraction a potential carbon sink in the long term (Six, 2011).

Significant differences (P<0.001) were observed in %N in the silt and clay fraction across treatments and sites but not across fertility gradients (Fig. 4). The silt and clay fraction contains a high CEC due to the presence of humus which is the end product of decomposed organic matter. Organic matter colloids have large quantities of negative charges which are essential in attracting soil nutrients such as nitrogen resulting in higher nitrogen being observed in the silt and clay fraction compared to the macro and micro aggregates. The significant differences in %N observed across sites can be attributed to the soil's mineralogy across the sites. Siaya has ferralsols which are made up of acidic parent rocks with high quartz amount whilst Vihiga soils are humic nitosols that are developed from volcanic rocks. The clay particles of the different sites

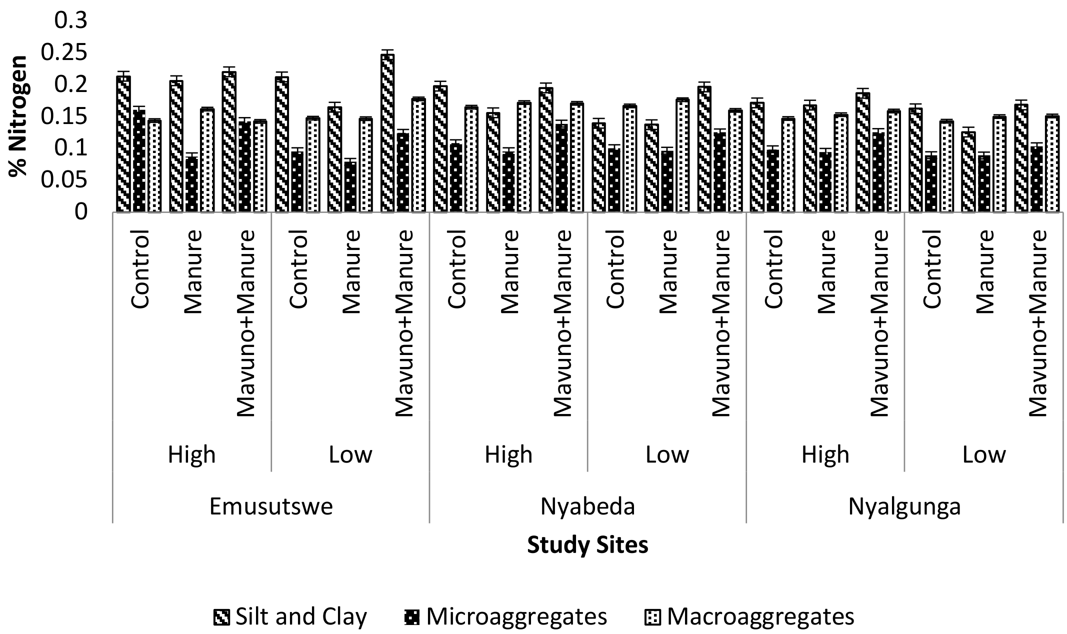

Figure 4: %N Composition in different fractions, treatments and sites

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This is in line with the findings of Loerch *et al*.(2012) that CEC varies according to the type of clay and is highest in montmorillonite clay. It is lowest in heavily weathered kaolinite clay, found in ferralsols, and slightly higher in the less weathered illite clay. Differences in %N across sites can also be attributed to previous cropping systems practiced by the farmers such as growing of legumes as practiced in Siaya.

The significant differences in %N of the silt and clay fractions across treatments can be explained by the improvement of soil structure upon addition of FYM in the manure and mavuno+manure treatments. Soil particles are held together in a better aggregation and decreases soil loss hence nutrient loss resulting in %N being maintained in the soil in the biologically stable aggregates. This is supported by Krull *et al*. (2003) who reported that FYM played a critical role in improving the soil's structure and also added nutrients to the soil that were acted upon by microorganisms, resulted in the formation of humus that was more stable.

No significant differences were observed in %N in the macro and micro aggregate fractions across sites fertility gradients or treatments. The macro and micro aggregates are less stable when compared to the silt and clay fractions. They act as temporary nutrients sources for the time in which they are able to hold the nutrients before they are taken up by plants. Thus at the time of sampling, plants had reached maturity and had been harvested and hence nutrients were mined in the process leaving the macro and micro aggregates mined of nutrients.

Conclusions

Organic carbon fraction distribution was not affected by site, application of mavuno and manure or fertility gradients. The %OC in the silt and clay fractions were affected by the treatments applied with the mavuno and manure treatments exhibiting higher %OC. The macro and micro aggregates were not affected by the site treatments or fertility gradients. The %N was affected by the sites and the treatments applied, but not the fertility gradients and the highest %N was in the silt and clay fraction in the mavuno +manure treatment. This implies that a soil's ability to sequester carbon is affected by the addition of organic fertilizer, inorganic fertilizer or both. Thus, an integrated approach to fertilizer application sequesters the most carbon as compared to individual application of either organic or inorganic fertilizers.

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