SOIL ORGANIC CARBON AND WATER RETENTION CAPACITIES OF WATER STABLE AGGREGATES AS AFFECTED BY LAND USE IN ENUGU STATE, SOUTH EASTERN NIGERIA.

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ABSTRACT.
Soil organic carbon (SOC) and water retention capacities at -33KPa and -1500Kpa of forest and cultivated soils in six locations: Ugbo-Okpara (L1), Ugbo-nabo (L2), Ugwogo-Nike (L3), Iyi-Ukwu (L4), Edem (L5) and Ngwo (L6) of Enugu state south eastern Nigeria were evaluated with respect to three different sized water stable aggregates (>2mm, >0.25mm and <0.25mm). Factorial analysis of variance in Completely Randomized Design for the factors location, aggregate size and land use was used. Cultivation significantly ($P \leq 0.05$) reduced SOC by 25%. Interaction of land use, aggregate size and location demonstrated general decline in SOC across all locations and aggregate size except in L1 and L2 with higher SOC in > 2mm of the cultivated sites which may be due to organic agriculture practiced in these locations. Land use had no significant ($P \leq 0.05$) effect on water retention at -33KPa and 1500KPa. But significant ($P \leq 0.05$) interaction of land use, aggregate size and location at -33KPa and -1500KPa was observed. Aggregates at the cultivated sites (L1, L2 and L3) recorded significantly ($P \leq 0.05$) higher water retention while decline in water retained by aggregates was observed in the other cultivated locations (L4, L5 and L6) compared to their adjacent forest locations. Result revealed that aggregate water retention probably was controlled by a combination of aggregate associated soil organic carbon and clay irrespective of land use. However there were contradictory results in water retained by aggregate sizes at L3 that could not be explained by content of clay or soil organic carbon. Higher values in cultivated sites (L1and L2) may be due to textural characteristics.
Key words: Land use, location, water stable aggregates, water retention, soil organic carbon.

INTRODUCTION

Aggregates determine the behaviour of the soil. Understanding the organic carbon and water retention capacities of different sized water stable aggregates is important for proper land use. In south eastern Nigeria conversion of forest to arable land is progressing rapidly due to population increase, low input agriculture and search for more fertile land. Paucity of information on soil organic carbon and water retention capacities of different sized water stable aggregates in this region has made this research needful.

Soil aggregation is regarded as a physical soil quality indicator that give knowledge on the soil's capacity to function as a key factor of the ecosystem (Martinez-Trinidad et al. 2012). Good structure enhances carbon sequestration thus mitigating global warming. It affects water and nutrient holding capacity of the soil. Aggregate stability is significantly correlated with soil organic carbon due to its binding action of humic substances and other microbial by-product (Tisdall and Oades, 1982; Haynes *et al*., 1997; Shepherd *et al.*, 2001, Six *et al.* 2002).

Land use change is known as an essential driver for soil organic matter dynamics (Zhang *et al.*2014). The depletion of SOC in arable land has been connected to soil disturbance (Eynard *et al.*, 2004) and change in plant litter composition**.**

Studies have shown that aggregate soil organic carbon in forested land were generally higher than those in farmland (Spaccini *et al.* 2001, Lui *et al.*2014). Aggregate soil organic carbon in forested land were more concentrated in the macro aggregates while in farm land was more concentrated in the smaller aggregates (Lui *et al.*2014). Shrestha *et al.* (2004), demonstrated that micro aggregates of <0.25mm had a higher SOC concentration than aggregates of 0.25mm – 0.5mm regardless of land use.

Soil water retention at field capacity (FC) and permanent wilting point (PWP) are crucial for irrigation water depth budgeting and could be affected by land use (Haghighi *et al.* 2011). Water availability is considered as an important component in evaluating the land area suitability for crop production (Sys *et al.* 1991). Soil water content controls the transport characteristics of water and solutes in soils and is needed for adequate soil and water management (Haghighi *et al.* 2011).The conversion of natural ecosystem to cultivated land can change water retention capacities of soils due to modification of pore geometry and connectivity (Sata and Kukal 2013).

Zhoug *et.al.* (2008) stated that land use effect on soil water retention may be significant at potentials -33KPa but at -1500KPa pressure head, water retention may not. Das and Gupta, (2008) indicated that difference in moisture releasing capacity particularly in the range 0.33-15.0 bar amongst different sized aggregates, was ascribed to different levels of clay and organic carbon in different-sized aggregates. Hudson (1994) noted that variation in water retention among textural class depend on the texture, bulk density and organic matter content. Rawls *et al.* (2003) reported that at low organic carbon content, responsiveness of water retention to alterations in organic matter content was highest in sandy soils. Awiti (2005), examined the effect of forest conversion and cultivation on water retention characteristics. He observed that water retention in forest soil was 4.2 - 3.3 times higher than in cultivated soil with 71 - 76 % decline in macro pores volume. Saha *et al.* (2013) noted that at different soil water suction, aggregates under farm land recorded lower water retention than in forest land use. The objective of this study is to evaluate the effect of land use on soil organic carbon and water retention capacities associated with different- sized water stable aggregates in south eastern Nigeria.

MATERIAL AND METHODS

Site Description:

The study locations are in Enugu State and within the same agro – ecological zone of southeastern Nigeria. The soils were collected from Ugbo-Okpara (L1), Ugbo-Nabo(L2), Ugwogo- Nike (L3), Iyi-Ukwu (L4), Edem([L5) and Ngwo (L6). LI and L2 are between latitude 6^o 10' N and longitude 7^o 25' E, L3, L4 and L5 are between latitude 6^o 26' N and longitude 7^o 29' E while L6 is between latitude 6^o 24' N and longitude 7^o 25' E. The study area has a tropical wet and dry climate with the rainy season lasting from April to October and the dry season from November to March. The average annual precipitation is between 1600 - 1800 mm with average temperature of 28^{o}C. The vegetation is derived savannah with patches of forests. Farming is done with traditional tools like hoes and machete and on subsistent level. Preliminary information from farmers in all locations revealed that they practice shifting cultivation and some common crops planted include cassava (*Manihot esculenta*), cocoyam (*Colocasia spp*.), melon (*Citrilus viligaris*) and maize (*Zea mays*). Other cultural practices include bush burning, cover cropping, mulching and ridging. L1 and L2 practiced organic agriculture while other locations use organic and inorganic fertilizers.

The soils of Enugu State are ferrasols and are of sedimentary origin (Balogun, 2000). According to Jungerius (1964), L1 and L2 are described as shallow brown soils derived from sandy shales. L3, L4 and L5 are red and brown soils derived from sand stones and shales while L6 is described as deep porous red soils derived from sandy deposit.

Field method

Soil samples from 0 – 20 cm depth were collected at random in triplicate from cultivated and adjacent forest lands in six locations of the study area. The different locations were selected based on the identification of virgin forests.

LABORATORY ANALYSIS

A total of 36 samples were air dried and passed through a 4.75 mm mesh to collect soil aggregates which were separated into different aggregate sizes to obtain enough WSA for further analysis. The aggregates were wet sieved using the technique as described by Kemper and Rosenau (1986), and the resultant size fractions were air dried. Sample number was reduced by pooling aggregates of size 4.75 mm – 2 mm and 2 mm – 1 mm together. Also 1 mm - 0.50 mm and 0.50 mm – 0.25 mm were pooled together to cope with the time frame for this research The different size fractionsin the determination of organic carbon, clay, low and high energy water retention associated with the aggregate sizes .

Particle size distribution associated with the water stable aggregates was determined by the hydrometer method (Gee and Bauder, 1986). The aggregate water content at different tension levels was determined by the Klute and Dirksen method using Tension Table. The aggregates were weighed and were capillary wetted to saturation. Pressure head at -33KPa was applied .The moisture content was determined when drainage has ceased. This procedure was repeated at -1500KPa. Organic carbon in the WSA was determined by the Walkley and Black method as modified by Nelson and Sommer (1982).

Statistical Analysis

Data generated from the water stable aggregates were subjected to a 6 x 2 x 3 factorial analysis of variance in Completely Randomized Design. These numbers represent the two (2) land use types, six (6) locations and three (3) aggregate sizes. Where the F - values were significant at P=0.05, the means were separated using the F LSD.

Results and Discussion

Soil organic carbon

Result revealed that land use was significant ($P \leq 0.05$) demonstrated by 25% lower aggregate soil organic carbon in the cultivated land than the forest land (Fig.1). The interaction of land use and aggregate size (Fig.2) was significant ($P \leq 0.05$) and revealed 29%, 12% and 21% higher aggregate soil organic carbon in >2mm , >0.25mm and < 0.25 mm size fraction in the forest land use respectively compared to the same size fractions in the cultivated site. However**,** the highest loss of SOC with cultivation was noticed in the >2mm macro aggregate. Ayoubi and Khormali (2000) have reported that the decline in soil organic carbon with cultivation is connected to the destruction of macro – aggregates while Ashangrie *et al., (*2005), have indicated that soil micro aggregation mediated by soil organic carbon to form macro aggregates is a labile fraction and sensitive to land use changes. The interaction of land use and location (Fig.3) was significant ($P \leq 0.05$) except in L1. Cultivation reduced SOC in L2, L3, L4, L5 and L6 by 7 %, 33 %, 33 %, 34 % and 41.5 % respectively compared to adjacent forest location. This result appears to suggest that the variations may probably be determined by textural characteristics, difference in forest species, and probably different soil management practices. Rate of soil organic carbon decline can be influenced by intensity of cultivation, type of soil texture and dominant mineralogy.

At a more detailed level of observation, which is the interaction of land use, location and aggregate size (Table 2), the same trend of higher SOC in forest soils across all locations and aggregate sizes was noted except in L1 and L2 of the arable land with higher SOC associated with >2mm compared to the adjacent forest location. This marked improvement at the highest macro aggregate level under study, probably may be ascribed to the predominant use of organic materials by farmers in these two locations. This result implies that organic farming might buffer the adverse effect of cultivation on soil organic carbon at the macro aggregate level. Furthermore, clay alone appear not to increase SOC because (i) in cultivated sites of L1 and L2, higher clay recorded in <.25 and >25mm aggregate sizes compared to the forest did not achieve a higher soil organic carbon value in the cultivated sites. (ii)L6 with very low clay content had the highest SOC at the >2mm aggregate size fraction compared to other locations with higher clay content. More study will be needed to investigate the effect of tree species and density on soil organic carbon associated with water stable aggregates. However apart from L1 and L2 it was obvious that forest conversion and subsequent cultivation decreased SOC in all locations across all aggregate sizes. This is consistent with the results of Gajic *et al.*, 2006; and Lal, 2004. SOC is a dynamic property of the soil controlling other important soil properties hence its reduction infers decline in soil quality.

Soil aggregate water retention at --33 KPa.

Land use (Fig.4) had no significant ($P \leq 0.05$) effect on water retention at this pressure potential. The interaction between land use and aggregate size (Fig.5) was significant ($P \leq 0.05$). From the result a slight but significant ($P \leq 0.05$) decline in water retained in the cultivated land use was in the magnitude of about 4 %, and 6 % in >2 mm and < 0.25 mm aggregate size respectively while surprisingly >0.25mm aggregate size in the cultivated land use showed a slight increase of about 6% of water retained despite its lower clay (Table1) and soil organic carbon content (Fig. 2) relative to the forest land use. Any way Mbagwu and Piccolo, (2004) have reported that composition and quality of soil organic matter could affect the ability of aggregates to retain water. Also the interaction of land use and location (Fig. 6) was significant ($P \leq 0.05$). Compared to the forest soil, average increase of 27 %, 18.7 %, and 11.9 % were indicated in cultivated sites of L1, L2 and L3 respectively while L4, L5 and L6 demonstrated a decline of 8.8 %, 29.5% and 30.1 % respectively. With exception of L3, it can be deduced from data on mean value of clay content of water stable aggregates in the locations (Table1), that the higher the clay content the higher the water retained by water stable aggregates regardless of land use. Grewal *et al.*, (1998), reported that clay content of the soil is the most essential factor that accounts for the differences in water retention.

Considering the combined effect of land use, location and aggregate size on the values of aggregate water retention (Table 3) L1, L2, and L3 had significantly ($P \leq 0.05$) higher water retention values in all aggregate sizes in the cultivated land use compared to the adjacent forest site except non-significant ($P \leq 0.05$).effects in < 0.25 mm of L2, >2 mm and < 0.25 mm of L3. But L4, L5 and L6 maintained higher water retention in the three aggregate sizes of the water stable aggregates in forest sites compared to the cultivated land use which might be attributed to its higher amount of clay (Table1) and SOC (Table2). The result seems to show that the higher the clay content, the higher the water retained. This might explain the higher water retained in cultivated sites of L1 and L2 compared to the forest site. Reports on water retention characteristics have shown that a combination of total clay and soil organic carbon enhance water retention at -33KPa (Rawls et al. 2003).

Soil Aggregate water retention at-1500Kpa

Land use had no significant ($P \leq 0.05$) effect on water retained at –1500KPa. (Fig.7). Also, the interaction of land use and aggregate size (Fig. 8) indicated a no significant ($P \leq 0.05$) effect on water retained in >2mm and > 0.25 mm aggregate size while about 7 % more water was retained in < 0.25 mm size fraction of the forest sites compared to the cultivated site. But interaction of land use and location (Fig.9) indicated significant reduction in water retention by 31% and 23 % in L5 and L6 respectively compared to adjacent forest soils. The higher water retention was a manifestation of the higher SOC (Fig.3) and clay content (Table1) in these forest sites which is in accord with the work of Oguike and Mbagwu, 2004 and Mbagwu *et al.,* 1993. Contrary to this result, mean values in L1, L2 and L3, indicated 14 %, 20 %, and 8 % higher water retention in cultivated sites respectively compared to the adjacent forest land (Fig.9). Values in L3 and non-significant effect in L4 cannot be explained by content of clay and organic carbon which is contradictory to the general trend of the result, However, it was clear from these results that regardless of land use, variation in water retention may be controlled by soil properties in a location such as clay and organic matter content and probably other characteristics not studied in this work.

Considering the combined effect of land use, location and aggregate size on the values of water retention (Table 4) L1, L2, and L3 had significantly ($P \leq 0.05$) higher water retention values in all aggregate sizes in the cultivated land use compared to the adjacent forest site except non-significant ($P \leq 0.05$) effects in >2mm and < 0.25 mm of L3, >.25 mm and < 0.25 mm of L2 and L1 respectively. But L4, L5 L6 maintained higher water retention in the three aggregate sizes in forest sites compared to the cultivated land use except for non-significant ($P \leq 0.05$) effect observed in >0.25mm and <0.25mm in L4 and >2mm of L6. From the result of this study, it was obvious that in about 66% of the locations (L1, L2 ,L5 and L6), water retention in the aggregate sizes was controlled by a combination of clay and soil organic carbon or either of them irrespective of land use.

However, water retention in about 33% of the locations (L3 and L4) could not be traced to either levels of soil organic carbon or clay contents as was observed that aggregates with higher clay and soil organic carbon under forest land use still exhibited lower water retention or non-significant ($P \leq 0.05$) effect. Rawls *et al* (2003) stated that relationship between soil organic carbon and water retention can be contradictory at -1500KPa pressure potential.

Conclusion

This study shows that conversion of forests to arable land caused a significant ($P \leq 0.05$) decline in soil organic carbon across all aggregate sizes and the highest decline was found in the largest aggregate.

Land use did not affect water retained at -33KPa and -1500KPa. Significant ($P \leq 0.05$) effects due to interactions of land use and location and aggregate sizes were observed. The variations in about 66% of the locations were controlled probably by a combination of clay and organic carbon content irrespective of land use while in about 33% of the locations, aggregate water retention at -1500Kpa was contradictory as it could not be traced either to clay, organic carbon content or change in land use. In two locations where organic agriculture was practiced, water retention was highest in most of the aggregate sizes in the arable land implying that organic agriculture has the potential to reduce the adverse impact of forest conversion on water retention capacities of water stable aggregates. Textural characteristics are important parameters to consider in land use change.

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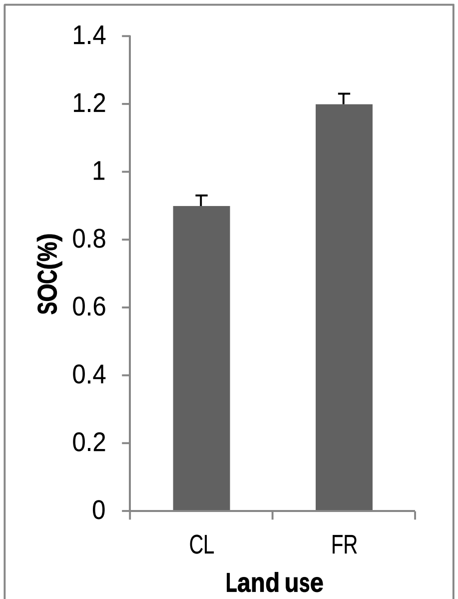

Fig.1:Effect of land use on SOC in WSA...

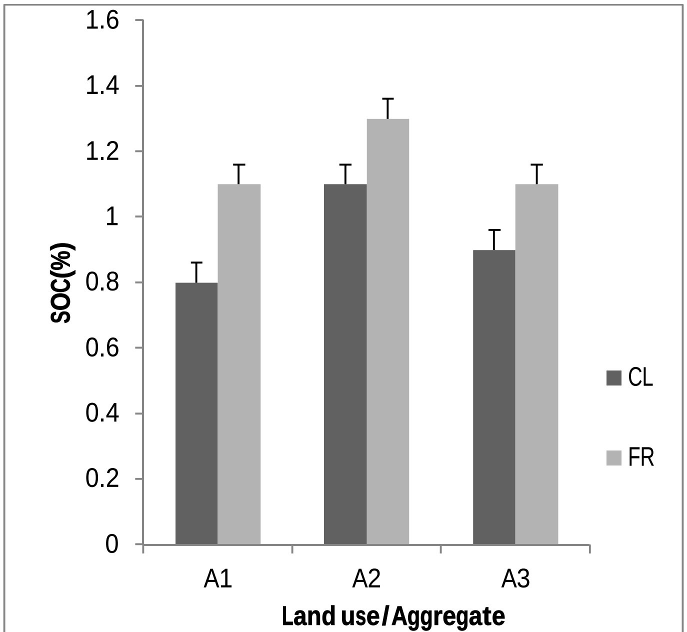

Fig. 2: Interaction ofLand use and aggregate size effect on SOC in WSA

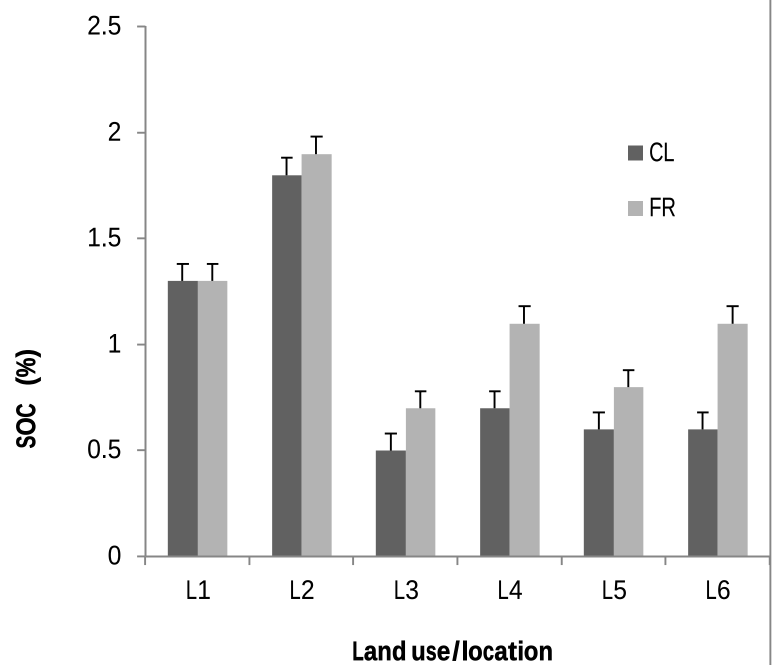

Fig. 3: Interaction of land use and location effect on soil organic carbon in WSA

CL-cultivated, FR----Forest Aggregate size: A1->2mm, A2--- >0.25mm, A3 <0.25mm
WSA-Water stable aggregate, SOC –Soil organic carbon

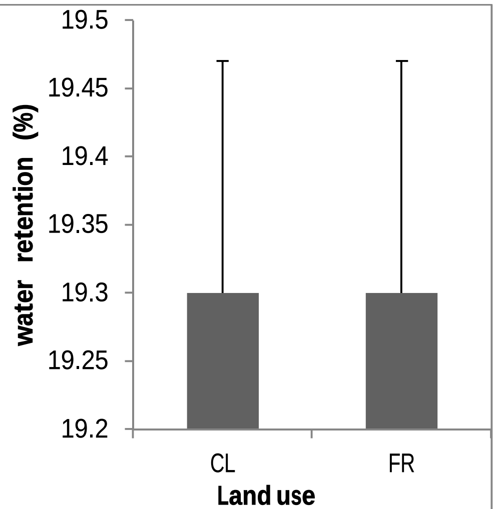

Fig. 4 Land use effect on water retention at-33KPa of WSA from forest and cultivated soils

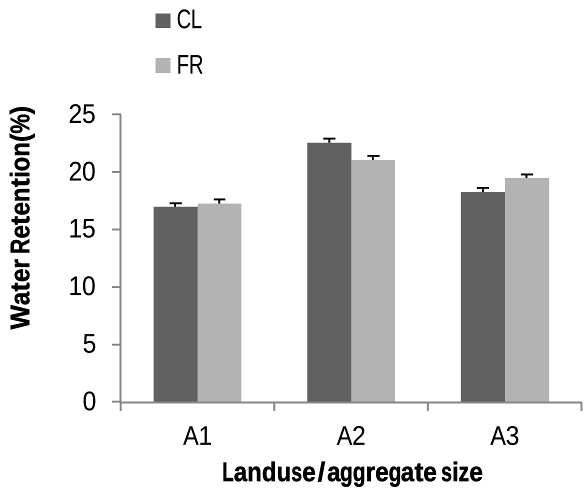

Fig. 5: Land use and aggregate size effect on water retention at -33KPa of WSA from...

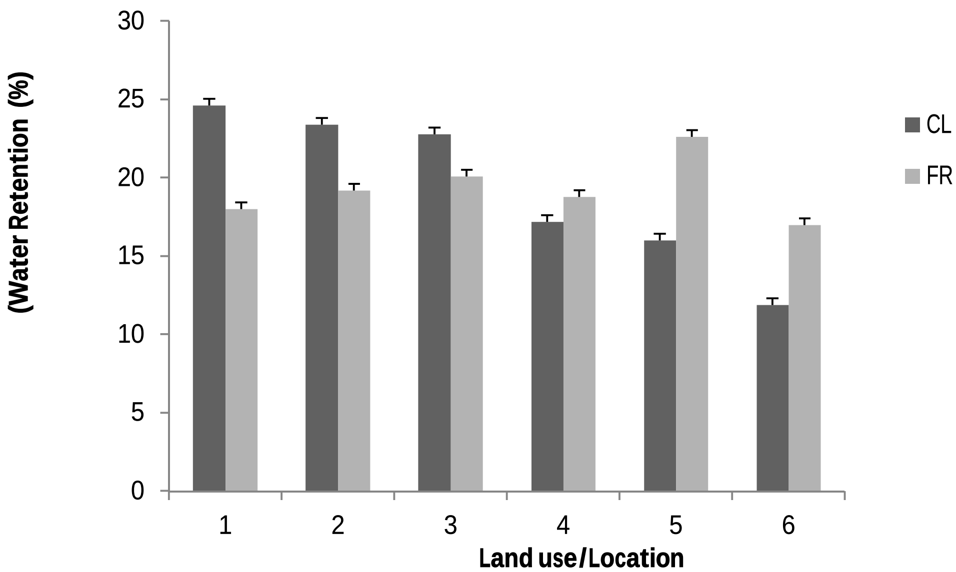

Fig. 6: I nteraction of Land use and location effect on water retention at -33KPa of WSA in forest and cultivated soils.

CL-cultivated, FR----Forest Aggregate size: A1->2mm, A2--- >0.25mm, A3 <0.25mm
WSA-Water stable aggregate

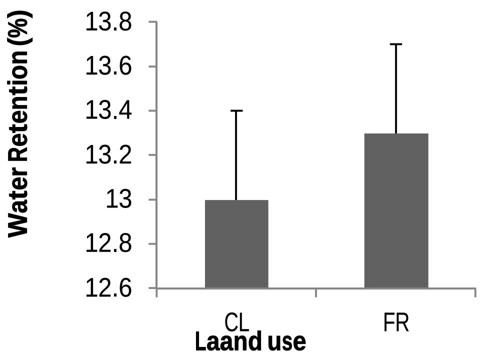

Fig. 7: Landuse effect on water retention at -1500KPa of WSAfrom forest and cultivated soils

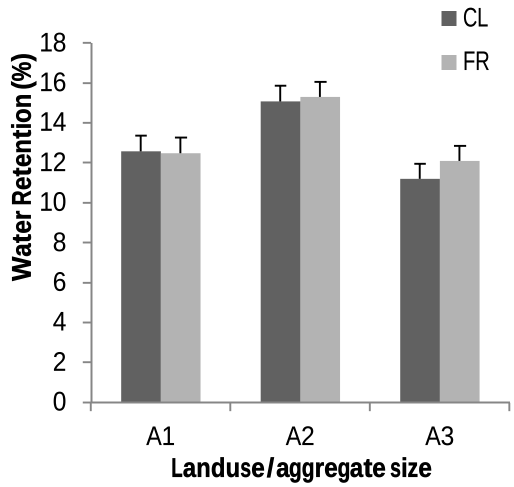

Fig. 8 :Interaction of land use and aggregate size effect on water retention at -1500KPa of WSA from...

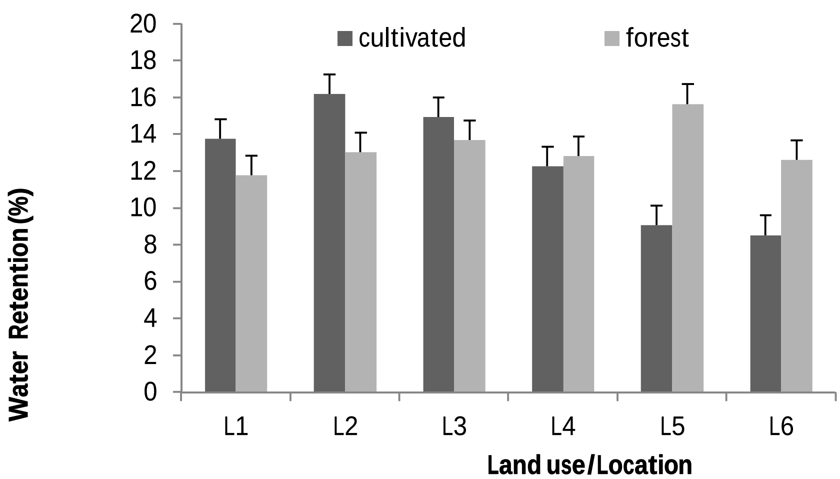

Fig. 9 : Interaction of land use and location effect on water retention at -1500KPaof WSA from forest and cultivated soil

CL-cultivated, FR----Forest Aggregate size: A1->2mm, A2--- >0.25mm, A3 <0.25mm
WSA-Water stable aggregate

Table 1: Clay content (%) in locations and water stable aggregates

Aggregate sizes	>2mm		>0.25mm		<0.25mm		Mean	
Location/landuse	CL	FR	CL	FR	CL	FR	CL	FR
L1	27	15	47	25	32	27	35	22
L2	21	9	45	35	23	24	30	23
L3	21	25	29	37	22	18	24	27
L4	11	25	31	42	22	27	21	31
L5	21	36	25	45	23	25	23	35
L6	8.0	15	6	11	6	6	7	11
Mean	18	21	31	32	21	31	23	25

Table 2: Interaction of land use, location and aggregate size on percentage soil organic carbon (SOC) in WSA from forests and cultivated soils.

Aggregate sizes	>2mm		>0.25mm		<0.25mm	
Location/landuse	CL	FR	CL	FR	CL	FR
L1	1	0.7	1.7	1.8	1.2	1.4
L2	1.0	0.6	2.2	2.4	2.1	2.6
L3	0.5	0.7	0.6	0.8	0.3	0.6
L4	0.5	1.4	0.9	1.2	0.7	0.7
L5	0.8	1.1	0.6	0.8	0.3	0.7
L6	1.0	2.0	0.3	0.6	0.7	1.1
LSD(0.05) land use*location* aggregate size			0.15			

Table 3: Interaction of land use, location and aggregate size on percentage moisture retention at –33KPa in WSA from forests and cultivated soils.

Aggregate sizes	>2mm		>0.25 mm		<0.25mm	
Location/landuse	CL	FR	CL	FR	CL	FR
L1	15.2	10.9	33.2	20.7	25.4	22.3
L2	18.9	11.1	28.6	23.1	22.7	23.3
L3	20.6	20.6	28.2	19.9	19.5	19.8
L4	16.5	18.3	16.9	19.3	18.1	18.8
L5	**17.1**	**25.6**	**15.6**	**22.2**	**15.2**	**20.1**
L6	13.6	17.2	13.3	21.4	8.8	12.4
LSD(0.05) land use*location* aggregate size			0.5			

Table 4: Interaction of land use, location and aggregate size on percentage moisture retention at –1500KPa in WSA from forests and cultivated soils.

Aggregate sizes	>2mm		>0.25mm		<0.25mm	
Location/landuse	CL	FR	CL	FR	CL	FR
L1	12.5	9.4	13.2	10.4	15.6	15.6
L2	16	10.0	16.8	15.7	15.8	13.4
L3	13.6	13.2	20.9	15.9	10.3	12.1
L4	10.0	12.4	14.6	14.6	12.2	11.5
L5	11.2	17.3	13.0	18.0	8.1	11.7
L6	12.1	12.8	12.2	17.0	5.0	8.1
LSD(0.05) land use*location* aggregate size 1.82						