

# MICRO NUTRIENT STATUS AND THEIR DISTRIBUTION IN AGGREGATE-SIZE FRACTIONS OF TROPICAL COASTAL PLAIN SANDS UNDER DIFFERENT LAND USE

Udom, B.E and Nuga, B.O

Department of Crop and Soil Science, University of Port Harcourt, P.M.B. 2353, Port Harcourt, P.M.B. 2353, Port Harcourt, Nigeria  
Corresponding author E-mail: [ebassidy@yahoo.com](mailto:ebassidy@yahoo.com)

## ABSTRACT

Micro nutrients are particularly sensitive to changes in land use and their availability in soil is influenced by their distribution and storage in stable aggregate fractions. Micro nutrient, (Fe, Mn and Zn) status and their storage in stable aggregate-size fractions in forested, rubber plantation, oil palm plantation, plantain plantation, and cassava soils were investigated. The result indicated that there were significant variations in Fe, Mn and Zn storage in whole soil and stable aggregates of the different land use types. Land use also led to changes in soil organic matter (SOM), pH and total N. The highest total N ( $4.7 \text{ mg kg}^{-1}$ ) was found in the 0-15 cm depth in forested soil, whereas, the lowest ( $2.3 \text{ mg kg}^{-1}$ ) was found in the rubber plantation soil. The highest Fe was found in oil palm and plantain plantation soils ( $103.7$  and  $89.6 \text{ mg kg}^{-1}$ ) respectively, in the topsoil, and  $132.7 \text{ mg kg}^{-1}$  and  $91.4 \text{ mg kg}^{-1}$  in the subsoil. Plantain plantation had the highest Zn and Mn storage in micro aggregates in the top and subsoil. Cassava plots had greater Fe and Zn storage in macro aggregates. This indicates that breakdown of macro aggregates to smaller fractions during cultivation in may lead to significant loss of Fe and Zn in cassava plots. Manganese (Mn) deficiency may likely occur in plantain plantation if the soil is converted to arable cropping. Iron (Fe) and Zn showed significantly negative relationship with pH ( $r = -0.461$  and  $r = -0.645$ ) respectively, indicating the significant role of soil pH in Fe and Zn availability in soils. Relationship between soil mineral particles showed that Mn increased as sand content increases, but showed inverse relationship with silt. Oil palm and plantain soils are good sources of Fe and Zn, and can be utilized in areas where these micro nutrients are limiting arable crop production.

**Keywords:** Stable aggregates, soil fertility, micro nutrient deficiency, organic matter, and nutrient storage.

## INTRODUCTION

Agriculture sustainability requires periodic evaluation of soil fertility status in terms of macro-and micro nutrients and their associations in soil aggregates, this is important in order to understand factors which impose serious constraints to crop production. Land use and management practice can influence the reserves of micro-nutrients (Smith *et al.*, 2006). Evaluation of nutrient status of soils, most especially, the micro-nutrients had hitherto been neglected. Micro nutrients have not received the amount of research attention as the macro-nutrients in Nigeria. This is because micro nutrient deficiencies are less visible and more difficult to assess in a crop field, whereas, farmers' emphases on N, P and K is due to the ability of crops to respond to these macro nutrients in a short period.

Micro nutrients are element required in very small amount for growth and development of plants (Foth and Ellis, 1997). They include Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Boron (Bo), Chlorine (Cl), and Molybdenum (Mo). Availability of micro-nutrients in the soil is influenced by their distribution in soil aggregate size fractions (Ibrahim *et al.*, 2011). Other soil physical properties such as soil structure, texture and temperature also influence the reserves and supply of micro-nutrients for optimum growth of plants and synthesis of plant food (Sharma and Chaudhany, 2007). The fact that micro nutrients are not

regularly added to soils by fertilizer application, has made them to become increasingly depleted, as crop removal of these essential elements continue without conscious effort by farmers to replenish the lost micro-nutrients.

Soil and plant tissue tests confirmed that Fe, Mn and Zn are limiting crop production over wide areas in the tropics. In most tropical environment, conversion of forest vegetation to agricultural land and the resultant decline in soil organic matter (SOM) and structural stability is one of the major production constraint (Chhabra *et al.*, (1996). Soil organic matter and soil aggregate size classes are crucial to micro-nutrient behaviour and soil fertility (Christensen, 1992; Miller and Gardinor, 2001). Micronutrients have positive relation with fine mineral fraction like clay and silt, while negative relations exist with coarse sand particles (Quiroga *et al.*, 1996). Micronutrients are also particularly sensitive to changes in land use (Proffitt *et al.*, 1996). It is speculated that the total levels of micro-nutrients in the soil are rarely indicative of plant availability, because their availability depends certain parameters such as soil pH, SOM and other physical, chemical and biological properties of the soil. Chhabra *et al.*, (1996) observed that availability of Mn, and Fe decreased with soil pH, and availability of Cu decreased with clay and soil organic carbon, whereas availability of Fe decreased as sand content increased.

Land use and management practices have been recognized increasingly as major drivers in the formation and stabilization of aggregates-associated micro-and macro-nutrients in the soil (Whalen and Chany, 2002). Assessing the effects of land use on micro-nutrient and their association in stable aggregates may provide essential information for assessing sustainability and environmental impact of changes in land use. Characterization of micro-nutrients, especially Fe, Mn and Zn status in soils under different land use in some West African soils will make valuable contribution to improving management of the ecosystem for sustainable productivity (Marquez *et al.*, 2004). However, there is poor knowledge and insufficient information on the distribution of these important micro-nutrients in soil and stable aggregates of most Nigerian soils. A few studies (Ibrahim *et al.*, 2011) reported that micro-nutrient availability in soil was influenced by their distribution in soil aggregates. Knowledge on the potential losses of micro-nutrients during aggregate disruption is very important in evaluating chemical fertility losses through soil erosion because soil particles are selectively removed during soil erosion. This study examined the distribution of Fe, Mn and Zn in stable aggregate fractions under various land use types in order to bridge the gap in current knowledge and provide input data to improve our knowledge on impact of land use on Fe, Mn and Zn reserves in the soil and stable aggregate size fractions.

## **MATERIALS AND METHODS**

### **Site Description and Sampling**

The study was carried out in University of Port-Harcourt within the south-south Agro-ecological zone of Nigeria, lying along the Bonny River (Latitude 04° 15<sup>1</sup>N and Longitude 07° 30<sup>1</sup>E). The soil is derived from unconsolidated coastal plain sands and alluvium of the Niger Delta (Soil Survey Staff, 1993). The area is characterized by the tropical hot humid rainforest climate with heavy rainfall between the months of April and October. Mean annual rainfall range from 2000 mm to 2500 mm. Five (5) land use types in 6 replications were selected viz:

0- Forested: Area under permanent vegetation with trees. 1- Rubber Plantation: In a flood plain with sparse vegetation; dominated by goat weed. (*Ageratum canyzoides*), guinea grass (*Panicum maximum*), *Cyanodon dactylon*, and herbs such as *Chromoleana odoraty*. 2- Oil Palm Plantation: Dominated by under growth shrubs (*Alchornea cordifolia* and *Ficus exasparata*). 3- Plantain Plantation: Dominated by under growth grasses such as: *Panicum*

*maximum*, goat weed (*Ageratum canyzooides*) and *Cyanodon dactylon*. 4- Cassava farm: Under continuous cropping. All the land use types studied have been under permanent condition for more than 15 years, each occupying an area of at least 10 hectares.

### **Soil Sample Collection**

Soil samples were collected in each of the 5 land use types at 0-15 and 15-30 cm depths. A total of 60 soil samples were collected (30 samples each at 0-15 cm and 15-30 cm). The soil samples were air-dried, sieved with 2 mm mesh sieve and stored in plastic containers for laboratory analysis. Soil samples for the determination of Fe, Mn and Zn in dry aggregates were sieved through nest of sieves of diameter 4.75, 2.0, 1.0, 0.5, and 0.25 mm.

### **Laboratory Analysis**

Particle size-distribution was determined by the Gee and Bauder (1986) method after dispersion with sodium hexametaphosphate. Soil pH was measured in glass electrode using a 1:2.5 soil/water ratio (McLean, 1982). Total organic carbon was determined by wet oxidation dichromate method (Nelson and Sommers, 1996) and converted to organic matter by multiplying the organic carbon value by the Van Bemmelen factor of 1.724 (Van Der Ploeg *et al.*, 1999).

### **Determination of Micro nutrients in Whole Soil and Dry Aggregates**

Dry soil aggregates 5.0-2.0, 2.0-1, 1-0.5, 0.5-0.25, and <0.25 mm size range were obtained by sieving the soil samples through a nest of sieves using the procedure of Hillel (2004). The fraction of stable aggregates  $\geq 0.25$  mm in diameter are defined as macro aggregates, and fraction of stable aggregate < 0.25 mm in diameter are defined as micro aggregates. Aggregate fractions collected on each sieve were stored and used for determination of the micronutrient. The micro-nutrients in the samples were extracted with concentrated HNO<sub>3</sub>-HCl in ratio of 3:2 (Carter, 1993). Micronutrients (Fe, Mn, and Zn) in the extract were determined using the atomic absorption spectrophotometer (AAS) Varian Spectra AA220FS. All determinations were in triplicates.

### **Data Analysis**

Statistical analyses were carried out using the SAS software (SAS Institute, 2001). Means were separated using the least significant difference FLSD according to the procedure of Fisher's protected test (Gomez and Gomez, 1984).

## **Results and Discussion**

### **Physico-chemical Properties**

The soils are dominantly sandy loam to loamy sand, with sand content ranging from 893 g kg<sup>-1</sup> in 0-15 cm to 810 g kg<sup>-1</sup> in 15-30 cm depths. However, the land use types did not alter the dominant textural class of these soils (Table 1). There was significant ( $P < 0.05$ ) difference in pH among the land use types in 0-15 cm and 15-30 cm. Low pH (4.8) was found in the oil palm and cassava soils in 0-15 cm and 4.7 and 4.2, respectively (Table 1). The low pH observed in cassava and oil palm plantation soils is an indication that cassava and oil palm have tendencies to reduce the pH of cultivated soils. The reason is most probably due to increased absorption of basic cation by these crops. The type of fertilizer used for these crops may also lead to the observed low pH (Brandy and Weil, 1990). Total N was highest in the topsoil (0-15 cm) of the forest soil, while plantain plantation had the highest N in the subsoil (15-30 cm) (Table 1). This could be explained by the fact that there is litter accumulation on the surface soil in the forest, which on decomposition liberates both basic cations in nitrogen into the surface soil. Six *et al.*, (2002) had reported the key roles played by SOM and aggregates which promote the reserves of both macro- and micro-nutrients. Rubber plantation had the lowest total N in the surface and subsoil, explaining that rubber contributes a little to N storage in the soil.

### **The Micronutrients**

#### **Iron (Fe)**

Distribution of Fe in the soils studied showed the highest level at the 0-15 cm and 15-30 cm depths in the oil palm plantation (103.7 mg kg<sup>-1</sup> and 132.7 mg kg<sup>-1</sup>) respectively, while Forest soil had the least Fe level both for the top and subsoil. Iron (Fe) levels among the land use in the surface soil (0-15 cm) was in the order of oil palm > plantain > cassava > rubber > forested, while in the subsoil (15-30 cm), the trend in distribution of Fe was in the order of oil palm > plantain > cassava > forested > rubber. Relationship between Fe and soil pH indicated that as soil pH decreased, Fe concentration increased ( $r = -0.461$ ,  $p < 0.05$ ) (Table 3). This implied that at low pH, Fe concentration in the soil will increase. Rajakumar *et al.* (1996) and Chinchmalatpure *et al.* (2000) had earlier obtained negative relationship between Fe and soil pH. Distribution of Fe in dry aggregates was highest in oil palm plantation soil in 5-2 mm and 2-1 mm aggregate size fractions, while cassava soil had the highest Fe content in the 0.5-0.25 mm aggregates (Figure 1). Micro aggregates < 0.25 mm had equal Fe distribution in the surface soil rubber, oil palm plantain and cassava soils, and while at 15-30 cm; forest soil had the highest content of Fe.

**Table 1: Some physical and Chemical Properties of the soil as influence by land use types**

Land use	Particle size (g kg <sup>-1</sup> )			Textural class	N (g kg <sup>-1</sup> )	OM (g kg <sup>-1</sup> )	pH (H <sub>2</sub> O)
	Sand	Silt	Clay				
<b>0-15 cm</b>							
Forested	782 <sup>a</sup>	124 <sup>b</sup>	94 <sup>a</sup>	SL	4.7 <sup>b</sup>	36.7 <sup>a</sup>	5.8 <sup>c</sup>
Rubber	762 <sup>a</sup>	183 <sup>c</sup>	55 <sup>b</sup>	SL	2.3 <sup>a</sup>	27.3 <sup>c</sup>	5.5 <sup>c</sup>
Oil palm	882 <sup>b</sup>	74 <sup>a</sup>	44 <sup>b</sup>	LS	3.7 <sup>c</sup>	27.0 <sup>c</sup>	4.8 <sup>b</sup>
Plantain	893 <sup>b</sup>	82 <sup>a</sup>	25 <sup>c</sup>	LS	3.3 <sup>c</sup>	30.3 <sup>b</sup>	5.0 <sup>b</sup>
Cassava	884 <sup>b</sup>	94 <sup>a</sup>	22 <sup>c</sup>	LS	3.9 <sup>c</sup>	33.6 <sup>d</sup>	4.8 <sup>b</sup>
<b>15-30 cm</b>							
Forested	742 <sup>a</sup>	178 <sup>b</sup>	80 <sup>a</sup>	SL	2.3 <sup>c</sup>	23.9 <sup>a</sup>	5.8 <sup>b</sup>
Rubber	722 <sup>a</sup>	179 <sup>b</sup>	99 <sup>a</sup>	SCL	1.5 <sup>b</sup>	22.9 <sup>b</sup>	5.7 <sup>b</sup>
Oil palm	769 <sup>b</sup>	146 <sup>c</sup>	85 <sup>a</sup>	SL	2.3 <sup>c</sup>	15.8 <sup>c</sup>	4.7 <sup>a</sup>
Plantain	781 <sup>b</sup>	130 <sup>c</sup>	89 <sup>a</sup>	SL	2.6 <sup>a</sup>	19.2 <sup>d</sup>	4.9 <sup>a</sup>
Cassava	810 <sup>c</sup>	142 <sup>c</sup>	48 <sup>b</sup>	SL	2.1 <sup>c</sup>	20.4 <sup>d</sup>	4.2 <sup>c</sup>

Means followed by the same letters within column were not significantly different at  $P > 0.05$

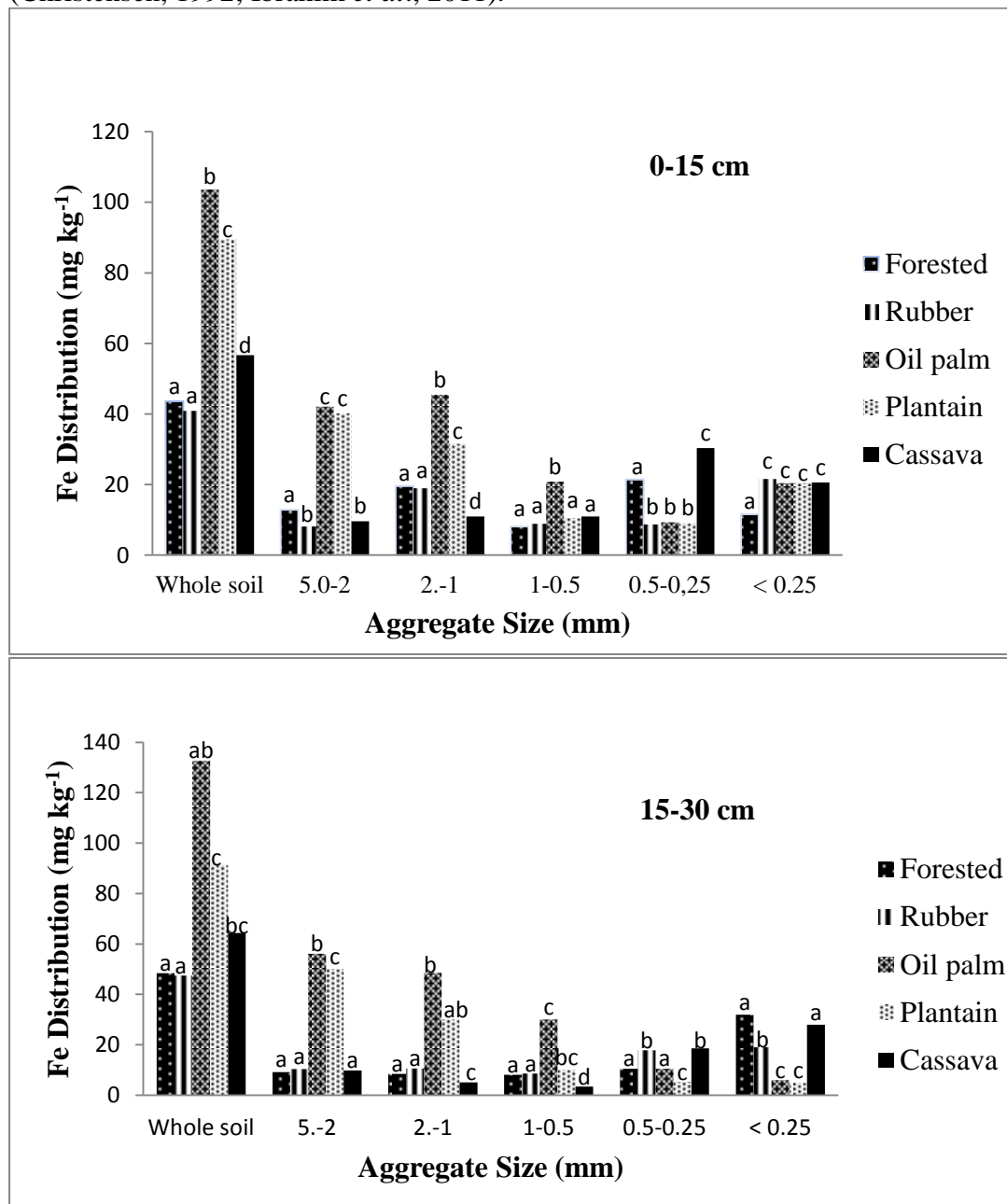
**Table 2: Iron, Manganese and Zinc distribution in land use types**

Land use	Fe (mg kg <sup>-1</sup> )	Mn (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
<b>0-15cm</b>			
Forested	43.6 <sup>d</sup>	36.8 <sup>ab</sup>	25.0 <sup>c</sup>
Rubber plantation	40.9 <sup>d</sup>	23.00 <sup>a</sup>	39.3 <sup>a</sup>
Oil palm plantation	103.7 <sup>a</sup>	56.9 <sup>c</sup>	41.5 <sup>a</sup>
Plantain plantation	89.6 <sup>b</sup>	68.5 <sup>b</sup>	88.0 <sup>b</sup>
Cassava Farm	56.7 <sup>c</sup>	76.1 <sup>b</sup>	26.9 <sup>c</sup>
<b>15-30cm</b>			
Forested	48.4 <sup>a</sup>	49.2 <sup>a</sup>	23.8 <sup>a</sup>
Rubber plantation	47.5 <sup>a</sup>	36.9 <sup>ab</sup>	21.1 <sup>a</sup>
Oil palm plantation	132.7 <sup>b</sup>	64.3 <sup>c</sup>	50.4 <sup>b</sup>
Plantain plantation	91.4 <sup>c</sup>	74.3 <sup>d</sup>	72.4 <sup>c</sup>
Cassava Farm	64.3 <sup>d</sup>	82.2 <sup>b</sup>	24.8 <sup>a</sup>

Means followed by the same letters within column are not significantly different at  $P > 0.5$

The lowest Fe storage (8.1 mg kg<sup>-1</sup>) was found in 5-2 mm dry aggregates for rubber soil and in 1-0.5 mm for forested soils. The high storage of Fe in macro aggregates > 0.5 mm at 0-15

cm depth for oil palm and plantain soils suggest that enormous amount of this micro nutrient can be lost from the soil during aggregate disruption by rain drop impact or frequent tillage (Christensen, 1992; Ibrahim *et al.*, 2011).



**Figure 1: Distribution of iron (Fe) in aggregate sizes as affected by land use types. Columns followed by the same letter for each aggregate size were not significantly different at  $P < 0.05$**

### Manganese (Mn)

The Mn concentration was significantly ( $P < 0.05$ ) higher in the cassava and plantain soils compared to other land use types at the top 0-15 cm depth (Table 2). The highest Mn storage (76.1 and 82.2 mg kg<sup>-1</sup>) was found for the cassava farm at 0-15 cm and 15-30 cm respectively, while the lowest Mn content was obtained in the rubber plantation soil at similar depths. There was a positive relationship between Mn and sand content ( $r = 0.524$ ,  $p < 0.05$ ) and a negative relationship between Mn and silt ( $r = -0.506$ ). This indicates that more Mn can be found in sand than in silt, explaining that soils with high sand content are rich in Mn (Table 3). Similar observation has been reported by Ibrahim *et al.*, (2011) when they obtained

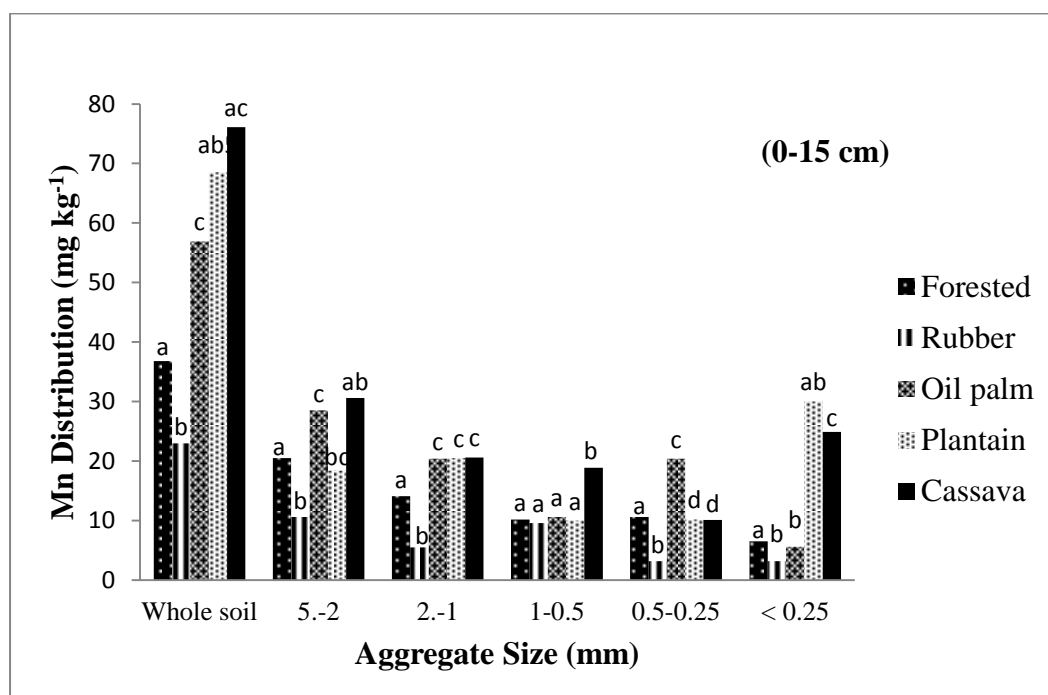
a negative correlation between Mn and silt. Also Mn had a non-significant negative relationship with clay.

**Table 3: Correlation “r” between micronutrients and some soil properties (N = 10)**

Micronutrients (mg kg <sup>-1</sup> )	OM (g kg <sup>-1</sup> )	pH (H <sub>2</sub> O)	N (g kg <sup>-1</sup> )	Sand (g kg <sup>-1</sup> )	Silt (g kg <sup>-1</sup> )	Clay (g kg <sup>-1</sup> )
Fe	0.055 <sup>ns</sup>	-0.461 <sup>*</sup>	-0.310 <sup>ns</sup>	0.239 <sup>ns</sup>	-0.173 <sup>ns</sup>	-0.294 <sup>ns</sup>
Mn	0.114 <sup>ns</sup>	-0.263 <sup>ns</sup>	0.392 <sup>ns</sup>	0.524 <sup>*</sup>	-0.506 <sup>*</sup>	-0.445 <sup>ns</sup>
Zn	-0.061 <sup>ns</sup>	-0.645 <sup>**</sup>	0.268 <sup>ns</sup>	0.370 <sup>ns</sup>	-0.380 <sup>ns</sup>	-0.279 <sup>ns</sup>

NS –not significant, \* significant at P ≤ 0.05, \*\* significant at P ≤ 0.01

Manganese storage in macro aggregates was particularly higher for cassava and plantain soils and lowest for rubber soil (Figure 2). Micro aggregates < 0.25 mm have the highest Mn for plantain soil at 15-30 cm depth.



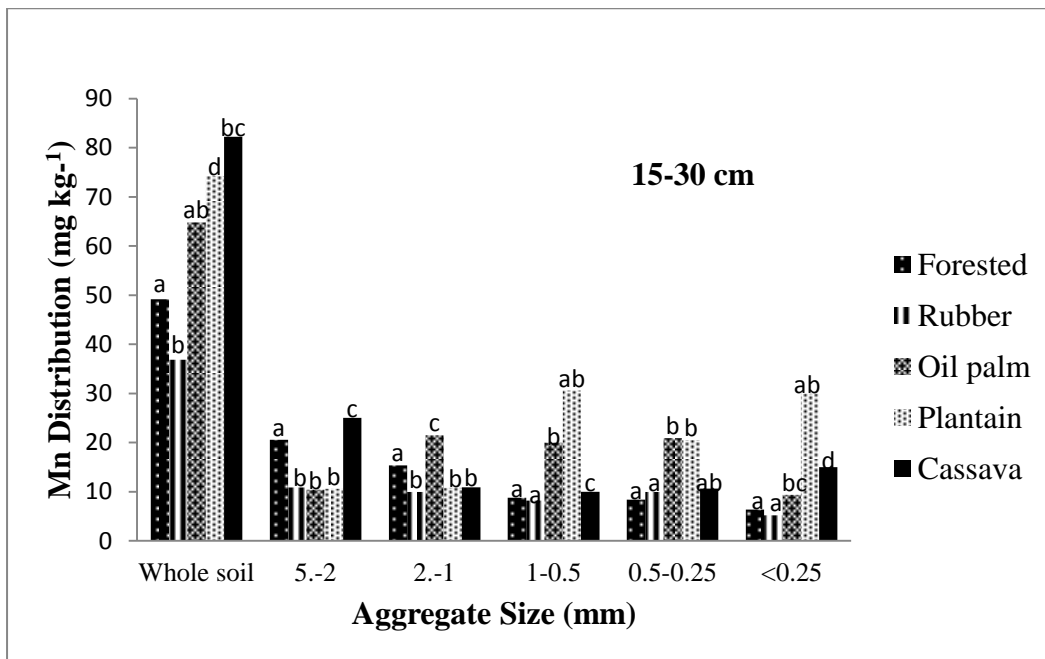
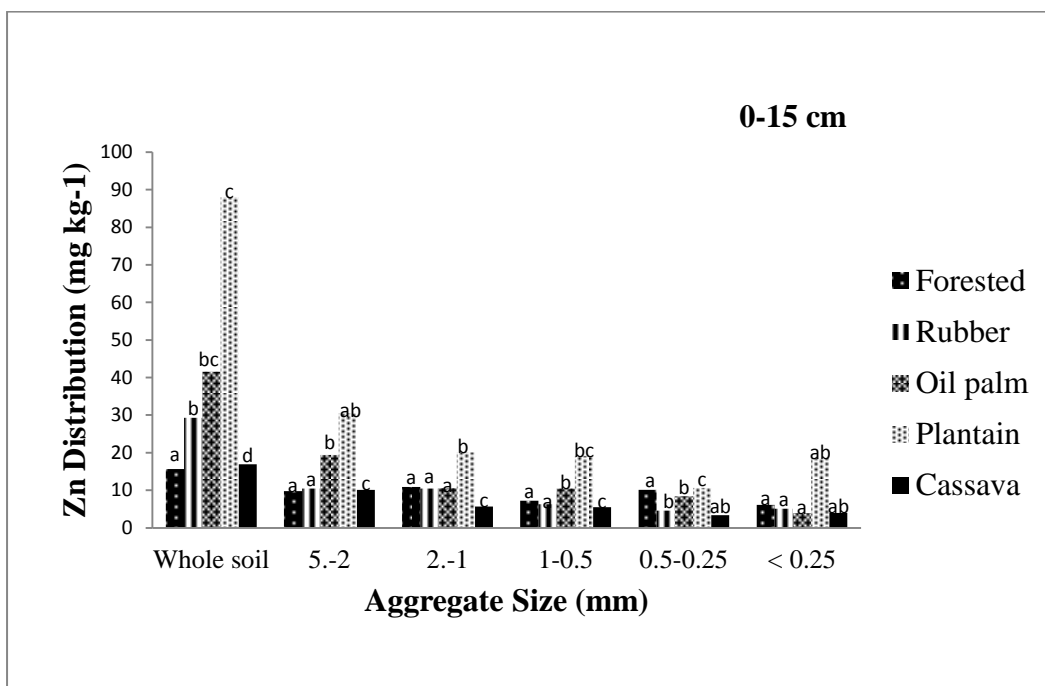


Figure 2: Distribution of manganese (Mn) in aggregate sizes as affected by land use types. Columns followed by the same letter for each aggregate size were not significantly different at  $P < 0.05$ .



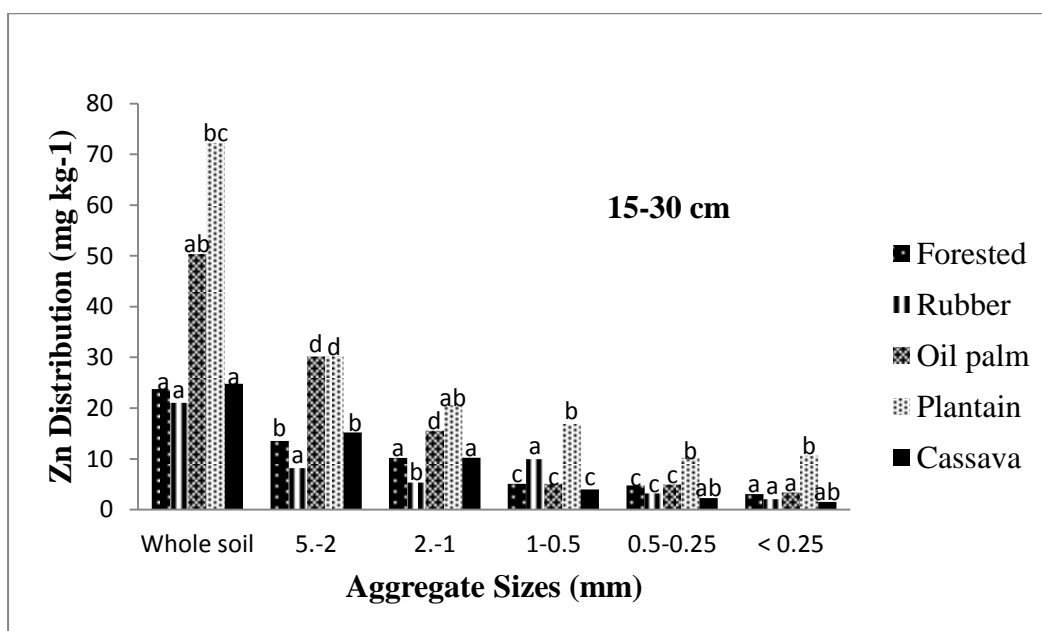


Figure 3: Distribution of zinc (Zn) in aggregate sizes as affected by land use types.

Columns followed by the same letter for each aggregate size were not significantly different at  $P < 0.05$ .

### Zinc (Zn)

The Zn concentration was significantly ( $P < 0.05$ ) different among land use types. The highest concentration of Zn ( $88.0 \text{ mg kg}^{-1}$ ) was found at 0-15 cm soil in plantain soil and also 15-30 cm depth ( $72.4 \text{ mg kg}^{-1}$ ) (Table 2). The lowest concentration of Zn was found for the forested soil at 0-15 cm depth. There was a negative relationship between Zn concentration and soil pH ( $r = -0.645$ ,  $p < 0.01$ ) (Table 3). It was observed that, Zn was negatively and significantly correlated with soil pH. Similar relationship had earlier been reported by Nazif *et al.*, (2006) and Perveen *et al.* (1993), and ascribe to organic matter (OM) decomposition in the soil. Zinc (Zn) storage was significantly ( $P < 0.05$ ) higher in whole soil and macro aggregates in plantain soil at 0-15 and 15-30 cm depths (Figure 3). Forest and cassava soils had significant ( $p < 0.05$ ) Zn storage in 5-2 mm dry aggregates. This suggest that oil palm and plantain soils are good sources of Zn, and can be utilized in areas where Zn is limiting growth of arable crops.

### CONCLUSION

Conclusions drawn from this study are that:

- i. There were significant variations in storage and distribution of Fe, Mn and Zn in whole soil and stable aggregates for the different land use types.
- ii. Oil palm and plantation soils have the highest levels of Fe in the top and sub-soil, while Mn storage was higher in cassava soil and Zn greater in plantain soils.
- iii. Plantain soils had the highest storage of Mn in micro-aggregate  $< 0.25$  mm, while, macro-aggregates  $> 1.0$  mm had the highest storage of Fe in oil palm plantation, and Zn in plantain plantation.
- iv. Breakdown of macro-aggregates to smaller size classes in these soils may lead to loss of Fe in oil palm plantation and loss of Zn in plantain plantation.
- v. There is tendency of Fe deficiency in rubber soil .
- vi. In forested soils, Fe, Mn and Zn were well distributed within macro and micro aggregate. Land use types that sustain crop production and protect soil aggregate against disruption will conserve soil resources.



## REFERENCES

- Brady, A.C. and Weil, R.R. (2002). The nature and Properties of Soils. 13<sup>th</sup> Ed. Prentice Hall, New Jersey.
- Carter, M.R. (1993). Soil Sampling and Methods of Analysis. Lewis Publishers. Boca Raton, Florida. 368pp.
- Chhabra, D. Srivastava, P.C., Ghosh, D. and Agrihotri, A.K. (1996). Distribution of available micronutrients cations as related to soil properties in different soil zones of Gola-kosi Interbasin. *Crop Research Hisar* 11: 296-303.
- Chinchmalatpure, A.R., Brij-Lal, O., Challa, J. and Sehgal, A. (2000). Available micronutrient status of soils in different parent material and landforms in a micro-water shed of Wuma catchment near Nagpur (Maharashtra). *Agropedology* 10: 53-58.
- Christensen, B.T. (1992): Physical fractionation of soil organic matter in primary particles and density separates. *Advances in Soil Science* 20:1-76.
- Foth, H.D. and Ellis, B.G. (1997). Soil Fertility. 2<sup>nd</sup> Edition. Lewis CRC Press LLC, USA, 290P.
- Gee, G.W., Bauder, J.W. (1986). Particle size analysis. In: *Methods of Soil Analysis*. Part 4, *Physical Methods*. Dane, J.H., Topp, G. C. (ed). *Soil Science Society of America*. Madison WI. pp 255-293.
- Gomez, K.A., Gomez, A.A. (1984). Statistical Procedures for Agricultural Research. 2<sup>nd</sup> ed. *Wiley Interscience Publication*, Singapore, pp 680.
- Hillel, D. (2004): Introduction to Environmental Soil Physics. *Elsevier Academic Press*, Amsterdam, pp. 494.
- Ibrahim A.K. Usman, A., Abubakar, B. and Aminu, U.H. (2011). Extractable Micronutrients Status in Relation to other soil properties in Billiri Local Government Area. *Journal of Soil Science and Environmental Management* 3:282-285.
- Marquez, C.O., Garlia, V.T.; Cambardella, C.A.; Schultz R.C. and Isenhardt, T.M. (2004). Aggregate-size stability distribution and soils stability. *Soil Science Society of American Journal* 68:725-736.
- Mclean E. O. (1982). Soil pH and Lime Requirement. In: Page, A.L.(ed). *Methods of Soil Analysis*, Part 2, 2<sup>nd</sup> ed. *Agronomy Monograph* 9, ASA-SSSA Madison WI:Pp 199-224.
- Miller, R.W. and Gardiner, D.T. (2001). Soils in our environment. 9<sup>th</sup> Edition. Prentice Hall In: Englewood cliffs, New Jersey: 671p.
- Nazif, W., Sajida, P. and Saleem, I. (2006). Status of micronutrients in soils of Districts Bhimber (Azad Jammu and Kashmir). *Journal of Agriculture and Biological Science* 1:25-35.
- Nelson, D. W., and Sommer, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page, A.L. (ed). *Methods of Soil Analysis*. Part 2, 2<sup>nd</sup> ed. Chemical and Microbiological Properties. *Agronomy Monograph*. 9. ASA-SSSA. Madison, W.I. Pp 539-579.
- Perveen S., Tarig M., Farmanullah, J., Khattak, K., and Hamid, A. (1993). Study of micronutrients status of some important sites of N.W.F.P. Pakistan, *Sarhad Journal of Agriculture*, 9:467-473.
- Proffitt, R.L., Scott, N.A., Ross, D.L., Sait, G.J. and Fate, K.R. (2003). Land use change effects on soil C and N transformations in soils of high N status: comparisons under indigenous forest pasture and pine plantation. *Biogeochem.* 66:20-227.
- Quiroga, A.R., Buschiazzo, D.E. and Peinemann, N. (1996). Soil organic matter particle size fractions in soils of the semi and Argentinian Pampas. *Soil Organic Matter* 161:104-108.

- Rajakumar G.R., Patil C.V., Prakash, S.S., Yeledhalli, N.A. and Math, K.K. (1996). Micronutrient distribution in Paddy soils in relation to parent material and soil properties. *Karnataka Journal of Agriculture Sciences*. 9:231-235.
- SAS (Statistical Analysis System) (2001). Institute SAS/STAT User`s Guide, 4<sup>th</sup> ed. Vol. 1, *SAS Inst.* Cary NC, USA
- Sharma, J.C. and Chaudhary, S.K. (2007). Vertical distribution of micronutrient cations in relation of soil characteristics in lower Shialika of Solan District in North West Himalayas. *Journal Indian Society of Soil Science* 55:40-45.
- Six, J., Conant, R.T., Paul, E.A., Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implication for C-saturation of soils. *Plant and Soil* 241,155-176.
- Smith, L.C., Alderman, H. and Aduayom, D. (2006). Food Insecurity in Sub Sahara Africa. New estimate from household expenditure surveys, Research Report, *International Food Policy Research Institute*, Washington DC: 122.
- Soil Survey Staff (1993). Soil Survey Manual, USDA, Soil Conservation Service, Agricultural Handbook No. 18, U.S. Govt. Print office, Washington, D.C. pp. 503
- Van Der Ploeg, R.R., Bohm, W. and Kirkham, M.B. (1999). "On the origin of the theory of mineral nutrition of plants and the law of the minimum". *Soil Sci. Soc. Am. J.* 63:1055-1062.
- Whalen, J.K. and Chany, C (2002). Macro-aggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Sci. Soc. Amer. J.* 66:1637-1647