EFFECTS OF LONG-TERM CATTLE GRAZING ON STRUCTURAL STABILITY AND SOME CHEMICAL PROPERTIES OF A SEASONALLY FLOODED VERTISOL

Udom,B.E., Nuga,B.O and Kamalu, O.J

Department of Crop and soil science University of Port Harcourt, P.M.B 5323, Port Harcourt, Nigeria
e-mail: ebassidy@yahoo.com

ABSTRACT

Destruction of soil structure can increase surface runoff with adverse consequences, leading to reduction in the area of land available for crop production. The impacts of long-term grazing by cattle on the structural stability and some chemical properties of a heavy clay soils, periodically submerged by water were studied. Results showed that total organic carbon (TOC) was high in the cattle grazing soil due to contributions from the cattle residues, but the organic residues did not enter into close associations with the soils aggregates. Mean weight diameter (MWD) of water-stable aggregates ranged from 1.16 to 1.13 mm in the cattle grazing soils and between 1.22 and 1.92 mm in the non-cattle grazing soil. More than 70% of aggregate sizes > 0.25 mm were stable in the 0-25 cm depth in all the profiles. Aggregated silt and clay was about 30% in the cattle grazing soils and 26% in the control. This development may be due to the shrinking and contracting behaviour of the soil rather than the residues from the cattle. Clay dispersion index (CDI) value of $0.3gg^{-1}$ and the negative values in potential structural enhancement index (PSEI) in the 0-25 cm and 25-50 cm soil indicate deleterious impact of cattle grazing on the soil structure. There was significant ($P<0.01$) positive correlation between ASI and MWD in Assang soils. Whereas increases in ASI lead to increases in MWD, the significant (P<0.01 positive correlation (r= 0.726) between CDI and OC in Assang soils implies that organic matter acted as disaggregating agent when not in close association with the soils particles. The exchangeable Ca, Mg and K were significantly high in the cattle grazing soils, evidencing the high chemical fertility of such soils. Intensive grazing by cattle promotes deformation of soil structure, especially under uncontrolled soil moisture content. Tillage within optimal moisture content will enhance the location of Ca, Mg, K and N for plant growth.

Key words: Structural stability, cattle grazing, heavy clay soil, organic carbon.

INTRODUCTION

Research on degradation of soil structure due to compaction has been heavily concentrated on arable agriculture. Increasing traffic of agricultural machines through the soil has been identified as one of the leading problems causing soil structural degradation (Canillas) and Salokhe, 2002). Different soil uses had also been reported to affect the physical and mechanical soil properties causing compaction and restricting root penetration (Gysi, 2001: Dias Junior, 2000. Horn *et al.*,(2000). It is however, less commonly recognized that animals may also destroy soil structure.

Aggregated type of soil structure is generally the most desirable condition for plant growth, especially on the critical early stages of germination and seedling establishment. The formation and maintenance of stable aggregates is the essential feature of the soil tilth, a qualitative term used to describe that highly desirable physical condition in which soil is optimally loose, friable and contains a porous assemblage of stable aggregates. This is turn permit free entry and movement of water and air, easy cultivation as well as germination, and emergence of seedlings and growth of roots (Hillel, 1982).

Destruction of soil structure has been shown to occur by cattle trampling even on coarse textural soils (Mulholland and Fullen, 1991), by the grazing of sheep on clay loam soil (Proffitt *et al.* 1995), and by cattle trampling on pasture in the Alps (Horn,1986). In the tropics when the soil is wetter than optimal for wheel traffic, excessive trampling by cattle decrease total porosity, size and continuity of the pores (Udom *et al.*, (2009). It also limits nutrient uptake, water infiltration and redistribution, seedling emergence and root development (Arvidson, 2001). In forest areas, soil structure degradation process has been occurring due to the traffic of harvest operations and wood transport under inadequate soil water conditions (Dias Junior, 2000). During the peak of rains, the destroyed soil structure however, will increase the ponding of the water and surface runoff and, consequently, increases vulnerability of soil to water erosion. In pastures with high P status at the soil surface due to cattle wastes and high organic residues, delayed infiltration can occur. On the other hand, aggregate breakdown and subsequent clay dispersion could occur due to organic matter dissolution and high microbial population associated with the cattle grazing activities. Thus, it can be speculated that intensive grazing by cattle promotes deformation of soil structure and accumulations of partially decomposed organic matter in the soil. Thus, these soils are either underutilized or completely abandoned for agricultural production due to lack of adequate knowledge on the physical conditions of such soils in order to define agricultural management practice which is compatible with the soils. Determination of the state of aggregation and structural stability of soils have been performed using various indices, but no universal prescription could be offered on which of these indices is preferred. The present study was undertaken to show the effects of intensive cattle grazing on preferred structural stability indices and some chemical properties of a fine-textured soil so as to understand how to manage such soil to increase the area of land available for arable agriculture.

MATERIALS AND METHODS

The study was carried out at Assang and Okpo (Lat. 5^0 16^1N and Long 7^0 58^1E) in Southern Nigeria. The site has been under intensive cattle grazing activities between 1994 - 2010. It occurs on nearly level lowland, floodplain of Enyong Creek. The soil is very poorly drained with clay content >700gkg $^{-1}$ and usually submerged by flood for over four weeks at the peak of rains. The soil when dried developed polygonal cracks whose width and depth depend on moisture content (Fig 1). The soil is derived from sub-recent alluvium and classified as Vertic epiaguults (USDA, 2008). Four (4) representative profile pits represented by Assang 1. Assang 2, Assang 3 and Assang 4 were sited at the area under intensive cattle grazing and another profile pit (control) represented by Obiousiere on the same area (about 500 m) but without cattle grazing activities. Disturbed and undisturbed core soil samples were collected in triplicate at 0-25, 25-50, 50-75-100, 100-125, and 125-150 cm depths, for determination of some physical and chemical properties.

Determination of Structural Stability Indices

Aggregate Stability Index

This was calculated by the method of pieri (1992) as:

$$\text{ASI} = \frac{1.72\,\text{OC (wt.\%)}}{(\text{Clay} + \text{silt})\,(\text{wt.\%})} x \frac{100}{1} \qquad (1)$$

Where ASI (%) is soil structural stability index, OC is organic carbon, and (clay + silt) is the soil's combined clay and silt content. ASI $\leq$ 5% indicates structurally degraded soil, ASI $\leq$ 7% indicates high risk of structural degradation, ASI $\leq$ 9% indicates low risk of soil structural degradation, and ASI > 9% indicates structurally stable soil.

Water-stable aggregates and Aggregate stability

Water stable aggregates were determined by the method of Kemper and Rosenau (1986). In this procedure, 50 g of < 4. 75 mm air-dried soil samples were put in the topmost of a nest of sieves of diameter 2.00, 1.00 and 0.5, and 0.25 mm and pre-soaked in distilled water for 30 minutes. The sieves and their contents were then oscillated vertically once per second in water 20 times, using a 4 cm amplitude. After wet-sieving, the aggregate left on each sieve and the unstable <0.25 cm aggregate were quantitative transferred into beakers, dried at 50^0C for 48 hours and weighed. The percentage ratio of the aggregates on each sieve represents the water-stable aggregates (WSA) of size classes, 4. 74-2, 2-1, 1-0.50, 0.50-0.25 and <0.25 mm. Aggregate stability was measured by the mean-weight diameter (MWD) of water stable aggregate and calculated as:

$$\text{MWD} = \Sigma \text{xi: wi} \qquad (2)$$

Where xi is the mean diameter of each size fraction and wi is the proportion of the total aggregates in each size faction. Large MWD values indicate higher proportion of water stable macro-aggregate.

The state of aggregation (SOA) was calculated using the Yoder (1936) method as:

$$\text{SOA} = \frac{A}{Y} x \frac{100}{1} \qquad (3)$$

Where A is the aggregated particles with diameter >0.25 mm, and Y is the original weight of oven-dried soil. Aggregated silt and clay (ASC) (i.e. silt and clay in Calgon –dispersed samples minus silt and clay in water-dispersed sample) was measured by the technique of Middleton (1930). The clay dispersion index (CDI) (i.e. clay in water-dispersed sample/clay in Calgon –dispersed sample) was by the procedure of Dong *et. al.* (1983). Potential structural enhancement index (PSEI) was calculated as:

$$\text{PSEI} = \frac{MWDc}{MWDt} x \frac{100}{1} \qquad (4)$$

Where PSEI is the potential structural enhancement index MWDc and MWDt are mean weight diameter of the non-cattle grazing and the cattle grazing soils respectively. Positive values indicate contribution to structural enhancement, where as, negative values indicate no contribution. Particles size distribution was measured by the method of Gee and Bauder (1986) with sodium hexametaphosphate as the dispersing agent.

Determination of soil pH, Organic carbon, Exchangeable Na, Ca, Mg, and K

Soil pH was measured with a glass electrode in a 1.2.5 soil/water aqueous solution (McLean, 1982).
Total organic carbon (TOC) was determined by the Walkley and Black wet dichromate oxidation method (Nelson and Sommer, 1982). Exchangeable Ca and Mg were determined using the EDTA complexometric titration method, and exchangeable Na and K by Flame photometry (McLean, 1982).

RESULTS AND DISCUSSION

Texture, Organic carbon and Aggregate Stability Index

Clay content is high in all the profiles, exceeding 800 gkg^{-1} and 500 gkg^{-1} in 0-25 cm and 125-150cm depths respectively. This is typical of high swelling and shrinking soils usually prone to puddling and compaction because of their plasticity and cohesion (Dias Junior, 2000). Organic carbon was significantly high in the 0-25cm depth in the cattle grazing soils due to the residues from the cattle activities (Table 1). Organic carbon value of 7.2% and 5.89% were observed in the 0-25 cm depth in Assang 3 and Assang 2 soils, respectively, but most of the organic carbon residues remained in the soils as discrete particles and only a part of it entered into close association with the soil aggregates. Conversely OC was well distributed and associated with the soil aggregates and particles in the non-cattle rearing soils. Consequently, the observed low values in mean AS1 and MWD in the cattle rearing soils is consistent with similar findings (Pietola *et al* 2005; Sharma et al, 1995) in puddle soils with continuous additions of organic residues. This suggests that organic matter if not in close association with the soil particles/aggregates acts as disaggregating agent especially when the soil is under wet conditions. Intensive use of such soils without moisture control can cause dissemination of soil compaction, causing in consequence, a reduction of the productivity in the areas of intense traffic.

Physico-structural properties

The mean weight diameter (MWD) of water stable aggregate showed macro-aggregate stability in the 0-25 cm and 25-50 cm depth in both soils. The values ranged from 1. 16 to 1.31mm in Assang soils and between 1.22 and 1.92 mm in Obiousiere soil (Table2). This suggests that the high clay contents and shrinking characteristics of the soil rather than the activities of the cattle may have been responsible for the macro-aggregate stability. This is in agreement with the findings of Mbagwu and Bazzoffi (1998) and Rinarose-Voase *et al* (2000). The sate of aggregation (SOA) showed that more than 70% of aggregates size > 0.25 cm were stable in the 0-25 cm depth in all the profiles, and that of the 125-150 cm depth exceeding 60%. Aggregated silt and clay as a measure of structural stability was about 30% in the cattle grazing soils and 26% in the non-cattle grazing soils, evidencing the effects of the trampling by the cattle on compaction of the soil. Clay dispersion index (CDI) was more than 0.3gg^{-1} and about 0.10 gg^{-1} in the 0-25 cm soils of Assang and Obiousiere respectively. Usually the higher the ASC or the lower of the CDI, the better the aggregate stability. These two, colloidal stability indices did not show this trend in this soil. The implications are that, the dispersed clay will seal the soil pores, restrict water entry into the soil, and in consequent, can lead to soil erosion. Soil sealing and crusting had been reported in soils with high dispersible clays, leading to low infiltration rates (Udom, *et al* 2001; Mbugwu and Bozzoffi, 1998, Pagliai, *et al;* 2004).

Potential structural enhancement index (PSEI) (Table 3) showed that the activities of the cattle did not make positive contribution to the structural stability of the soil in the 0-25 cm and 25-50 cm depth. However there were positive contributions in the 50-75 cm and 75-100 cm depth. Mean PSEI were -11.92, -13.93, -14.03 and -18.13 for Assang 1 Assang 2, Assang 3 and Assang 4 respectively. It is possible that the trampling of the soil by cattle may have converted the soil into a plastic mud with a massive structure. Bhagat *et al.* (1999) and Sharma *et al.* (1995) had reported significantly low water stable aggregates WSA > 0.25 mm as well as mean weight diameter MWD in a continuously trampled silt clay soil by cattle.

Relationships among the Structural Indices

The correlation among some structural indices of the soil is shown in Table 4. There was significant ($P < 0.01$) positive correlation between ASI and mean weight diameter MWD in the cattle grazing soils. Also the significant ($p < 0.05$) positive correlation between MWD and SOA and OC was not surprising, since OC play important role in stability of soil aggregate, confirming the results in Table 2, where macro aggregate stability were recorded in 0-25 and 25-50 cm soil depth with about 79% WSA > 0.25 mm in cattle grazing soil. The relationships, ($r = -0.472$) between CDI and MWD though not significant, indicate that the lower the CDI, the more stable the soil aggregates. However, the negative correlation ($r = -0.167$) between OC and SOA in the cattle grazing soils indicate that the organic residues from the cattle was not wholly responsible for stability of aggregates > 0.25cm. Similarly, the significant positive ($P < 0.01$) correlation between CDI and OC in the cattle grazing further confirmed the findings of Sharma *et al.* (1995) and Mbagwu *et al.* (1991) that organic matter can act as disaggregating agent if not properly associated with the soil practices/aggregates. The significant ($p < 0.05$) positive relationship between OC and MWD, ASI and ASC and the significant negative relationship between CDI and OC in the non-grazing soils (Table 4),indicate that as OC increase the CDI decreases, hence the greater the ASI. This suggests that these indices could be used to evaluate the structural stability of soils.

Chemical Properties

Soils pH was low, ranging between 3.7 in the subsoil and 4.5 in the 0-25 cm depth in Assang soils and a mean of 4.4 in Obiousiere soils (Table 5). Exchangeable Ca, Mg, k, and Na showed significant ($p < 0.05$) changes in both soils. However, exchangeable Ca and K were relatively higher in Assang soils evidencing the effects of organic residues from the cattle on the soil. This is consistent with reported findings on the positive contribution of cow dung to the improvement of soil fertility (Mbagwu *et al.* 1991). From this result, the soil is very fertile for arable crop production, provided tillage is carried out at optimum soil moisture condition so as to enhance the structural stability indices of the soil.

CONCLUSION

Result obtained from the study showed that structural stability of the heavy clay soil was adversely affected by cattle trampling, effects, and severely restricted water movement due to high CDI. Negative values in PSEI and the positive relationship between CDI and OC imply that organic residues from the cattle activities contributed only slightly to the enhancement of structural stability because a part of it remained as discrete particles on the soil. Despite the high chemical fertility status of the soil, intensive use of the soil for cattle grazing especially during very wet condition disseminated puddling and compaction, causing a reduction in productivity in the areas of intense cattle traffic.

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Fig 1. The Vertic soils with cracked surface

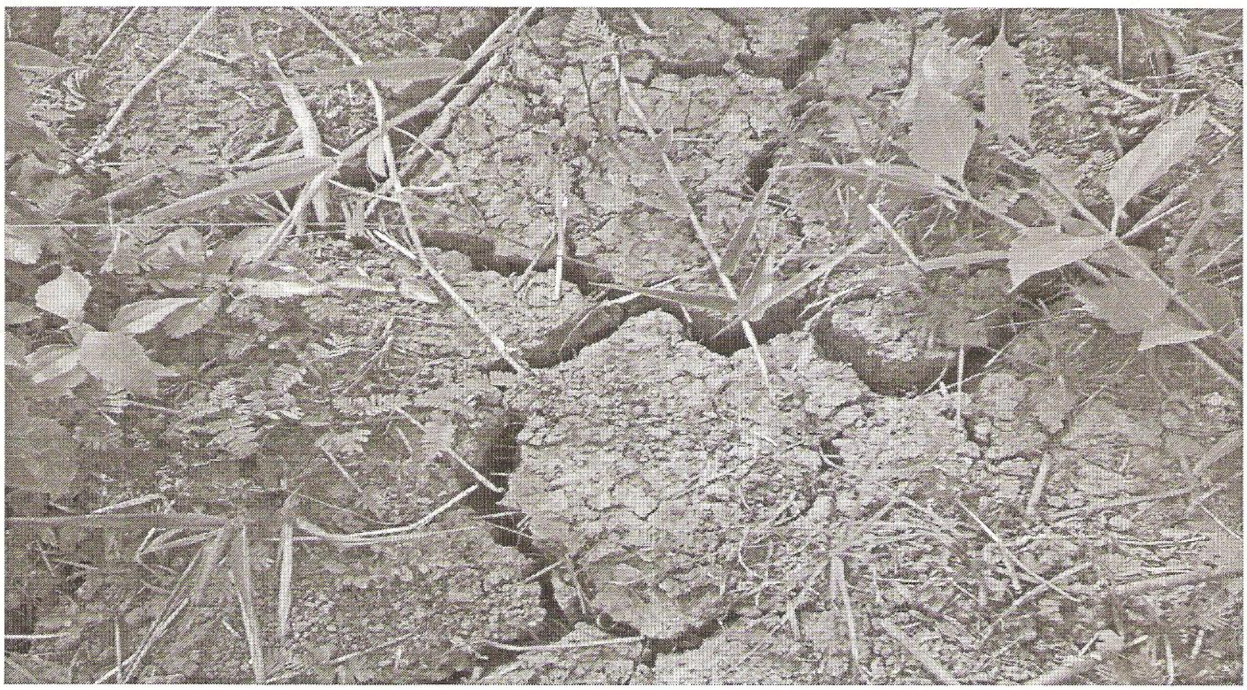

Table 1: Particle-size distribution, organic carbon and structural stability index of the soils

		Particle-size distribution (gkg $^{-1}$)				OC	
Soil	**Depth**	**sand**	**silt**	**Clay**	**Texture**	**(%)**	**ASI**
	0-25	290	90	620	C	2.90	0.10
	25-50	150	10	840	C	0.56	0.02
Assang 1	50-75	90	50	860	C	1.22	0.02
	75-100	150	130	720	C	1.47	0.1
	100.125	90	230	680	C	0.93	0.02
	125-180	210	250	540	C	1.66	0.04
	Mean	160	130	710	C	1.29	0.03
	LSD(O.05)	60	84	NS	-	0.68	0.05
	0-25	210	270	520	C	5.89	0.20
	25-50	150	10	840	C	1.22	0.03
Assang 2	50-75	150	50	800	C	1.96	0.04
	75-100	210	10	780	C	0.65	0.02
	100-125	150	30	820	C	0.84	0.02
	125-150	150	40	810	C	0.80	0.02
	Mean	170	70	760	C	1.89	0.04
	LS(0.05)]	NS	62	190	-	0.35	0.04
	0-25	520	260	220	SCL	7.20	0.3
	25-30	150	30	820	C	1.60	0.04
Assang 3	50-70	150	10	840	C	1.12	0.02
	75-100	150	10	840	C	1.40	0.3
	100-125	190	10	800	C	1.78	0.04
	125-150	190	20	790	C	1.50	0.03
	Mean	230	50	720	C	2.45	0.10
	LS(0.05)	106	97	118	-	0.98	0.08
	0-25	490	210	300	SCL	2.62	0.10
	25-30	150	10	840	C	2.06	0.04
	50-75	150	30	820	C	1.31	0.03
	75-100	150	50	800	C	1.96	0.04
	100-125	140	60	800	C	1.29	0.03
	125-150	140	60	800	C	1.20	0.03
	Mean	200	70	730	C	1.74	0.04
	LSD(0.05)	117	58	103	-	0.63	0.08
	0-25	240	110	650	C	2.74	0.08
obiousiere	25-50	160	210	630	C	2.33	0.05
(control)	50-75	140	230	630	C	1.08	0.02
	75-100	140	210	650	C	1.25	0.03
	100-125	200	350	450	C	1.83	0.04
	125-150	100	370	470	C	1.48	0.03
	Mean	173	247	580	C	1.79	0.04
	LSD(0.05)	NS	89	107	-	0.09	NS

Table 2: Some structural stability indices of the cattle grazing non cattle grazing soils

Soil	Depth (cm)	MWD (mm)	SOA (%	ASC (%	CDI (gg^{-1}
Assang1	0-25	1.19	79.8	33.0	0.09
	25-50	1.16	73.2	35.0	0.08
	50-75	1.17	79.1	33.0	0.14
	75-100	0.79	64.9	40.0	0.21
	100-125	0.75	63.3	31.0	0.21
	125-150	0.62	63.8	28.0	0.20
	Mean	0.47	66.7	31.67	0.16
	LSD(0.05)	0.16	10.1	NS	0.07
	0-25	1.19	69.4	37.0	0.10
	25-50	1.19	69.2	41.0	0.11
	50-75	0.93	71.6	38.0	0.23
	75-100	0.77	63.1	28.0	0.21
Assang2	100-125	0.62	62.9	23.0	0.19
	125-150	0.60	62.9	23.0	0.16
	Mean	0.90	68.2	31.67	0.15
	LSD(0.05)	0.19	NS	5.43	0.05
	0-25	1.24	76.2	14.0	0.12
	25-50	1.20	71.9	36.0	0.15
	50-75	0.92	66.1	31.0	0.15
Assang3	75-100	0.82	67.1	33.0	0.22
	100-125	0.56	69.6	29.0	0.16
	125-150	0.55	61.8	24.0	0.11
	Mean	0.898	68.7	27.83	0.15
	LSD(0.05)	0.11	9.4	8.61	0.07
	0-25	1.18	72.2	19.0	0.08
	25-50	1.31	80.4	34	0.08
	50-78	1.04	75.2	34.0	0.12
	73-100	0.82	73.6	28.	0.18
Assang4	100-125	0.59	68.1	28.0	0.20
	125-150	0.53	68.2	28.0	0.19
	Mean	0.92	72.9	28.5	0.14
	LSD(0.05)	0.12	10.01	6.95	0.04
	0-25	1.22	74.1	31.0	0.09
	25-50	1.92	69.6	26.0	0.08
	50-75	0.86	67.9	26.0	0.08
Obiousiere (control	75-100	0.74	63.9	26.0	0.11
	100-125	0.80	63.3	22.0	0.10
	125-150	0.82	69.4	23.0	0.10
	Mean	1.06	68.0	25.67	0.09
	LSD(0.05)	0.98	NS	NS	NS

MWD- Mean weight diameter, SOA- State of aggregation, ASC- Aggregated silt and clay
CDI – Clay dispersion index

Table 3. Potential structural enhancement index of the soil under cattle grazing

Soil				**Depth (cm)**			
Cattle grazing	0-25	25-50	50-75	75-100	100-125	125-150	Mean
Assang1	-2.50	-64.60	21.70	6.60	-0.90	-31.80	-11.92
Assang2	35.70	-61.10	7.30	3.30	-29.80	-39.00	-13.93
Assang3	8.90	-60.30	6.00	9.0	-43.00	46.80	-14.63
Assang4	-3.4	-46.50	17.4	10.0	-35.8	-50.5	-18.13
Obiousiere (control)	-	-	-	-	-	-	-
Mean	9.68	-57.52	13.10	7.23	-27.38	-42.03	-14.50

Table 4: Correlations among some structural indices of the soil

			Correlation Co efficient (r)			
Structural Indices	**MWD (mm)**	**ASI**	**SOA (%)**	**ASC (%)**	**OC (%)**	**CDI (gg^{-1})**
Cattle grazing soil (N=24)						
MWD (mm)	1.0					
ASI	0.782**	1.0				
SOA (%)	0.549*	0.610*	1.0			
ASC (%)	0.416^{NS}	0.536*	0.661*	1.0		
OC (%)	0.698*	0.937**	-0,167^{NS}	0.937**	1.0	
CDI (gg^{-1})	-0.472^{NS}	-0.638*	-0.581*	-0.492^{NS}	0.726**	1.0
Non cattle grazing so (N=6)						
MWD (mm)	1.0					
ASI	0.516^{NS}	1.0				
SOA (%)	0.441^{NS}	0.684*	1.0			
ASC (%)	0.383^{NS}	0.507^{NS}	0.613*	1.0		
OC (%)	0.618*	0.772*	0.559 ^{NS}	0.794*	1.0	
CDI (gg^{-1})	-0.435^{NS}	-0.701*	-0.496^{NS}	-0.552^{NS}	0.698*	1.0

*Significant at $P < 0.05$ and * Significant at $P < 0.01$

Table 5: Some chemical properties of the cattle and non cattle grazing soils

Soil	Depth (cm)	pH ($H_2 0$)	Ca	Mg	K	Na
			←	mg kg^{-1}	→	
Assang1	0-25	4.5	14.8	0.8	0.18	0.33
	25-50	3.8	5.2	3.6	0.16	0.48
	50-75	3.7	9.2	0.4	0.13	0.57
	75-100	3.7	7.2	1.2	0.13	0.67
	100-125	4.0	7.2	1.2	0.13	0.45
	125-150	4.1	9.6	8.8	0.20	0.74
	Mean	4.0	8.9	2.7	0.16	0.53
	LSD(0.05)	0.3	6.8	0.94	0.04	0.16
	0.25	4.2	22.0	2.0	0.26	0.48
	25-50	4.3	20.4	1.2	0.12	0.40
	50-75	4.1	18.0	1.2	0.12	0.35
	75-100	3.9	18.0	4.0	0.12	0.62
Assang2	100-123	4.3	20.4	0.4	0.10	0.49
	125-150	4.1	21.6	0.5	0.10	0.47
	Mean	4.2	20.1	3.4	0.14	0.47
	LSD (0.05)	NS	1.6	2.2	0.07	0.18
	0-25	4.1	10.0	2.0	0.18	0.40
	25-50	4.0	10.0	2.4	0.15	0.41
	50-75	3.8	11.6	2.4	0.14	0.44
	75-100	3.9	12.0	4.8	0.21	0.75
Assang3	100-125	4.1	13.2	4.8	0.14	0.47
	125-150	4.0	13.8	4.8	0.16	0.48
	Mean	4.0	11.8	3.5	0.16	0.49
	LSD (0.05)	NS	1.9	2.3	NS	0.06
	0-25	4.3	7.6	3.2	0.15	0.39
	25-50	3.8	10.0	6.0	0.81	0.61
	50-75	3.9	17.6	6.4	0.11	0.61
	75-100	4.0	13.6	7.6	0.14	0.60
Assang4	100-125	3.7	20.8	10.2	0.18	0.59
	125-150	3.9	20.8	6.4	0.14	0.37
	Mean	3.9	15.1	6.6	0.26	0.51
	LSD (0.05)	NS	3.7	2.8	0.03	0.07
	0-25	4.6	2.8	5.2	0.14	0.30
	25-50	4.2	3.6	0.8	0.18	0.42
Obiousiere (control)	30-75	4.6	4.4	1.6	0.17	0.34
	75-100	4.4	4.8	2.4	0.14	0.37
	100-125	4.3	2.6	2.6	0.13	0.36
	125-150	4.3	2.6	1.4	0.12	0.36
	Mean	4.4	3.5	2.3	0.15	0.36
	LSD (0.05)	NS	1.2	1.0	NS	0.09