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# Soil Water Retention, Infiltration and Aggregate Stability of a Seasonally Flooded Vertisol Under Intensive Cattle Grazing

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## Abstract

Water retention curves, infiltration and aggregate stability of a poorly textured, submerged soil under intensive cattle grazing for 14 years was studied and compared with similar soil without cattle activities. Water release pattern was low in the top 0-25 cm soil and maintained the low water release pattern in the cattle trampling soils. Soil water retention at – 6Kpa ranged between 0.36 cm cm<sup>-3</sup> and 0.43 cm cm<sup>-3</sup> in the top 0-25 cm soil, indicating that the soil can retain water for crop use for a longer period of the year. Total porosity ranged from 43.26% to 64.04% in the top 0-25cm soil. Infiltration rates varied between 153 mm hr<sup>-1</sup> at the initial time and attained steady state infiltration of 3 mm hr<sup>-1</sup> before 2 hours in most of the soils under cattle grazing. Generally, zero infiltration rates were attained before 60 minutes in 75 percent of the soils. When puddle, the soil became very hard upon drying, and progressively developed cracks whose width and depth increased with months depending upon the moisture content. Macro-aggregate stability was observed in the top soil and micro-aggregate stability in the subsoil. Although there was built-up of organic residues in the soil due to activities of cattle – rearing, however, much remained in the soil as discrete particles and only a part of it entered association with the soil aggregates.

**Key words:** Submerged soil, cattle rearing, aggregate stability and porosity

## Introduction

Water retention, infiltration and aggregate stability are the most important soil physical properties affecting crop production, because they determine the depth that roots can penetrate, the amount of water available for crop use, and the movement of air, water and soil fauna<sup>1,2</sup>. Intensive cattle movements on seasonally submerged soil can affect pore-size distribution, with both storage and residual porosity increasing at the expense of transmission porosity. Different soil uses had been reported to affect the physical and mechanical soil

properties<sup>3</sup> causing in consequence, soil compaction and restricting root penetration<sup>4</sup>. When the soil is wetter than optimal for wheel traffic, excessive trampling by cattle decrease total porosity, size and continuity of the pores<sup>5,6</sup>. It also limits nutrient uptake, water infiltration and redistribution, gas exchange, seedling emergencies, and root development<sup>7</sup>. Factors that influence aggregate stability are important in evaluating the potential of soils to crust and /or seedling emergencies and in predicting the capacity of soils to sustain long term crop production. It was observed that puddling decreased water transmission pores from 14.6 –

10.9 percent in loamy sand, 10.2 to 6.8 percent in silt loam, 23.2 to 7.3 percent in loam and 17.6 to 4.9 percent in clay loam<sup>8</sup>. The hydrophobic coating from organic manure reduced soil slaking in water; thereby maintaining aggregate stability and preventing soil loss by run off<sup>9</sup>.

Intensive cattle grazing on submerged soils affects soil water content, soil water retention and soil water diffusivity and structural stability. These properties in turn affect hydraulic processes such as infiltration, water flow through soils, drainage and evaporation. In tropical conditions, when the soil is under long term effects of cattle trampling, management and tillage practices that will maintain optimum threshold values of infiltration and water retention for sustainable crop production are very important. Therefore, it is essential to have information on water characteristic and structural stability of such soils in order to understand and manage the soils. Thus, a consensus of which some soil physical properties should be used as a universal indicator of soil structure sustainability is needed. There are a few evidences in literature indicating the influence of cattle trampling on soil water characteristics and aggregate stability<sup>8, 10</sup>. In this study, we quantify soil water characteristics, infiltration and aggregate stability of seasonally flooded soils under intensive cattle grazing, so as to improve our understanding of the management of such soil to increase the area of land available for crop production.

## Experimental

The study was carried out on irrigation project site in Assang and Okpo in Odukpani, in Cross River State, Nigeria (lat<sup>5</sup>016°N and Long 07°58°E). The site has been under intensive activities of cattle rearing for a period of 14 years. It occurs on nearly level lowland, floodplain of Enyong creek. The soil is derived from sub-recent alluvium and classified as Vertic epiaguults<sup>11</sup>. The soil is very poorly drained with clay content >700g kg<sup>-1</sup> and is usually submerged by flood for over four weeks at the peak of rains. Based on the physiographic position within the landscape, slope, and drainage, four (4) representative profile pits, represented by Assang 1, Assang 2, Assang 3 and Assang 4, were sited at the cattle rearing areas and one profile pit represented by Obiousiere, at the area without cattle activities but is submerged

by water. Disturbed and undisturbed core soil samples were collected in duplicate at 0-25, 25-50, 50-75, 75-100, 100-125, and 125-150 cm depths. Soil moisture characteristic curves and bulk density were determined with the undisturbed core samples, while the disturbed soil samples were used for determination of aggregate stability, and the risk of sealing.

Particle size distribution was determined using sodium hexametaphosphate as the dispersing agent<sup>12</sup>. Crusting hazard (risk of sealing "R" was calculated and classified using standard methods<sup>13</sup> as

$$R(\%) = \frac{\text{Organic matter} \times 100}{\text{Clay} + \text{Silt}}$$

R values  $\leq 5\%$  were considered high, 7%, threshold value, and  $> 9\%$ , low.

Total organic carbon (TOC) was measured by standard method<sup>14</sup>, and converted to organic method by multiply the organic carbon (OC) values by 1.724.

## Measurement of Soil Water Retention And Infiltration

Water retention capacity at Okpa – 10kpa was measured with the aid of tension tables by the hanging column desorption test method<sup>15</sup>. Infiltration was carried out in the field using the double-ring infiltrometer having inner diameter of 30 cm, and outer diameter of 60 cm, until steady state infiltration was obtained<sup>16</sup>. Infiltration capacity was calculated using:

$$I = \frac{Q}{A \times t} \quad \text{Eq. 1}$$

Where Q is the volume quantity of water infiltrating (cm<sup>3</sup>), A is the area of the soil surface (cm<sup>2</sup>) exposed to infiltration and t is time (s).

## Aggregate Stability and Porosity

Aggregate stability was measured by the mean-weight diameter (MWD) of water-stable aggregate wet-sieving method<sup>17</sup>. In this procedure, 40g soil samples of < 5 mm aggregates were placed on the top of a nest of sieves of diameters 2, 1, 0.5, and 0.25 mm and presoaked in distilled water for

30 min. before oscillating vertically once per second in water for 20 times, using a 4 cm amplitude. The mean weight diameter (MWD) of water-stable aggregates was calculated as:

$$\text{MWD} = \sum_{i=1}^n X_i W_i \quad \text{Eq. 2}$$

Where,  $X_i$  is the mean diameter of each size fraction (mm), and  $W_i$  is the proportion of the total aggregate in each size fraction and  $n$  is the number of sieves used. Water-stable aggregate (WSA) was calculated as:

$$\text{WSA} = \frac{\text{MR} \times 100}{\text{MT}} \quad \text{Eq. 3}$$

Where, MR is the mass of resistant aggregate (g), and MT is the total mass of wet-sieved soil (g).

Soil porosity was measured using water retention data<sup>18</sup> as

$$\text{Total porosity} = \frac{\text{Volume of water in the soil at 0 kPa (cm}^3\text{)}}{\text{Volume of soil (cm}^3\text{)}}$$

## Results and Discussion

### Texture, Organic matter and Crusting hazards

The particle size distribution (Table 1) showed that the soil is clayey. The average sand, silt and clay contents range from 160 – 230, 50 – 240, and 580 – 760 g kg<sup>-1</sup>, respectively. The variations in the particle size fractions and the activities of the cattle rearing, does not alter the soil textural class. Clay content was high, confirming the general characteristics of vertisols<sup>11</sup>. Soil organic matter (SOM) was high in the cattle rearing soil, ranging from 45.2 - 82.5 g kg<sup>-1</sup> in the top 0 – 25 cm soil. The build-up of high SOM in this soil is a result of the contributions of organic residues by the cattle, thus making the soil suitable for most arable crop production<sup>19</sup>. The risk of sealing was within threshold value in the top 0 – 25 cm soil due to build up of SOM, and its ability to reduce structural crusting. Conversely, there was high risk of sealing in the subsoil due to the biological mat and /or structural crust formed in the subsoil due

to the build – up of soil organic matter. Positive relationship between SOM and crusting hazards was also reported previously<sup>2</sup>.

### Aggregate Stability Porosity

Aggregate stability as measured by wet-sieving and total porosity are shown in Table 2. The soil is generally extremely porous at the top 0 – 25 cm and highly porous in the subsoil. The top soil porosity ranged between 36% and 46%, whereas that of the subsoil ranged between 37% and 38%. (Table 2). Aeration porosity was hampered by high clay content and the mechanical impact of cattle grazing on the soil. The structural stability of the soil aggregates against the slaking effect and kinetic energy disruption of moving water showed that the cattle grazing soil has relatively more stable aggregates in the macro-aggregate fractions than the non-cattle grazing soil (Table 2). The mean weight diameter (MWD) varied from 1.175 mm to 1.889 mm in the top 0 – 25 cm soil. The percent water stable aggregates < 0.25 mm were generally high in the subsoil. Conversely, the relatively more macro-aggregate stability in the cattle-grazing soils was not surprising. This confirmed the binding and/or aggregating role of the organic residues reported earlier<sup>9</sup>. However, the very low infiltration rates (Fig 2) indicate that water entry into the soil was restricted indicating blocking of soil pores due to organic matter dissolution<sup>21</sup>, and trampling effects<sup>3</sup>.

### Soil Water Retention Curve (SWRC)

Soil water retention curves (SWRCs) of the soils are shown in Fig.1. Water retention at – 6 kPa (representing field capacity) ranged between 0.36 cm cm<sup>-3</sup> and 0.43 cm cm<sup>-3</sup> in the top 0-25 cm soil and between 0.37 cm cm<sup>3</sup> and 0.49 cm cm<sup>-3</sup> in the 125 – 150 cm depth. Water release pattern was generally low in the top soil, and maintained the slow release pattern through the profiles, indicating that the soil can retain water for crop use for a longer period of the year. Water retention in the untrampled soil range from 0.40 cm cm<sup>3</sup> in the surface soil, to 0.30 cm cm<sup>3</sup> in the subsoil. The build-up of organic residues retained water on the soil surface for a short period of drying. Wet trampling of the soil and built-up of discrete organic residues in the soil due to activities of cattle rearing was responsible for the slow water release pattern observed. This confirmed similar observation

**Table 1.** Particle size distribution, organic matter and crusting hazards of the soil

Soil	Depth (cm)	Particles size distribution (g kg <sup>-1</sup> )			Texture	Organic matter (g kg <sup>-1</sup> )	Crusting hazards
		Sand	Silt	Clay			
Assang I	0 – 25	290	90	620	C	50.0	7.0
	25 – 50	150	10	840	C	9.7	1.1
	50 – 75	90	50	860	C	21.0	2.3
	75 – 100	150	130	720	C	8.1	9.5
	100 – 125	90	230	680	C	16.0	1.8
	125 – 150	210	250	540	C	63.1	8.0
	Mean	160	130	710	C	28.0	3.3
Assang 2	0 – 25	210	270	520	C	82.5	1.0
	25 – 50	150	10	840	C	21.0	2.5
	50 – 75	150	50	800	C	33.8	4.0
	75 – 100	21	10	780	C	12.7	1.6
	100 – 125	150	30	820	C	14.5	1.7
	125 – 150	150	40	810	C	14.7	1.7
	Mean	170	70	760	C	29.9	3.6
Assang 3	0 – 25	520	260	220	SCL	7401	15.4
	25 – 50	150	30	820	C	29.0	3.4
	50 – 75	150	10	840	C	21.0	2.5
	75 – 100	150	10	840	C	24.1	2.8
	100 – 125	190	10	800	C	30.7	3.8
	125 – 150	190	20	790	C	22.0	2.7
	Mean	230	50	720	C	33.5	4.4
Assang 4	0 – 25	490	210	300	SCL	45.2	8.9
	25 – 50	150	10	840	C	35.5	4.2
	50 – 75	150	30	820	C	22.6	2.7
	75 – 100	150	50	800	C	33.8	4.0
	100 – 125	140	60	800	C	55.7	6.5
	125 – 150	140	60	800	C	54.1	6.3
	Mean	200	70	730	C	41.2	5.2
Obiousiere (control)	0 – 25	240	110	650	C	47.2	6.2
	25 – 50	160	210	630	C	40.2	4.8
	50 – 75	140	230	630	C	18.6	2.2
	75 – 100	140	210	650	C	21.6	2.5
	100 – 125	200	350	450	C	31.6	4.0
	125 – 150	200	370	470	C	27.6	3.5
	Mean	180	240	580	C	31.1	3.8

C= clay, SCL = sandy clay loam,

reported earlier on studies of both storage and residual porosity of residue treated soils under intensive puddling<sup>2,8</sup>. The result further showed that about 85% of the total water holding capacity of the top soil was held at -6 Kpa, indicating high water adsorption capacity of organic residues.

### Infiltration

Infiltration rates varied from 153 mm hr<sup>-1</sup> to 197 mm hr<sup>-1</sup> at the initial time and attained

steady state infiltration of 3 mm hr<sup>-1</sup> before 120 min. Zero infiltration rates were attained before 60 min in 75 percent of the soils of the site (Fig 2). General observations were that the formation of biological mat or crust and the dispersal clay effectively blocked the pores between the micro-aggregates, leading to an extremely low infiltration rates. Infiltration was also severely impeded by the compacted layers of the soil by the cattle, leading to limited drainage.

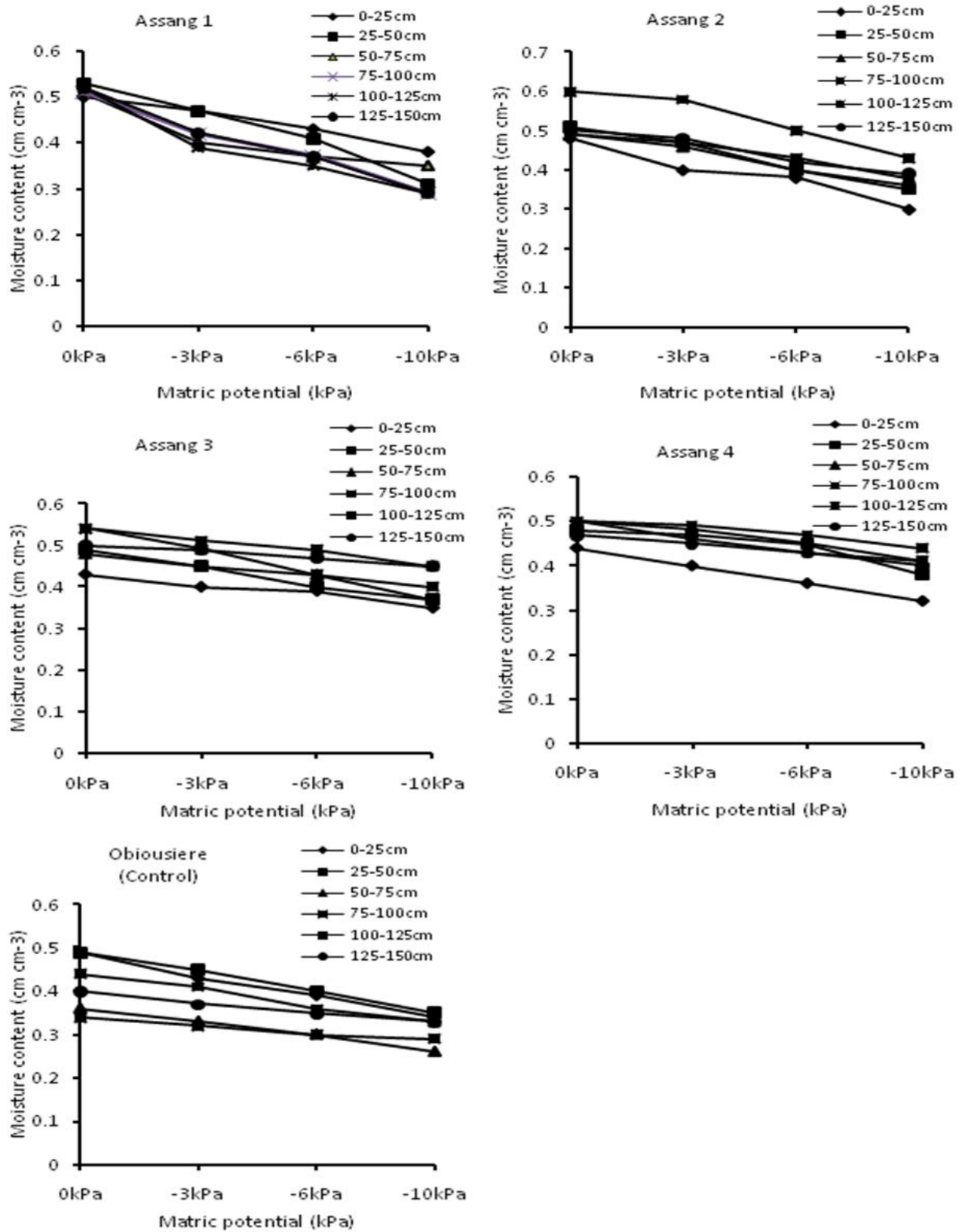


Fig. 1: Soil Water retention curves of soils of the site.

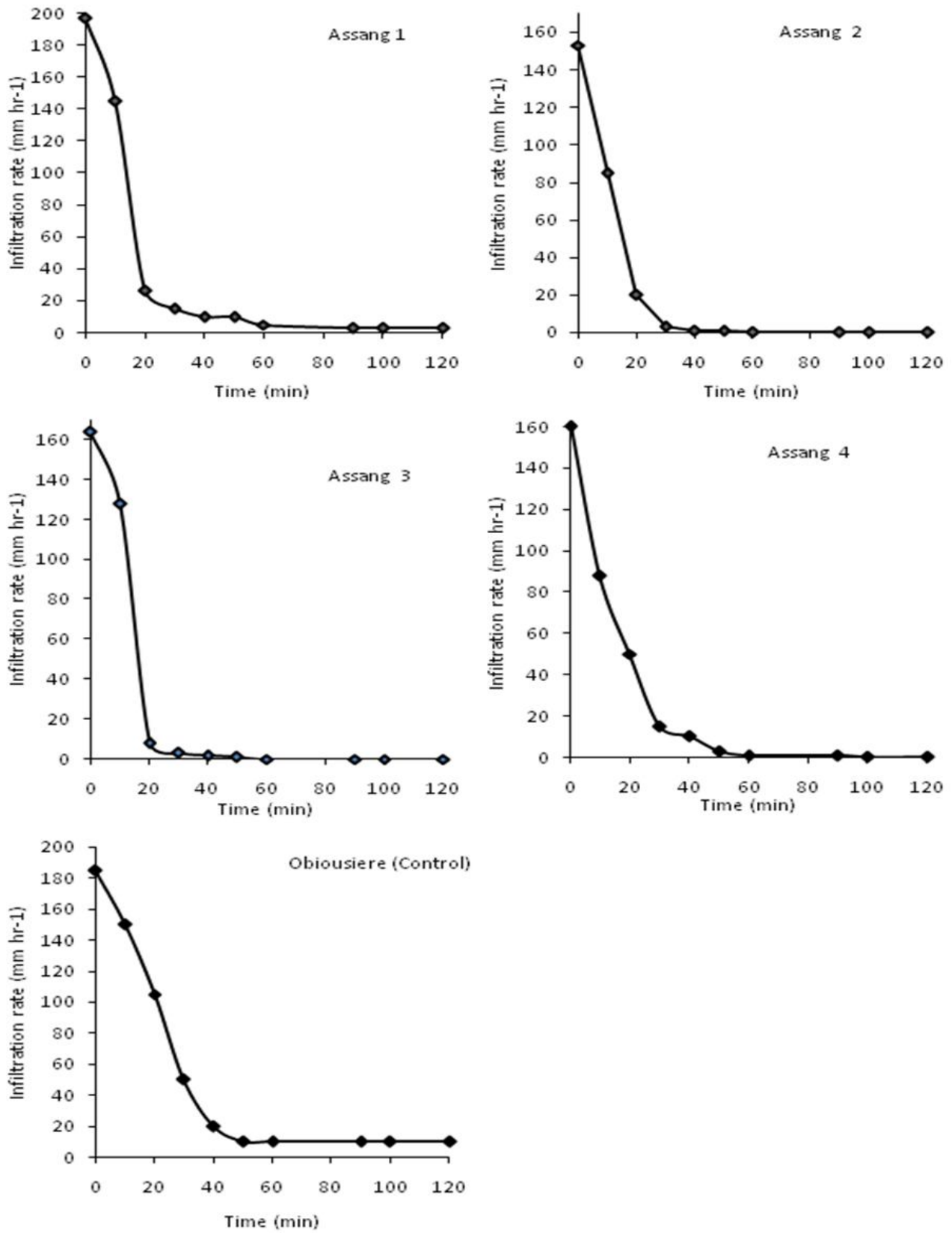


Fig. 2: Infiltration rate (double ring method) of soil of the site.

**Table 2.** Aggregate stability and total porosity of the soil

Soil	Depth (cm)	Aggregate sizes (mm)					MWD (mm)	Total porosity (%)
		5 – 2	2 – 1	1 – 0.5	0.5 – 0.25	< 0.25		
Assang 1	0-25	19.2	17.3	13.7	29.6	29.6	1.185	43.02
	25-50	21.3	10.1	11.9	29.9	29.9	1.163	40.04
	50-75	20.8	11.4	15.3	32.4	32.4	1.171	38.20
	75-100	8.6	11.9	15.5	35.1	35.1	0.793	37.08
	100-125	8.6	10.1	22.0	36.7	36.7	0.794	36.84
	125-150	2.1	10.6	28.8	36.2	36.2	0.622	36.57
	Mean	13.4	11.4	18.4	33.3	33.3	0.955	38.63
Assang 2	0-25	20.8	12.8	14.9	20.9	30.6	1.888	45.50
	25-50	20.5	14.2	13.8	20.7	30.8	1.190	43.19
	50-75	10.1	17.3	20.8	23.4	28.4	0.929	38.52
	75-100	7.4	10.3	23.6	21.8	36.9	0.766	36.91
	100-125	2.3	7.4	34.2	20.0	37.1	0.617	36.91
	125-150	1.1	10.2	31.2	20.4	37.1	0.596	36.23
	Mean	10.4	12.0	23.1	21.2	31.8	0.877	39.60
Assang 3	0-25	23.6	17.2	15.3	20.1	23.8	1.335	40.47
	25-50	20.9	13.3	14.0	23.7	28.1	1.196	43.02
	50-75	13.1	10.6	14.4	28.0	33.9	0.916	41.11
	75-100	8.0	14.8	16.3	28.0	32.9	0.814	39.20
	100-125	1.0	10.7	18.8	39.1	30.4	0.560	38.95
	125-150	1.0	9.6	18.1	32.9	38.4	0.545	38.35
	Mean	11.3	12.7	16.2	28.6	31.3	0.894	40.18
Assang 4	0-25	20.2	13.0	15.7	25.3	27.8	1.175	41.32
	25-50	22.3	18.3	14.7	25.1	19.6	1.309	40.04
	50-75	19.3	15.9	20.0	20.0	24.8	1.043	36.31
	75-100	6.1	10.0	37.0	30.5	26.4	0.823	35.75
	100-125	2.0	10.0	21.1	35.1	31.9	0.590	35.47
	125-150	0.0	10.0	20.9	37.3	31.8	0.527	34.19
	Mean	11.7	12.9	21.6	28.9	27.1	0.911	37.18
Obiousiere (control)	0-25	18.6	20.7	14.6	20.8	25.9	1.215	41.25
	25-50	16.1	12.4	11.5	29.6	30.4	1.917	39.56
	50-75	9.4	11.2	28.4	18.9	32.1	0.861	22.41
	75-100	6.0	11.0	26.5	20.4	36.1	0.741	21.05
	100-125	8.6	11.2	20.9	23.6	36.7	0.807	20.46
	125-150	10.0	10.6	20.6	21.1	30.6	0.820	19.44
	Mean	8.6	12.9	24.1	22.6	32.0	0.940	27.36

The build-up of high organic residues in the soil as a result of cattle – rearing did not improve the soil infiltration because much of the organic residues remained in the soil as discrete particles and only a part of it entered into close association with the soil aggregates. Similar observations on a

lowland puddle rice soil in Asia were reported<sup>22</sup>. This implies that adequate combinations of a typical uncontrolled flooded management practices will provide positive modifications in the soil infiltration rates and other physical properties.

## Conclusion

Cattle rearing activities on the submerged soil improve aggregate stability and water retention at -3, -6, and -10 Kpa due to accumulation of organic residues. Infiltration rate of the soil is slow as a result of the trampling effect of cattle movement on the soil. Appropriate tillage at optimal soil water content will improve the soil physical conditions for optimum crop production.

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