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Development of mini-infiltrometer for soil sorptivity test in the humid tropical climate of Nigeria

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Mini-infiltrometer for determining soil sorptivity, hydro-repellency and other hydraulic properties of soil using water and other forms of fluid was designed and developed. It was made of quality pyrex glass tubes and calibrated to metric standard after manufacture. The component of the mini-infiltrometer include: the infiltrometer tube, which bears a porous sponge at the tip for moisture metering into soil samples, 'U' tube manometer, capillary tube, rubber hose (joints) and glass valves. Experimental tests were conducted on the manufactured mini-infiltrometer to determine soil sorptivity to water by the steady state flow on soil samples obtained at depths 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 m from four different locations at the Federal University of Technology, Akure (FUTA) in the southwestern part of Nigeria. The experimental procedures involve measurement of water uptake at negative pressure heads from a small circular porous membrane in contact with the surface of the aggregates. Soil samples from location L2, which were predominantly clay, had the lowest mean total porosity (0.12 ± 0.02)%, and were characterized by low mean value of sorptivity (0.406 ± 0.06) mms$^{-1/2}$. Soil sorptivity to water increased from the surface soil layer (10 cm) to the 20 cm depth with values 0.801(±0.04), 0.753(±0.15) and 0.777(±0.04) in soil samples from locations L1, L3 and L4, respectively, except for aggregates from location L2, which exhibited reductions in sorptivity from the 10 cm to the 70 cm soil layer. The successive reduction in sorptivity of L2 with depth is an indication of the influence of reduced porosity of samples as clay content increased with depth. High coefficients of correlation r^2 = 0.98, 0.97, 0.97 and 0.88 at p = 0.05 were obtained from the relationship between the manufactured mini-infiltrometer and standard disk infiltrometer. The results show that soil hydraulic and sorptivity properties are dependent on soil aggregate composition, total porosity and organic matter content.

Key words: Infiltrometer, sorptivity, porosity, infiltration, bulk density.

INTRODUCTION

Mini–infiltrometer is an apparatus that is used to determine soil hydraulic properties such as soil sorptivity, hydro-repellency, hydrophobicity and hydraulic conductivity (Leeds-Harrison and Young, 1997). The determination of these soil properties is very significant to the explicit analysis of a soil in a particular geographical location. It is also very useful in determining the use to which the soil will be put. Determination of water and ethanol sorptivity of air-dried soil aggregates, 15 mm in diameter and approximately spherical in shape by a steady-state flow using a mini-infiltrometer was reported by Vogelmann et al. (2010). Angulo-Jaramillo et al. (2000) and Reynolds et al. (2002b) enumerated the various types of infiltrometer in use today such as single

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ring, double ring and mini-disk infiltrometer as well as their significance. Most of the infiltrometers are used *in-situ* on the field, while the mini-infiltrometer developed in this study is purely a laboratory apparatus.

Hydraulic properties of soil aggregates such as hydraulic conductivity, infiltration, sorptivity and moisture retention affect water and solute movement in soil aggregates (Gerke and Kohne, 2002). The importance of these hydraulic properties is mostly significant by the fact that large inter-aggregate pores are drained off first under prevalent field conditions and water and solutes transport are influenced by the properties of the individual aggregate and contact between them. (Horn and Smucker, 2005). Also, pore structures affects the hydraulic properties of soil aggregates (Horn and Smucker, 2005; Lipiec et al., 2007) and are modified by soil compression and tillage practices (Kutilek et al., 2005; Lipiec et al., 2006).

Compacted aggregates characterized with increased contribution of finer pores reduce the accessibility of water for roots due to its availability only at more negative pore water pressures (Horn and Smucker, 2005). Other authors acknowledge the influence of high pH values, particularly above 6.5 on the reduction of water repellency of some soils (Bayer and Schaumann, 2007; Mataix-Solera and Doerr, 2004) which may be indirectly linked to the specific surface area and texture of the soil (Doerr et al., 2006; Woche et al., 2005).

Hallet (2008) reported the reduction in infiltration of water into the soil and resulting reduction in the amount of water available for seed germination as well as growth and development of the plant. Shakesby et al. (2000) observed that increase in surface water may lower the rate of infiltration especially in slope topography and increase the risk of erosion. Also, the main problem of water repellency in soil is the inactivity of pesticides and fertilizers (Blackwell, 2000). Some recent studies indicated that increased soil stability and water infiltration can be a result of the combined effect of internal aggregate strength and wettability (opposite to repellency) (Czarnes et al., 2000; Goebel et al., 2004; Eynard et al., 2006). Therefore, soil compaction which increases the contact points or forces among soil aggregates must have been responsible for internal aggregate strength and stability (Chenu et al., 2000; Ferrero et al., 2007) as well as lower wettability (Goebel et al., 2004; Eynard et al., 2006). The degree of water repellency is a function of aggregate sizes and the hydrophobicity is mostly concentrated at the outer skin, while the inner part of the aggregates is less hydrophobic (Jasinska et al., 2006; Urbanek et al., 2007). Considering the importance of these soil parameters to soil moisture management and crop productivity, there is the need for the development of indigenous and low-cost mini-infiltrometer for use in the determination of water repellency of tropical soils of Nigeria and other countries in the sub-Saharan Africa. The objective of this study was to develop and calibrate a low-cost mini-infiltrometer for the laboratory determination of soil sorptivity and water repellency.

MATERIALS AND METHODS

Design considerations and material selection

The purpose and functions of the equipment were first considered at the preliminary design stage. The development of the equipment involved the coupling of some components, which include: infiltrometer tube with porous sponge at the tip, ‘U’ tube manometer, capillary tube, glass valves and rubber tubes. Another important component of the system is an adjustable glass soil table for engaging and disengaging the soil samples to be tested. Considering the stress during usage and the expected life span of the equipment, Pyrex glass which is stronger and tougher was chosen for the construction of the equipment instead of very fragile soda glass, while transparent Perspex was used for the construction of the adjustable soil table and rubber tubes used at the various connections.

Manufacturing procedures

Manufacturing of ’U’ tube manometer

The ‘U’ tube manometer was made from a pyrex glass tube with 6 mm internal diameter and 9 mm external diameter. The tube was bent by gravity to ‘U’ shape using oxy-butane flame supplied by hand touch burner at the temperature of about 1200°C. Points where the tube was to be bent were heated to a semi-liquid state until the tube bent under its own weight (by gravity). Air was blown into the tube to correct the imperfection in the diameter of the bent section. After completing the bending, the tube was annealed with the flame supplied by the pre-mixed bench burner before allowing it to cool by natural air.

Manufacturing of the infiltrometer tube

The production process of the infiltrometer tube involved tapering and cutting. A straight pyrex tube of 6 mm internal diameter and 9 mm external diameter was subjected to necking at a point by heating to a temperature above 1200°C using bench burner and at the same time stretching it until the tube was separated apart at the point of necking. The conical end of the infiltrometer tube was then truncated to diameter 5 mm using flat diamond glass cutter and flame-polished in order to ensure the smoothness of the cut edge. The infiltrometer tube was then annealed and air-cooled. A porous sponge was fixed to the tapered end so as to make the infiltrometer outlet semi-permeable.

Manufacturing of the capillary tube

The capillary tube was made of a thicker glass of 3 mm internal diameter and 9 mm external diameter so as to ensure hydraulic conductivity of fluid even under high pressure through it. It was a straight glass tube which was cut into 20 cm length by hot-flaming process.

Manufacturing of the adjustable soil table

Through our creative design ability in the project group, the adjustable glassy table was designed as envisaged to allow the

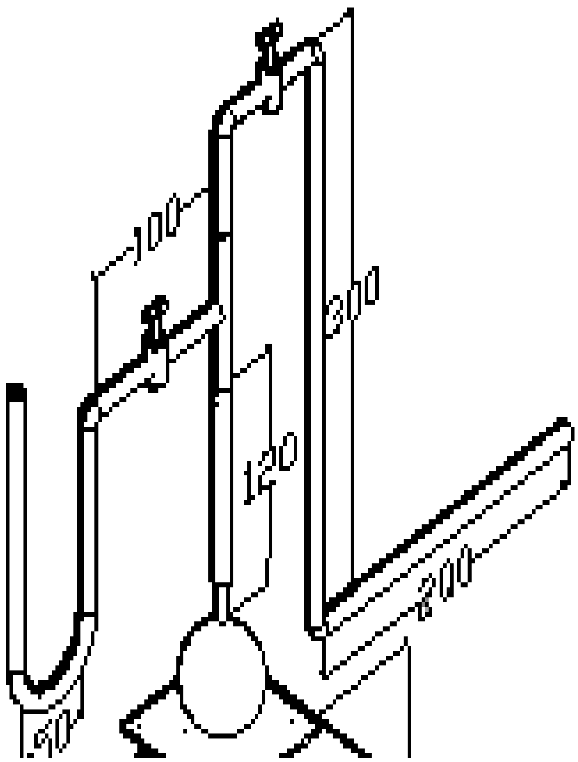

Figure 1. Arrangements of the mini-infiltrometer for hydraulic conductivity measurement.

variable depths or heights of any tested specimen on the table. The dimension of the top was 8.5 cm by 7.5 cm while that of base was 10 × 15 × 20 cm. Rack and pinion meshing with shaft was designed as the mechanism for raising and lowering the table top. The materials for the construction of the table were cut from white transparent Perspex sheet as earlier dimensioned. Some of the Perspex sheets were melted into liquid gum used for joining the Perspex sheets by using Tri – chloromethane. Injecting syringe was used to apply adhesive while joining the perspex plates to make the soil table.

Assembly of the infiltrometer system

After the successful production of all the components, the whole system was formed by assembling all the components together. Rubber tubes were used at every joint so as to make the dismantling of the components possible and for the neatness of the system. The infiltrometer system was held in place with the help of retort stand. Figure 1 shows the isometric view of the mini-infiltrometer for measuring soil hydraulic conductivity.

Equipment test and calibration

The experiment was conducted at the Agricultural Engineering Laboratory of Federal University of Technology, Akure (FUTA), Ondo State, Nigeria to test the effectiveness of the mini-infiltrometer at measuring soil sorptivity. Akure, on latitude 7°14'N, longitude 5°08'E and about 351 m above mean sea level is located within the humid region of Nigeria and lies in the rain forest zone with a mean annual rainfall of between 1300 to 1600 mm and with an average temperature of 27°C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. Four locations were randomly selected for the test. The first location (L1) is on latitude 7° 10'N and longitude 5° 05' E, while the second location (L2) is on latitude 7° 10'N and longitude 5° 07'E. The third (L3) and fourth (L4) locations are on latitude 7° 12'N and longitude 5° 11'E, and latitude 7° 14'N and longitude 5° 10'E, respectively. Soil samples from four different locations (L1, L2, L3, L4), approximately 150 m apart were collected at depths 10, 20, 30, 40, 50, 60 and 70 cm using soil corers of diameter 5 cm and height 4 cm.

The soil samples were taken to the laboratory, molded to ball of approximately 25 mm in diameter and air-dried for two days and soil sorptivity test conducted using the developed mini-infiltrometer. The equipment is consisted of a tube connected to a tank with a small sponge making contact with the narrow tip of the tube as described in Vogelmann et al. (2010). Two different liquids (distilled water and ethanol) with different angles of contact, densities and viscosities were used to conduct the soil sorptivity test. Hydraulic pressure differences within the column of fluid in the reservoir and the infiltrometer, which could affect flow, were eliminated. The soil samples were held in contact with the tip of the infiltrometer (sponge) for 2 min, and the cumulative mass of water or ethanol, which infiltrates the soil by capillary, was recorded by analytical balance to accuracy of 0.0001 g, from the difference in initial and final weight of the reservoir of liquid. The sorptivity (s) of each soil sample was calculated using the formula suggested by Leed – Harrizon et al. (1994).

$$S = \sqrt{\frac{Qf}{4br}} \qquad (1)$$

where,
Q = fluid flow (m^3/s)
f = total porosity (m^3/m^3)
r = radius of the tip of the infiltrometer
b = parameter dependent on the function of diffusion of water in the soil. 0.55 was adopted, according to White and Sully (1987), Vogelmann et al., (2010), and Olorunfemi and Fasinmirin (2011).

Other parameters such as flow (Q) through soil and total porosity (*f*), bulk density were determined as follows:

The following quantities were obtained from the experiment:

w_1 = initial weight of soil sample (g)
w_2 = final weight of soil sample (g)
w_w = weight of water absorbed (g)
$w_w = w_2 – w_1$ (g)
V_w = Volume of water absorbed by soil (cm^3)

$$V_w = \frac{\text{Weight of water absorbed}}{\text{Density of water}} = \frac{w_w}{\rho_w} \qquad (2)$$

where $\rho_w = 1$ g cm^{-3}

$$Q = \frac{Vw}{\text{Time}} = \frac{Vw}{2\text{ min}} = \frac{Vw}{120\text{ s}} \quad (cm^3/s) \qquad (3)$$

$$\text{Total porosity} = 1 - \frac{\textit{Bulk density}}{\textit{Particle density}} \quad \text{Kay and Angers (2002)} \qquad (4)$$

Particle density is assumed 2.65 for soils of the experimental site following the work of Osunbitan et al. (2005)

$$\text{Total porosity} = 1 - \frac{Bulk\ density}{2.65}$$

$$\text{Bulk density} = \frac{weight\ of\ soil}{volume\ of\ soil} = \frac{w}{v} \text{ (Blake and Hartge, 1986)} \quad (5)$$

$$\text{Total soil volume (V)} = 4/3\ \pi r^3 \quad (6)$$

The soil volume per sample was made constant (65.45 cm^3) for all the collected samples. The manufactured mini-infiltrometer was calibrated with a standard mini-disk infiltrometer manufactured in 2007 by Decagon Devices, Pullman, Washington, which measures soil sorptivity to water *in-situ* on the field. The measurements were conducted around the spots where soil was sampled and hydraulic conductivity of soil was then calculated using the method of Zhang (1997). The method requires measuring cumulative infiltration versus time and fitting the results with the infiltration function.

$$I = C_1 t + C_2 \sqrt{t} \quad (7)$$

where C_1 (m s^{-1}) and C_2 (m $s^{-1/2}$) are parameters. C_1 is related to hydraulic conductivity (K), and C_2 is the soil sorptivity.

The hydraulic conductivity of the soil (K) was then computed using the relationship in Equation 8.

$$K = \frac{C_1}{A} \quad (8)$$

where C_1 is the slope of the curve of the cumulative infiltration vs. the square root of time, and A is a value relating the van Genuchten parameters for the soil type under investigation to the suction rate and radius of the infiltrometer disk. A was computed from the relationship:

$$A = \frac{11.65(n^{0.1} - 1)\exp[2.92(n - 1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad n \geq 1.9 \quad (9)$$

$$A = \frac{11.65(n^{0.1} - 1)\exp[7.5(n - 1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad n < 1.9 \quad (10)$$

where n and α are the van Genuchten parameters for the soil, r_0 is the disk radius, and h_0 is the suction at the disk surface.

Statistical analysis

Sorptivity data obtained were subjected to statistical analysis such as mean and standard deviation and analysis of variance (ANOVA). Regression analysis was conducted on measured data from laboratory experiment using the manufactured mini-infiltrometer and field measured data from disc infiltrometer.

RESULTS

Particle size distribution of sampled soils

The result of particle size distribution of sampled soils from the different locations is shown in Table 1. The sampled soils were generally Alfisol (Soil Survey Division Staff, 1993). The soils of location L1 is characterized by high sand content of above 70% especially at depths 20 to 30 cm. The soil of this layer is principally loamy sand from the superficial layer up to the 30 cm depth, while the soils of depths 40 to 60 cm are sandy clay loam in texture. Soils of location L2 is characteristically clay loam up to the 30 cm depth and had an increase in clay content of above 60% from the 40 cm up to the 70 cm depth. Similar observation was reported by Streck et al. (2008) that high clay content is characteristic of Alfisols. The sand content of location L3 was well above 50% from the surface soil up to the 50 cm soil depth. However, soil samples of L1, L2 and L3 were primarily clay from the 60 cm to the 70 cm soil depth.

Water flow rate in soil samples

The result of the performance test and calibration of the developed mini-infiltrometer is presented in Tables 2 to 4. Mean water flow rate was highest in soil sample L2 at the 10 cm soil layer with value of 0.0093 (±0.87) cm^3s^{-1} and lowest in soil sample L1 at depth 50 cm with a value of 0.0016 (±0.92) cm^3s^{-1}. The highest moisture flow rate observed in sample L2 must have resulted from the large number of macropores, which promote the absorption of water overtime.

However, the lowest flow rate in sample L1 must have been caused by the high organic matter content, which tends to inhibit moisture movement into soil and the reduced internal aggregate strength and soil instability. Similar findings were reported by Czarnes et al. (2000), Goebel et al. (2004) and Vogelmann et al. (2010). These researchers confirmed the increase in soil stability and water infiltration due to combined effects of internal aggregate strength and wettability. Wallis and Horne (1992) found cases of extreme water repellency in sandy soils due to the coating of sand by hydrophobic substances, a behaviour which was adduced to high organic matter content in the soil fraction.

Soil bulk density, porosity and organic matter content

The mean bulk densities (BD) of collected soil samples ranged from 1.43(±0.07) to 1.74(±0.09), 1.51(±0.06) to 1.88(±0.02), 1.46(±0.03) to 1.76(±1.16) and 1.45(±0.08) to 1.78(±0.07) Mg m^{-3} for soil samples of locations L1, L2, L3 and L4, respectively (Table 3). Though, soil BD increases from the soil superficial layer to the subsurface layers of sampled soil depths, the highest and lowest soil BD values, 1.88 and 1.53 Mg m^{-3} were observed at depths 60 and 10 cm in soil of locations L2 and L1, respectively. These values of BD are lower than the limits that are critical up to the 50 cm soil depth in samples

Table 1. Means of particle size distribution and silt/clay relationship of the 28 soil depths sampled.

Soil	Depth	Sand	Silt	Clay	Silt/clay	Soil type
L1	10	52.65	8.01	39.34	0.20	Loamy sand
L1	20	77.54	10.45	11.98	0.87	Loamy sand
L1	30	79.34	10.45	10.21	1.02	Loamy sand
L1	40	55.42	11.80	32.78	0.36	Sandy clay loam
L1	50	63.12	11.13	25.75	0.43	Sandy clay loam
L1	60	44.35	17.20	38.45	0.45	Silt clay loam
L1	70	28.38	7.80	46.36	0.17	Sand clay
L2	10	47.65	19.02	33.33	0.57	Clay loam
L2	20	51.65	13.91	34.44	0.40	Clay loam
L2	30	46.87	15.79	37.34	0.42	Clay loam
L2	40	19.61	20.13	60.26	0.33	Clay
L2	50	18.08	18.46	63.46	0.29	Clay
L2	60	16.83	17.81	65.36	0.27	Clay
L2	70	16.54	18.02	65.44	0.25	Clay
L3	10	62.02	22.11	15.87	1.39	Sandy loam
L3	20	60.64	21.02	18.34	1.15	Sandy loam
L3	30	50.76	14.01	35.23	0.39	Sandy clay loam
L3	40	54.65	13.03	32.32	0.40	Sandy clay loam
L3	50	53.66	9.56	36.78	0.26	Sandy clay
L3	60	45.65	9.71	44.64	0.22	Clay
L3	70	40.22	13.04	46.74	0.28	Clay
L4	10	60.22	15.46	24.32	0.64	Sandy loam
L4	20	55.86	14.23	29.91	0.47	Sandy loam
L4	30	51.65	19.91	34.44	0.58	Clay loam
L4	40	46.87	15.79	37.34	0.42	Clay loam
L4	50	48.44	12.24	39.32	0.31	Sandy clay
L4	60	36.42	6.55	57.03	0.11	Clay
L4	70	42.22	6.52	51.26	0.12	Clay

from location L1, while BD of samples from location L2 fell into the critical range from the 30 cm soil depth and above. This must have been due to high clay content coupled with the no-till condition of the soil when sampling was conducted. Reichert et al. (2009) suggested critical values of BD close to 1.6 Mg m^{-3} as a function of clay content, especially on tropical soils. Hence, soils whose BD value exceeds 1.6 Mg m^{-3} are considered as restrictive to root growth. In addition, bulk density values that limit root growth are dependent on soil moisture content (Pabin et al., 1998) and it range between 1.46 and 1.90 Mg m^{-3} (Campbell and Henshall, 1991).

Total porosity was lowest (0.12±0.02 cm^3 cm^{-3}) at the 20 cm depth of sample L2 but highest (0.51±0.06 cm^3 cm^{-3}) in sample from location L4 at the 10 cm soil layer. Due to high bulk density, the soils of location L2, which is predominantly clayey, had decreased total porosity. The high organic matter content in soils of location L4 must have positively influenced the total porosity. Numerous studies have also indicated that crop residues decrease soil compatibility (Gupta et al., 1994; Ohu et al., 1985) and consequently improve soil total porosity.

Soil organic matter (OMC) decreased from top soil to the subsoil probably due to increased soil BD down the soil profile. Highest OMC (2.15±0.12%) was observed at depth 20 cm in samples from location L1, while the lowest OMC (0.34±0.17%) was found at depth 60 cm of samples from location L2. OMC decreased as clay content increased with increasing soil profile of L2. Decrease in OMC from surface to subsurface must have been caused by the accumulation of organic materials on soil surface layer under no-till condition. Logsdon et al. (1990) reported similar occurrence and emphasized that higher levels of OMC results to smaller bulk densities.

Sorptivity values of calibrated mini-infiltrometer

The highest and lowest sorptivity values of 0.885(±0.18) and 0.314(±0.04) mm $s^{-1/2}$ were recorded at depths 10 and 50 cm in soil of locations L2 and L1, respectively

Table 2. Mean water flow rate (Q) for each soil sample (cm ^{3}/s).

Soil samples	Depth (cm)	Initial weight of dry soil (w_1)	Final weight of wet soil (w_2)	Weight of water absorbed ($w_w = w_2 - w_1$)	Fluid flow ($Q = v_w/t$) cm^3/s
L1	10	106.00(±0.20)	107.00(±0.10)	1.00	0.0083(±0.71)
L1	20	99.00(±0.18)	100.00(±1.19)	1.00	0.0083(±1.13)
L1	30	129.00(±0.04)	130.00(±0.68)	1.00	0.0083(±0.76)
L1	40	107.00(±0.67)	107.70(±0.21)	0.70	0.0058(±0.68)
L1	50	114.00(±1.02)	114.19(±0.88)	0.19	0.0016(±0.92)
L1	60	116.00(±0.98)	116.90(±0.29)	0.90	0.0075(±0.58)
L1	70	87.16(±0.21)	87.95(±1.14)	0.79	0.0066(±0.68)
L2	10	91.50(±1.04)	92.61(±0.18)	1.11	0.0093(±0.87)
L2	20	134.11(±0.69)	135.16(±0.42)	1.05	0.0087(±0.28)
L2	30	129.47(±0.74)	130.15(±1.04)	0.68	0.0057(±0.19)
L2	40	151.76(±0.79)	152.67(±0.94)	0.91	0.0076(±1.03)
L2	50	103.47(±0.38)	104.22(±1.05)	0.75	0.0063(±0.07)
L2	60	122.41(±0.09)	123.12(±0.19)	0.71	0.0059(±0.14)
L2	70	113.58(±1.32)	114.42(±0.53)	0.84	0.0070(±0.08)
L3	10	92.06(±1.19)	92.79(±0.86)	0.73	0.0061(±0.03)
L3	20	93.53(0±0.61)	94.35(±0.58)	0.82	0.0068(±0.37)
L3	30	117.98(±0.48)	118.73(±1.52)	0.75	0.0062(±0.93)
L3	40	115.87(±0.42)	116.66(±0.28)	0.79	0.0066(±0.18)
L3	50	117.61(±0.89)	118.33(±0.79)	0.72	0.0060(±0.27)
L3	60	132.40(±0.13)	133.04(±0.52)	0.64	0.0053(±0.85)
L3	70	130.98(±1.18)	131.70(±1.42)	0.72	0.0060(±0.57)
L4	10	84.95(±0.94)	85.61(±0.82)	0.66	0.0055(±0.48)
L4	20	71.22(±0.44)	71.90(±1.04)	0.68	0.0057(±0.83)
L4	30	77.61(±1.10)	78.30(±0.96)	0.69	0.0057(±1.15)
L4	40	65.59(±0.59)	66.37(±0.59)	0.78	0.0065(±0.79)
L4	50	70.44(±1.21)	71.10(±0.91)	0.66	0.0055(±1.53)
L4	60	83.35(±0.28)	83.96(±0.62)	0.61	0.0051(±0.84)
L4	70	66.33(±0.91)	66.98(±1.78)	0.65	0.0054(±0.93)

(Table 4). Increased soil sorptivity was observed in all samples from the surface soil up to the 20 cm depth. However, inconsistencies were recorded form the 30 cm to the 70 cm soil depth. Sorptivity characteristics of samples showed that the soils of the various locations have the tendency for quick infiltration of water at the superficial layer of soil comparatively with other soil layers considered within the soil profile. Soil samples of location L2 were particularly noted for sorptivity decrease from the soil surface to the 60 cm soil depth.

Mini-infiltrometer calibration with disk infiltrometer showed higher sorptivity values in the disk infiltrometer. The means of soil sorptivity measured at depth 10 cm from the mini and disk infiltrometers were 0.77(±0.08) and 0.84(±0.60) mms$^{-1/2}$, respectively. No significant difference in sorptivity was observed at the $p = 0.05$ in each depth considered at the four locations. Also, multiple comparisons of means of sorptivity showed no significant difference in samples obtained from the 10 and 30 cm, 10 and 50 cm, and between 10 and 60 cm at $p = 0.05$. The correlation coefficients (r) between sorptivity measured from mini and disk infiltrometers in locations L1, L2 and L3 were > 0.9, while r from sorptivity calibration in soil of location L4 was least with r = 0.87 (Figures 2 and 3). Generally, the manufactured mini-infiltrometer had a negligible under-prediction of soil sorptivity when compared with the disk infiltrometer.

DISCUSSION

The physical properties of the soil samples collected at various depths from different locations considered varied significantly as shown in Tables 1, 2 and 3 and the observed variability, especially the particle size distribution affected the sorptivity of the different soils. Similar observation was reported by Gupta et al. (1994) and Russo and Brester (1981) who also stated that the variability have appreciable effects on infiltration process and its related parameters.

Table 3. Mean values of soil parameters from the sampled plots.

Soil samples	Depth (cm)	Bulk density (g/cm^3)	Porosity (f) (cm^3/cm^3)	Organic matter content (%)
L1	10	1.43(±0.07)	0.38(±0.04)	1.89(±0.45)
L1	20	1.47(±0.03)	0.42(±0.13)	2.15(±0.12)
L1	30	1.49(±1.01)	0.25(±0.05)	1.48(±0.26)
L1	40	1.55(±0.08)	0.38(±0.08)	1.43(±0.17)
L1	50	1.58(±0.04)	0.34(±0.13)	1.59(±0.44)
L1	60	1.69(±1.12)	0.33(±0.07)	1.84(±1.01)
L1	70	1.74(±0.09)	0.29(±0.10)	1.75(±0.14)
L2	10	1.51(±0.06)	0.47(±0.08)	0.67(±0.06)
L2	20	1.57(±0.01)	0.22(±0.11)	1.21(±0.31)
L2	30	1.69(±0.07)	0.25(±0.01)	1.04(±0.09)
L2	40	1.73(±1.17)	0.12(±0.02)	0.54(±0.10)
L2	50	1.84(±0.08)	0.30(±0.13)	0.46(±0.04)
L2	60	1.88(±0.02)	0.29(±0.06)	0.34(±0.17)
L2	70	1.85(±0.06)	0.34(±0.03)	0.37(±0.21)
L3	10	1.46(±0.03)	0.47(±0.07)	1.34(±0.18)
L3	20	1.48(±0.05)	0.46(±0.15)	0.64(±0.08)
L3	30	1.51(±0.14)	0.32(±0.08)	0.46(±0.13)
L3	40	1.68(±0.06)	0.33(±0.01)	0.38(±0.20)
L3	50	1.71(±0.07)	0.32(±0.03)	0.52(±0.15)
L3	60	1.73(±0.03)	0.23(±0.05)	0.54(±0.23)
L3	70	1.76(±1.16)	0.24(±0.10)	0.47(±0.02)
L4	10	1.45(±0.08)	0.51(±0.06)	1.97(±0.16)
L4	20	1.56(±0.02)	0.50(±0.03)	1.32(±0.13)
L4	30	1.59(±0.01)	0.41(±0.09)	1.54(±1.16)
L4	40	1.61(±0.05)	0.46(±0.01)	0.95(±0.15)
L4	50	1.69(±1.01)	0.47(±0.05)	1.22(±0.06)
L4	60	1.73(±0.03)	0.42(±0.09)	0.76(±0.03)
L4	70	1.78(±0.07)	0.41(±0.02)	0.69(±0.11)

These variations in the soil properties had a lot of effects on the bulk density, hydraulic conductivity, porosity, sorptivity and other hydraulic properties of the soil. This was also confirmed by Gerke and Kohne (2002) and Green et al. (2003).

The soil samples collected from location L1 was characterized by high organic matter content with a considerable mixture of sand and silt. This was physically reflected in its dark colour. Samples collected from location L2 were high in clay content and that might be the reason for the relatively higher bulk densities recorded. Streck et al. (2008) documented similar observation of high bulk density in Oxisol and Alfisols due to high clay content. The soil of location L3, which was readily pulverized, was predominantly sandy loam with high total porosity and low bulk density. The same observation was made by Kay and Angers (2002) and Ringrose–Voase (1996) that the total porosity showed an inverse relationship with the bulk density. Unrestrained values of bulk density were found in the soil samples. This observation was in line with the findings of Reichert et al. (2009).

Soil samples from location L4 were high in clay content with coarse aggregate and gravel concentration down the soil horizon. The porosity of soils of this site was high because of the even mixture of coarse aggregate and gravel content in the soil. This kind of aggregation has a great effect on soil pore spaces as reported by Horn and Smucker (2005), Lipiec et al. (2007), Goebel et al. (2004) and Eynard et al. (2006). The largest percentage of the plants found there were mono-cotyledons, which were characterized as shallow rooted plants. However, common to each of the four locations used for the experiment was the high sorptivity values at the soil superficial layers than the subsurface layers. Also, there was a reduction in organic matter content down the horizon. This agrees with the report of Streck et al. (2008) that the soil organic matter content in the subsurface horizon was below the observed values in all surface horizons examined. In most of the locations sampled, coarse aggregates increases down the soil profile, this resulted to high soil sorptivity below the horizon B.

Table 4. Mean sorptivity of sampled soils as recorded from mini-infiltrometer and disc infiltrometer.

Soil samples	Depth (cm)	Sorptivity (mms$^{-1/2}$) Mini-infiltrometer	Sorptivity (mms$^{-1/2}$) Disk infiltrometer
L1	10	0.761(±0.12)	0.875(±0.14)
L1	20	0.801(±0.04)	0.865(±0.10)
L1	30	0.616(±0.16)	0.698(±0.05)
L1	40	0.634(±0.07)	0.702(±0.07)
L1	50	0.314(±0.04)	0.436(±0.12)
L1	60	0.667(±0.15)	0.712(±0.32)
L1	70	0.768(±0.20)	0.832(±0.08)
L2	10	0.885(±0.18)	0.897(±0.03)
L2	20	0.593(±0.14)	0.655(±0.18)
L2	30	0.507(±0.09)	0.533(±0.07)
L2	40	0.406(±0.06)	0.496(±0.11)
L2	50	0.673(±0.03)	0.747(±0.17)
L2	60	0.559(±0.17)	0.661(±0.21)
L2	70	0.658(±0.19)	0.702(±0.15)
L3	10	0.717(±0.21)	0.812(±0.13)
L3	20	0.753(±0.15)	0.845(±0.02)
L3	30	0.599(±0.10)	0.642(±0.08)
L3	40	0.626(±0.18)	0.651(±0.20)
L3	50	0.589(±0.07)	0.610(±0.17)
L3	60	0.475(±0.11)	0.554(±0.07)
L3	70	0.512(±0.21)	0.524(±0.01)
L4	10	0.712(±0.18)	0.765(±0.25)
L4	20	0.777(±0.04)	0.814(±0.08)
L4	30	0.757(±0.18)	0.772(±0.02)
L4	40	0.854(±0.02)	0.866(±0.27)
L4	50	0.768(±0.16)	0.834(±0.16)
L4	60	0.690(±0.09)	0.704(±0.28)
L4	70	0.777(±0.18)	0.767(±0.16)

However, the reverse was the case for the soils of location L3.

Sorptivity of soil depth in Location 1

Table 3 showed the wide variation in hydraulic properties of the soil at different depths down the soil profile. The soil of location L1 appears rich in organic matter probably as a result of the deposition of animal matters and waste (plant wastes). There was no relationship between particle sizes and the occurrence of hydro-repellency (that is, the extent to which the soil repelled water), which conforms to the findings of Scott (2000). Soil sorptivity was initially high but started decreasing with increasing soil depth up to the 50 cm layer, where appreciable reduction of sorptivity was observed. This reduction must have resulted from the influence of organic matter deposition up to the 50 cm, despite the high clay percentage of the soil. Similar situation was reported by Doerr et al. (2000) and Vogelmann et al. (2009) that decrease in water repellency with increased soil depth was caused by the decreased organic matter content down the soil profile. There was a high hydrophobicity or hydro-repellency at depth 50 cm, which had expansive clays, and this agrees with Lichner et al. (2006), who established that the type of clay mineral can influence hydro-repellency.

Sorptivity of soil in Location 2

The soil samples collected from location 2 had the lowest total porosity at depth 40 cm when compared with all other soil samples collected at similar depth from other locations. This was as a result of high bulk density of the soil which was caused by soil compaction and excessive exposure of the soil to direct effects of climate. The value of soil sorptivity at the upper layer of the soil was high enough to make water available to plants, while aggregate strength and stability increased down the horizon. The results of sorptivity in Table 3 showed that

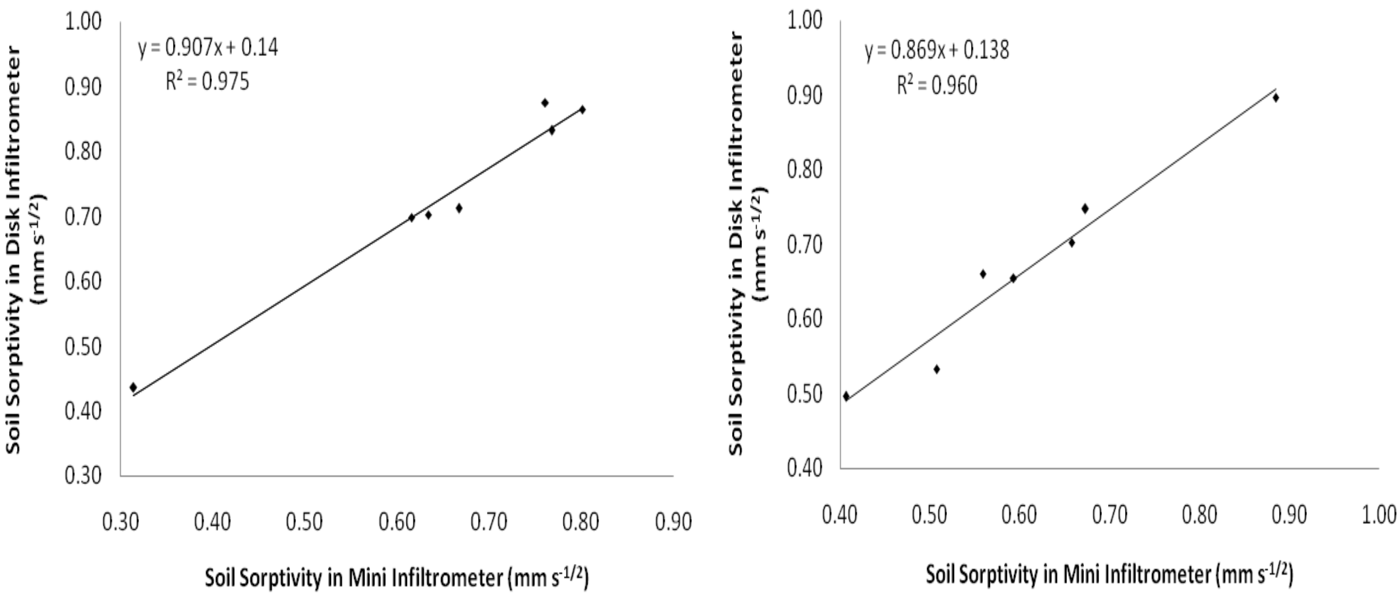

Figure 2. Sorptivity calibration curve of the mini-disc infiltrometer with the disk infiltrometer in locations L1 and L2.

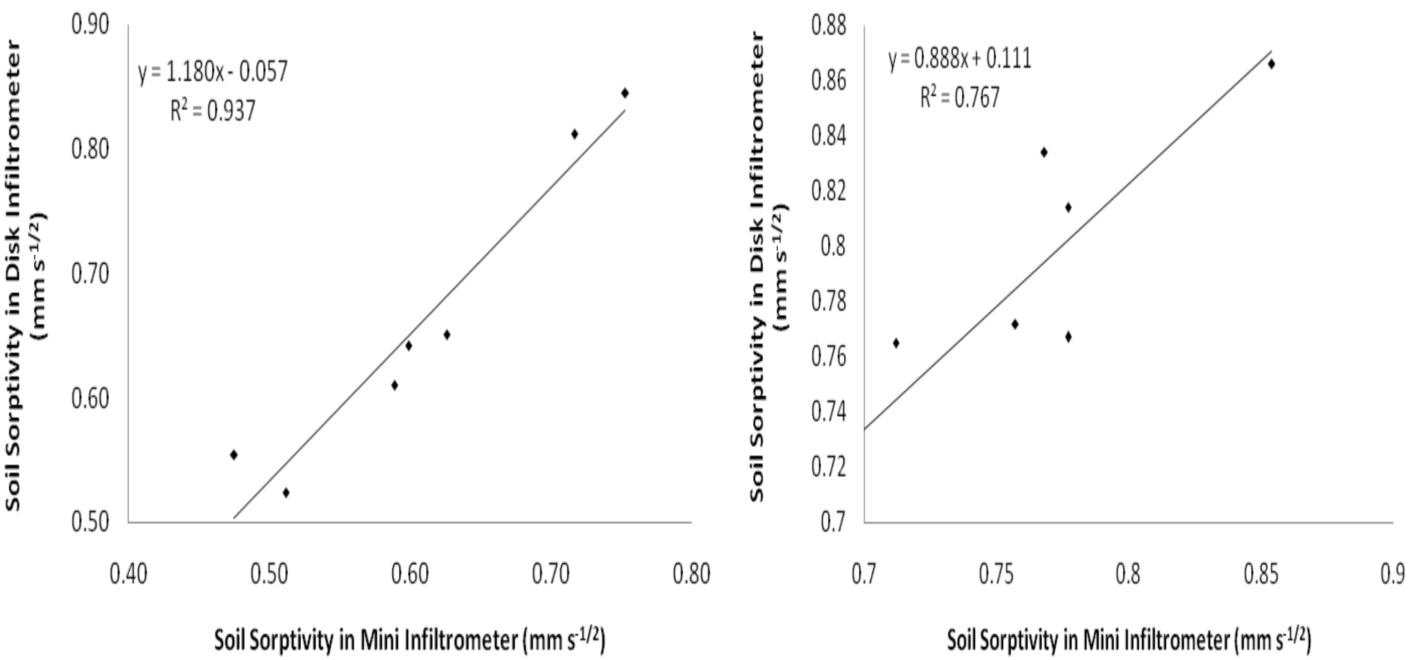

Figure 3. Sorptivity calibration curve of the mini-disc infiltrometer with the disk infiltrometer in locations L3 and L4.

the superficial layer of the soil was not as compacted as soils of B horizon (subsoil). Czarnes et al. (2000), Goebel et al. (2004) and Eynard et al. (2006) reported that increased soil stability and water infiltration can be a result of the combined effect of internal aggregate strength and wettability. This was also in line with Horn et al (1994a, b), Chenu et al. (2000) and Ferrero et al. (2007), who reported that soil compaction, which increased the contact points or forces among soil aggregates, must have been responsible for internal aggregate strength and stability. The fact that the sorptivity suddenly increased at depth 50 cm before the observation of reduction is an indication that the compaction was not uniform.

Sorptivity of soil in Location 3

The soil sample from location 3 is typically a sandy clay soil, characterized by high clay and sand content with some gravels. The soil is however very low in organic matter content. Table 3 shows that the soil has a considerable percentage of sorptivity, it reduced with depth down the soil horizon. Moreover, it was clearly observed during the experiment that the clay content increased with increasing soil depth in location L3. This must have been responsible for the reduction in sorptivity in accordance with the findings of Lichner et al. (2006) and Streck et al. (2008) about the effects of the presence of expansive clay minerals on soil moisture content.

Sorptivity of soil in Location 4

The sorptivity of soil in location L4 was high from one successive depth to another as shown in Table 3. The variation in sorptivity between successive depths in the soil profile was not significantly high comparatively with soils of other location. These must have been caused by the loose soil structure, thereby increasing pore spaces for easy passage of fluids. This finding was in line with that of Horn and Smucker (2005) and Lipiec et al. (2007) who recorded that pore structures affect the hydraulic properties of soil aggregates. Kutilek et al. (2005) and Lipiec et al. (2006) suggested that this type of soil can be modified by compression and tillage practices. Doerr et al. (2006) and Woche et al. (2005) also added that this may be directly linked to the increased specific surface area and improved texture of the soil.

CONCLUSION AND RECOMMENDATION

A mini-infiltrometer for laboratory test of soil hydraulic properties such as soil sorptivity, hydro-repellency and hydrophobicity has been successfully designed and developed. The preliminary test of the system on various types of soil from different locations and depths gave a satisfactory result. The series of tests conducted on the manufactured infiltrometer showed that it can be used for soil sorptivity and hydrophobicity measurement in any soil condition and climate provided that appropriate porous sponge is used. The sorptivity test conducted on soils from different locations and depths gave a wide variation in physical and hydraulic properties from one location to another. However, the sorptivity of soil is particular a function of organic matter content and pore structure of soil.

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