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HYDRAULIC PROPERTIES OF DRYLAND SOILS OF USMANU DANFODIYO UNIVERSITY TEACHING AND RESEARCH FARM, SOKOTO, NIGERIA

A. Nabayi[1], J. Garba[2], N.M. Danmowa[3], S.A. Hashim[4], S. Usman[1], A.T. Mahmud[1], N.G. Hayatu[3], M.S. Abubakar[1] and H.A. Santuraki[1]

[1]Department of Soil Science, Faculty of Agriculture, Federal University Dutse, Jigawa state,
[2]Department of Agricultural Education, Zamfara State College of Education Maru, Zamfara state, Nigeria
[3]Department of Soil Science and Agricultural Engineering, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria
[4]Department of Agronomy, Faculty of Agriculture, Taraba State University, Jalingo, Taraba State, Nigeria

ABSTRACT

Water characteristics of dryland sandy soils could have greater impact in explaining the low yield of the soils due to its very high infiltration rates. Sandy soils have low organic carbon (OC), low CEC and higher bulk density (Db), infiltration rate and saturated hydraulic conductivity (K*sat*). The study was setup to evaluate some physical properties and the infiltration and saturated hydraulic conductivity (K*sat*) of the dryland soils under conventional tillage. Randomised completely block design was used with six (6) sampling spots as the treatments at two (2) different depths (0-15 and 15-30 cm), totalling 36 samples. Infiltration study was carried out in situ with aid of double ring infiltrometer while *Ksat* was determined in the lab using undisturbed cores. The texture of the soil was found to be sand in 0-15 cm depth and loamy sand in the 15-30 cm depth. Significant ($p<0.05$) higher Db, Ksat and lower TP and OM were obtained in spots A and B which differed significantly from C and E. Following a t-test, 0-15 cm had a higher K*sat* (13.3 cm hr^{-1}), organic matter (1.73%), porosity (46.7%) and lower Db (1.41 Mg m^{-3}) which differed significantly ($p<0.05$) from 15-30 cm depth. Significant ($p<0.05$) higher initial infiltration rate, cumulative infiltration and steady state infiltration rates were obtained in spots labelled A and F. Simple linear regression analysis showed that sand and OM content are important factors that determine Ksat positively and negatively respectively at both sampling depths. Conclusively, adoption of conservation tillage practices such as no-tillage would improve the water transmission and physical properties there by reducing leaching and increasing the plant available water content of the soils and consequently improve the soil productivity and minimize erosion.

Keywords: Infiltration rate; hydraulic conductivity; bulk density; organic matter; steady state infiltration rate

INTRODUCTION

The Usmanu Danfodiyo University Dryland Teaching and Research Farm is located within the University premises in Dundaye District of Wammako Local Government Area of Sokoto State. The farm is dominated by sandy soils characterised by low organic matter and cation exchange capacity (CEC), poor soil structure and low plant available water content. Intensive and uneven rainfall is known to cause erosion and poor aggregation (Franzluebbers, 2002).

Infiltration rate (IR) is the vertical movement of water into the soil matrix from the soil surface per unit time. It determines the amount of water storage in soils, which is available to plants and influences the amount of runoff and erosion (Sauwa *et al*., 2013). Estimation of crop water requirement in drylands needs information on soil infiltration characteristics. This information is vital in the management of dryland which can offer knowledge on the crop water requirement during growing seasons (Ayu *et al*., 2013). Wang *et al*. (2012) proved that water is essential to the biological and physical processes to sustain ecosystem and food production functions in drylands. Drylands are usually found on a landscape that was not flooded during certain times of the year, and relies on rain water (Ayu *et al*., 2013). Different soils need different estimation of water needs based on the soil physical properties (Ayu *et al*., 2013). Saturated hydraulic conductivity (*Ksat*) of a soil is its ability to conduct water after all pores are full of water (Lal and Shukla, 2004) suggesting that combined influence of IR and Ksat could significantly influence water regime of a soil (Sauwa *et al*., 2013). Benjamin (1993) attributed greater *Ksat* found in no tillage (NT) system to greater pore continuity via a few large pores. Earthworm burrowing channels were identified among the important conduits for water movements through soil (Kladivko *et al*., 1986). While Jabro *et al.* (2008) reported no significant difference between *Ksat* of conventional tillage (CT) and NT after a long period of practice, Mielke and Wilhelm (1998) reported lower *Ksat* in the NT treatment compared to CT and sub-till treatments.

Infiltration is the hydrological parameters that are difficult to evaluate or measure accurately (Ayu *et al*., 2013). The rate of infiltration and evaporation are the two important parameters in soil water conservation and infiltrability reflecting the capability of a soil profile to absorb water (Asdak, 2004; Mawardi 2011; Mawardi, 2012). Many studies have been carried out on the effects of soil physical properties, such as bulk density, total porosity and particle size distribution on the behaviour of infiltration upon which they concluded that greater infiltration was obtained in soils with higher sand proportion and porosity (Melvis, 2001; Chu and Marino, 2005).

Generally, there are difficulties in generalizing the results of soil hydraulic properties particularly infiltration and hydraulic conductivity from tillage effects, suggesting the need for more research in many regions of the world, for better understanding of the influence of tillage on hydraulic properties of soils and for efficient soil and water management (Sauwa *et al*., 2013). Researchers have studied tillage effects on soil hydraulic properties, particularly water transmission properties where different results were obtained in different soils and climates (Benjamin, 1993; Singh *et al*., 1995; Azooz and Arshad, 1996; Jabro *et al*., 2008; Sauwa *et al*., 2013). Selecting best tillage practice on the farm would go a long way in alleviating water conductance and characteristics problem thereby increasing the productivity of the soil.

Organic Matter (OM) is known to affect the hydraulic properties of a soil (Nemes *et al*., 2005). It is often assumed that higher soil OM will result in higher saturated hydraulic conductivity (*K*sat) (Nemes *et al*., 2005). The reason behind such assumption is that, better soil aggregation is attributed to greater OM contents (Beare *et al*., 1994), OM content and Bulk density (Db) tend to be negatively correlated (Adams, 1973; Rawls *et al*., 2005) and therefore OM content and porosity are thought to be positively correlated (Nemes *et al*., 2005). Several authors (Auerswald, 1995; Mbagwu and Auerswald, 1999; Lado *et al*., 2004) have shown that greater porosity leads to greater hydraulic conductivity.

The objective of the study was to assess the infiltration rate and saturated hydraulic conductivity of the dryland farm under conventional tillage practice and to determine the relationship between some measured variables.

MATERIALS AND METHODS

Experimental site

The study was conducted at the Dryland Teachings and Research Farm, Usmanu Danfodiyo University, Sokoto. The farm is located within the University premises in Dundaye District of Wammako Local Government Area of Sokoto State on latitude 13° 02¹N and longitude 5° 02¹E. The soils of the area are primarily sandy in texture and have very low organic matter content. The ecological zone is Sudan savannah which comprises of scattered trees and sparse vegetation. Total mean annual rainfall ranges between 500-700mm and falls between the months of June and October. Mean annual temperature is greatly variable ranging from 15°C to 40°C (SERC., 2010).

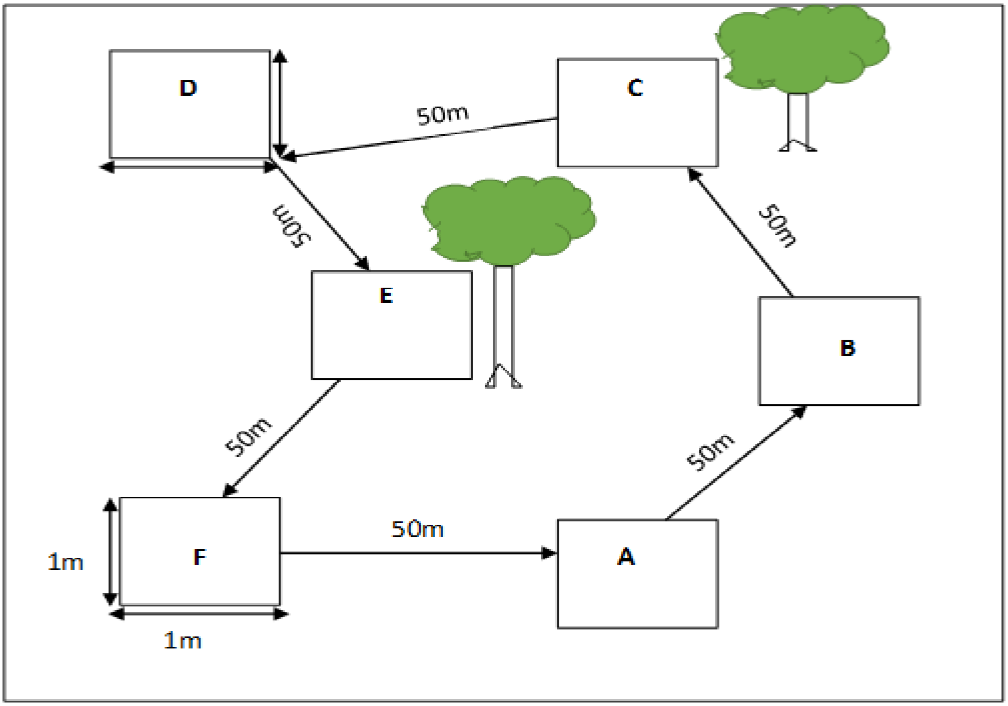

Figure 1: Sampling spots

Sample Collection and Preparation

A purposive sampling technique was used in selecting the spots at 50 m interval. These consist of eighteen (18) soil samples each from 0-15 cm and 15-30 cm, making a total of thirty-six (36) samples. Additional soil samples were taken for analysing some selected physical and chemical properties. The samples were crushed and sieved to pass through <2 mm sieved for analysis and transferred to a nylon bag, labelled and taken to laboratory for analyses.

Determination of Physical Properties

Bulk density was measured using core method, where undisturbed samples were taken in a core of a constant and known volume (Blake and Hartge, 1986). Bulk density of the samples was calculated from the ratio of the oven dried mass to the field volume of the soil as given by the volume of the core sampler (Jamison *et al.*, 1950).

$$\text{Bulk density (Db)} = \frac{Oven\ dried\ mass\ of\ a\ soil\ at\ 105\ oC}{Volume\ of\ the\ soil}\ \text{Mg m}^{-3} \text{------------------------(1)}$$

Porosity was determined indirectly from the measured bulk density and the assumed particle density value of mineral soils (2.65 Mg m^{-3}) using the following equation (Baver *et al.*, 1972).

$$\text{Total porosity (\%)} = 1 - \left(\frac{Bulk\ density}{Particle\ density}\right) \times 100 \text{ --(2)}$$

Particle size analysis was conducted using Bouyoucos hydrometer method as described by Gee and Bauder (1986). The USDA textural triangle was used to determine the textural class of the soils.

Determination of Organic Matter

Walkley-Black (1934) wet combustion method was employed in Organic carbon determination in which the soil samples were treated with standard $K_2Cr_2O_7$ and Conc. H_2SO_4 and was titrated with standard ammonium sulphate solution ($(NH_4)_2SO_4$). After organic carbon, has been determined, the result was multiplied by a factor 1.724 to obtain the organic matter content of the soil (Jones, 2001).

Determination of Hydraulic Properties

Two metal rings were used in determining the infiltration rate of the dryland soils together with plastic ruler, water and stop watch. Three (3) spots (A, C and F) were selected for the infiltration studies based on the topography and physical appearance of the spots. The diameter and height of both inner and outer rings were measured which were found to be 30 and 50 cm respectively. The outer ring was driven into the soil first, then the inner ring was placed and driven into the soil at the middle of the outer one. About 30 cm height above the ground level was left for each ring. The outer ring was first filled with water to avoid lateral water flow, then followed by the inner one, while the infiltration was recorded at different time intervals (Bouwer, 1986).

The saturated hydraulic conductivity of the soil samples was determined by constant head method (Klute and Dirksen, 1986). To determine the hydraulic conductivity, the calibrated measuring cylinder was first placed on the stand followed by funnel on top of the cylinder, then a brass ring (core ring) containing saturated soil samples with one side covered with white cloth and tighten with rubber band was placed in the funnel. Volumetric flask with the known amount of water was tilted upside down with aid of clamp and then the water was released by removing the stopper of volumetric flask to the brass ring which contained soil sample and the water drop was collected into the measuring cylinder. The quantity of dropped water was measured as well as time taken.

Hydraulic conductivity was calculated using the formula given by Darcy (1856) to describe the water flow as;

$$\mathrm{Ksat} = \frac{QL}{ATH} \text{ -- } (3)$$

where Ksat (cm min^{-1}) is the saturated hydraulic conductivity, Q (cm^3) volume of water collected; T- time (minutes); A (cm^2) -cross-sectional area of the sample; H (cm) -hydraulic head difference and L (cm) -length of the soil column.

Experimental design and Data analysis

The treatments were the sampling spots which were replicated three (3) times each and as such, randomised completely block design was used. All data collected were tested using Statistical Analyses System (SAS Institute Inc., 2011). Analysis of Variance was used to determine the significant treatment effect on various measured properties ($p<0.05$). Tukey's Honesty Significant Difference (HSD) test was employed for the mean separation to detect significant difference between means. Minitab (version 16) was used for correlation and regression of some of the measured variables.

RESULTS AND DISCUSSION

Table 1 show the results of the particle size distribution of the soils. The results indicated that the soils of the dryland farm are predominated by sand which gives them sandy texture across the spots at different depths. At 0-15cm depth, the values of sand, silt and clay obtained ranged from 93-96%, 2% and 2-5% respectively, with a textural class of sand. At 15-30 cm depth, the spots had a value range of 81-91%, 2-7% and 6-13% of sand, silt and clay respectively, with a textural class of sandy loam. The soils had a sand texture in all the spots at both depths except spot C and E which were sandy loam at 15-30 cm depth. The differences observed in the spots was due to higher OM content of the spots because of its proximity to shelterbelt which can increase the soil aggregation. Jones and Wild (1975) reported that soils of savannah are predominantly sandy.

Table 1: Particle size distribution and textural class of the soils at different depths

Particle size distribution	Sand (%)	Silt (%)	Clay (%)	Textural class
Sampling spots		0-15 cm depth		
A	96a	2a	2b	Sand
B	96a	2a	2b	Sand
C	93a	2a	5a	Sand
D	94a	2a	4a	Sand
E	95a	2a	3ab	Sand
F	95a	2a	3ab	Sand
SE (±)	1.33	0.30	0.44	
		15-30 cm depth		
A	89a	5a	6bc	Sand
B	91a	2b	7b	Sand
C	81b	6a	13a	Sandy Loam
D	91a	2b	7b	Sand
E	81b	7a	12a	Sandy Loam
F	90a	2b	8b	Sand
SE (±)	0.67	0.3	0.33	

Means followed by the same letter(s) within the same column at each sampling depth are not significantly different from each other at 5% level of significance according to Tukey (HSD). SE- standard error.

Table 2 shows the results of Db, total porosity (TP), OM and *Ksat*. There was no significant difference ($p>0.05$) in the interaction between sampling spot and depth, but significant difference ($p<0.05$) was observed on the main effect of sampling spot and depth on the parameters measured. Spots A, B, D and F differed significantly ($p<0.05$) from C and E with lower Db values and higher TP and OM. The values of Db in spots C and E decreased in the range of 2.1-2.7% while the values of TP and OM increased in the range of 2.1-2.3% and 13.9-14.9% respectively than other sampling spots. In terms of depth, lower Db (1.41 Mg m^{-3}) was recorded in 0-15 cm with higher TP (46.7%) and OM (1.73%) than its 15-30 cm depth counterpart. At 0-15 cm depth, Db value decreased by 2.8% while TP and OM increased by 3.2% and 9.8% relative to 15-30 cm depth. Lower Db and higher TP and OM obtained in spots C and E was due to the influence of organic residues from the shelterbelt that were close to the sampling spots (Figure 1). Increase in OM contents are known to reduce the soil density and increase the TP because of the concurrent improvement in the soil aggregation. Linear regression equations were fitted between the OM content and the soil Db at both 0-15 and 15-30 cm depth with coefficient of determination (R^2) values of 77 % each as shown in equation 4 and 5, respectively.

Table 2: Means of Db, TP, OM and *Ksat* of the different sampling spots

Sampling spot (SP)	Db (Mg m^{-3})	TP (%)	OM (%)	*Ksat* (cm min^{-1})
A	1.44a	45.8b	1.57b	12.4a
B	1.44a	45.6b	1.58b	12.0a
C	1.41b	46.5a	1.79a	8.1c
D	1.44a	45.5b	1.54b	10.8b
E	1.40b	46.7a	1.81a	9.5c
F	1.44a	45.6b	1.58b	11.2ab
SE (±)	0.005	0.154	0.024	0.564
Depth (d)		Mean		
0-15 cm	1.41b	46.7a	1.73a	13.5a
15-30 cm	1.45a	45.2b	1.56b	7.7b
SE (±)	0.04	0.19	0.012	0.2
SP x d	Ns	Ns	ns	ns

Means followed by same letter(s) within the same column (for a given parameter) are not significantly different from one another at 5% level of significance by Tukey (HSD). SE- Standard error, ns- not significant.

Db (0-15 cm) = 1.58 - 0.103 OM; R^2= 0.77---(4)

Db (15-30 cm) = 1.69 - 0.151 OM; R^2= 0.77---(5)

The above equations showed that for every unit increase in OM, there is corresponding 0.103 and 0.151 decrease in Db for the 0-15 and 15-30 cm depths respectively. The findings agree with Adams (1973) and Rawls *et al*. (2005) who reported that OM content decreases soil Db and it also consolidates Nemes *et al*. (2005) who reported a positive relationship between OM and TP.

Greater *Ksat* were recorded in spots A (12.4 cm h^{-1}) and B (12.0 cm h^{-1}) which differed significantly ($p<0.05$) from D (10.8 cm h^{-1}), C (8.1 cm h^{-1}) and E (9.5 cm h^{-1}), but they did not differ ($p>0.05$) from spot F (11.2 cm h^{-1}). Lower values were obtained in spots C and E which did not differ significantly ($p>0.05$). Spots A and B had a value range of about 23-34 % increase in *Ksat* than C and E despite greater Db values and lower TP in the spots relative to other spots (Table 2). Similar observations in *Ksat* values were reported by Sauwa *et al*. (2013) and Singh *et al*. (1995) in tillage practices with higher Db and lower TP values. Lower *Ksa*t in C and E could be due to the higher OM content of the spots which increased the proportion of the smaller soil aggregates while, higher values in A and B could be as a result of higher proportion of sand in the spots as shown in Table 1. Linear regression analysis shown in equation 6 and 7 indicates that sand content in the dryland soil increased *Ksat* at both 0-15 and 15-30 cm depth. On the other hand, OM content had a significant negative linear relationship with *Ksat* at both depths which explains the significant decrease in *Ksat* at spots C and E because of higher OM content of the spots (Table 2). The above reason of lower *Ksat* in C and E due to higher OM content is supported by the established negative linear relationship between *Ksat* and OM content as shown in equations 8 and 9 at both 0-15 and 15-30 cm depths.

Ksat (0-15 cm) = - 105 + 1.25 SND; R^2= 0.89---(6)

Ksat (15-30 cm) = - 33.3 + 0.469 SND; R^2= 0.84---(7)

Ksat (0-15 cm) = 23.4 - 5.69 OM; R^2=0.31---(8)

Ksat (15-30 cm) = 36.7 - 18.4 OM; R^2= 0.71---(9)

Equations 6 and 7 showed that for every unit increase in sand content, there is a corresponding 1.25 and 0.469 unit increases in K*sat* at both 0-15 and 15-30 cm depth respectively. *Ksat* values were significantly different ($p<0.05$) at 0-15 (13.5 cm h^{-1}) and 15-30 cm (7.7 cm h^{-1}) depths. There is an increase of about 43% *Ksat* at the 0-15 cm depth than the lower depth. Higher *Ksat* obtained in 0-15 cm depth despite higher OM content than the lower depth was because of the higher sand proportion. Equation 5 and 6 showed that sand is an important parameter in determination of *Ksat* of a soil. the result disagrees with the findings of Chiroma *et al*. (2006) who reported no significant difference in *Ksat* between 0-15 and 15-30 cm depths in a sandy loam soil.

Equation 8 and 9 showed that for every unit increase in OM, there is a corresponding 5.69 and 18.4 unit decrease in *Ksat* for both 0-15 and 15-30 cm depths respectively. The regression result between OM and *Ksat* disagrees with Sauwa *et al*. (2013) who reported a positive relationship between OC and *Ksat* of a sandy loam soil.

Infiltration rate and cumulative infiltration as a function of time of the three (3) measured spots were significantly different ($p<0.05$) as shown in Figure 1 to 3 for spots A, C and F. The initial infiltration rates of the spots differed significantly ($p<0.05$) with spots A and F having greater IR values of 3 and 2.9 cm min^{-1} respectively, which differed from C (2.3 cm min^{-1}). Similar trend of values was obtained in terms of cumulative infiltration with A and F having 109.3 and 108.8 cm respectively, which differed significantly from C that had only 72.8 cm. The infiltration studies lasted for only 50 minutes due to the nature of the soil (sandy), as such, cumulative infiltration was only for 50 minutes and steady state infiltration rate could not be reached on the field. The cumulative infiltration and the time needed to obtain steady state infiltration rate are influenced by soil texture and structure, roughness of land surface and uniformity of soil profile and initial soil water content (Mawardi, 2011). To determine the steady state infiltration rate, a slope using $\frac{\Delta y}{\Delta x}$ of cumulative infiltration curve was used. Two (2) values were taken from both X-axis (cumulative time) and Y-axis (cumulative water intake) of the three (3) different spots (A, C and F), and the steady state infiltration rates were determined. The steady state infiltration rate was found to be influenced by locations with higher values in spots A (1.92 cm min^{-1}) and F (1.9 cm min^{-1}) which differed significantly from spot C (1.3 cm min^{-1}). The result showed that spot C reached its steady state infiltration rate faster than spots A and F. This could be due to higher percentage of clay and silt in the spots relative to spots A and F (Table 1). Similar results were reported by Singh *et al*. (1995) and Sauwa *et al*. (2013). The constant infiltration rate is of importance to soil and water management since it justifies the crops to be grown as well as the risk of erosion and overland flow under rainfed farming. In this study, the infiltration rate is controlled by the coarse nature of the soil. The result agrees with Shukla (2013) who reported that soil texture greatly influences soil water infiltration as higher clay content decreases infiltration rate.

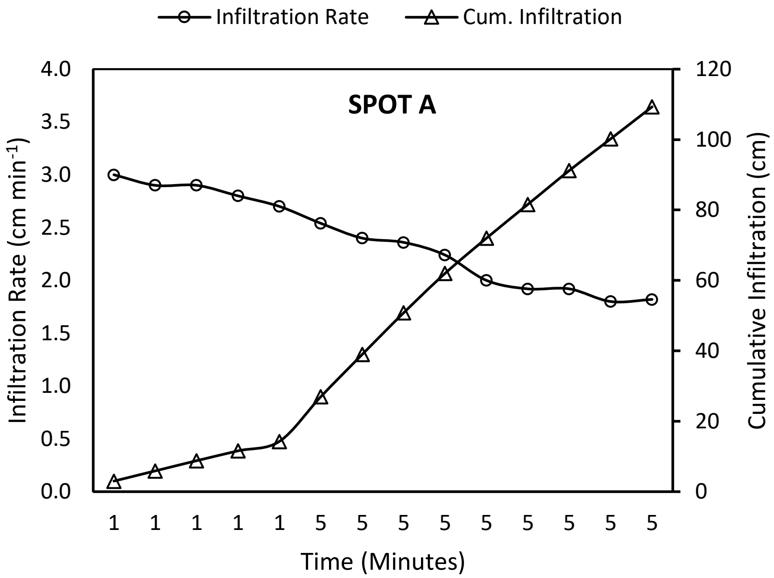

Figure 2: Infiltration rate and cumulative infiltration of spot A

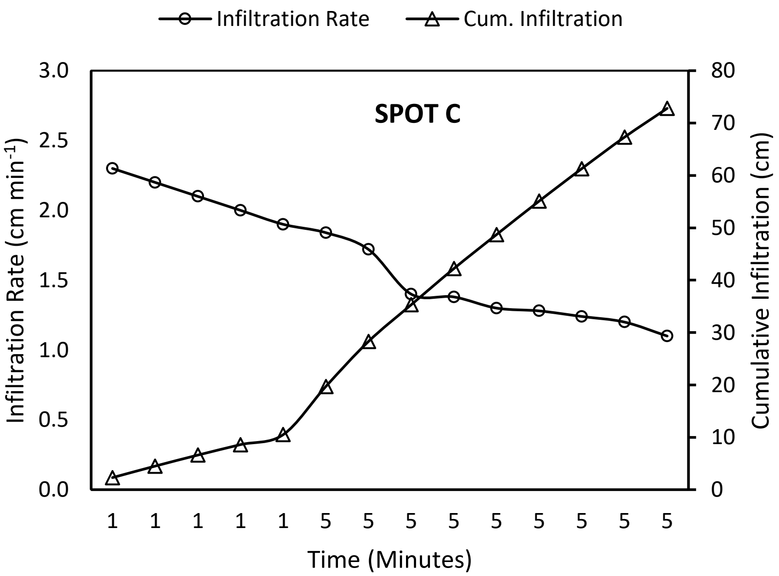

Figure 3: Infiltration rate and cumulative infiltration of spot C

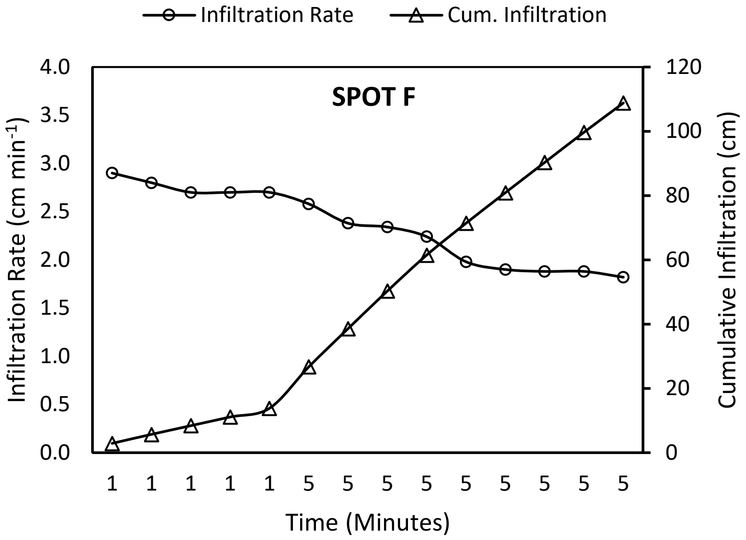

Figure 4: Infiltration rate and cumulative infiltration of spot F

CONCLUSION

The study revealed that significant differences exit from one spot to another in terms of most of the parameters measured largely due to the differences in OM of the soils. Spots with lower OM content had higher Db, *Ksat* and lower TP values. Significant differences also exist between the two (2) different sampling depths with higher OM content, *Ksat* and TP and lower Db at 0-15 cm depth. The infiltration rate and steady state infiltration rate of the dryland soils were very rapid which could lead to leaching and erosion. Very rapid infiltration was largely due to the sandy nature of the soil which increased the infiltration rate thereby reducing the plant available water. Conservation tillage (no-tillage) practices should be adopted in the farm to improve the physical and water characteristics properties of the soil.

REFERENCES

Adams, W. A. (1973). The effect of organic matter on the bulk and true densities of some uncultivated Podzolic soils. *Journal of Soil Science*, 24:10–17.

Asdak, C. (2004). *Hydrology and Watershed Management* (Hidrologi dan Pengelolaan daerah Aliran Sungai). Gadjah Mada University Press, Yogyakarta.

Auerswald, K. (1995). Percolation stability of aggregates from arable top soils. *Soil Science*, 159:142–148.

Ayu, W.I., Sugeng, P. and Soemarno (2013). Assessment of infiltration rate under different drylands types in Unter-Iwes subdistrict Sumbawa Besar, Indonesia. *Journal of Natural Sciences Research*, 3(10): 71-76.

Azooz, R.H. and M.A. Arshad (1996). Soil infiltration and hydraulic conductivity under long term no–tillage and conventional tillage systems. *Canadian Journal of Soil Science,* 76: 143 – 152.

Baver, L.D., Gardner, W.H. and W.R. Gardner (1972). *Soil Physics,* 4th Edition. Wiley & Sons, New York.

Beare, M.H., P.F. Hendrix, and D.C. Coleman (1994). Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Science Society of American Journal*, 58:777–786.

Benjamin, J.G. (1993). Tillage effects on near-surface soil hydraulic properties. *Soil and Tillage Research,* 26(4): 277-288.

Blake, G.R. and K.H. Hartge (1986). Bulk density. *In*: A. Klute (Ed.), *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods* (2nd edition) (pp. 363-375). Wisconsin: ASA-SSSA. pp 363-375.

Bouwer, H. (1986). Intake rate: cylinder infiltrometer. *In:* Klute, A. (ed). Methods of Soil Analysis. Part 1. *Physical and Mineralogical Methods*. 2nd Edition. ASA-SSSA, Wisconsin, pp. 825-844.

Chiroma, A.M., O.A., Foloronso, and A.B. Alhassan (2006). The effects of land configuration and wood- shavings mulch on the properties of a sandy loam soil in Northeast Nigeria. 2. Changes in physical properties. *Tropicultura*, 24(1): 33-38.

Chu, X. and M. A. Marino (2005). Determination of ponding condition and infiltration into layered soils under unsteady rainfall. *Journal of Hydrology*, 313: 195-207.

Darcy, H. (1856). D'etermination des lois d'e'coulement de l'eau a' travers. Les fontaines publiques de la ville de Dijon. Victor Dalmont, Paris.

Franzluebbers, A.J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research*, 66:197-205.

Gee, G.W. and J.W. Bauder (1986). Particle-size analysis. *Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods,* (methodsofsoilan1). pp383-411.

Jabro, J.D., U.M. Sainju, W.B. Stevens, A.W. Lenssen and R.G. Evans (2008). Long-term tillage frequency effects on dryland soil physical and hydraulic properties. *International Soil Conservation Organisation Conference Proceedings*. May 15-23, 2008, Budapest, Hungary. pp 1-4.

Jamison, V.C., H.H. Weaver and I.F. Reed (1950). A hammer driven soil core sampler. *Soil Science,* 69: 487-496

Jones, J.B. (2001). *Laboratory Guide for Conducting Soil Tests and Plant Analysis*. CRC Press, Boca Raton, FL.

Jones, M.J. and A. Wild (1975). *Soil of the West African Savanna*; the maintenance and improvement of their fertility. Commonwealth Agricultural Bureaux. pp.52-57.

Kladivko, E.J., A.D. MacKay and J.M. Bradford (1986). Earthworms as a factor in the reduction of soil crusting. *Soil Science Society of American Journal,* 50: 191-196.

Klute, A. and C. Dirksen (1986). Hydraulic conductivity and diffusivity: Laboratory methods. In: A. Klute (Ed.), *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods* (2nd edn.). Wisconsin: ASA-SSSA. pp 687-734.

Lado, M., A. Paz and M. Ben-Hur (2004). Organic matter and aggregate size interactions in saturated hydraulic conductivity. *Soil Science Society of American Journal*, 68:234–242.

Lal, R. and M.K. Shukla (2004). *Principles of Soil Physics*. Marcel Dekker Inc. NewYork. Pp 405- 411.

Mawardi, M. (2011). *Principles of Irrigation and Soil Conservation* (Asas Irigasi dan Konservasi Tanah). Bursa Ilmu, Yogyakarta. pp 1-57.

Mawardi, M. (2012). Soil and Water Conservation Engineering (Rekayasa Konservasi Tanah dan Air). Bursa Ilmu, Yogyakarta. pp 1-48.

Mbagwu, J.S.C. and K. Auerswald (1999). Relationship of percolation stability of soil aggregates to land use, selected soil properties, structural indices and simulated rainfall erosion. *Soil and Tillage Research,* 50: 197-206.

Melvis, E.G. (2001). *Land-use and Water Resources in Temperate and Tropical Climates*. Cambridge, Cambridge University.

Mielke, L.N. and W.W. Wilhelm (1998). Comparisons of soil physical characteristics in long term tillage winter wheat fallow tillage experiments. *Soil and Tillage Research,* 49:29-35.

Nemes, A., J.R. Walter and A.P. Yakov (2005). Influence of organic matter on the estimation of saturated hydraulic conductivity. *Soil Science Society of American Journal*, 69:1330–1337.

Rawls, W.J., A. Nemes, and Y.A. Pachepsky (2005). Effect of soil organic matter on soil hydraulic properties. p. 95–114. *In:* Ya. A. Pachepsky and W.J. Rawls (eds.) *Development of Pedotransfer Functions in Soil Hydrology*. Elsevier, Amsterdam-New York.

SAS Institute Inc (2011). *The SAS System for Windows*, Release 9.2. Statistical Analysis Systems Institute, Cary, NC, USA.

Sauwa, M.M., A.M. Chiroma, U.U. Waniyo, A.L. Ngala, and N.M. Danmowa (2013). Water transmission properties of a sandy loam soil under different tillage practices in Maiduguri, Nigeria. *Agriculture and Biology Journal of North America*, 4(3): 227-234.

SERC (2010). Sokoto Energy Research Center Weather Record for 2009, 2010, 2011 and 2012.

Shukla, M.K. (2013). *Soil Physics*: *An Introduction*. CRC Press, Boca Raton, FL. Pp 27-38.

Singh, B., D.S. Chanasyk and W.B. McGill (1995). Soil hydraulic properties of an orthic black chernozem under long-term tillage and residue management. *Canadian Journal of Soil Science*, 76: 63-71.

Walkley, A. and I.A. Black (1934). An examination of the degtjareff method of determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science,* 37: 29-38.

Wang, L., P. D'Odorico, J.P. Evans, D. Eldridge, M.F. McCabe, K. K. Caylor and E. G. King (2012). Dryland ecohydrology and climate change: critical issues and technical advances in Hydrology and Earth System Sciences (HESS). www.hydrol-earth-syst-sci-discuss.net/9/4777/2012, Accessed 1-02-2013.