Original Research Article

COMPARISON OF INFILTRATION RATES OF SOILS FOR RUN-OFF MANAGEMENT AND IRRIGATION PLANNING IN MAKURDI BENUE STATE, NIGERIA

Abstract

Understanding of initial infiltration rates and steady state infiltration rates of soil is very important for runoff management and irrigation scheduling. Therefore, a field experiment was conducted at the Teaching and Research Farm of Joseph Sarwuan Tarka University, Makurdi in 2018 to evaluate the initial and steady state infiltration rates of soils in Makurdi, Nigeria. Infiltration test was carried out using double ring infiltrometer at eighteen points. Initial and steady state infiltration rates and the cumulative infiltration were then calculated. Soil samples were collected from the adjacent area of the marked points at 0-15 cm and 15-30 cm depths for routine analysis. Undisturbed soil samples were also collected for the measurement of saturated hydraulic conductivity, bulk density, total porosity and moisture content determination. Simple descriptive statistic of mean, variance and standard deviation was used to analyze the data. The soils were predominantly sandy loan texture, with percentage sand, silt and clay as 710.7, 118.9, and 170.4 g kg^{-1} respectively. Soil bulk density and saturated hydraulic conductivity were 1.40 g cm^{-3} and 10.27 cm hr^{-1} at 0 – 15 cm depth, while soil organic carbon and CEC were 0.67 % and 6.62 cmol/kg respectively. The initial infiltration rate ranged from 7.40 - 87.46 mm hr^{-1} with a mean of 44.09 mm hr^{-1}, meanwhile, the steady state infiltration rate ranged between 4.99 – 22 mm hr^{-1}, with a mean value of 15.42 mm hr^{-1}. High soil bulk density caused moderate to low infiltration capacity. The mean values for the steady state infiltration rate suggest that the soils of the study area have moderate infiltration capacity, therefore, water application for irrigation should be less or equal to the infiltration capacity of the soils to minimize water loss by surface runoff and erosion.

Keywords: infiltration rates, steady state infiltration rates

1.0 INTRODUCTION

Soil water is undoubtedly one of the most important in agriculture as it plays a vital role in water availability for plants in the various root zones of the soil (Musa and Adeoye, 2010). Infiltration is the process of water movement from the ground surface into the soil and is an important component in the hydrological cycle (Haghiabi *et al*., 2011). Infiltration and percolation cannot be treated independently, because the rate of infiltration is controlled by the rate of percolation below the surface (Hsu *et al*. 2002). However, infiltration has received a great deal of attention from soil and water scientist because of its fundamental role in – surface and subsurface hydrology, irrigation and agriculture (Mishra *et al*., 2003).

Soil water is one of the principal factors limiting the growth of plants not only in the arid and semi-arid environment where total crop water requirements usually exceed water supply, but also in the humid environment where poor rainfall distribution and water management result in occasional water stresses (Musa and Adeoye, 2010). Quantification of infiltration is necessary to determine the availability of water to crops and to estimate the amount of additional water needed for irrigation. It is also needed in watershed management to predict flooding, erosion, and pollutant transport.

The objectives of the Study were therefore, to compare the initial and steady states infiltration rates of selected sites in the study area; evaluate the effects of soil physical properties on these properties.

2.0 MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out at the Teaching and Research Farm of the University of Agriculture, Makurdi, Benue State, Nigeria in 2018. This area falls within the southern Guinea Savannah Zone of Nigeria with the mean rainfall of 1,200 mm per annum and temperature of 25-30 ^{0}c.

2.2 Field Methods

The field was divided into six strips of 100 m by 30 m. Three points at 30 m interval, the length was marked out and infiltration test were carried out at those points for each strip. A total of eighteen infiltration runs were carried out across the strips. Infiltration measurement was carried out using a double ring infiltrometer. The dimensions of the rings were 60 by 30 cm for the outer ring and 30 by 30 cm for the inner ring. The infiltrometer was driven into the soil to a depth of 15 cm and a measuring tape was fixed inside the inner cylinder from where readings were taken. Water was maintained at the outer ring to minimize lateral flow. Readings were then taken at intervals to determine the amount of water infiltrated during the time interval with an average infiltration head of 5 cm maintained.

2.3 Soil sampling

Disturbed and undisturbed soil samples were collected at 0 – 15 cm and 15 – 30 cm depths adjacent to the point of infiltration runs for routine analysis (ref) and determination of soil physical properties. Soil bulk density (SBD), total porosity, saturated hydraulic conductivity as well as gravimetric water content were determined using standard procedures (Blake and Hartge, 1998).

2.5 Data Analysis

A simple descriptive statistics of mean was used to analyze the data.

3.0 Results and discussion

3.0 Result

The textural class of the soils of the Eighteen infiltration points was sandyloam (SL). Sand, Silt and Clay averaged 710.70 g kg^{-1}, 118.90 g kg^{-1} and 170.00 g kg^{-1} respectively (Table 1). The soils of this area were slightly acidic with pH range of 6.10 – 6.43. Organic carbon and total nitrogen content were generally low with mean values of 0.67 and 0.1 % respectively (Table 1). The exchangeable bases (EB) ranged from 4.70 – 5.55 Cmol kg^{-1}, also, cation exchange capacity (CEC) ranged from 5.70 – 7.52 Cmol kg^{-1}. Soil bulk density (SBD) was higher at 15 – 30 cm depth with a mean of 1.53 g cm^{-3} compared with mean of 1.40 g cm^{-3} recorded at 0 – 15 cm depth in the study area (Table 2). Conversely, the soil total porosity was higher at 0 – 15 cm depth (47.02 %) compared with a mean of 41.56 % obtained at 15 – 30 cm depth. Soil moisture content averaged 5.66 % at 0 – 15 cm depth which was lower than the average value (6.14 %) obtained at 15 – 30 cm depth. The saturated hydraulic conductivity (Ksat) of infiltration points A – R raged from 3.32 – 29.86 mm hr^{-1} at 0 – 15 cm depth and 2.86 – 28.19 mm hr^{-1} at 15 – 30 cm depth (Table 2). The initial, and steady state infiltration rates of the Eighteen Points A – R are stated on Table 3. This Table also indicate the GPS coordinates and the elevation of the infiltration points. The initial infiltration rates (fo) varied widely at the infiltration points with point J having the highest fo (144.94 mm hr^{-1}) and the lowest fo was obtained at point K (7.40

mm hr^{-1}). Steady state infiltration rate was observed to be highest at point J (33.25 mm hr^{-1}) and lowest at Point K (4.99 mm hr^{-1}). Infiltration rates varied widely at beginning of infiltration with variance of 1205 mm hr^{-1} and standard deviation of 17.48 (Table 3), however, as infiltration progressed to steady state, the variance was 43.29 for steady state infiltration rates. Figure 1 shows the relationship between soil physical properties and the steady state infiltration for the Eighteen points. The reduction in soil bulk density at point A caused an increase in soil total porosity and saturated hydraulic conductivity (Figure 1). Also, an increase in soil bulk density at point N caused reduction in total porosity and saturated hydraulic conductivity. Meanwhile, at point K where soil bulk density was highest (1.70 g cm^{-1}), steady state infiltration rates was lowest (4.99 mm hr^{-1}), suggesting that high bulk density could cause reduction in steady state infiltration rate of the soil.

Table 1: Particle size distribution and chemical properties of the study area

Points	pH	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Text class	O. C %	N %	P mg/l	K cmol/kg	Na cmol/kg	Mg cmol/kg	Ca cmol/kg	EB cmol/kg	EA cmol/kg	CEC cmol/kg	BS %
A	6.13	728.00	122.00	150.00	SL	0.56	0.05	2.80	0.26	0.22	2.70	2.91	6.09	1.00	7.09	85.90
B	6.22	730.80	120.00	149.20	SL	0.40	0.04	2.81	0.22	0.20	2.64	2.90	5.96	1.04	7.00	85.14
C	6.43	702.80	112.60	184.60	SL	0.94	0.06	3.00	0.26	0.61	1.40	2.52	4.79	1.10	5.89	81.32
D	6.30	687.20	103.10	209.70	SL	0.90	0.08	3.80	0.25	0.60	1.37	2.61	4.83	1.30	6.13	78.79
E	6.15	711.10	121.10	167.80	SL	0.95	0.21	2.51	0.28	0.45	2.38	2.94	6.05	1.00	7.05	85.82
F	6.14	710.00	102.80	187.20	SL	0.66	0.14	3.25	0.23	0.50	1.58	3.28	5.59	1.14	6.73	83.06
G	6.31	721.30	120.20	158.50	SL	0.54	0.06	3.11	0.23	0.47	2.62	2.42	5.74	1.04	6.78	84.66
H	6.23	710.5	103.10	186.40	SL	0.78	0.17	2.68	0.21	0.60	2.64	3.06	6.51	1.01	7.52	86.57
I	6.13	698.30	134.60	167.10	SL	0.68	0.11	2.80	0.26	0.65	2.70	2.65	6.25	1.11	7.36	84.92
J	6.41	696.00	123.00	181.00	SL	0.92	0.20	2.16	0.21	0.45	2.60	2.78	6.04	1.02	7.06	85.55
K	6.24	722.30	113.60	164.10	SL	0.52	0.04	3.12	0.23	0.22	1.57	2.90	4.92	1.00	5.92	83.11
L	6.15	730.20	120.80	149.00	SL	0.56	0.06	3.10	0.22	0.61	1.39	2.52	4.74	1.04	5.78	82.01
M	6.20	701.60	120.30	178.10	SL	0.43	0.03	3.31	0.25	0.20	2.18	2.71	5.34	1.10	6.44	82.92
N	6.10	723.10	122.00	144.90	SL	0.64	0.10	2.62	0.22	0.45	2.22	2.61	5.50	14.00	6.64	82.83
O	6.30	728.60	120.00	151.40	SL	0.40	0.09	2.89	0.28	0.60	2.14	2.28	5.30	1.04	6.34	83.60
P	6.43	718.60	120.20	161.20	SL	0.56	0.05	3.00	0.23	0.20	1.74	2.53	4.70	1.00	5.70	82.46
Q	6.37	692.10	116.10	191.80	SL	0.90	0.20	2.81	0.26	0.22	1.89	2.90	5.27	1.08	6.35	82.99
R	6.22	671.10	144.10	184.80	SL	0.64	0.14	2.92	0.22	0.61	2.61	2.91	6.35	1.05	7.40	85.81
Mean	6.25	710.70	118.90	170.00		0.67	0.10	2.93	0.24	0.44	2.13	2.75	5.55	1.78	6.62	83.75
Median	6.23	710.80	120.20	167.50		0.64	0.09	2.91	0.23	0.46	2.20	2.75	5.55	1.04	6.69	83.35
Minimum	6.10	671.10	102.80	144.90		0.40	0.03	2.16	0.21	0.20	1.37	2.28	4.70	1.00	5.70	78.79
Maximum	6.43	730.80	144.10	209.70		0.95	0.21	3.80	0.28	0.65	2.70	3.28	6.51	14.00	7.52	86.57
Standard deviation	0.11	1.69	1.02	1.84		0.19	0.06	0.35	0.02	0.18	0.51	0.25	0.60	3.05	0.58	1.98
Variance	0.01	2.85	1.04	3.38		0.04	0.00	0.12	0.00	0.03	0.26	0.06	0.36	9.30	0.34	3.92

Keys: A – R = Sampling Points; SL = Sandy loam

Table 2 Physical properties of the study area

Infiltration	**Bulk density (g cm^{-3})**		**Total Porosity (%)**		**Gravimetric water content (%)**		**Hydraulic conductivity Ksat (mm hr^{-1})**	
Point	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
A	1.29	1.26	51.34	54.52	4.51	4.83	29.85	28.19
B	1.25	1.52	52.81	42.56	5.14	4.54	12.92	11.35
C	1.31	1.41	50.58	46.85	4.69	4.75	8.90	4.19
D	1.46	1.62	44.86	38.93	5.14	4.47	3.32	4.63
E	1.34	1.57	49.40	40.81	4.75	4.80	3.58	3.32
F	1.26	1.28	52.50	51.74	4.83	5.13	18.60	16.64
G	1.59	1.47	40.00	44.50	4.91	5.00	21.91	20.16
H	1.32	1.37	50.20	48.31	5.13	5.23	7.68	8.38
I	1.31	1.68	50.62	36.56	5.13	5.00	9.95	8.81
J	1.40	1.53	47.23	42.31	16.40	5.21	14.66	13.18
K	1.48	1.72	53.60	38.53	6.34	11.52	10.12	7.94
L	1.41	1.61	46.82	39.20	6.61	10.91	3.75	2.85
M	1.49	1.62	43.80	38.91	4.92	10.81	7.24	6.02
N	1.47	1.67	44.52	35.80	6.20	5.91	7.59	6.63
O	1.40	1.57	44.24	40.75	4.20	5.10	5.32	3.32
P	1.56	1.51	41.33	43.04	4.91	5.42	6.20	4.80
Q	1.52	1.51	42.64	43.34	4.00	5.92	8.90	4.12
R	1.50	1.68	43.42	36.64	4.04	5.90	4.36	6.28
Mean	1.40	1.53	47.22	40.41	5.66	6.14	10.27	8.93
Median	1.40	1.55	47.02	41.56	4.92	5.17	8.29	6.46
Minimum	1.23	1.26	40.00	4.84	4.00	4.47	3.32	2.85
Maximum	1.59	1.70	53.60	54.52	16.40	11.52	29.85	28.19
Std. dev	0.11	0.13	4.26	10.28	2.78	2.32	7.08	6.79
Variance	0.01	0.02	18.18	105.70	7.71	5.38	50.18	46.09

A – R = Sampling Points; BD = Bulk Density; TP = Total Porosity; Ksat = Saturated Hydraulic Conductivity, Std. dev= standard deviation.

Table 3: Initial, final and steady state infiltration of the study area

Points	Degree North	Degree East	Elevation (m)	Fo mm hr^{-1}	Ic mm hr^{-1}
A	07^{o} 47’ 46.5” N	008^{o} 36’ 54.6”E	109	40.65	10.64
B	07^{o} 47’ 45.9” N	008^{o} 36’ 54.8”E	108	40.48	12.85
C	07^{o} 47’ 45.9” N	008^{o} 36’ 53.8”E	111	87.46	18.72
D	07^{o} 47’ 45.8” N	008^{o} 36’ 53.8”E	104	60	9.3
E	07^{o} 47’ 45.9” N	008^{o} 36’ 53.4”E	105	24.81	10.66
F	07^{o} 47^{o} 46.1” N	008^{o} 36’ 54.3”E	103	46.51	13.53
G	07^{o} 47’ 45.6” N	008^{o} 36’ 54.6”E	103	50	19.35
H	07^{o} 47’ 45.5” N	008^{o} 36’ 53.6”E	107	69.93	14.26
I	07^{o} 47’ 45.4” N	008^{o} 36’ 54.3”E	90	31.84	8.98
J	07^{o} 47’ 45.1” N	008^{o} 36’ 54.1”E	106	144.92	33.25
K	07^{o} 47’ 45.7” N	008^{o} 36’ 54.0”E	103	7.4	4.99
L	07^{o} 47’ 45.6” N	008^{o} 36’ 54.1”E	99	131.00	15.75
M	07^{o} 47’ 44.9” N	008^{o} 36’ 53.5”E	102	46.8	16.62
N	07^{o} 47’ 45.3” N	008^{o} 36’ 53.8”E	101	28.84	9.86
O	07^{o} 47’ 45.3” N	008^{o} 36’ 53.6”E	95	45.52	22.76
P	07^{o} 47’ 45.4” N	008^{o} 36’ 53.5”E	98	41.32	14.92
Q	07^{o} 47’ 45.5” N	008^{o} 36’ 53.4”E	101	50	18.5
R	07^{o} 47’ 45.1” N	008^{o} 36’ 45.1”E	110	46.22	22.55
		Mean		44.09	15.42
		Median		45.22	14.59
		Standard deviation		17.48	6.58
		Variance		1205	43.29

KEYS; A – R = Sampling Points; Fo = Initial Infiltration rate; Ic = Steady state infiltration rate

Fig 1: The relationship between soil physical properties and the steady state infiltration for the Eighteen points

Discussion

Soil physical properties on infiltration rates

Runoff as one of the major causes of soil erosion usually occur when the volume of water either from rainfall or irrigation water exceed the infiltration capacity of the soil. This becomes evident in the detachment and transport of soil particles including available nutrient from one point to another (Adaikwu *et al,* 2017). The entry of water into the soil is very crucial to crop survival and subsequently crop yield in any location.

The initial infiltration rates (fo) for the Eighteen infiltration points varied widely from one point to another which may be due to variation in initial moisture content at the different points and soil bulk density. It was observed that the infiltration rate IR was generally very high at the onset of application of water under continues ponding condition, decreases rapidly and then more slowly until it approaches a constant rate asymptotically (steady state infiltration rate). Many aspects of hydrology and agricultures as well as surface runoff and water content of the soil are affected by the infiltration rate of the soil (Marshall and Holmes, 1988).

Soils of the study area though belong to the same textural class, sandyloam texture, responded differently to application of water in the infiltration study. The steady state infiltration rates from point A to R show high to moderate infiltration capacity which may be largely due to the textural composition (Sandyloam) of the soil and its bulk density. Soil texture is an inherent, non-modifiable factor that affect soil infiltration rate (USDA-NRSC). Sandyloam textured soil generally have larger pores that allow easy flow of water through them, than clayey soils with smaller pores that rather transmit water more slowly, particularly when the clay is compacted with little or no structure or aggregation. Water distribution during infiltration is not uniform because most soil profiles are differentiated into horizons. According to Ogban (2017), textural characteristics specifically the percentages of clay and sand affect infiltration because they determine whether infiltration rate is dominated by gravitational forces or capillarity forces, under a given rainfall intensity. Infiltration is gravity driven in coarse – textured soil and capillarity - driven in fine – textures (Reynolds *et al*, 2002) and is higher in the former than in the latter. Where a coarse layer overlays a fine textured layer, the initial and final infiltration rates are controlled by the course and the fine-textured layer respectively (Hillel, 1982). Soil texture directly affects soil moisture redistribution through its effect on soil permeability and on the hydraulic conductivity which expresses how easily water flows through the soil as well as the water holding capacity, and ultimately the infiltration rate. With the high to moderate infiltration capacity characteristics of the soils of this study area, the soils are likely to be less predisposed to surface ponding from either rainfall or irrigation water with less tendency for surface runoff and erosion. Water application for irrigation should be less or equal to the infiltration capacity of the soils to minimize water loss by surface runoff and erosion.

High soil bulk density and low saturated hydraulic conductivity were associated with low infiltration rates at initial and steady state infiltration rates in this study. Soil bulk density and hydraulic conductivity are properties that are fundamental to soil compaction and related agricultural management issues (Strudly *et al*, 2008). According to Hillel, 1982, for loose ploughed layer overlaying compact subsoil and a surface crust with higher bulk density and lower hydraulic conductivity, it is the layer of the lowest hydraulic conductivity that controls the infiltration rates, whereas in the case of a crusted soil where the hydraulic conductivity of the surface layer is lower than that of the subsoil, the crusted layer determines the initial infiltration.

Pores with different shape and size influence the infiltration, storage and drainage of water, the movement and distribution of gases, and ease of penetration of soil by growing roots (Kay and Vandenbygaart 2002). Radke and Berry (1993) observed that increases in soil bulk density due to soil use and management e.g tillage operation as well as rain drop impact reduced infiltration rate. Mukhtar *et al*, (1985) reported that the presence of macro pores determines the amount of water entering the soil. Increased infiltration rate associated with well-structured soil, decreases surface run off and in turn reduces soil erosion (Ogban, 2017).

The soil moisture content was higher at 15 – 30 cm depth than at 0 – 15 cm depth. This may be due to presence of smaller pores at higher depths that retain water at grater suction than the larger pores at the surface depths which could transmit water more rapidly. Soil moisture is the source of water to plant use particularly in rain fed agriculture (Mweso, 2003). Soil moisture is highly critical in ensuring good and uniform seed germination and seedling emergence, crop growth and yield.

Conclusion

This study was undertaken to compare the infiltration rates of soils in eighteen selected point within the study area as well as evaluate the effect of soil physical properties on soil infiltration rates. Field infiltration runs were conducted using double ring infiltrometer to obtain initial and steady state infiltration rates. High bulk density and low saturated hydraulic conductivity caused decrease in the infiltration rates of the soil. The initial infiltration rates (fo) varied widely at the infiltration points with point J having the highest initial infiltration and the lowest was obtained at point K. Likewise, the steady state infiltration rates were recorded at point J. The mean values for the steady state infiltration rate suggest that the soils of the study area have moderate infiltration capacity, therefore, water application for irrigation should be less or equal to the infiltration capacity of the soils to minimize water loss by surface runoff and erosion.

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