Arid Zone Journal of Engineering, Technology and Environment. October, 2004; Vol.4, 16-22
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Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

COMPARISON OF DIFFERENT METHODS FOR DETERMINING SATURATED HYDRAULIC CONDUCTIVITY ON ALLUVIAL FLOODPLAIN SOILS IN A SEMI ARID ENVIRONMENT

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Abstract

Soil saturated hydraulic conductivity is an important parameter for flow and transport related processes in the soil but the different methods of its measurement vary under different field conditions. The performance of three *in situ* methods were evaluated at 20, 40 and 80 cm depths on an alluvial floodplain soil classified as fine loamy isohyperthermic aeric Trapaquept. The Guelph permeameter method gave the lowest estimates of saturated hydraulic conductivity, possibly because of small sample size, whereas the Disk permeameter method gave maximum values for saturated saturated hydraulic conductivity with minimum variability, possibly due to large sample size. The estimates of saturated hydraulic conductivity were most comparable for the velocity permeameter and the laboratory method using a constant head permeameter.

1. Introduction

Soil saturated hydraulic conductivity is required in estimation of infiltration, runoff, soil water balance, water and chemical transport to ground water via the vadose zone and the other components of the hydrologic cycle. Several infiltration measurement techniques have been developed over the years for a range of applications. However, the reliability and usefulness of these techniques for different field conditions is a cause for concern by soil scientists, engineers and hydrologists. Many studies have been carried out in recent times in order to address this problem for different methods under field conditions (Mohanny *et al*., 1994; Paige and Hillel, 1993). Interestingly, the different methods have shown different trends under different soil textures and field conditions. Research on the appropriateness of the different methods for different soil types and field conditions (tillage practices, macroporosity, tillage depths and morphology) is a subject for further research.

Hydraulic properties of soils at different depths and different spatial locations can be investigated by different measuring techniques. Such studies often produce variable results. Mohanty *et al.* (1994) have observed that the variability of saturated hydraulic conductivity within the field could be as a result of the measuring technique effect. The objective of this study was to compare estimated saturated hydraulic conductivity from different in situ measuring techniques with a standard laboratory technique on an alluvial floodplain soils (locally referred to as *fadama*).

2. Materials and methods

2.1 The study area

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The study was carried out on the alluvial floodplain of the Komadugu-Yobe in the upper Yobe river system around Gashua (12^o 49.15'N, 11^o 05.52'E) situated in the semi arid region of Nigeria. The upper Yobe river system comprises the Hadejia and Jama'are rivers that originate from the Jos plateau and flow across the rocks of the basement complex to the sedimentary Chad formation. The two rivers meet in an area of complex drainage upstream of Gashua. In all, the rivers drain in an area of about 60,000 km^2 (Sellars, 1981).

The Chad formation consists of sediments of tertiary and quaternary age deposited by rivers flowing into the Yobe basin (Bawden *et al.*, 1972). The sediments are poorly graded, comprising coarse and fine sands, silts and clays. The basement complex lies to the west and south east, and to the south, there are the cretaceous rocks of the upper Benue River, the Kerri-Kerri formation and the basalts of Biu plateau (du Preez and Barber, 1965). The topography of the *fadama* areas is characterised by a gently undulating plain with shallow depressions.

2.2 Determination of soil physical properties

The laboratory analyses carried out on soil samples include the following: particle-size analysis, determination of soil bulk density and total porosity. The physical properties were determined in accordance with specifications (Bascomb, 1974).

2.3 Determination of saturated hydraulic conductivity

Saturated hydraulic conductivity measurements using different methods were made on the soil at depths of 20, 40 and 80 cm. The different methods used were:

2.3.1 Guelph permeameter method

A Guelph permeameter (Elrick *et al.*, 1989) is a constant head permeameter that measures a composite of vertical and horizontal saturated hydraulic conductivity in the field. A 5 cm-diameter and 100 cm deep vertical borehole was augered at site, taking all precautions to minimise wall smearing. The permeameter was set up to maintain a constant head of 10 cm depth of water in the borehole and the change in water level per unit time was recorded in a data sheet for three consecutive readings. The taking of stable readings lasted between 1.5 to 3.5 hours depending on antecedent soil moisture conditions.

2.3.2 Velocity permeameter

A velocity permeameter was adapted for field use (Everts and Kanwar, 1989). An 8.5 cm diameter cylinder was pushed to about 10 cm into the soil. Some compaction was experienced when the sample cup was hammered into the ground. The top of the cylinder was closed and then connected to two hoses, one of which was connected to a reservoir providing water for infiltration and the other hose was used to ventilate the cylinder.

Saturated hydraulic conductivity for the soil inside the cylinder was calculated based on the cylinder geometry and the rate of fall of the water level in the observation tube. Measurements of saturated hydraulic conductivity were made as the wetting front moved through the soil. When the wetting front advanced away from the *in situ* soil core, the estimates of saturated hydraulic conductivity approached a pseudo-constant value, which can be taken as hydraulic conductivity of the sample. Depending on the depth and saturated hydraulic conductivity, sample measurements took between 20 – 60 minutes. In comparison with the Guelph permeameter method which measured the soil mass around the borehole, this method gave the saturated hydraulic conductivity of a smaller volume of soil sample present inside the core. This represents a point measurement, facilitating the study of microheterogenity in the spatial variability in infiltration properties.

2.3.3 Disk permeameter

Infiltration measurements were made using a disk permeameter at four different supply potentials and the saturated hydraulic conductivity was estimated based on the calibrated empirical relationship at zero supply potential (Perroux and White, 1988). A single infiltration reading required between 50 – 70 minutes. The instrument was set up above the ground, thus minimising soil disturbance.

2.3.4 Constant head permeameter (laboratory core)

Measurements of saturated hydraulic conductivity of soils was based on the direct application of Darcy's equation to a saturated soil column of uniform cross sectional area. A hydraulic head difference was imposed on the soil column and the resulting flux of water was measured. Three replicates of detached soil cores 7.6 cm in length and 7.6 cm in diameter were collected from each site and at each depth using a core sampler. The cores were saturated in the laboratory by capillarity. The saturated hydraulic conductivity of the soil cores was measured in sequence at 20, 40 and 80 cm. *In situ* measurements were taken close to each other with a minimum separation distance of 20 cm to avoid compaction or influence of other previous measurement sites. The measurements with different methods for each site were done in sequence rather than simultaneously. This method measures vertical conductivity. The average time required to achieve a study-state ready for soil cores was between 30 and 75 minutes.

3. Results and discussion

The soil, classified as loamy isohyperthermic aeric Tropaquept (Kundiri, 1995) was grey or dark brown clay loam of about 50 – 70 cm in thickness, overlying a light-grey or brown clay, sandy clay loam or sandy material of variable thickness but commonly more than 60 cm thick. The dry bulk density of the soil was observed to range from 1.3 to 1.5 Mgm^{-3}. The general characteristics of the soil are given in Table 1.

After setting the instrument at each site, the time required to achieve a steady-state condition before making the saturated hydraulic conductivity estimation is an important factor in comparing the efficiency of these methods. Measurements by the Velocity permeameter method took the least net time of all the *in situ* methods, followed by Disk permeameter. Except for the Guelph permeameter method, all others were labour intensive for subsoil saturated hydraulic conductivity measurements because they needed excavation of the soil to the depth for which measurements were to be made.

Table 1: Particle size analysis of the soils of the experimental area

	Depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm^3)	Porosity
Profile 1							
Apg	0-25	Clay loam	41.42	28.98	29.6	1.49	0.41
Bg	25-50	Clay	18.19	38.11	43.71	1.45	0.42
Bcg	50-75	Clay loam	39.73	36.12	24.02	1.40	0.43
Cg	75-100	Sand	96.05	1.15	2.79	1.37	0.41
Profile 2							
Apg	0-25	Clay	5.12	25.94	68.86	1.45	0.43
Bg1	25-50	Clay	6.44	20.5	73.06	1.44	0.42
Bg2	50-75	Clay	8.66	25.49	68.85	1.36	0.44
Bcg	75-100	Sandy clay loam	61.41	18.31	7.25	1.31	0.42
Profile 3							
Apg	0-25	Clay	15.04	22.44	62.52	1.37	0.43
Bg	25-50	Clay	11.28	24.96	63.76	1.35	0.43
Cg	50-75	Clay	12.15	26.67	61.18	1.34	0.41
2Cg	75-100	Loamy sand	87.96	8.14	3.91	1.33	0.42
Profile 4							
Apg	0-25	Clay	7.7	23.96	68.34	1.42	0.41
Bg	25-50	Clay	5.3	24.45	70.25	1.41	0.39
bcg	50-75	Clay	12.44	26.23	61.32	1.40	0.38
Cg	75-100	Sand	98.09	0.88	1.03	1.34	0.40
Profile 5							
Apg	0-25	Clay loam	39.16	21.57	39.24	1.37	0.38
Bcg	25-50	Sandy clay loam	59.53	17.72	22.35	1.33	0.37
Cg	50-75	Sand	90.91	8.26	0.85	1.32	0.35
2Cg	75-100	Sandy loam	65.12	17.99	6.99	1.33	0.41

The results obtained from the different methods used for measuring saturated hydraulic conductivity are presented in Table 2. The different methods were compared on the basis of the mean saturated hydraulic conductivity values obtained.

Table 2: Saturated hydraulic conductivity measurements (mmh^{-1}) using different methods at different sites

Site number	Depth (cm)	Guelph permeameter	Velocity permeameter	Disk permeameter	Laboratory core
1	20	2.32	10.22	6.19	1.10
	40	0.82	1.42	31.10	4.82
	80	1.00	1.16	5.69	2.96
2	20	0.14	0.30	5.51	0.49
	40	0.01	5.90	9.36	8.43
	80	25.2	19.68	5.34	9.47
3	20	2.19	1.42	19.30	0.73
	40	4.61	11.56	36.70	27.65
	80	0.11	17.56	16.88	14.18
4	20	0.14	0.94	36.00	0.58
	40	1.07	1.53	7.04	1.32
	80	0.03	9.94	11.52	9.47
5	20	1.23	2.03	6.16	2.10
	40	0.15	1.12	14.83	10.00
	80	0.27	4.39	11.12	2.43

The statistical significance and multiple mean comparison of the different methods using the $\log_{10}$ transformed saturated hydraulic conductivity methods is presented in Table 3. The saturated hydraulic conductivity obtained using the Guelph permeameter method had the highest standard deviation and coefficient of variability compared to the other in situ methods. Similar results were reported by Kanwar *et al.* (1989).

Table 3: Some descriptive statistics of saturated hydraulic conductivity (mmh^{-1}) obtained by all the four methods on forty five samples

	Guelph permeameter	Velocity permeameter	Disk permeameter	Laboratory core
Maximum	25.2	19.68	36.70	27.65
Minimum	0.01	0.30	5.34	0.49
Mean	2.68	12.54	21.60	8.91
Standard deviation	6.00	24.91	42.00	12.57
Geometric mean	0.37	3.20	14.69	2.32
Coefficient of variation (%)	224	199	194	141

The high variability exhibited by the Guelph permeameter method could be as a result of wall smearing of the hole under wet soil conditions, variability in macro pore distribution (Mohanty *et al.*, 1994), air entrapment during the initial filling of the borehole (Elrick *et al.*, 1989). The Guelph permeameter measurements gave significantly lower saturated hydraulic conductivity values (P = 0.05) than the other methods used. The estimates of saturated hydraulic conductivity by Velocity permeameter method were generally higher than those obtained by the Guelph permeameter method even though they were smaller than those obtained using the Disk permeameter method (Table 2). The saturated hydraulic conductivity measurements by the Disk permeameter method were quite similar to those from soil cores in the laboratory. This could be so because both methods are point measurements of the vertical conductivity.

The saturated hydraulic conductivity obtained by the Disk permeameter showed higher values (P = 0.05) than those obtained by the other methods, probably as a result of three-dimensional infiltration. The Disk permeameter method has the least disturbance, thus increasing the probability of macro pore flow since no pores are cut off. The estimates given by the different methods in descending order were Disk, Velocity and Guelph. This may be attributed to variable amount of preferential flow caused by the variable amount of macroporosity in the soil sample (Singh and Kanwar, 1991). The different methods were subjected to different amounts of variability across depths. The variability could be as a result of susceptibility to factors such as pore size distribution, soil pore ratio, soil texture and soil water content.

4. Conclusion

Four different methods of measuring soil saturated hydraulic conductivity on alluvial floodplain soils (Guelph permeameter, Velocity permeameter, Disk permeameter and Laboratory core) were compared. There were variations in the results obtained fromthese methods. The Guelph permeameter method gave the least estimate of saturated hydraulic conductivity probably as a result of the small sample size, wall smearing and air entrapment. The Laboratory core method gave low values at shallow depths due to small sample size, presence of open-ended pores and slight soil compaction. There was a slight agreement between the estimates of saturated hydraulic conductivity by Velocity permeameter method and the Laboratory core method.

The Disk permeameter method predicted higher saturated hydraulic conductivity values in comparison with the other methods as a result of the large sample size. Therefore, the Velocity permeameter and the Laboratory core gave better estimates of saturated hydraulic conductivity on the Komadugu-Yobe alluvial soils and could serve as methods for determining the parameter on such soils.

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