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Determination of Saturated Hydraulic Conductivity of Different Soil Texture Materials

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Abstract: *The hydraulic conductivity of the soil is function of soil water pressure, soil water content, and the soil moisture retention. The soil hydraulic properties are needed for understanding water balance, irrigation and transport processes. Hence, saturated hydraulic properties of surface soils influence rainfall and snowmelt into runoff and soil water storage. The hydraulic conductivity for soil material provides the ability to properly design water control structures, earthen storage water facilities and runoff forecasting. Saturated hydraulic conductivity measurement was made on different soil material, having length of soil columns 8.5 cm for constant head permeameter. Three soil columns were filled having different percentages of soil texture; and textural classified of soil sample is sandy loam soil. Porosity is determined by the saturation method for soil sample materials; the porosity is varying from 32 to 40% for sandy loam and about 43% for clay soils. The saturated hydraulic conductivity of these soil samples was measured by constant head permeameter the results indicated that its average value obtained as 0.00142 cm/sec and falling head permeameter the results observed average hydraulic conductivity of sandy loam is 0.00123, 0.00172 and 0.00144 and clay is 0.0000146 cm/sec.*
Keywords: *Permeameter, Porosity, Saturated Hydraulic Conductivity, Soil Property*

I. Introduction

Water is becoming a restrictive source for crop production in many parts of the world, especially developing countries like Pakistan [1]. Pakistan has world largest gravity driven canal irrigation system but due to unsatisfactorily maintenance, its efficiency is being continuously declining day by day [2]. Groundwater is gradually revolving saline along with increase in depth of water table. The high groundwater pumping costs putting limitation towards its use by many small farmers [3].

Saturated hydraulic conductivity (K_{sat}) is a main concern regarding to soil property. As a result, many methods have been developed over time for field and laboratory measurement for K_{sat} [4]. Unfortunately, these methods often yield substantially dissimilar results, as K_{sat} is extremely sensitive to sample size, flow geometry and soil characteristics. It was observed that most of its measurement methods are neither appropriate for all applications nor accurate for all soil types and conditions. The literature [5] shows that regardless of the land practices, a small portion of the soil volumes transports a large portion of the water flow, indicating that the spatial hydraulic characteristics of soils are highly variable. K_{sat} measurements should therefore be evaluated carefully to ensure that these values obtained are accurate and appropriate for the intended use.

An important soil property involved in the behavior of soil water flow is the conductivity of the soil to water. Qualitatively, hydraulic conductivity is the ability of the soil to transmit water [6]. Knowledge of the hydraulic conductivity for soil materials provides the ability to properly design water control structures, earthen storage facilities, and provide improved flood and runoff forecasting. Topography or slope gradient, pore-size distribution and pore continuity, and land use are among the main soil and management factors that affect hydraulic properties of surface soils [7, 8]. Thus, knowledge of surface soil hydraulic properties with respect to these soil and management factors is essential for efficient use of land and better water management.

The design criterion and execution of subsurface drainage systems depends to a great extent of saturated hydraulic conductivity of soil. All drain spacing equations are involving this parameter. The value of saturated hydraulic conductivity is subject to variation in time and space. Therefore, it is time-consuming as well as costly, so a balance has to be struck between budget limitations and desired accuracy. As yet, no best possible surveying technique exists. It requires good practical person for conducting survey. The K-value of a saturated soil represents its average hydraulic conductivity, which depends mainly on the soil particle size, shape, and particles arrangement etc. It also depends on the soil temperature; and viscosity and density of the water.

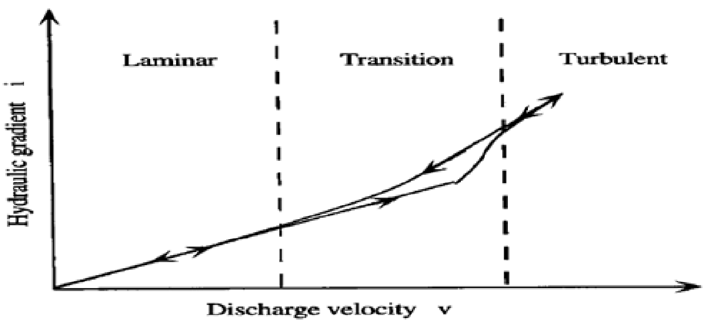

Figure 1: Zones of laminar and turbulent flows [9]

Soil texture refers to the percentage of sand, silt, and clay particles in the soil. Texture or textural class is often used for the correlation of K values with other hydraulic properties of the soil e.g. water-holding capacity and drainable pore space [10]. Saturated hydraulic conductivity of the soil is directly related to its effective porosity [11] and is thus determined by soil structure. Factors influencing soil structure and hence Ks can be roughly differentiated into static, soil-inherent properties such as clay mineralogy and particle size distribution and dynamic properties such as organic carbon content or biotic activity; the latter are greatly influenced by land use and land cover. Permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil. This property is necessary for the calculation of seepage through earth dams or under structure constructed on the pervious strata , the calculation of the seepage rate from waste storage facilities (landfills, ponds, etc.), and the calculation of the rate of settlement of clay soil deposits. In this paper, both constant head and falling head permeability test methods have been used. The constant head test method is used for permeable soils ($k > 10^{-4}$ cm/s) and the falling head test is mainly used for less permeable soils ($k < 10^{-4}$ cm/s).

II. Material And Methods

The experiments were conducted in the laboratory of Land and Water Management Department, Faculty of Agricultural Engineering, Sindh Agriculture University, Tando Jam, Sindh Pakistan in January 2014. The saturated hydraulic conductivity was determined using different soil samples, having length of soil columns 8.5 cm for constant head permeameter. Three soil columns were filled having different percentages of texture and textural class of sandy loam soil. The objective of the study is to determine the saturated hydraulic conductivity. In this connection, both laboratory performed methods, viz. Constant head and Falling head, have been adopted, which are discussed in details under section of Experimental Approach.

Soil Texture:

Soil texture classification has been determined by the hydrometer method. Soil texture is the composition of the soil particles expressed as the percent of particles in the sand, silt and clay size separating after organic matter, carbonates, and iron and manganese oxides and other cementing or binding agents are removed.

Soil Porosity:

Porosity has been determined by the saturation method. Porosity can be calculated by dividing the volume of water filled in the soil voids to total volume of the sample. The result is expressed as a percentage. It dictates how much water a saturated material can contain and has an important influence on bulk properties of root zone of soil, e.g. bulk density (Dry and Wet), heat capacity, seismic velocity, etc.

$$\eta = \frac{V_v}{V_t} * 100 \qquad \textbf{(1)}$$

Where, η is the porosity of the soil sample [%], Vv is the volume of voids in the soil sample [L^3] and Vt is the total volume of the soil sample [L^3].

Permeability Tests

The permeability test is a measure of the rate of the flow of water through soil pores. In this test, water is forced by a known constant pressure through a soil specimen of known dimensions and the rate of flow is determined. This test is used primarily to determine the suitability of sands and gravels for drainage purposes, and is made only on remolded samples. The test is limited to materials which have a coefficient of permeability of approximately 300 mm/day or greater.

Experimental Approach

There are relatively simple and inexpensive laboratory tests that may be run to determine the hydraulic conductivity of a soil i.e. constant-head method and falling-head method.

Constant Head Method

The constant-head method is typically used on granular soil (see Figure 2). This procedure allows water to move through the soil under a steady state head condition while the quantity (volume) of water flowing through the soil specimen is measured over a period of time. The coefficient of permeability (k) using constant head method has been calculated using the following equation:

$$K = \frac{QL}{Ath} \quad \textbf{(2)}$$

Where, k is coefficient of permeability, Q is quantity of water discharged, L is distance between manometers, A is cross-sectional area of specimen, t is total time of discharge and h is difference in head on manometers.

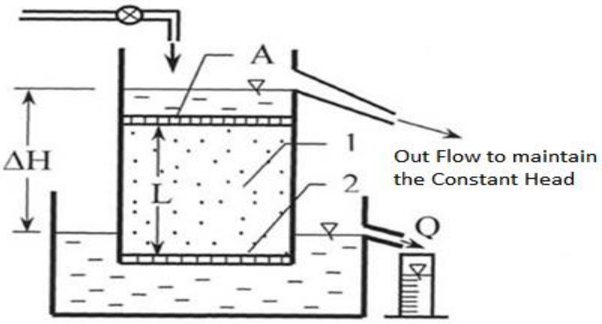

Figure 2: Constant head method for determination of saturated hydraulic conductivity [12]

Falling Head Method

The falling-head method (see Figure 3) is similar to the constant head methods in its initial setup; however, the advantage to the falling-head method is that it can better be used for fine-grained soils. The soil sample is first saturated under a specific head condition. The water is then allowed to flow through the soil without maintaining a constant pressure head. The calculation of coefficient of permeability (k) under falling head method has been made using following equation:

$$K = \frac{aL}{At} Ln\left(\frac{h_0}{h_1}\right) \quad \textbf{(3)}$$

Where, a is cross sectional area of stand pipe, L is length of soil column, A is cross section area of soil column, t is time interval to head drop, h_0 is total head before test and h_1 is total head after test.

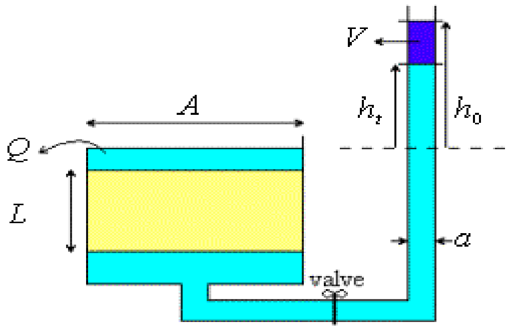

Figure 3: Falling head method for determination of saturated hydraulic conductivity [12]

III. Results And Discussions

In order to achieve the objectives of the study, the soil samples collected from field were analyzed and the results have been described in Table I. The constant head and falling permeability tests were performed for measuring the saturated hydraulic conductivity in the laboratory. The observed values of saturated hydraulic conductivity are presented in Table II.

Table I: Detail Of The Soil Samples Textural Analyses

Sample #	% Clay	% Silt	% Sand	Textural Class
10	18	12	70	Sandy Loam
20	17	11	72	Sandy Loam
40	15	17	68	Sandy Loam
100	65	20	19	Clay

Table II: Detail Of The Porosity Of The Soil Samples

Sample #	Saturated Weight (g)	Dry Weight (g)	Volume of Core (cm^3)	Porosity (%)
10	107.7	92.5	37.07	40.00
20	103.3	90.3	41.45	32.00
40	89.5	74.8	37.53	39.10
100	103.3	90.3	30.01	43.33

However, Table I explains classification of soil texture of collected samples from field nearby Agricultural farm of Nasarpur which is located in Tando Allahyar district of Sindh, Pakistan. Soil texture of three locations is almost identical throughout the soil profile in which sandy loam dominate as per result of analyzed soil samples.

The porosity of soil sample material has been calculated. The calculated result soil material of porosity of all the locations is ranging from 32 % to 43.33 % and an average of the porosity is found 38.58%.

It has been observed and founded that high permeability of soil (e.g. sands and gravel) a constant head test is normally performed in field as well in laboratories. The hydraulic conductivity has been calculated through constant head method. The results shown in Table III of saturated hydraulic conductivity is 0.00166, 0.00148, 0.00113 cm/sec while average (K_{avg}) is 0.00142 cm/sec.

Table III: The K (Sat) Values Of Constant Head Method For The Samples Of 10, 20 And 40 Meshes

Test #	Outflow Volume (cm^3)	Length of Sample (cm)	Time (min)	Area of Specimen (cm^2)	Total Constant Heads (cm)	Hydraulic Conductivity K (sat) cm/sec
1	310	8.5	5	181.76	h1 : (100-71)	0.00166
2	590	8.5	10	181.76	h2 : (71-31)	0.00148
3	870	8.5	15	181.76	h3 : (40-0)	0.00113

The Fig. 4 shows the relationship of the saturated hydraulic conductivity measured by the constant head permeameter for different sample material. The correlation R^2 is 0.966 of measured permeability displayed good resolution in different soil sample materials with temporal variation.

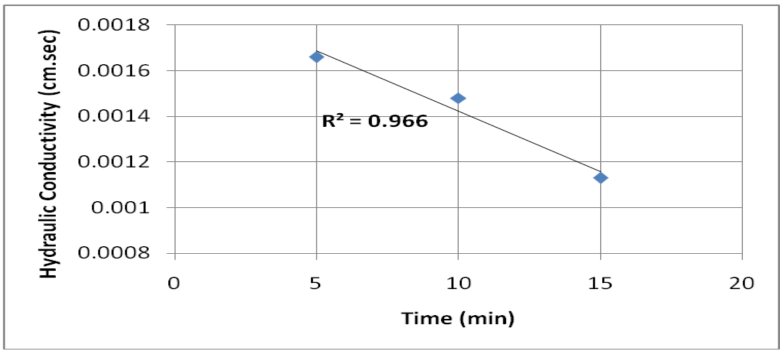

Figure 4: Hydraulic conductivity using constant head method w. r. to time for samples of 10, 20 and 40 meshes

The saturated hydraulic conductivity/permeability of collected soil sample material has been determined through falling head method for the sample of 10 sieve number. The measured hydraulic conductivity (K) through falling head method has been found i.e. 0.00149, 0.00109 and 0.00111cm/sec for varying head and time; their average (K_{avg}) comes 0.00123 cm/sec (see Table IV). The Fig. 5 shows the relationship of the saturated hydraulic conductivity of falling head method with respect to time is fair but observed variation with tests.

Table IV: The Hydraulic Conductivity K values of falling head method for the sample of 10 Sieve

Test #	h°	h¹	Cross Sectional Area of Stand Pipe (cm^2)	Length of Soil Column (cm)	Cross Sectional area of Soil Column (cm^2)	Time interval for head drop (sec)	Hydraulic Conductivity (k) (cm/sec)
1	99	75	0.342	15	31.65	30	0.00149
2	99	66	0.342	15	31.65	60	0.00109
3	99	53	0.343	15	31.65	90	0.00111

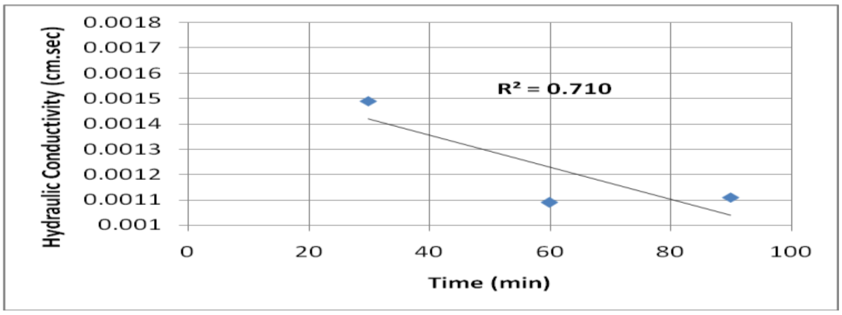

Figure 5: Relationship to hydraulic conductivity of falling head method with respect to time for sample 10

Table V: The Hydraulic Conductivity K values of falling head method for the sample of 20 Sieve

Test #	h°	h¹	Cross Sectional Area of Stand Pipe (cm^2)	Length of Soil Column (cm)	Cross Sectional area of Soil Column (cm^2)	Time interval for head drop (sec)	Hydraulic Conductivity (k) (cm/sec)
1	99	70	0.342	15	31.65	30	0.00183
2	99	52	0.342	15	31.65	60	0.00172
3	99	40	0.343	15	31.65	90	0.00162

The hydraulic conductivity (K) has been measured through falling head method. The calculated results of hydraulic conductivity found i.e. 0. 00183, 0.00172 and 0.00162 cm/sec while average (K_{avg}) is 0.00172 cm/sec. Figure 6 shows the relationship of the saturated hydraulic conductivity of falling head method with respect to time very nice.

The hydraulic conductivity (K) values obtained using falling head method is shown in Table VI. The hydraulic conductivity of different test is 0. 00169, 0.00135 and 0.00129 cm/sec while an average (K_{avg}) is 0.00144 cm/sec and Figure 7 shows the relationship of the saturated hydraulic conductivity of falling head method with temporal and correlation factor is 0.856 which represents fair well.

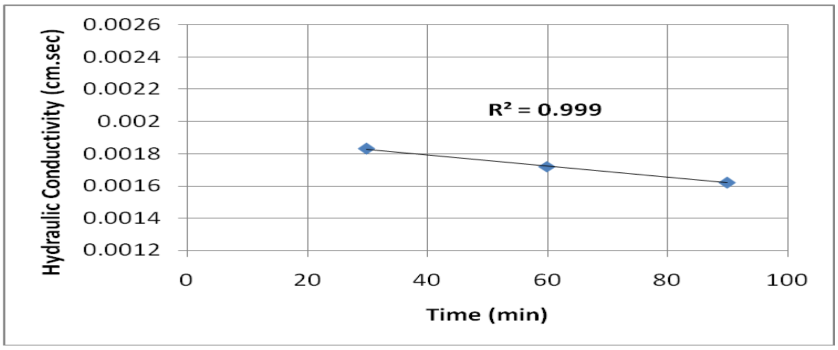

Figure 6: Relationship of saturated hydraulic conductivity of falling head method w. r. to time for sample 20

Table VI: The Hydraulic Conductivity K values using falling head method for the sample of 40 Sieve

Test #	h°	h¹	Cross Sectional Area of Stand Pipe (cm^2)	Length of Soil Column (cm)	Cross Sectional area of Soil Column (cm^2)	Time interval for head drop (sec)	Hydraulic Conductivity K (cm/sec)
1	99	72	0.342	15	31.65	30	0.00169
2	99	60	0.342	15	31.65	60	0.00135
3	99	48	0.343	15	31.65	90	0.00129

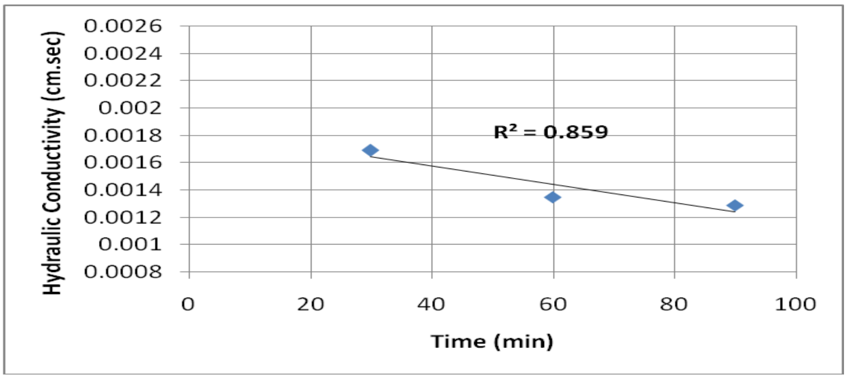

Figure 7: Relationship of saturated hydraulic conductivity of falling head method w. r. to time for sample of 40

Table VII: The Hydraulic Conductivity K values using falling head method for the sample # 100

Test #	h^o	h^1	Cross Sectional Area of Stand Pipe (cm^2)	Length of Soil Column(cm)	Cross Sectional area of Soil Column (cm^2)	Time interval for head drop (sec)	Hydraulic Conductivity (k) (cm/sec)
1	99	91	0.342	15	31.65	30	0.0000165
2	99	89	0.342	15	31.65	60	0.0000144
3	99	85	0.342	15	31.65	90	0.0000129

The hydraulic conductivity (K) (shown Table VII) measured through falling head method which is 0.0000165, 0.0000144 and 0.0000129 cm/sec respectively and an average is 0.0000146 cm/sec.

However, Figure 8 demonstrates relationship of the saturated hydraulic conductivity of falling head method with respect to time is good.

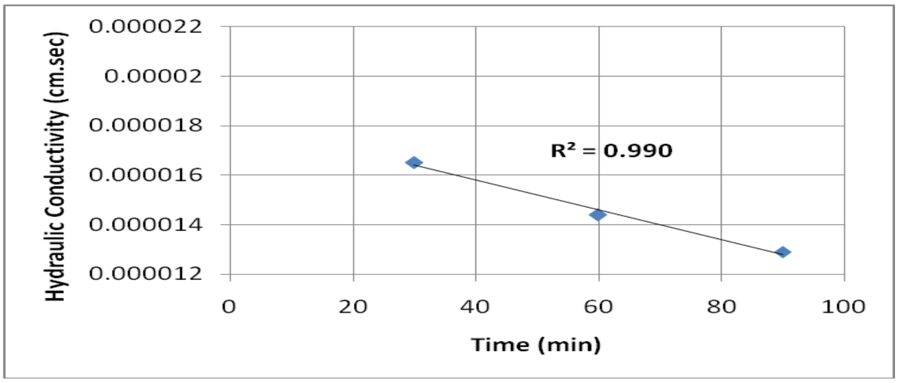

Figure 8: Relationship between Saturated hydraulic conductivity of falling head method with respect to time for sample of 100 Mesh

The result regarding comparison saturated hydraulic conductivity with theoretical values by (Rawls et al. 1998 [8], Clapp and Hornberger 1978 [13]) was presented in following Table VIII.

The values of saturated hydraulic conductivity and porosity matches with reported literature. The results of hydraulic conductivity and porosity of present research study through constant head and falling head displayed nice relationship with results of [8, 13] in open literature.

Table VIII: Comparison Of Results Of Present Study With Other Researchers

Soil Texture Class	Rawls et al. (1998) [8]		Clapp and Hornberger (1978)[13]		Observed Data	
	K_{sat} (ft/hr)	Porosity (%)	K_{sat} (ft/hr)	Porosity (%)	K_{sat} (ft/hr)	Porosity (%)
Sandy Loam	0.0425-0.18131	0.37-0.47	0.1453	0.44	0.145-0.203	0.32-0.40
Clay	0.0071-0.0060	0.48-0.40	0.0071	0.48	0.00194	43.33

IV. Conclusions

The porosity varies between 32 to 43.33 % in all soil sample material. The texture and textural class of the collected soil samples were conducted through Boucyoucos hydrometer method which shows Sandy Loam Soil.

The Clay soil sample was analyzed for falling head permeameter and the saturated hydraulic conductivity, while average comes 0.0000146 cm/sec. The values of saturated hydraulic conductivity of constant head K_{avg} 0.00142 cm/sec and falling head K_{avg} 0.00123, 0.00172 and 0.00144 cm/sec respectively. The saturated hydraulic conductivity values increase in case of medium to coarse textured soil layer and decrease in case of fine textured soil layers.

It is observed that the falling head method is more accurate whereas in comparison of constant head in case of three samples simultaneously. Soil texture and structure can affect the porosity and saturated hydraulic conductivity therefore the experiment may be conducted in field conditions using different methods (Inverse auger-hole method and auger-hole method etc).

However, results of current research works compared with saturated hydraulic conductivity and porosity with theoretical values by (Rawls et al. 1998, Clapp and Hornberger 1978) were found nice resolution with open literature.

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