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Assessment of different infiltration equations for cultivated and pasture land

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■ **ABSTRACT :** The measure of infiltration of water into the soil is an important indication concerning: the efficiency of irrigation and drainage optimizing the availability of the water for plant improving the yield of the crop and minimizing the erosion. By knowing proper infiltration characteristics and intake capacity of soil, deep percolation losses can be prevented and proper utilization of water may take place. Keeping the importance of infiltration characteristics in mind the study of infiltration was taken. In this study most appropriate methods for determination of infiltration under different land uses were selected among most popular methods. Some of the well-known equations are Kostiakov equation, Modified Kostiakov equation and Horton equation. These three equations were studied for the assessment infiltration equation. Assessment of these equations was done under different lands covers such as Cultivated land cover, Pasture land cover. From the analysis of the data, it is concluded that for cultivated land cover correlation coefficients for cumulative infiltration were found to be 0.9569, 0.9687 and 0.9724 for Kostiakov, Modified Kostiakov and Horton equation, respectively. As correlation co-efficient for Horton equation is higher, this equation was found best fit for cultivated land cover. Similarly, for pasture land cover the correlation co-efficients for cumulative infiltration were found to be 0.9876, 0.9706 and 0.9891 for Kostiakov, Modified Kostiakov and Horton equation, respectively. As correlation co-efficient for Horton equation is higher, this equation was found best fit for pasture land cover.

■ **KEY WORDS :** Infiltration, Infiltration rate, Infiltration equation, Land use

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Infiltration is one of the most important components in irrigation. It is difficult to design an irrigation system without a proper knowledge of infiltration characteristics of soil because water is key resource and has to be utilized with a great care. The movement of water from the ground surface into the soil is called Infiltration. Water infiltration is driving force influencing crop growth, soil erosion and chemical leaching process. The infiltration characteristics of soil are one of the most important or dominant variables influencing irrigation. Infiltration rate is soil characteristics determining the maximum rate at which water can enter the soil under specific condition, including presence of excess water (Roy and Ghosh, 1982).

There are two general approaches to determine capacity of soil infiltration rate. That is first analysis of hydrograph of runoff from natural rainfall in plots and watersheds. Secondly, use of infiltrometer with artificial application of water to enclosed sample areas, concerning hydrograph analysis (Baxla *et al.,* 2001).

The measure of infiltration of water into the soil is an important indication concerning: the efficiency of irrigation and drainage optimizing the availability of the water for plant improving the yield of the crop and minimizing the erosion.

By knowing proper infiltration characteristics and intake capacity of soil, deep percolation losses can be prevented and proper utilization of water may take place. Keeping the importance of infiltration characteristics in mind the study of infiltration was taken. In this study most appropriate methods for determination of infiltration under different land were selected among most popular methods.

Many simple analytical equations have been proposed to determined infiltration rate for hydrographs analysis (Parlange *et al.,* 1982). Some of well-known equations are Kostiakov Equation, Modified Kostiakov Equation, Horton Equation (Swartzendruber and Clague, 1989). Evaluation of these equations was done under different lands covers such as Cultivated land cover, Pasture land cover.

The present study was undertaken with specific objectives as measurement of infiltration by double ring infiltrometer under different land cover and compare different infiltration equation for different land cover.

■ METHODOLOGY

Different infiltration equations of Kostiakov, Modified Kostiakov, and Horton have also been outlined for comparison. Instruments such as double ring infiltrometer, bucket, oven, electric weight balance, jar (one lit), scale, stopwatch, mechanical shaker, core cutter, pycnometer, hammer, screw auger etc. were used.

Experiment site:

The site for conducting the experiment was selected at college farm near Dr. Ulhas Patil College of Agricultural Engineering and Technology, Jalgaon. The experimental sites consist of silt loam soil. Two-land covers were selected for study *viz.,* cultivated land and pasture land for measurement of infiltration.

Location and climate:

The study was confined in Jalgaon. Jalgaon is situated in the Khandesh region which from the four region of the state of Maharashtra. The Jalgaon district is situated in between latitude 21.3° N-S and longitude 74.34° E-W and altitude 208.5 m above the sea level.

The climate of Jalgaon is hot and dry sub-tropical. The summer is too dry and hot. The winter is too cold and the rainy season starts from the first week of June and continuous up to September with maximum rainfall in July. The average minimum and maximum temperature varies between 4° C to 17° C and 40° C to 46° C, respectively. May is the driest and January is the coolest month. The average annual rainfall is about 750 mm.

Determination of infiltration:

Double ring infiltrometer was used for measurement of infiltration because of its reliability and accuracy. The complete set up consists of two cylinders, outer cylinder with diameter 60 cm and 25 cm height. Inner cylinder with diameter 30 cm. One hook gauge for measurement of water level, stop-watch and water container, one of the two cylinders, one was used to form buffer pond in order to avoid the lateral movement of water (Nagar and Saini, 2003).

The cylinders were installed 10 cm deep in the soil care was taken to maintain the same instruction depth in all the experiments. Cylinders were inserted in the field by means of a mild steel plate and a hammer. Gentle hammering was done to avoid the soil in getting distributed from their natural condition. The depth of water in all the experiments was kept equal (Michael, 1978).

Water level in the cylinder was recorded with help of point gauge and stop watch. The point gauge was used to record the water levels at the cylinder. The water level in the cylinder was brought to initial level often a regular interval of one hour. Observations were continued till the infiltration rate approaches to basic infiltration rate.

Determination of moisture content of the soil:

Soil auger was used to collect the sample for measurement of moisture content. The soil samples were taken always from 20 cm depth in all the observations. A standard procedure for moisture content determination suggested by Punmia, 2004 was used.

Determination of bulk density of soil:

Bulk density of soil was found out by core cutter. The core cutter was used to take undisturbed soil samples. The cylinder of core sampler has cutting edge was driven into soil and an uncompacted core obtained within tube. The samples were carefully trimmed at both ends of core cylinders. They were dried in an oven at 105° C for 24 hours until all the moisture was driven off and the sample weight again. The volume of soil core cylinder was measured (Punmia, 2004).

Determination of specific gravity of the soil:

The pycnometer method was used for determining the specific gravity of soil (Punmia, 2004).

Determination of field capacity:

Field capacity was determined by ponding water on the soil surface in an area of about one square meter and permitted it to drains for one day with surface evaporation prevented. Evaporation was prevented by spreading a polythene sheet on ground surface. After a one day soil sample were collected with an auger from different soil depths. The moisture content was determined by oven drying method (Michael, 1978).

The results obtained are presented in Table A.

Infiltration equations:

Kostiakov equation:

$F = at^{\alpha}$

$f = \alpha\, a\, t^{\alpha-1}$

where, F = Cumulative infiltration (cm)

a, α = Constant parameter

f = Infiltration rate (cm/hr)

Taking logarithm of both side of equation

$\text{Log } F = \log a + \alpha \log t$

$\text{Log } f = \log a + (\alpha - 1) \log t$

The parameter a and α were estimated by plotting and log-log paper. The infiltration rate f or accumulated infiltration F against time t and fitting a straight line. To compare the measured cumulative infiltration and estimated cumulated infiltration, the linear regression line was fitted. Correlation co-efficient was determined.

Modified Kostiakov equation:

The functional relationship between F and t is best represented by the equation

$F = at^{\alpha} + b$

The values of constants a, α and b were determined by the method of averages using the procedure suggested by Davis (1943). The first step is to plot F against t and choose two points (t_1, F_1) and (t_2, F_2) near the extremities of a smooth curve representing the data. Now a point $t_3 = \sqrt{t_1 * t_2}$ is a chosen. F_3 is read against t_3. The value of b determined by using following equation.

$$B = \frac{F_1F_2 - F_3^2}{F_1 + F_2 - 2F_3}$$

where, B = parameter

a> 0, 0 < b < 1

F_1, F_2, F_3 = cumulative infiltration at time t_1, t_2 and t_3, respectively.

Horton equation:

Horton equation is one of the popular infiltration equations. Horton recognized that the infiltration capacity decreased with time until it approaches a more or less constant value. He hypothesized that infiltration is a similar to exhaustion process. According to which the rate of performing work is proportional to the amount work remaining to be performed.

The Horton equation can also be expressed in terms of a infiltration rate an cumulative infiltration.

$F = f_c t + l/a\,(fo - fc)\,(1 - \exp(-at))$

$f = f_c + (f_t - fc)\, \exp(-at)$

The Horton equation is a simple in a form and fits well to experimental data. The principle weakness of the equation is in determination of reliable values of its parameters fo, fc and a. As the rule of thumb, the ratio of a fo /fc is a of the order of 5. The parameter fc can be interpreted as the hydraulic conductivity at natural saturation. The simplest method is estimated parameters by curve fitting on field observation of infiltration.

Table A : Moisture content, bulk density, specific gravity and field capacity for cultivated and pasture land

Sr. No.	Properties of the soil							
	Moisture content		Bulk density		Specific gravity		Field capacity	
	Cultivated land	Pasture land	Cultivated land	Pasture land	Cultivated land	Pasture land	Cultivated land	Pasture land
1.	16.30	11.78	1.72	1.61	2.86	2.87	25.26	28.36
2.	16.25	11.70	1.77	1.59	2.89	2.88	24.12	29.95
3.	16.27	11.73	1.82	1.62	2.94	2.89	27.81	26.25
Avg.	16.27	11.73	1.77	1.61	2.897	2.88	25.73	28.19

First take logarithm of equation

$\ln (f-f_c)=\ln(fo-fc).at$

Above equation represents a straight line when plotted on semi log paper whose slope is a and intercept ln (fo - fc) were radially be determined. For a given infiltration data fc is taken as the lowest value of 'f' when it tends to become constant. The value of f-fc at t=0 is fo-fc.

RESULTS AND DISCUSSION

The study was undertaken to test the validity of different infiltration equations *i.e.* Kostiakov, Modified Kostiakov and Horton equation. These equations were tested under the cultivated land cover and pasture land cover.

Under each land cover the suitability of the appropriate infiltration equation was tested by comparing the estimated and measured values of infiltration rate and cumulative infiltration.

Infiltration under cultivated land cover:

The infiltration depth at the selected time intervals was measured. Infiltration rate was calculated using the actual infiltration depth and time period. The measured and estimated values are given in Table 1.

Kostiakov equation:

The a and α for the Kostiakov equation were found to be 0.48 and 0.47, respectively. Using the developed parameters, cumulative infiltration and infiltration rate were estimated. A comparison was made between measured and estimated cumulative infiltration. Also between measured and estimated infiltration rate. The linear relationships between them are shown in Fig. 1. The correlation coefficient was found to be 0.9569.

Modified Kostiakov equation:

The a, b and α for the Modified Kostiakov equation were found to be 0.36, 0.585 and 0.914, respectively. The linear relationship between measured cumulative infiltration and estimated cumulative infiltration is shown in Fig. 2. The correlation co-efficient was found to be 0.9687.

Horton equation:

The a, f_c and f_0 for the Horton Equation were found to be 0.08, 1.28 cm/hr and 23.48, respectively. The linear relationship between measured cumulative infiltration and estimated cumulative infiltration is shown in Fig. 3. The correlation co-efficient was found to be 0.9724

Infiltration under pasture land cover:

The infiltration depth at the selected time intervals was measured. Infiltration rate was calculated using the actual infiltration depth and time period. The measured values are given in Table 2.

Kostiakov equation:

The a and α for the Kostiakov equation were found to be 0.25 and 0.44 respectively. The linear relationship between measured and estimated cumulative infiltration is shown in Fig. 4. The correlation co-efficient was found to be 0.9876.

Table 1 : Measured cumulative infiltration and infiltration rate and estimated cumulative infiltration and infiltration rate by different equations under cultivated land (Moisture Content = 16.27 %)

Sr. No.	Time (min)	Measured values		Estimated values					
		Cumulative Infiltration (F) cm	Infiltration Rate (f) cm/hr.	Kostiakov equation		Modified Kostiakov equation		Horton equation	
				F (cm.)	f (cm/hr)	F (cm)	f (cm/hr)	F (cm)	f (cm/hr)
1.	1	0.51	30.6	0.48	13.51	0.21	25.75	0.4	21.8
2.	2	0.62	18.6	0.66	9.36	0.53	15.52	0.73	20.19
3.	3	0.74	14.8	0.8	7.58	0.75	11.55	1.05	18.7
4.	5	0.92	11.04	1.02	5.78	1.07	7.95	1.63	16.16
5.	10	1.34	8.04	1.41	3.99	1.58	4.79	2.76	11.25
6.	15	1.89	7.56	1.71	3.22	1.92	3.57	3.55	7.96
7.	30	2.80	5.92	2.36	2.25	2.06	2.15	4.85	3.3
8.	60	3.70	3.7	3.28	1.54	3.42	1.30	5.87	2.45
9.	120	4.80	2.4	4.55	1.12	4.41	0.78	7.18	1.78
10.	180	5.10	1.7	5.4	0.86	5.08	0.58	8.46	1.55
11.	240	5.10	1.28	6.29	0.74	5.60	0.47	9.7	1.28

Modified Kostiakov equation:

The a, b and α for the Modified Kostiakov Equation were found to be 0.092, 0.207 and 0.689, respectively. The linear relationship between measured and estimated cumulative infiltration is shown in Fig. 5. The correlation co-efficient was found to be 0.9706.

Table 2 : Measured cumulative infiltration and infiltration rate; and estimated cumulative infiltration and infiltration rate by different equations under pasture land (Moisture Content = 11.73 %)

Sr. No.	Time (min)	Measured values		Estimated values					
		Cumulative infiltration (F) cm	Infiltration rate (f) cm/hr.	Kostiakov equation		Modified Kostiakov equation		Horton equation	
				F (cm)	f (cm/hr)	F (cm)	f (cm/hr)	F (cm)	f (cm/hr)
1.	1	0.30	18.0	0.25	15	0.15	10.66	0.27	12.87
2.	2	0.35	10.5	0.34	10.2	0.29	6.89	0.4	11.58
3.	3	0.42	8.4	0.41	8.2	0.39	5.34	0.58	10.43
4.	5	0.50	6.0	0.5	6.0	0.54	3.87	0.88	8.49
5.	10	0.69	3.72	0.68	4.08	0.795	2.50	1.23	5.21
6.	15	0.75	3.0	0.82	3.28	0.977	1.94	1.26	3.37
7.	30	1.10	2.2	1.06	2.22	1.36	1.25	1.68	1.45
8.	60	1.81	1.81	1.52	1.52	1.85	0.81	2.51	1.013
9.	120	3.00	1.5	2.06	1.03	2.49	0.53	3.71	1.0
10.	180	3.80	1.27	2.6	0.86	2.95	0.41	4.6	1.0
11.	240	4.00	1.0	2.79	0.75	3.32	0.34	5.18	1.0

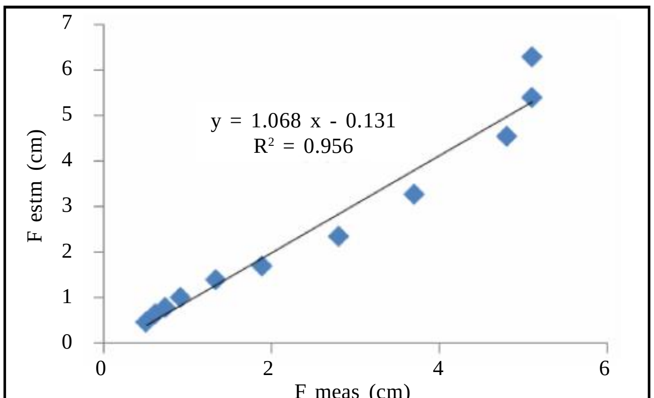

Fig. 1 : Measured and estimated cumulative infiltration by Kostiakov equation under cultivated land

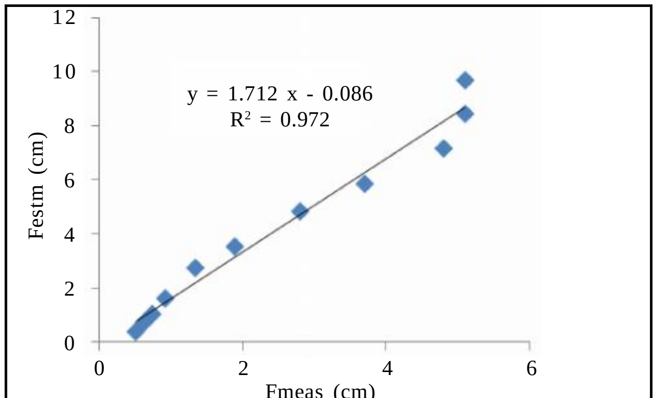

Fig. 3 : Measured and estimated cumulative infiltration by Horton's equation under cultivated land

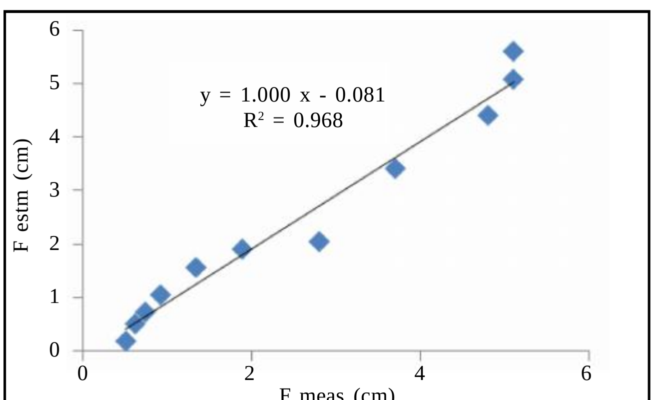

Fig. 2 : Measured and estimated cumulative infiltration by Modified Kostiakov equation under cultivated land

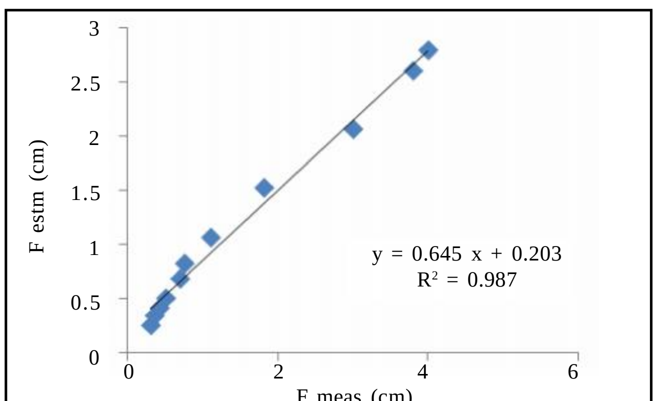

Fig. 4 : Measured and estimated cumulative infiltration by Kostiakov equation under pasture land

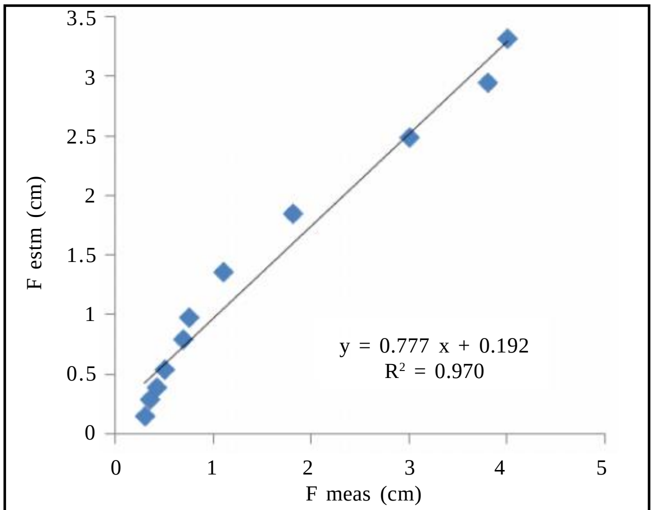

Fig. 5 : Measured and estimated cumulative infiltration by Modified Kostiakov equation under cultivated land

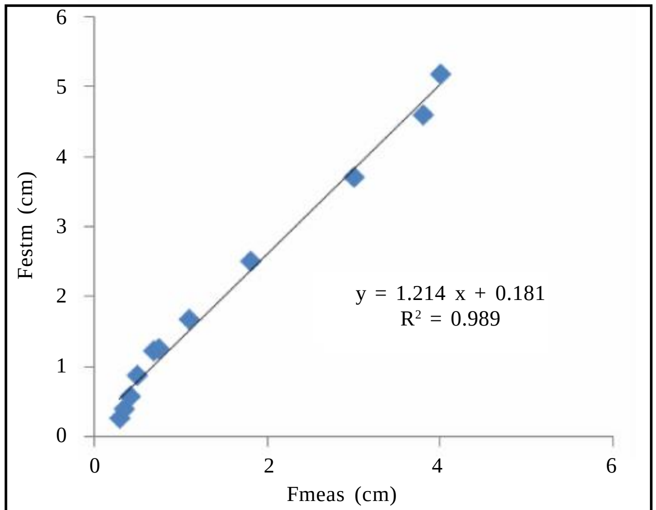

Fig. 6 : Measured and estimated cumulative infiltration by Horton's equation under pasture land

Horton equation:

The a, f_c and f_0 for the Horton Equation were found to be 0.115, 2.59 cm/hr. and 14.317, respectively. The linear relationship between measured and estimated cumulative infiltration is shown in Fig. 6. The correlation coefficient was found to be 0.9891.

Summary and conclusion:

Infiltration is an important parameter in irrigation Planning. The study was undertaken to measure the infiltration under different land covers. A comparison of various infiltration equation *i.e*. Kostiakov, Modified Kostiakov and Horton equation were work out. The two types of land covers were cultivated and pasture land.

Three sets of observations were taken under each land cover by double ring infiltrometer. The analysis of the data was made for each land cover for all the above equations.

From the analysis of the data, it is concluded that for cultivated land cover correlation co-efficients for cumulative infiltration were found to be 0.9569, 0.9687 and 0.9724 for Kostiakov, Modified Kostiakov and Horton equation, respectively. As correlation co-efficient for Horton equation is higher, this equation was found best fit for cultivated land cover. Similarly, for pasture land cover the correlation coefficientsfor cumulative infiltration were found to be 0.9876, 0.9706 and 0.9891 for Kostiakov, Modified Kostiakov and Horton equation, respectively. As correlation coefficient for Horton equation is higher, this equation was found best fit for pasture land cover.

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