ISSN: 2456-1452
Maths 2023; SP-8(6): 1054-1059

https://www.mathsjournal.com
Received: 13-11-2023
Accepted: 16-12-2023

Dhenge AR
M.Sc. Student, Division of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India

Kamble BM
Head, Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

Shinde KM
M.Sc. Student, Division of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India

Bandgar VK
M.Sc. Student, Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

Kothule KS
M.Sc. Student, Division of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India

Arya Satheesan
M.Sc. Student, Division of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India

Corresponding Author:
Dhenge AR
M.Sc. Student, Division of Soil Science and Agricultural Chemistry, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India

Evaluation and model predictability of infiltration rate models in the sodic soils of Kasbe Digraj of Sangli District

Dhenge AR, Kamble BM, Shinde KM, Bandgar VK, Kothule KS and Arya Satheesan

Abstract
Knowledge of water infiltration into a soil is essential for efficient soil and water management and conservation, especially when the water supply is through rainfall. For efficient irrigation water management, once field infiltration values are constant and the curve established for a particular soil, it is possible to determine how long it will take to infiltrate a certain amount of water during irrigation. The aim was to determine the infiltration capacity of the soil with slope positions and to fit the infiltration data into the Philip, Kostiakov and Horton infiltration models to quantify the hydrological behavior of the soil and the ability of these models to predict infiltration into the Sodic soils of Kasbe Digraj of Sangli District. It can be deduced that Kostiakov's model was more suitable than Philip's and Horton's model for predicting water infiltration in Sodic soils of Kasbe Digraj of Sangli District.

Keywords: Sodic soil, infiltration rate, cumulative infiltration rate, Kostiakov's model, Philip's model and Horton's model

Introduction
Infiltration, defined as the downward movement of water from the surface into the soil profile (Lal, 1990) [6], plays a pivotal role in soil and water conservation. It determines the extent of runoff over the soil surface during rainfall events, influencing the distribution of water between runoff and storage in the root zone (Pla, 2007) [10]. The soil's ability to absorb heavy rainfall or irrigation depends on its infiltration behavior. Ogban *et al.* (2000) [7] noted that low infiltration values indicate a potential for high runoff and erosion on slopes, impacting the water economy of plant rooting zones.

In addressing water limitations for crop production, knowledge of soil infiltration behavior is crucial for effective design and operation of surface irrigation systems (Hume, 1993) [5]. Quantifying infiltration characteristics occurs when field infiltration data are mathematically fitted to infiltration models, such as those proposed by Kostiakov, Philip, and Horton. However, not all models are universally applicable to all soil types.

In this study, constant infiltration rates of various soils under diverse conditions were calculated using the double-ring infiltrometer method. These values were then compared with estimates from Kostiakov, Philip's, and Horton's infiltration models. The suitability of these models for predicting infiltration rates in specific soil and condition combinations was assessed using correlation coefficients, decision factors and standard errors as evaluative tools.

If the provided soil's infiltration rate is lower than the intensity of the rainfall, water will accumulate on a surface. There was very little information available in the literature about the evaluation and model predictability of infiltration rate models in the sodic soils of Kasbe Digraj of Sangli District. Using several infiltration models that facilitate localized control of soil and water deterioration in agricultural systems. the goal of the current study is to characterize the spatial variability of the infiltration rate and its relation to soil physical and chemical parameters. Therefore, the goal of this study is to provide some information evaluation and model predictability of infiltration rate models in the sodic soils of Kasbe

Digraj Village to confirm the existence of a potential salt problem addressing the environmental issue.

Materials and Methodology

The present research program, conducted in the year 2023, focuses on the "Evaluation and Model Predictability of Infiltration Rate Models in the Sodic Soils of Kasbe Digraj of Sangli District". Infiltration tests were carried out to evaluate and predict the performance of infiltration models, aiming to identify the most suitable empirical model for estimating infiltration rates. This chapter provides comprehensive information on the experimental details, including instrumentation, the experimental setup, and the collection of information about the experiment site, such as location, climate, soil type, and land status. The various infiltration models utilized in this research to simulate the infiltration process are thoroughly explored in this chapter.

The method described by Xu *et al.* (2012) [11] was used in the current investigation to compute the constant infiltration rates of sodic soil under various abiotic stress conditions. The calculated values from the Kostiakov's, Modified Kostiakov's, Horton's and Philip's models will be compared with the values from the field data using the correlation coefficient.

Modelling of Infiltration Equation

Different type of infiltration model available in literature to estimate infiltration rate which have been listed below:

1. Kostiakov equation
2. Philip equation
3. Horton equation

1. Kostiakov's equation (1932)

$I = a\, t^{-b}$

$i = a\, t^{-(b+1)}$

Where, I = Cumulative Infiltration (mm)

i = Infiltration rate (mm h^{-1})

t = Time (min)

a = Equation coefficients

b = Equation coefficients

2. Philip's equation (1957)

$fp = St^{1/2} + Kt$

Differentiating above equation infiltration capacity may be expressed as:

$fp = 1/2\, St^{-0.5} + K$

Where, fp= Infiltration rate at any time t from start

S = a function of soil suction potential called sorptivity (mm $h^{-1/2}$)

K = Darcy's hydraulic conductivity i.e., permeability (mm h^{-1})

3. Horton's equation (1933)

$I = fc + (f_0 - fc)\, e^{-kt}$

Where, I = Infiltration capacity or potential infiltration rate (mm h^{-1})

f_0= Initial infiltration capacity (mm h^{-1})

fc= final steady state infiltration capacity (mm h^{-1})

k = Hortons decay coefficient which depends upon soil characteristics

t = is the time starts (min)

The correlation coefficient is a pivotal measure in evaluating experimental models, quantifying the strength and direction of the linear relationship between observed and calculated infiltration rate data, ranging from -1.0 to +1.0. Positive values signify a positive relationship, negative values indicate a negative one, and 0 denotes no relationship. Estimating correlation coefficients via Gomez and Gomez's (1987) [4] method assesses physical and chemical property relationships, contributing to the coefficient of determination (R^2). The standard error, a crucial parameter for assessing coefficient accuracy, is calculated as $\sqrt{(1 - R^2)} / \sqrt{(n - 2)}$, where R^2 is the coefficient of determination, and n is the number of samples. A smaller standard error implies a more accurate estimate, always yielding positive values. The decision factor, $\eta = R^2 - SE$, aids in model selection, with the highest decision factor indicating the most suitable fit closely aligning with observed field data.

Results and Discussions

A non-linear regression analysis was conducted on the infiltration rate data over time for the sodic soils in the region of Kasbe Digraj, located in Sangli District. The resulting equation from this analysis is given as:

Infiltration Rate (Y) = $61.282e^{-0.022X}$ ($R^2 = 0.6532$)

Furthermore, a separate exponential regression analysis was performed on the cumulative infiltration rate data of the same sodic soils in Kasbe Digraj. The exponential equation obtained from this analysis is:

Cumulative Infiltration Rate (Y) = $172.81e^{0.01X}$ ($R^2 = 0.7403$)

Time (min)	Average Infiltration Rate	Average Cumulative IR
2	117.39	113.91
5	75.16	179.56
10	38.08	228.86
20	24.78	253.65
30	18.78	273.47
60	15.81	343.27
90	12	362

Infiltration models

Infiltration data was analyzed by using the Kostiakov, Philip and Horton models. The model's parameters were estimated through the fitting process and graphical representations were constructed. The observed and predicted values for each model were compared and graphed to illustrate the findings.

1 Kostiakov model

The Kostiakov model was applied sodic soils of Kasbe Digraj studied in this research. In the Kostiakov model, the parameter 'a' represents the initial infiltration rate (mm h^{-1}). The average value of 'a' for the sodic soils of Kasbe Digraj was 117.39 mm h^{-1}. This inferred that the Kostiakov model could be used to evaluate water infiltration during irrigation projects in the farms of sodic soils of Kasbe Digraj. The coefficient of determination R^2= 0.987 was recorded as average in the farm soils at sodic soils.

$I = 174.62 * t^{-0.614}$

showed the values of the estimated parameters. The values of the time exponent of Kostiakov equation were observed to be -0.614 in sodic soils. The infiltration decay constants obtained were negative (-0.614), indicating that the soils were saturated at the time when the experiments were conducted.

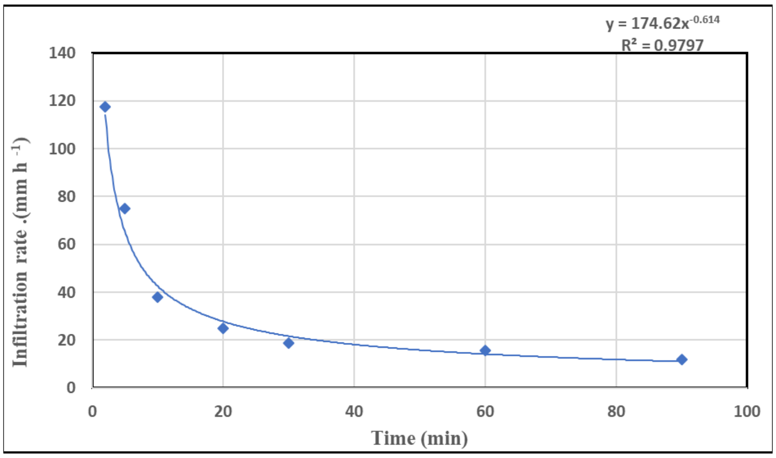

Fig 1: Infiltration rate vs time for Kostiakov's model in sodic soil of Kasbe Digraj.

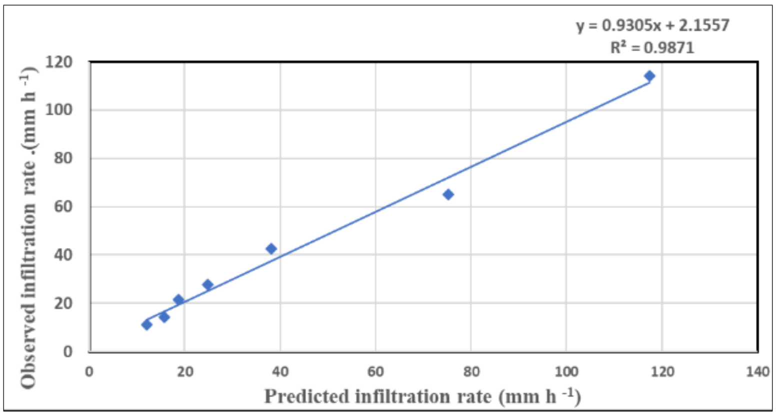

Fig 2: Observed vs predicted infiltration rate for Kostiakov's model in sodic soils of Kasbe Digraj.

2 Philip model

In the case of sodic soils, the sorptivity parameter (S) was determined to be 363.42 mm h^{-1}. Sorptivity is influenced by factors such as the initial soil water content and pore space, and it plays a crucial role in the infiltration process. On the other hand, the saturated hydraulic conductivity parameter (K) for sodic soils was found to range from -11.662 mm h^{-1}. Saturated hydraulic conductivity is a measure of the ability of the soil to conduct water under saturated conditions. By using the Philip model, the infiltration equation for sodic soils was derived as

$$I = 0.5 \times 363.42\ t^{-1/2} + (-11.662)$$

where 'I' represents the infiltration rate and 't' is the time. The coefficient of determination (R^2) for the sodic soils was computed to be 0.9835. This value signifies a strong correlation between the observed infiltration data and the predictions made by the Philip model, indicating that the model fits the sodic soil data very well.

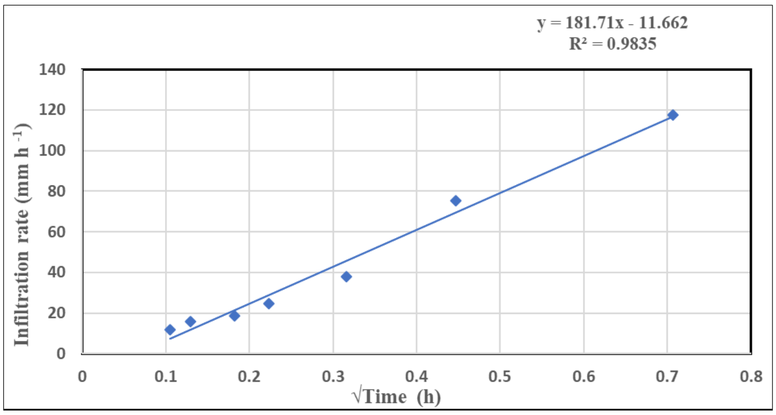

Fig 3: Infiltration rate vs time for Philip's model in sodic soils of Kasbe Digraj.

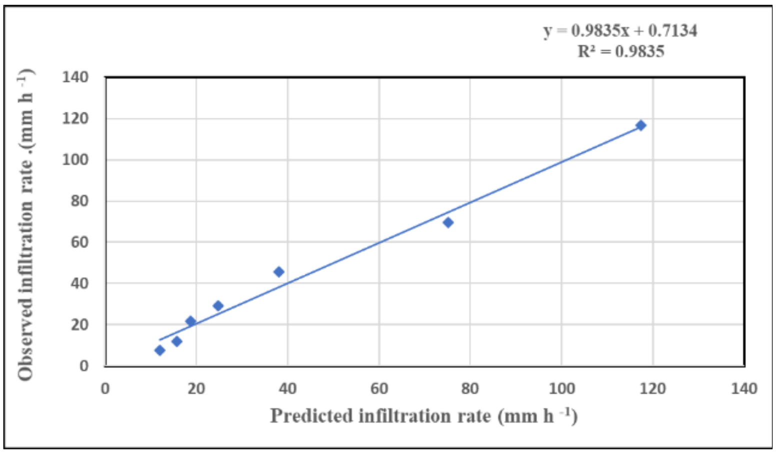

Fig 4: Observed vs predicted infiltration rate for Philip's model in Sodic soils of Kasbe Digraj.

3 Horton model

For sodic soils, a specific value of 'K' was determined to be 0.0397. It's important to note that a negative value of 'K' indicates a decreasing initial infiltration rate, which eventually reaches the steady state. The Horton equation formulated for sodic soils is given by:

$$I = 12 + 107.39 \times e^{(0.0397t)}$$

The coefficient of determination (R^2) for the sodic soils was calculated to be 0.8675. This value indicates a reasonably good fit of the Horton model to the observed infiltration data for sodic soils.

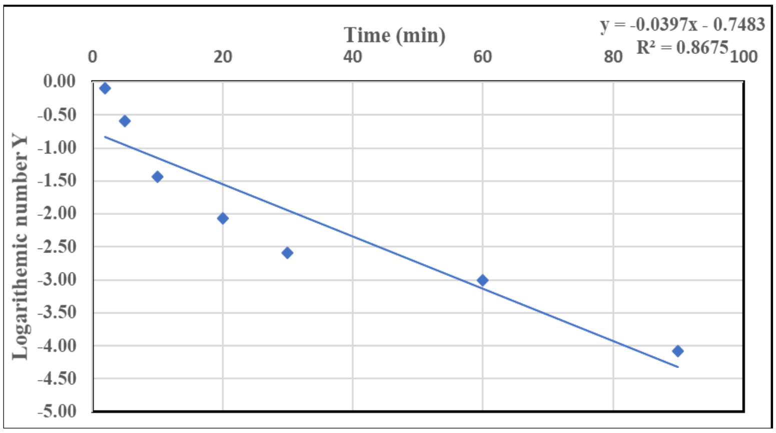

Fig 5: Time vs ln (y) for Horton's model in sodic soils.

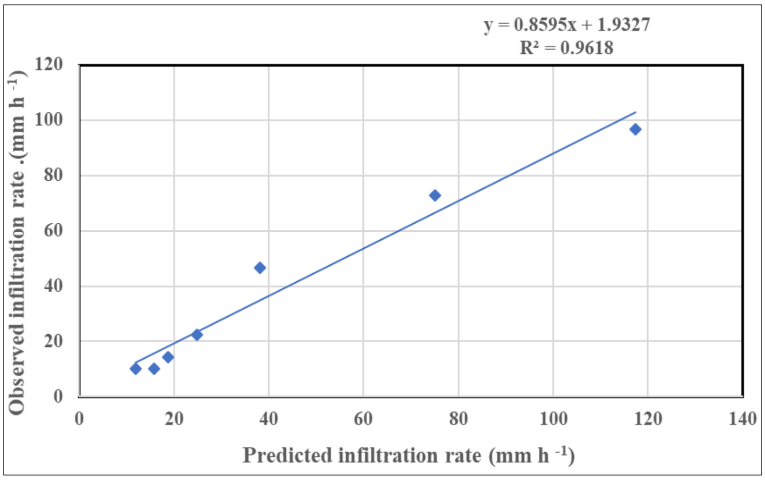

Fig 6: Observed vs predicted infiltration rate for Horton's model in Sodic soil

Table 1: Constants and coefficients of determination of different infiltration models in sodic soils of Kasbe Digraj of Sangli District.

	Kostiakov's Model			Philip's Model			Horton's Model	
Parameters	**A**	**B**	**R^2**	**S**	**K**	**R^2**	**K**	**R^2**
Soils	174.62	-0.614	0.987	363.42	-11.662	0.9835	0.0397	0.8675

Table 2: Observed and predicted infiltration rates of various models in Sodic Soils of Kasbe Digraj of Sangli district.

Time(min)	Observed IR (mm h^{-1})	Predicted values of Infiltration rates with models		
		Kostiakov's	Philip's	Horton's
2.00	117.39	114.09	116.83	96.63
5.00	75.16	65.00	69.60	72.77
10.00	38.08	42.47	45.80	46.69
20.00	24.78	27.75	28.97	22.54
30.00	18.78	21.63	21.51	14.28
60.00	15.81	14.14	11.80	10.17
90.00	12	11.02	7.49	10.01

Observed and predicted infiltration rates of Sodic soils of Kasbe Digraj of Sangli District

According to the data in Table, the Philip's model is considered suitable for predicting average infiltration rates at 5 and 10 minutes. The Kostiakov's model showed similar predicted infiltration values at 2, 60 and 90 minutes, closely matching the observed infiltration rate. However, the Kostiakov's model is more appropriate for predicting average infiltration rates at 20 and 30 minutes. At 2 minutes, the observed initial infiltration rate for Sodic soils was 117.39 mm h^{-1}. The predicted values by Kostiakov's, Philip's and Horton's models were 114.09, 116.83 and 96.63 mm h^{-1}, respectively. For the Kostiakov's, Philip's and Horton's models, the predicted infiltration rate decreased from 295.43 to 53.80, 372.46 to 37.79, and 390.16 to 64.66 mm h^{-1}, respectively.

Among the models, the Horton's model exhibited higher variation in predicting average infiltration rates compared to the other models. It is clearly indicated that Kostiakov's infiltration model shows most near values of observed and predicted infiltration rate.

Table 3: Infiltration model equations, standard error, decision factor and predicted and observed coefficient of determination (R^2) in sodic soils of Kasbe Digraj of Sangli.

Soil type	Models	Model equation	Derived equation	Observed R^2	Standard error	Decision factor	Predicted R^2
Sodic soils	Kostiakov's	$I=at^{-(b+1)}$	$I=174.62\ t^{-0.614}$	0.987	0.032	0.9554	0.9871
	Philip's	$I = 1/2\ St^{-1/2} + K$	$I=0.5\times363.42t^{-½} + (-11.662)$	0.9835	0.036	0.9479	0.9835
	Horton's	$I = i_c + (i_o - ic)\ e^{-kt}$	$I=12+107.39*e^{(0.0397t)}$	0.8675	0.101	0.7665	0.9618

Among them, the Kostiakov's models seem to be more accurate and reliable, with slightly higher observed R^2 values and lower standard errors as compared to the Horton's model. Researchers and practitioners can choose the most appropriate model based on specific needs and data availability, but the Kostiakov's model show promise for predicting infiltration rates in sodic soils of Kasbe Digraj.

Conclusion

The Kostiakov's Model showed that the observed R^2 value of 0.987, with a low standard error of 0.032, demonstrates a strong fit of the model, exceeding the decision factor of 0.9554. The predicted R^2 of 0.9871 confirms the model's reliability and accuracy in predictability of infiltration rate of sodic soils. The observed R^2 value is 0.9835 having standard error 0.036 and decision factor is 0.9479. However, in Horton's model observed R^2 value is 0.8675 having standard error 0.101 and decision factor 0.7665, the observed and predicted R^2 value is 0.9618 is lower as compared to Kostiakov's and Philip's model.

From the study, it can be concluded that the Kostiakov's infiltration model was found most accurate and reliable for predicting and evaluating infiltration rate of Sodic soils of Kasbe Digraj of Sangli District as compared to Philip's and Horton's model. The cumulative infiltration rate was negatively significant correlation with calcium carbonate, bulk density, exchangeable sodium and cation exchange capacity of sodic soil.

Acknowledgement

I sincerely express my gratitude and indebtedness for Agricultural Research Station, Kasbe Digraj, Sangli District and RCSM College of Agriculture, Kolhapur for providing necessary facilities to conduct of the experiment.

References

1. Adenji FA, Umara BG, Dibal JM, Amali AA. Variation of infiltration rates with soil texture. Int. J Eng. Innov. Technol. 2013;3:454-458.
2. Adindu RU, Igbockwe MU, Ughegbu AC, Eke KT, Chigbu TO. Characterization of infiltration capacities of the soils of Michael Okpara University of Agriculture, Umudike - Nigeria. Geosciences. 2014;3:99-107.
3. Fitzpatrick RW, Merry RH, Cox JW, Rangasamy P, Davies PJ. Assessment of physicochemical changes in dry land saline soils when drained or disturbed for developing management options, CSIRO Land and Water Technical Report. South Australia, Australia; c2003.
4. Gomez KA, Gomez AA. Statistical procedure for agricultural research (2ed.). John Wiley and Sons, New York; c1984. p. 680.
5. Hume IH. Determination of infiltration characteristics by volume balance border check irrigation. Agric Water Manage. 1993;23:23–30.
6. Lal R. Tropical Soils: Distribution properties and management. Resource Manage Optim. 1990;7:39–52.
7. Ogban PL, Madeakor O, Akwe IP. Infiltration characteristics and erosion potentials of catenary soils in Southeastern. Nigeria. In: Babalola O, editor. Proceedings of the 26th Annual Conference of the Soil Science Society of Nigeria. Ibadan, Nigeria; c2000. p. 90–93.
8. Osuji GE, Okon MA, Chukwuma MC, Nwarie II. Infiltration characteristics of soil under selected land used practices in Owerri, South Eastern Nigeria. World J Agric Sci. 2010;6(3):322–326.
9. Padalkar RC, Jadhav PL, Jadhav AS, Raut PD. Use of sub-surface drainage treatment for reclamation of saline soil: A case study of Kasbe Digraj village, District:

Sangali, State: Maharashtra. Proceedings of International Conference SWRDM; c2012. p. 269-280.
10. Pla S. Infiltration. Paper presented at College on Soil Physics. In: Abdus Salam International Centre for Theoretical Physics. Trieste, Italy; c2007.
11. Xu X, Lewis C, Liu W, Albertson JD, Kiely G. Analysis of single ring infiltrometer data for soil hydraulic properties estimation, comparison of BEST and Wu methods. Agric Water Manage. 2012;107:34-41.
12. Ieke, Wulan, Ayu. Soemarno PS. Assessment of infiltration rate under different Drylands types in Unter-Iwessub district Sumbawa Besar, Indonesia. J Nat. Sci. Res. 2013;3:1-6.
13. Maliwal GL, Somani LL. Nature, Properties and Management of Saline and Alkali Soils, ISSN 978-81-8321-177-2; c2010.
14. Mirmare, Tristae. Soil physical properties influencing the fitting parameters in Philip's and Kostiakov's infiltration models. Int. J Theor. Phys; c1994. p. 94-97.