Journal of AgriSearch, 7(3):147-153
An Open Access International Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v7i03.18689

Assessment of variability of Soil Infiltration Characteristics under Forage Cover

AKRAM AHMED[1], AK PAL[2], VK PANDEY[2], MAHENDRA PRASAD[3] AND ASHUTOSH UPADHYAYA[1]

ARTICLE INFO
Received on : 09-05-2020
Accepted on : 18-08-2020
Published online : 01-09-2020

ABSTRACT

In India, very limited knowledge of soil infiltration characteristics in forages are available. In this study, infiltration characteristics of land covered by six forages have been studied with respect to bare land in sandy loam soil. Two empirical (Kostiakov and Horton) and two physically-based (Phillip and Green–Ampt) models have been employed to estimate infiltration characteristics and compared with observed field infiltration data. The steady-state infiltration rates measured in forages and bare land were significantly ($p<0.05$) different. The highest average steady-state infiltration rate was measured in *Panicum maximum* (9.00 cm h^{-1}) followed by TSH (7.40 cm h^{-1}) and least was recorded in *Cenchrus ciliaris* (2.65 cm h^{-1}) whereas the average steady-state infiltration rate recorded for bare land was 1.90 cm h^{-1}. Results showed that the Kostiakov and Phillip model simulated the field infiltration characteristics with higher accuracy than the two other models except for *Chrysopogon fulvus* and bare land in which the Horton model outperformed other models. Higher steady-state infiltration rates in forages were attributed to more porosity measured in the soils under forages as compared to bare land.

KEYWORDS
Infiltration, forage, infiltration models, soil properties, root properties

INTRODUCTION

Infiltration of water through soil is a natural process and it is one of the important key components of the hydrological cycle (Singh *et al.*, 2018). When the soil is dry, water infiltrates into the soil at a faster rate. It is termed as initial infiltration rate. As water moves down and occupies pore spaces, the rate of infiltration reduces and eventually reaches a steady rate. This is termed as a steady-state infiltration rate or constant infiltration rate. Knowledge of infiltration characteristics of soil has great importance in irrigation study, drainage system design, groundwater recharge study, non-point source pollutant transport in the soil profile, rainfall-runoff modelling (Igbadun *et al.*, 2007), etc. Groundwater is one of the important sources of water especially for irrigation and drinking purposes in many parts of India. Knowledge of the infiltration process of an area gives an idea of potential zones of groundwater recharge (Deepa *et al.*, 2016). Water from the soil profile reaching the water table through the infiltration process helps in quantifying the amount of groundwater recharge.

Grassland in India covers about 24% of its geographical area (Rawat *et al.*, 2015). These grasslands comprise various forage species (Singh *et al.*, 2009), which are the food of many herbivorous animals (Singh *et al.*, 2010). Different forage species in Indian grasslands and their spatial prevalence over India mentioned in Mohan *et al.*, (2015). Grasslands are important zones for groundwater recharge as reported by many researchers(Kim *et al.*, 2012; Huang *et al.*, 2017) and many infiltration studies in grasslands were conducted in many parts of the world(Naeth *et al.*,1990; Kalhoro *et al.*, 2019). However, infiltration studies in Indian grasslands, as well as the influence of forage species on infiltration, are not available.

Measuring infiltration characteristics within a small spatial scale is possible. However, measuring infiltration characteristics for a larger spatial scale is a daunting work and incorporates a huge cost, labour, and time. Therefore, efforts were made to model infiltration characteristics in soil with varying soil physical properties, vegetation types, etc. which resulted in the development of many analytical models. These models are classified in two categories as empirical models, viz., Kostiakov model (Kostiakov *et al.*, 1932), Horton model (Horton *et al.*, 1940), Mezencev model (Mezencev, 1948), Modified Kostiakov (Smith and Parlange, 1978), etc. and physically-based models, viz., the Green-Ampt model (Green and Ampt, 1911), Philip two - term model (Philip, 1957), Brutsaert model (Brutsaert *et al.*, 1977), Swartzendruber model (Swartzendruber,1987), etc. A review of these models in great detail in mentioned in Ravi and Williams (1998). Machiwal *et al.* (2006) and Mahapatra *et al.*(2020) have evaluated the performance of these soil infiltrations models in under various field conditions (Machiwal *et al.*, 2006; Nie *et al.*, 2017; Mahapatra *et al.*, 2020). For example, Mahapatra *et al.*(2020) evaluated the efficacy of seven infiltration models in simulating infiltration characteristics and steady-state infiltration rates under various soil and land use and land cover conditions. They found that the Brutsaert model and Swartzendruber model were more robust with the least uncertainty and less sensitive to land use and land cover.

[1]ICAR Research Complex for Eastern Region, Patna, Bihar, India
[2]SV College of Agricultural Engg. and Tech. & Research Station, FAE, IGKV, Raipur, India
[3]Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India
*Corresponding author email : akrambckv@gmail.com

Keeping the above facts and research gaps in view, an in-depth field study was carried out to investigate infiltration characteristics in six forage species at Jhansi in Central India and the results of the infiltration study on forages were compared with bare land (control). Also, the performance of four infiltration models was evaluated in simulating the infiltration process in forages and bare land.

MATERIALS AND METHODS

Study area

This study was carried out during the year 2017-2018 at the research farm of ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, Uttar Pradesh. The geographical position of the study location is 25.43º N latitude and 78.58º E longitude with an elevation of 284 metres above the Mean Sea Level. The climate is sub-humid type characterized by a hot dry summer and cold winter. The normal annual rainfall of Jhansi is approximately 800 mm. The texture of the soil of study location is sandy loam type (% sand: 69, % silt: 21 and % clay: 10) with poor water holding capacity. The field capacity (%w) and permanent wilting point (%w) moisture content of the soil were measured as 13.0 % and 5.2 %, respectively. Bulk density of the plots ranged from 1.82 to 2.09 g/cc. The porosity of the soil in the plots was observed to be ranges from 14 to 29%. The pH, EC, and % organic carbon in the plots were measured as 7.71, 0.14 dSm^{-1} and 0.48, respectively.

Infiltration test in experimental fields

In-situ field infiltration test in six mature forages and bare land (control) was carried out during November 2017 using Double Ring Infiltrometer (DRI) (Fig. 1a). A DRI consists of one inner ring (diameter 29.5 cm) and one outer ring (diameter 49.5 cm). Detailed methodology for measurement of infiltration rate using DRI can be found in Sihag *et al*. 2017. Six forages i.e., (i) *Cenchrus ciliaris*, (ii) *Dicanthium annulatum*, (iii) *Heteropogon contortus*, (iv) Tri Specific Hybrid (TSH), (v) *Panicum maximum* and (vi) *Chrysopogon fulvus* have been selected for this experiment. The infiltration test was replicated thrice for each forage grass and bare land. Fig. 1b shows the field view of the grass plots and bare land. The duration of each infiltration experiment extended for more than four hours and the depth of water infiltrated down was measured at predefined time intervals. As the infiltration rate is high at the beginning of the experiment, the depth of infiltrated water was recorded at every 30 seconds time interval for the initial 5 minutes. Then, the interval of recording depth of infiltrated water was increased due to a decrease in the infiltration rate. The last reading of the depth of infiltrated water was taken at 266 minutes in each experiment.

Fitting of infiltration models

To study hydrological processes such as the design of hydraulic structures, design of urban drainage system, estimation of design flood, groundwater recharge, solute dynamics, etc., availability of spatial infiltration rate data are inevitable. However, it is labourious, time-consuming, and impractical to measure spatio-temporal infiltration rate at a larger scale. To solve this problem, different empirical and physical-based infiltration models were developed to represent the variation of the infiltration rate in soil using minimum parameters. Among the empirical models, the Horton model and the Kostiakov model, and among physically-based models, Phillip's two-term model and Green-Ampt model were used in this study. The procedure for predicting the infiltration rate employing these empirical and physically-based models can be found in Subramanya (2013). A brief description of the infiltration models is presented below:

Kostiakov model

Kostiakov (1932) proposed a simple empirical infiltration equation based on curve fitting from field infiltration data. It relates infiltration rate to time as a power function:

$$f_p = \alpha K t^{\alpha-1} \quad (1)$$

Where f_p is infiltration rate; t is time after infiltration starts; K as well as α are the constants and depend on the soil and initial conditions. The parameters, K and α must be evaluated from measured infiltration data.

Horton model

Horton (1940) assumed that the infiltration rate (f_p) decreases with time and tends to a minimum constant rate (f_c) with the elapse of time. He related the infiltration rate to the rate of work performed and the change in infiltration capacity from f_p to f_c as the work remaining to be performed, with β as the proportionality factor. The final form of the Horton equation is obtained as,

$$f_p = f_c + (f_0 - f_c)e^{-\beta t} \quad (2)$$

Phillip model

For a uniform soil with uniform soil-moisture content, and the excess water supply rate at the surface, Philip (1957) found a solution to the flow equation in the form of an infinite series. Because of rapid convergence, the first two terms of the series are considered sufficient and constitute the Philip two-term model. It is represented as,

$$f_p = \frac{St^{-0.5}}{2} + A \quad A \quad (3)$$

where S is termed as soil sorptivity which depends on initial soil moisture content and soil-water diffusivity; and A is a parameter represents an approximate estimate of *in-situ* saturated hydraulic conductivity.

Green-Ampt Model

Green and Ampt (1911) proposed an approximate model that directly applies to Darcy's law. The original equation was derived for infiltration from a ponded surface into a deep homogeneous soil with uniform initial water content. The infiltration rate predicted by the model is expressed as,

$$f_p = K(1 + \frac{\eta_{S_c}}{F}) \quad (4)$$

Where K is the hydraulic conductivity of the wetted zone, η is the porosity of the soil

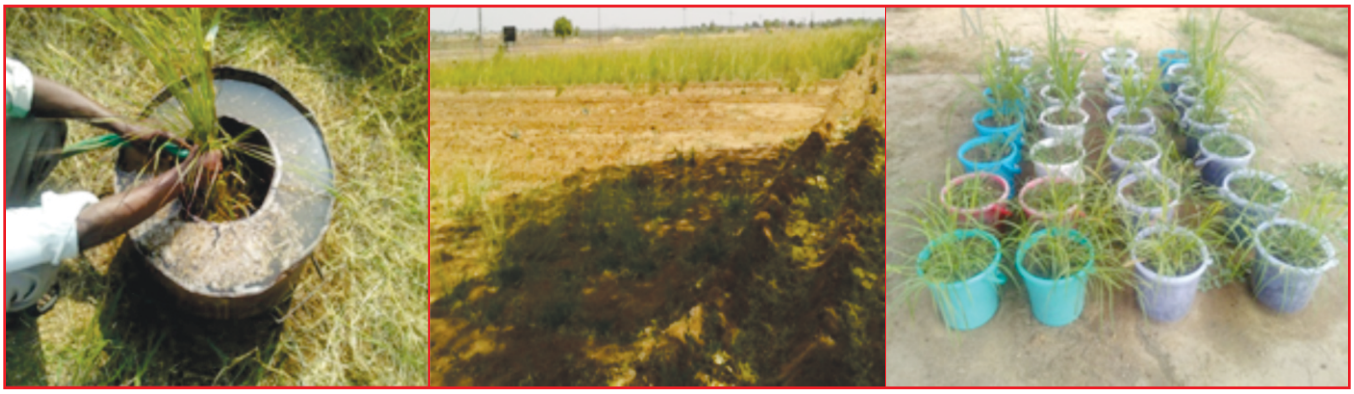

Fig. 1: (a) Measurement of infiltration in grasses using double ring infiltrometer **(b)** field view of the forage plot and bare land **(c)** forage grasses planted in buckets

Measurement of other relevant data

Soil cores were sampled adjacent to forage tussock using core sampler to measure the bulk density and porosity of the soil of experimental forage plots. It is difficult to measure *in-situ* root volume by excavating forage roots from the soil. In doing so, most of the root gets damaged while the forage was tried to pull up with force using a chain-pulley system or excavated using a spade. Rooted slips of each forage were planted in six plastic buckets (top diameter 0.3 m, bottom diameter 0.25 m, and height 0.3 m) in August 2017. Three of the buckets out of those six buckets were allocated for measuring the volume of roots and rest three buckets were allocated for measuring the average lateral length of primary roots of the forages (Fig. 1c). At the mature stage of the forages in buckets, the shoot of each forage was removed carefully followed by separation of the closed end of the bucket from the bucket-forage assembly with a sharp knife without damaging roots. A sieve was placed at the cut end of the bucket-forage assembly to collect the broken roots of forages while removing adhered soil from the roots in the bucket-forage assembly through a gentle sprinkling of water. Washed roots, as well as roots, collected from the sieve, were air-dried.

Then, the air-dried roots of each forage were carefully bundled and dipped into a graduated transparent bucket partially filled with water. The rise in the water level in the bucket represents the volume of the root of forage. To measure the average lateral length of primary roots of the forages, similar steps followed during removing soil adhered to roots while measuring the volume of the root of forages. Then primary roots and other comparatively thinner roots were separated from the tussock of the forages and the average length of the primary roots was measured with a scale. These roots were then air-dried for measuring the tensile strength of the roots of the forages. The tensile strength of the roots of various diameter ranges of each forage was measured using the instrumentation described in Pal *et al.* 2019. The tensile strength (Mpa) of roots was measured using the following equation,

$$T = \frac{F_{max}}{\pi(\frac{D^2}{4})} \quad (5)$$

Where F_{max} is the maximum force (N) needed to break the root and D is the mean diameter (mm) of the root near the point of rupture.

Performance evaluation of the infiltration models

The infiltration rate was predicted using the empirical and physical models at the same time intervals followed while recording actual infiltration rates in forages. Accuracy of infiltration models was assessed using Correlation Coefficient (r) and Root Mean Square Error (*RMSE*) by comparing the infiltration rate predicted by the models with respect to observed infiltration rate. The correlation coefficient (r) and *RMSE* are expressed as:

$$r = \frac{N\left(\sum_{i=1}^{N} Ps_i * Po_i\right) - \left(\sum_{i=1}^{N} Ps_i\right)\left(\sum_{i=1}^{N} Po_i\right)}{\sqrt{\left[N\left(\sum_{i=1}^{N} Ps_i^2\right) - \left(\sum_{i=1}^{N} Ps_i\right)^2\right]\left[N\left(\sum_{i=1}^{N} Po_i^2\right) - \left(\sum_{i=1}^{N} Po_i\right)^2\right]}} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Ps_i - Po_i)^2}{N}} \quad (7)$$

Where Ps_i and Po_i are the predicted and observed infiltration rates and N is the number of data.

Statistical analysis

The infiltration data recorded for the forages and bare land, as well as various attributes such as bulk density and porosity of the soil, tensile strength of root, etc. related to forages and bare land, were subjected to analysis of variance (ANOVA) to test for any significant difference in those attributes. Duncan's multiple range test (DMRT) was applied to measure specific differences between the pairs of means related to each attribute at $p < 0.05$.

RESULTS AND DISCUSSION

Infiltration tests in forages were carried out in the apparently dry condition of the soil. The infiltration rate measured in each forage is shown in Fig. 2a. It shows a frequent variation in infiltration rate with time, which makes it difficult in interpretation. To represent Fig. 2a more vividly, five points moving average method was applied on measured infiltration data and the result is shown in Fig. 2b. It showed that initially infiltration rate was very high due to initial dryness in soil and gradually infiltration rate decreased with time and after a considerable time it reached to steady-state infiltration rate.

Infiltration rate averaged over the whole duration as well as steady-state infiltration rate measured in forages and bare land is shown in Table 1. ANOVA test showed significant differences ($p<0.05$) in the infiltration rate and steady-state infiltration rate measured for forages and bare land. The

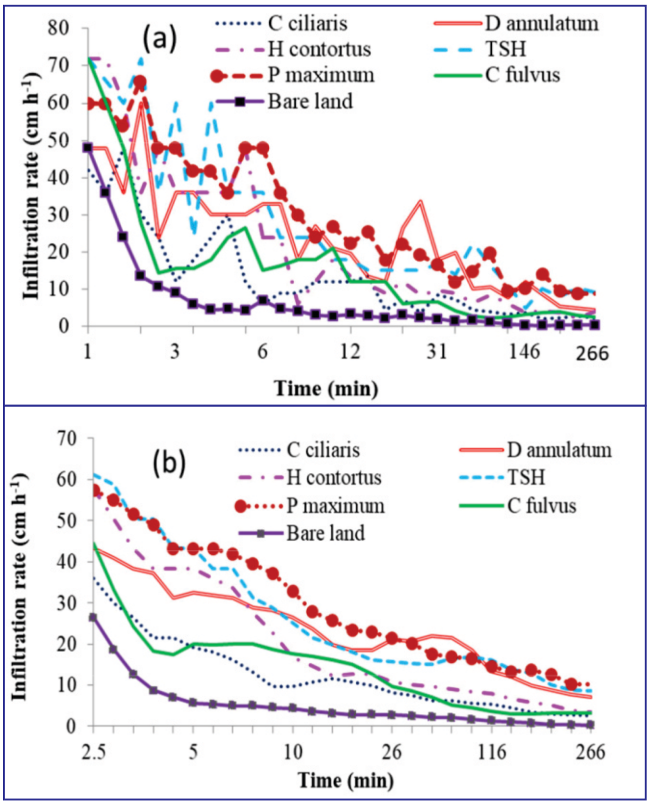

Fig. 2: **(a)** Observed infiltration rate measured in forages and bare land (b) observed infiltration rate after employing of 5-point moving average method

average infiltration rate and steady-state infiltration rate measured in forages were found significantly different in comparison to bare land as per the DMRT test (Table 1). The highest average infiltration rate and steady-state infiltration rate were observed for *P maximum* i.e. 29.36 cm hr^{-1} and 9.00 cm hr^{-1}, respectively followed by TSH i.e. 26.71 cm hr^{-1} and 7.40 cm hr^{-1}. On the contrary, the lowest average infiltration rate and steady-state infiltration rate were observed for bare land (control) i.e. 5.04 cm hr^{-1} and 1.90 cm hr^{-1}, respectively. The average infiltration rate and steady-state infiltration rate was observed in the order of *P maximum* > TSH >*D annulatum*>*H contortus*>*C fulvus*>*C ciliaris*> bare land.

The infiltration rate predicted by the infiltration models is shown here only for *C ciliaris*and *D annulatum*in Fig. 3 and Fig. 4, respectively. Poor prediction of infiltration rate by the Horton model has been observed particularly during the initial period of the experiment (Figs. 3a & 4a). Similarly, it has been observed that the infiltration rate predicted by the Green-Ampt model deviates significantly from the observed infiltration rate near to the steady-state infiltration rate region (Fig. 3c & 4c). The infiltration rate predicted by Phillip and Kostiakov model fits well with the observed infiltration rate (Fig. 3b, 3d, 4b, and 4d). Accuracy in predicting the observed infiltration rate by infiltration models for forages and bare land in terms of correlation coefficient (*r*) and *RMSE* is shown in Table 2. More the value of *r* and less *RMSE* valuerepresents the superiority of an infiltration model in predicting the observed infiltration rate. The highest *r* and lowest *RMSE* were observed almost for all forages and bare land when infiltration was predicted with Phillip and Kostiakov model (Table 2).

Table 2: Values of r and RMSE for the infiltration models with respect to forage and bare land

Forage/ Bare land	r, RMSE			
	Horton	Phillip	Green–Ampt	Kostiakov
C ciliaris	0.67, 10.38	0.89, 5.63	0.79, 7.53	0.89, 5.75
D annulatum	0.75, 9.37	0.81, 7.96	0.67, 10.07	0.84, 7.69
H contortus	0.63, 22.84	0.83, 14.57	0.67, 19.28	0.82, 15.02
TSH	0.43, 75.87	0.79, 19.68	0.54, 26.82	0.79, 21.21
P maximum	0.83, 15.28	0.89, 18.00	0.71, 11.97	0.92, 6.67
C fulvus	0.89, 15.10	0.67, 18.94	0.41, 29.01	0.69, 22.07
Bare land	0.88, 13.98	0.86, 11.01	0.54, 18.48	0.78, 22.40

It signifies the infiltration rate predicted by Phillip and Kostiakov models are more accurate than the other two models. However, the highest *r* and lowest *RMSE* values were observed for *C fulvus* in case of infiltration rate predicted by the Horton model. It indicates that the Horton model is more accurate for predicting the infiltration rate for *C fulvus*. In the case of bare land, the highest *r* value was obtained for the Horton model followed by Phillip model whereas the lowest

Table 1: Measured infiltration rate in forages and bare land as well as other soil and forage attributes

Forage/bare land	Steady-state infiltration rate (cmh^{-1})	Average infiltration rate (cmh^{-1})	Bulk density (gcm^{-3})	Porosity	Tensile strength (Mpa)	Lateral root length (cm)	Root volume (cm^3)	Average primary root dia. (mm)
C ciliaris	2.65f	12.30f	1.84bc	0.25c	135.50b	14.00d	22.46d	0.76b
D annulatum	4.40d	23.56c	1.84bc	0.27b	99.86e	10.80e	24.21c	0.42f
H contortus	4.00e	20.63d	1.85b	0.25c	140.56a	16.00c	21.39de	0.49e
TSH	7.40b	26.71b	1.82bc	0.28ab	51.23f	23.00a	37.76a	0.82a
P maximum	9.00a	29.36a	1.82c	0.29a	106.64c	21.50b	30.30b	0.58d
C fulvus	6.00c	14.18e	1.85b	0.27b	62.60e	11.00e	20.65e	0.71c
Bare land	1.90g	5.04g	2.09a	0.14d				

Different letters in column are significantly different at $p < 0.05$ according to Duncan Multiple Range Test (DMRT).

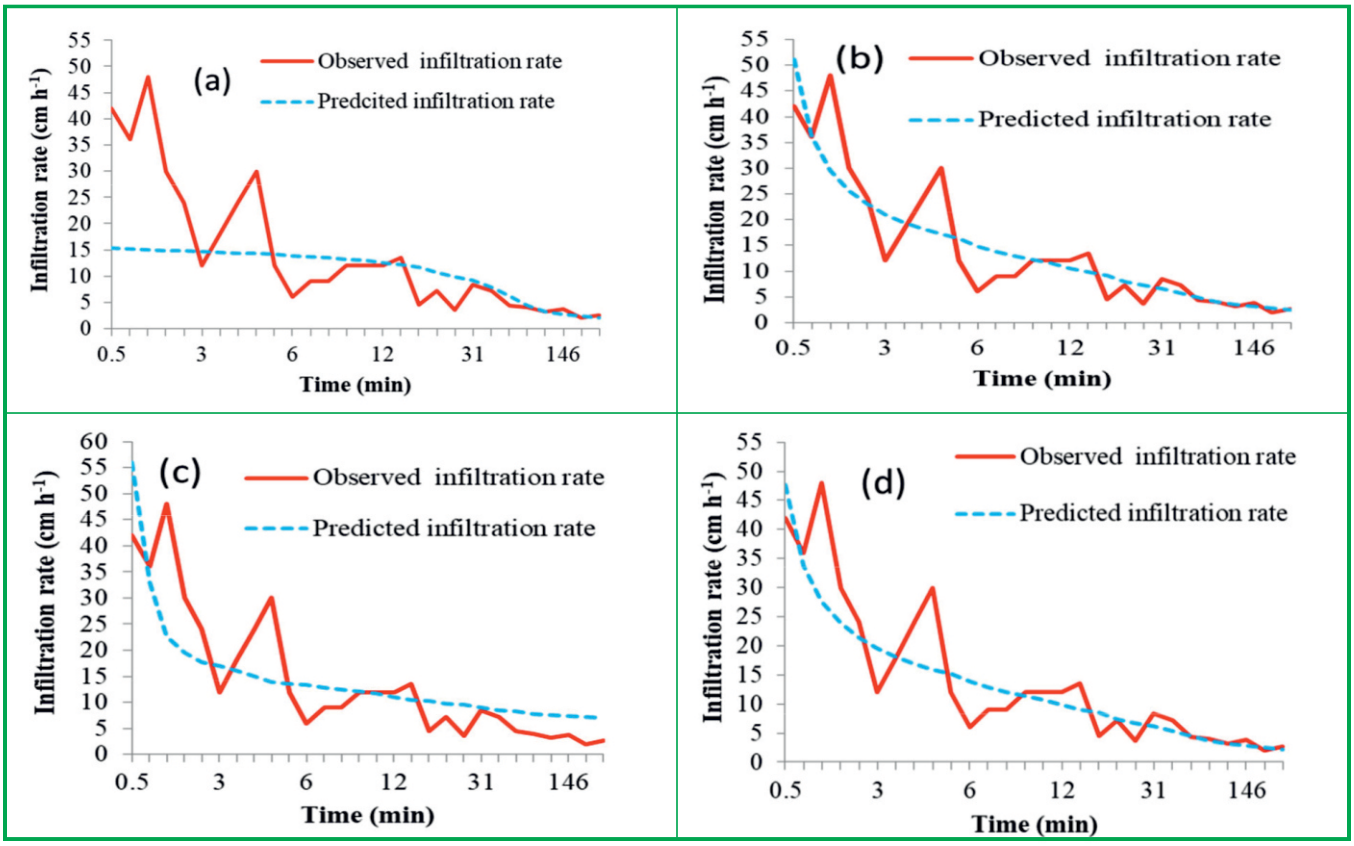

Fig. 3: Predicted infiltration rate *C ciliaris* **(a)** Horton, **(b)** Phillip, **(c)** Green–Ampt, and **(d)** Kostiakov model

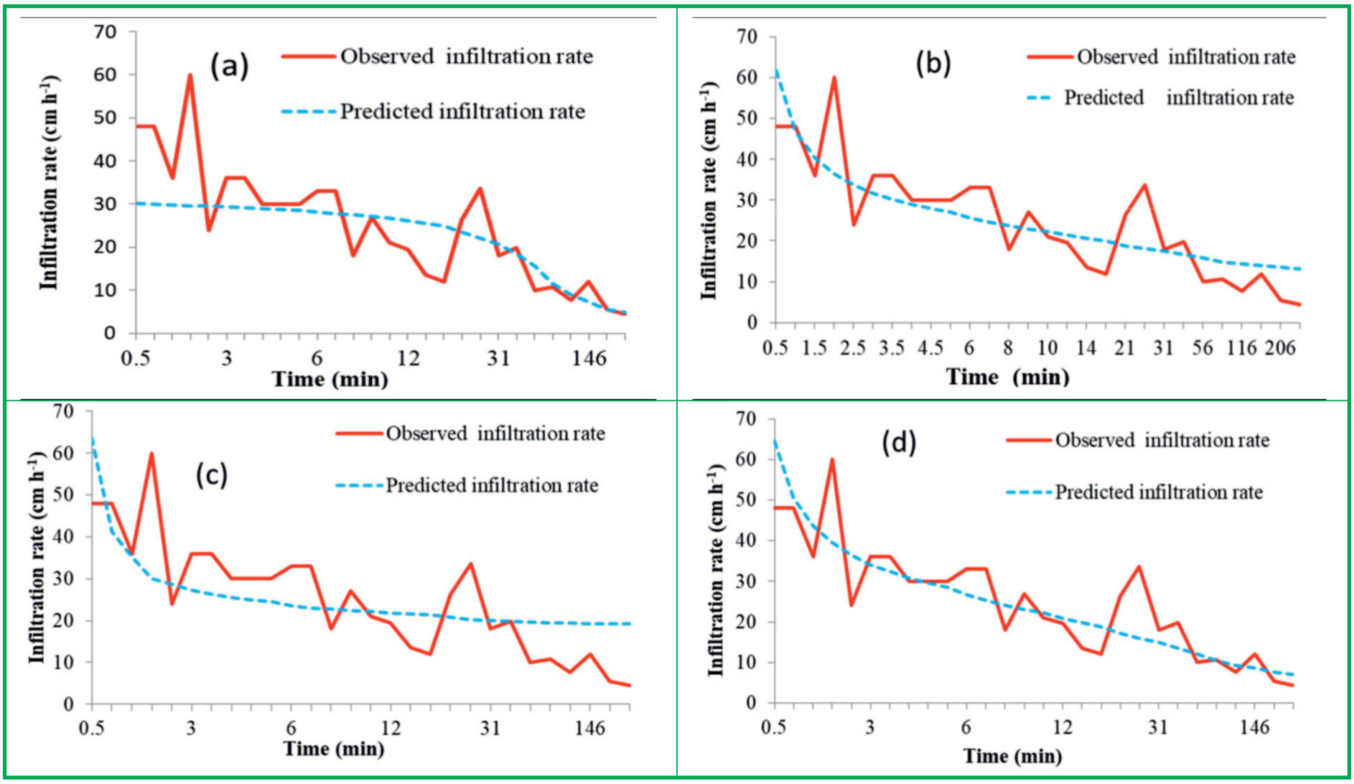

Fig. 4 : Predicted infiltration rate *D annulatum* **(a)** Horton, **(b)** Phillip, **(c)** Green–Ampt, and **(d)** Kostiakov model

Table 3: Value of infiltration model parameters for forages and bare land

Forage / bare land	Horton			Phillip		Kostiakov	
	f_0	f_c	β	$S/2$	A	K	α
C ciliaris	42	2.60	1.22	4.66	0.13	8.76	0.5
D annulatum	48	4.35	0.90	4.62	11.04	18.27	0.64
H contortus	72	3.95	1.01	9.19	-0.95	15.61	0.44
TSH	72	7.35	0.15	10.51	1.66	21.72	0.62
P maximum	60	8.95	1.36	11.73	6.44	23.15	0.65
C fulvus	60	5.9	1.32	7.13	19.16	27.73	0.54
Bare land	72	1.85	1.55	7.98	3.74	18.74	0.29

RMSE was obtained for Phillip followed by the Horton model. It signifies that Horton and Phillip models both are equally accurate than the other two models for prediction of infiltration rate for bare land. From this analysis, it has been observed that Phillip and Kostiakov models are superior to the other two models for most experimental forages. However, the Horton model was found superior in predicting the infiltration rate for *C fulvus* and bare land than the other three infiltration models. The infiltration rate predicted by the Green–Ampt model was observed less accurate than the other three models. Hence, only parameters related to each infiltration model except the Green-Ampt model was presented in Table 3. Using the model parameters corresponding to an infiltration model, the infiltration rate at any time can be predicted. These model parameters presented in Table 3 are useful to simulate the infiltration rate during hydrological modeling in a watershed in sandy loam soil in Central India.

ANOVA followed by DMRT statistical tests showed a significant difference in the average primary root diameter in forages considered in this study (Table 1). The highest average primary root diameter was measured for TSH (0.82 mm) followed by *C ciliaris* (0.76 mm) and *C fulvus* (0.71 mm) whereas the lowest was observed for *D annulatum* (0.42 mm). A significant difference ($p<0.05$) in root volume in forages has been observed from the ANOVA test. The DMRT statistical test showed that the root volume measured in TSH is significantly different ($p<0.05$) than the root volume measured in other forages. Similarly, root volumes measured in *P maximum*, *D annulatum*, and *C ciliaris* are significantly different ($p < 0.05$). Root volumes measured in *C ciliaris* and *H contortus* are at par. Similarly, root volumes measured in *H contortus* and *C fulvus* are at par. From the visual appearance of the shoot of the forages, above ground biomass in TSH and *P maximum* is significantly more than the other forages. More root volume measured in TSH (37.76 cm^3) and *P maximum* (30.30 cm^3) might be to support its above-ground biomass. The average lowest root volume was measured for *C fulvus* (20.65 cm^3). ANOVA followed by the DMRT test carried out in forages showed a significant difference in their average lateral root length and tensile strength of the roots of forages. Average lateral root length measured at origin of roots from the tussock of the forages showed maximum for TSH (23.00 cm) followed by *P maximum* (21.50 cm) and the lowest average lateral length was observed in *C fulvus* (11.00 cm). Average tensile strength measured over the diameter range of roots of the forages showed the highest average tensile strength in *H contortus*(140.56 Mpa) followed by *C ciliaris* (135.50 Mpa) and the lowest average tensile strength was measured in TSH roots (51.23 Mpa). It signifies although roots of TSH are having the highest average root diameter and root volume, its roots are weak in comparison to other forages. Generally, bulk density and porosity are inversely proportional to each other. It means lowest the bulk density highest the porosity and vice versa. Bulk density and porosity measured in soils corresponding to the forages and bare land vary significantly as per the ANOVA test. Table 1 shows the inverse relationship between bulk density and porosity for the forages and bare land. The average lowest bulk density was observed for *P maximum* (1.82 g/cm^3) and TSH (1.82 g/cm^3) and the highest porosity was observed for *P maximum* (0.29) and TSH (0.28), respectively, which is in accordance with the relationship between bulk density and porosity. The highest bulk density (2.09 g/cm^3) and lowest porosity (0.14) were observed for bare land.

Roots of forages are the fibrous type, which consists of primary, secondary, and tertiary type roots. Secondary type roots originate from the primary root and tertiary roots originate from secondary roots. Soil removed after gently and carefully washing the roots of forages planted in buckets showed significantly more voluminous fibrous root in TSH and *P maximum* than other forages which is evident from the root volume measurement (Table 1). Although more root volume was observed in TSH than *P maximum*, porosity measured in *P maximum* is slightly more than TSH. Table 1 shows that the roots of *P maximum* are having significantly higher tensile strength than TSH. It signifies that roots of *P maximum* are stronger than roots of TSH and therefore, roots of *P maximum* can penetrate more comfortably into the soil than TSH roots. Thus, roots of *P maximum* have more capability than TSH roots to dislodge more soil particles from soil aggregates during its penetration into the soil. That might be the possible reason for explaining slightly higher porosity in the soil in *P maximum* than in TSH. Roots create channels in soil and thus facilitate more water to infiltrate down through those channels. As the number of roots is more in *P maximum* and TSH, the roots of these forages create more channels in soil and facilitate more volume of water for moving down in compared to other forages. This is why average infiltration measured in *P maximum* and TSH was comparatively more than other forages. Macleod *et al.* (2013) reported similar observations while studying infiltration for two years in rye grass and meadow fescue and their hybrids rates in the UK. They observed overall the highest infiltration rate and lowest runoff in one of their hybrid. The reason they reported was the establishment of the horizontal and vertical extensive and distributed root system in that hybrid, which created more channels in the soil for the quick passing of the infiltrated water in comparison to others. More average infiltration rate and infiltration capacity rate in *P maximum* than TSH might be due to more porosity in the soil in case of *P maximum* than TSH. On the contrary, a very little amount of roots are expected to be present in the soil in bare land due to the absence of vegetation. As a result, porosity measured in the soil in bare land is significantly less than porosity measured in the soil in forages. Thus, a low average infiltration rate and infiltration capacity in bare land than forages can be attributed to the presence of less porous space soil in bare land. A similar finding was also reported by Leung *et al.* (2018) while comparing infiltration rates at different ages of the willow tree and Festulolium grass with respect to fallow land in the UK. They explained a higher steady-state infiltration rate in willow plants with respect to Festulolium grass of the same age is because of its higher root biomass and root length.

CONCLUSION

In this study, infiltration experiments were carried out in six forages and compared with the bare land followed by testing the performance of four infiltration models in simulating the infiltration tests. The steady-state infiltration rate measured in forages were significantly ($p< 0.05$) higher than bare land. Among forages, the highest steady-state infiltration rate was measured in *P maximum* followed by TSH and the least infiltration rate was measured in *C ciliaris*. A higher infiltration rate in forages is attributed to the presence of more porous spaces in soil than in bare land. Among forages, significantly more steady-state infiltration rate recorded in *P maximum* and TSH than others is attributed to their higher root volume. Among the infiltration models, it has been observed that overall Phillip and Kostiakov models were more accurate than the Horton and Green–Ampt models. The results obtained from this study will help in understanding the water dynamics in the soil profile in grasslands comprising of these types of forages. However, more study is needed in this direction to work out infiltration characteristics in other forages generally found in Indian grasslands in different type of soils.

REFERENCES

Brutsaert W. 1977.Vertical infiltration in dry soil. *Water Resour. Res.***13**: 363–368.

Deepa S, Venkateswaran S, Ayyandurai R, Kannan R and Prabhu MV. 2016. Groundwater recharge potential zones mapping in upper Manimuktha Sub basin Vellarriver Tamil Nadu India using GIS and remote sensing techniques. *Model Earth Syst. Environ.* **2**(3):137.

Green WH and Ampt G. 1911. Studies of Soil Physics, Part 1. The flow of air and water through soils. *J. Agr. Sci.* **4**: 1–24.

Horton RE. 1940. An approach toward a physical interpretation of infiltration capacity. *Soil Sci. Soc. Am. J.* **5**: 399–417.

Huang T, Pang Z, Liu J, Yin L and Edmunds WM. 2017. Groundwater recharge in an arid grassland as indicated by soil chloride profile and multiple tracers. *Hydrol. Process.* **31**(5): 1047–1057.

Igbadun HE and Idris UD. 2007. Performance evaluation of infiltration models in a hydromorphic soil. *Niger. J. Soil Environ. Res.* **7**(1): 53–59.

Kalhoro SA, Ding K, Zhang B, Chen W, Hua R, Shar AH and Xu X. 2019.Soil infiltration rate of forestland and grassland over different vegetation restoration periods at Loess Plateau in northern hilly areas of China. *Landsc. Ecol. Eng.* **15**(1): 91–99.

Kim JH and Jackson RB. 2012. A global analysis of groundwater recharge for vegetation, climate, and soils. *Vadose Zone J.* **11**(1).

Kostiakov AN.1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity of studying it from a dynamic point of view for purpose of amelioration. Transactions of the Sixth Congress of International Society of Soil Science, Moscow, Russia, Part A, pp. 17–21.

Leung AK, Boldrin D, Liang T, Wu ZY, Kamchoom V and Bengough AG. 2018. Plant age effects on soil infiltration rate during early plant establishment. *Géotechnique*. **68**(7): 646–652.

Machiwal D, Jha MK and Mal BC. 2006. Modelling infiltrtaion and quantifying spatial soil variability in a watershed of Kharagpur. *India. Biosyst. Eng.* **95**(4): 569–582.

Macleod CJA, Humphreys MW, Whalley WR, Turner L, Binley A, Watts CW, Skot L and Joynes A. 2013. Hawkins, S, King, I. P,O'donovan, S, and Haygarth, P. M, A novel grass hybrid to reduce flood generation in temperate regions. *Sci. Rep.* **3**(1): 1-7.

Mahapatra S, Jha MK, Sabinaya B and Debasis S. 2020.Assessing Variability of Infiltration Characteristics and Reliability of Infiltration Models in a Tropical Sub-humid Region of India. *Sci. Rep.* **10**(1).

Mezencev VJ. 1948. Theory of formation of the surface runoff. Meteorol. *Gidrol*.**3**: 33–46.

Mohan A, Bhardwaj GS, Sen S, Jhala YV and Shivkumar K. 2015. Ecology and Management of Semi-arid Grasslands in India with Special Reference to Endangered Lesser FloricanSypheotidesindica Miller. In: Ecology and Management of grassland habitats in India. ENVIS Bulletin, *Volume 17*, Wildlife Institute of India, Dehradun, India.

Naeth MA, Rothwell RL,Chanasyk DS and Bailey AW. 1990. Grazing impacts on infiltration in mixed prairie and fescue grassland ecosystems of Alberta. *Can. J. Soil Sci.***70**(4): 593–605.

Nie W, Ma X and Fei L. 2017.Evaluation of infiltration models and variability of soil infiltration properties at multiple scales. *Irrig. Drain.* **66**(4): 589–599.

Pal AK, Ahmed A and Pandey VK. 2019. Soil binding capacity of different forage grasses in terms of root reinforcement ability toward soil slope stabilization. *Indian J. Hill Farming.***32**(1): 137–143.

Philip JR. 1957. The theory of infiltration: The infiltration equation and its solution. *Soil Sci.***83**: 345–357.

Ravi V and Williams JR. 1998. Estimation of infiltration rate in the vadose zone: compilation of simple mathematical models. Volume I, United States Environmental Protection Agency (EPA). National Risk Management Research Laboratory, Ada, Oklahoma EPA/600/R-97/128a, pp 26.

Rawat GS and Adhikari BS. 2015.Ecology and management of grassland habitats in India. ENVIS Bulletin, Wildlife & Protected Area, 17, Wildlife Institute of India, Dehradun, India.

Sihag P, Tiwari NK and Ranjan S. 2017. Estimation and inter-comparison of infiltration models. *Water Sci*. **31**(1): 34-43.

Singh AK, Singh Lal, Kumar C, Kumar P and Dimree SK. 2010. Para grass hybrid (*Brachiaria sp.*) – A potential forage *for India***.** *Envi. & Ecol.* **28** (3): 1715-1721.

Singh AK, Verma Nidhi, Yadav SK, Mohanty Aparajita, Singh SP and Singh Surender. 2009. Indian Forage Genetic Resources: Perspectives and Strategies. *Prog. Agri.* **9** (2): 250-256.

Singh B, Sihag P, and Singh K. 2018.Comparison of infiltration models in NIT Kurukshetra campus. *Appl. Water Sci.* **8**(2): 63.

Smith RE and Parlange JY. 1978. A parameter-efficient hydrologic infiltration model. *Water Resour. Res.* **14**(3): 533–538.

Subramanya K. 2013. Engineering Hydrology. Tata McGraw-Hill Publishing Company Limited New Delhi.

Swartzendruber D. 1987. A quasi-solution of Richards' Equation for the downward infiltration of water into soil.*Water Resour. Res.* **23**(5): 809–817.

Citation:
Ahmed A, Pal AK, Pandey VK, Prasad M and Upadhyaya A. 2020. Assessment of variability of infiltration characteristics in forage crops. *Journal of AgriSearch* **7**(3):147-153