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Infiltration Modelling in 'Bun' Method of Shifting Cultivation in a Hilly Micro-Watershed of Meghalaya

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ABSTRACT

Experiments were conducted to characterize the infiltration process (instantaneous infiltration rate, basic infiltration rate or infiltration capacity, cumulative infiltration and average rate of infiltration) under BUN method of shifting cultivation in a small hilly watershed near Umroi in Ri-Bhoi district of Meghalaya. The study was carried out at three different elevations namely top of hill, mid-elevation and bottom of hill on slopes under BUN of different age and in the low land paddy area in valleys. The infiltration rate in BUN system varied from 0.26 to 4.2 cm/min and the cumulative infiltration varied from 1.5 to 69.3 cm in about 70 to 90 minutes. The infiltration rate is very high and therefore, the water seeps in to deeper root zone rapidly. It was also observed that infiltration behaviour of abandoned BUNS improved over a period of time possibly due to the establishment of weeds of first and second order whereas the furrows between BUNS became less permeable due to compaction resulting from the movement and working with farm tools. The burning of biomass in BUN improved the infiltration behaviour in Burning BUNS. The burial of forest biomass in Burried BUNS though improved the infiltration characteristics yet was slightly less effective than burning BUNS. Analysis of the data resulted a comprehensive understanding of the infiltration behaviour of forest soils in hilly terrain. Mathematical equations were developed from the data to predict infiltration parameters without actually spending time and resources for planning watershed management activities in steep hilly watershed in remotest localities having similar soil type and land use conditions.

Key words: Infiltration, Land Use Systems, Micro-watershed

Introduction

The basic information on soil infiltration characteristics is required for soil and water conservation, irrigation scheduling and management, drainage, solute transport and development of hydrological models. Increasing water use efficiency also requires basic information and evaluation of water management strategies through better understanding of infiltration characteristics under different land use systems. The infiltration process has been extensively studied world wide since early 20th century. (For example, Duley, 1939; Kitteredge, 1948; Musgrave, 1955; and Wood, 1977). Mistry and Chatterjee (1965) conducted infiltration studies in Bihar. Mathur *et al.* (1982) reported higher infiltration rates in forest soils over adjacent agricultural lands subjected to continuous cultivation. CSWCRTI, Dehradun, also reported high infiltration rates under soils with different forest covers (saha *et al.*, 1995).

The present study aims at developing simple mathematical models (equations) for representing infiltration rate (i) and cumulative infiltration (I) to characterise the infiltration behaviour of forest soils subjected to various forms of shifting cultivation (at the different stages of indigenous land use, that is, BUN Cultivation) in Khasi Hills region.

Infiltration modelling

Infiltration into the soil and rainfall or irrigation water determine the amount of runoff, water available for crop growth and ground water recharge. Thus it is the most important hydrological process in a watershed, which has received considerable attention from researchers. The theory and process of infiltration has been reviewed by Phillips (1957, 1969), Hillel (1971), Morel-Seytouse (1973) and Baver *et al.*, (1972). Although infiltration may involve water movement in 2 or 3 dimensions, for most purposes it can be treated as one dimensional vertical flow which is discussed here. Infiltration rate is normally expressed in units of length (depth of water) per unit of time (or volume per unit area per unit time [L3/ L2 T]) eg. in hr^{-1}, cm hr^{-1} or mm hr^{-1}. The infiltration rate can be expressed as :

$$i(t) = f(t) + C \qquad \ldots 1$$

Total infiltration volume or cumulative infiltration at any time t may be expressed as:

$$I(t) = \int i(t)\, dt \qquad \ldots 2$$

where,

i (t) = Infiltration rate, cm/min

t = Elapsed time, minutes

I (t) = Cumulative infiltration, cm

C = Constant

Several attempts have been made in the past to develop mathematical equations for representing infiltration process under varied conditions [Richards (1931), Kostiakov (1932), Horton (1940), Phillips (1957), Holton (1961), Holton and Lopez (1971), Mein and Larson (1971, 1973), Slack and Larson (1981) and Green and Ampt (1911)].

Shifting cultivation in North East (NE) India

In the North-Eastern Region of India, the shifting cultivation is widely practised by the farmers for sustenance. In the process of evolution and modification of shifting method of cultivation many indigenous land use systems have also been evolved by the farmers of the region using their ingenuity and traditional knowledge. The farmers of Meghalaya have evolved an altogether different method of cultivation locally known as BUN method of cultivation for growing crops on raised beds scientifically known as Broad Based Ridge and Furrow System having some very distinct and peculiar features. However, no scientific evaluation of this system has been done so far to generate the information on the effects of this system on soil physical properties particularly on the infiltration characteristics. The present investigation was carried out to evaluate the infiltration characteristics of BUN method of cultivation and its variation spatially and temporally.

'BUN' method of shifting cultivation of Meghalaya

BUN cultivation is another form of shifting cultivation. "BUN" system of growing crops is an indigenous method of cultivation which is highly popular in Ri-Bhoi, East and West Khasi Hills and to a limited extent in Jaintia Hills districts of Meghalaya (Fig.1). Under this system, crops are raised on a series of alternate raised beds and channels formed along the slopes of the hills in mixed sequence. The shrubs and grasses are cut and left in open field for drying. Dried vegetation are collected and then put in the form of raised beds along the slopes.

Later, dried vegetation is covered by a thin layer of topsoil from the surroundings and burnt in anaerobic conditions. The planting is done on the ridges after pulverising the soil and removal of unburnt hard wood (Fig. 2). Sometimes covered vegetations are not burnt but planting is done directly on raised bed by applying small amounts of FYM. This form of cultivation is locally known as Kinton, another modification of BUN. This system involves more soil disturbance than in Jhuming leading to large amount of soil erosion. It is observed that two tones of soil is lost for every tones of potato produced under this system. The soil is sometimes eroded to such an extent that even grasses fail to grow due to exposure of bed rocks.

An experiment was conducted in the Umroi experimental watershed of ICAR Research Complex, Umiam (Meghalaya) during the December' 2000, selected under the National Agriculture Technology Project on Hydrological Behaviour of Small Watersheds and Sustainability

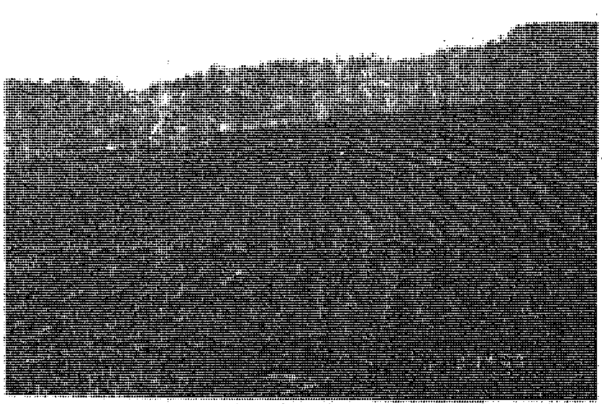

Fig. 1. A panoramic view of newly constructed BUNS in Meghalaya

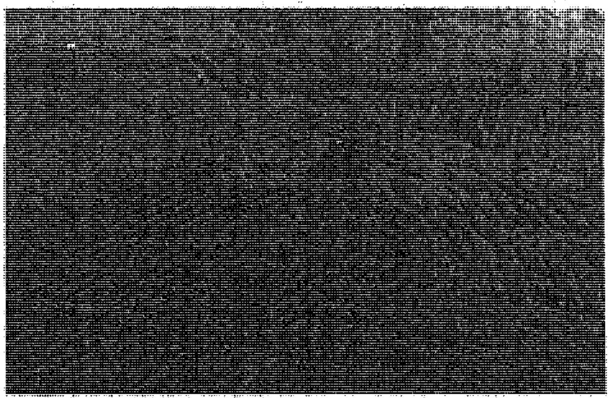

Fig. 2. Cultivation of crops on BUNS in Meghalaya

of Production Systems (HBSWSPS). The BUNs of different ages have been selected and the infiltration experiments were carried out in the BUN plots at three elevations viz., top of hill, mid-elevation and bottom of hill (Elevations 1000, 990 and 980 m MSL respectively). The abandoned BUN plots after first, second and third year of abandoning (i.e. first through sixth year since cultivation started), were also selected for the present study. The infiltration studies in following different land uses have been carried out in Umroi micro-watersheds:

1. Newly constructed Burried BUN
2. BUN cultivation - First year
3. BUN cultivation - Second year
4. Recently Abandoned BUN
5. Abandoned BUN (3-5 years)
6. Paddy cultivation in valley lands

Umroi watershed

The Umroi watershed is located at 91^0 58' E longitude and 91^0 43' N latitude in village Umdoh Byrthith, Umroi district Ri-Bhoi, Meghalaya. The Umroi watershed was delineated from the Survey of India (SOI) topo-sheet no. 78 O/14 on 1: 50,000 scale. A watershed of an area > 1000 ha having a combination of land uses, has been selected for study under NATP on HBSWSPS. The present study was conducted in a micro-watershed; WS2, part of the main-watershed having an area of 17.56 ha. The micro-watershed (WS2) has extensive BUN cultivation. The micro-watershed (WS2) has the natural forest in about 20 per cent of the area and about 80 per cent area under traditional BUN cultivation. Out of the BUN cultivated area approximately 60 per cent is under current BUN and 40 per cent under abandoned BUN conditions. The infiltration experiments have been conducted at different locations in the micro-watershed and at three elevations namely; top of hill, mid-elevation and bottom of hill. The results therefore, are representative of the infiltration characteristics of the entire micro-watershed.

Three locations namely; top of hill, mid elevation and bottom of hill (Elevations 1000, 990 and 980 m MSL respectively) were selected for conducting infiltration experiments. A double ring infiltrometer with constant head of 15 cm was used to record the infiltration behaviour. Observations were made initially at one minute interval for five minutes and subsequently at 2, 5, 10 minutes interval till the constant rate has been achieved. The detailed treatments for data collection for studying the infiltration characteristics are given in the Table 1.

Table 1. Details of treatments for data collection for infiltration behaviour

S.No.	Treatments	Particulars
1	T1	Second year BUN on mid elevation
2	T2	Second year BUN on mid-elevation after contouring and upland paddy
3	T3	First year BUN on bottom of hill with newly constructed contour bunds
4	T4	First year BUN on top of hill with newly constructed contour bunds
5	T5	Low land paddy unploughed on bottom of hill
7	T6	Low land paddy BUN on bottom of hill (extreme lower end)
6	T7	Abandoned BUN on bottom of hill
8	T8	Newly constructed buried BUN furrows
9	T9	Abandoned BUN on mid elevation
10	T10	Abandoned Bun on top of hill
11	T11	Permanently abandoned BUN after 3-5 years

In the present study the data have been fitted to mathematical equations of the form given below to develop the relationships or models for predicting infiltration rate denoted by i (t), and cumulative infiltration denoted by I (t), at an elapsed time t [T] using the Microsoft Excel Spreadsheet software (Mishra *et al.*, 2001).

$$i(t) = \alpha t^{\beta} \quad ...3$$

$$I(t) = \gamma t^{\delta} \quad ...4$$

where,

i (t)	=	Infiltration rate, cm/min
t	=	Elapsed time, minutes
I (t)	=	Cumulative infiltration, cm
α, β, γ and δ	=	Constants

Results and Discussion

The infiltration characteristics at different stages of BUN method of shifting cultivation mainly described by initial rate of infiltration (i), infiltrability or basic infiltration rate (i_c) and average infiltration rate (i_{av}) have been worked out and are presented in Table 2.

The fitted equations of infiltration rate and cumulative infiltration in different land uses have been presented in Tables 3.

Table 2. Infiltration behaviour under different stages of BUN Cultivation method

S. No.	Treatments	Infiltration Characteristics		
		Initial infiltration rate (cm/ minute) (i)	Average infiltration rate (cm/ minute) (iav)	Infiltrability or Basic infiltration rate (cm/ minute) (i_c)
1	T1	3.6	0.23	0.6
2	T2	3.5	0.30	0.58
3	T3	3.6	0.41	0.95
4	T4	4.2	0.61	1.31
5	T5	0.7	1.36	0.32
7	T6	0.7	0.08	0.03
6	T7	2.6	0.36	0.73
8	T8	1.5	0.39	0.26
9	T9	3.0	1.09	0.85
10	T10	3.2	0.6	0.3
11	T11	5.0	1.67	1.2

Table 3: Fitted equations for infiltration rate (i) and cumulative infiltration (I)

S.No.	Land use	Infiltration Rate		Cumulative Infiltration	
		Equation	R^2	Equation	R^2
1.	T1	$i=2.6186\ .t^{-0.3883}$	0.9345	$I= 3.5777.\ t^{0.6314}$	0.9995
2.	T2	$i=2.4106.\ t^{-0.3692}$	0.8517	$I= 3.3911.\ t^{0.639}$	0.9979
3.	T3	$i=4.386\ .t^{-0.339}$	0.9661	$I=4.7671.\ t^{0.7329}$	0.996
4.	T4	$i=3.6544\ .t^{-0.3986}$	0.9685	$I=3.0199.\ t^{0.7239}$	0.997
5.	T5	$i=0.6716\ .t^{-0.2144}$	0.9531	$I=0.7308.\ t^{0.8105}$	0.9994
6.	T6	$i=0.9307.\ t^{-0.9806}$	0.9498	$I= 0.9693.t^{0.3807}$	0.8986
7.	T7	$i=2.8353\ .t^{-0.3918}$	0.9096	$I= 3.1149.\ t^{0.696}$	0.9897
8.	T8	$i=1.3156\ .t^{-0.3717}$	0.9185	$I= 1.6374.\ t^{0.6113}$	0.9961
9.	T9	$i= 2.9213\ .t^{-0.3717}$	0.9453	$I= 3.3233.\ t^{0.6993}$	0.9969
10.	T10	$i= 2.8433\ .t^{-0.6756}$	0.9715	$I= 3.4304.\ t^{0.4968}$	0.9922
11.	T11	$i= 6.0094.\ t^{-0.4723}$	0.9224	$I= 6.0684\ .\ t^{0.6636}$	0.9836

The results clearly show that in general the soil has very high rate of infiltration. The results have been discussed in the following paragraphs:

Infiltration behaviour of slopy lands

The fine particles of the soils of Meghalaya get washed with excessive amount of rainfall (duration and intensities being too high) if exposed and subjected to any type of disturbance particularly cultivation. On the top of hill the infiltration rates are very high and decreases on mid elevation and bottom of hill. In the present study it was found that though the initial rate of infiltration (i) did not change much along the slope under BUN method of cultivation yet the infiltrability (i_c) reduced from 0.95 to 0.6. This can be attributed to the deposition of finer soil particles washed down from the upper slopes with rainfall that subsequently gets deposited below (Fig. 3 and 4).

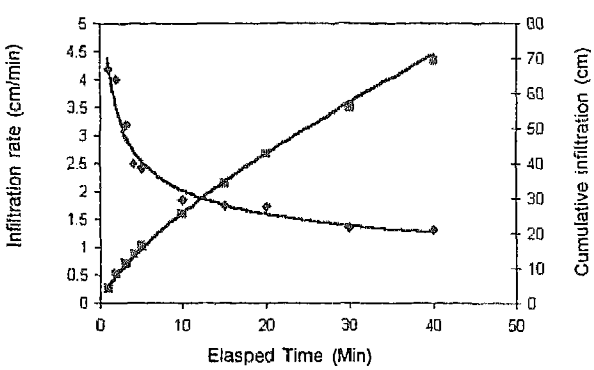

Fig. 3. Infiltration characteristics in first year BUN on bottom of hill

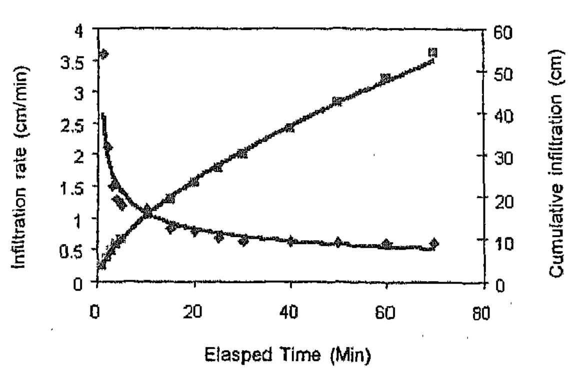

Fig. 4. Infiltration characteristics in second year BUN on bottom of hill

Infiltration behaviour of active BUN cultivation methods

The analysis of infiltration behaviour of active BUN cultivation revealed that the initial rate of infiltration (f_i) varied from 1.5 cm/min in Burried BUN furrows to 4.2 cm/min in Burning BUN. It has been observed that the alternate furrows in BUN cultivation generally become compacted under pressure by being tramped while in construction as well as the beating action of raindrops as they are exposed more to rain as compared to the cultivated ridge portion. The presence of iron and aluminium compounds in high amount as compared to other cations could be other reasons for unusually high compactness of Alfisols that needs to be ascertained experimentally (Fig 5). Mathur *et al.* (1982) also reported an increase in the infiltration rate followed by burning of forest biomass.

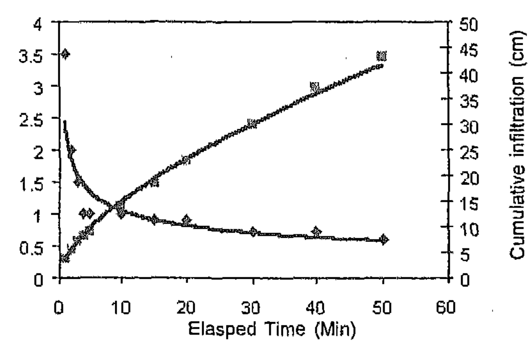

Fig. 5. Infiltration characteristics in second year BUN on mid-elevation, after paddy

Infiltration behaviour of buried BUN

An excessively high rate of initial infiltration rate in Burning BUN can be described by the presence of burnt organic matter that is quite porous. The initial infiltration rate on newly constructed Buried BUNS are also expected to be excessively high owing to mainly two reasons:

1. Due to working with soil and making it loose;
2. Due the decomposed, vegetative a material that in turn creates fine capillaries through which water may seep down.

Figure 6 shows the infiltration characteristics of the Buried Bun furrows that are quite compact due to use of farm implements and repeated walking on it while working. It is expected that the initial infiltration rate and infiltrability on the ridges of Buried BUN would have resulted many folds than that of the furrows.

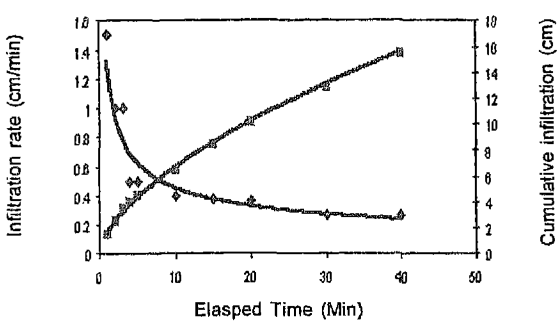

Fig. 6. Infiltration characteristics in newly constructed burried BUN furrows

Infiltration behaviour of recently abandoned BUN

After the cultivation of three successive years in BUN cultivation method the plots are abandoned. The recently abandoned BUN (generally after upland paddy) has shown that the i, i_c as well as i_{av} have reduced. In the present study it has been observed that i varied from 3.2 to 2.6 cm/min (Fig. 7, 8). However, the regeneration takes place very fast due to high rainfall amounts that this area receives. After one or two years of abandoning the BUN plots are covered with first order of weeds. Following the extensive weed growth the infiltration characteristics improve.

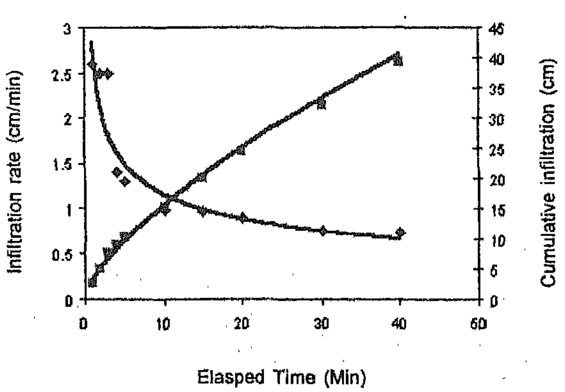

Fig. 7. Infiltration characteristics in recently abandoned BUN on bottom of hill

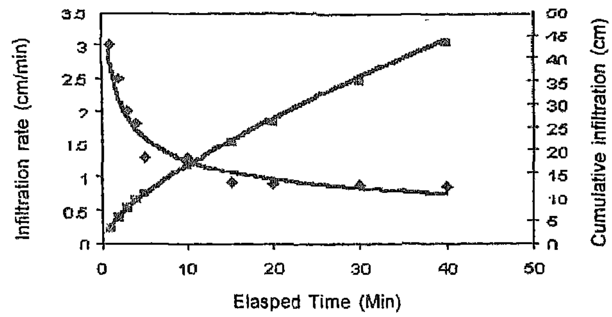

Fig. 8. Infiltration characteristics in recently abandoned BUN in mid-elevation

Infiltration behaviour of long abandoned BUN (3-5 years

The infiltration characteristics in long abandoned BUN (3-5 years) have been found to be improving. The i was as high as 5.0 cm/min, i_c also improved drastically (1.2 cm/min)as compared to the recently constructed BUN and recently abandoned BUN. The average rate of infiltration (iav) was found to be continuously higher reaching to a value of 1.67 cm/min (Fig. 9).

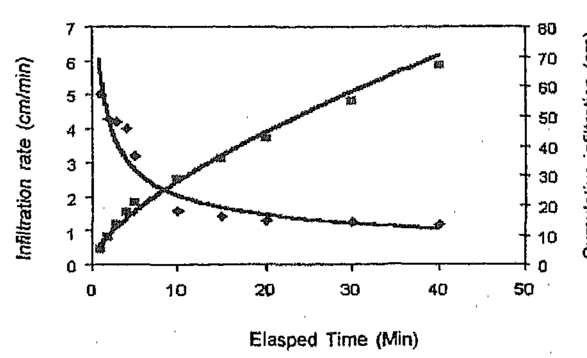

Fig. 9. Infiltration characteristics in long abandoned BUN (3-5 years)

Summary and conclusions

Cultivation of crops on Broad Based Raised Beds & Furrows System, locally referred as BUN, is the most prevalent method of cultivation in the watersheds of Khasi-Jaintia hills districts of Meghalaya. The initial infiltration rates in different stages of BUN system varied from 5.0 to1.5 cm/min and the basic infiltration rates varied from 0.26 to 1.31 cm/min. The average infiltration rates varied from 0.23 to 1.67 cm/min. The infiltration rates are very high and therefore, the water seeps in the deeper soil layers rapidly. Also, due to the high elevation difference resulting in steep gradient, the action of gravitational force is more predominant in rapid water loss from the root zones. Therefore, soon after the seizure of rainfall, the soil moisture regime of upper hill slopes become less favourable for growing crops. However, in the lower elevations the soil moisture regime remains higher and at some places the water logging also takes place due to the seepage of water from upper reaches as well as the inherent soil properties such as low hydraulic conductivity (K) of valley lands. In this paper an attempt has been made to quantify the infiltration characteristics of these soils under BUN method of shifting cultivation for the first time. It is possible to predict the infiltration rate in the similar situations defined by soil type, soil depth etc. by using the infiltration models developed in the present study without actually conducting the field experiments. This will save a lot of time and resources in conducting field experiments in difficult terrain situations. The knowledge of infiltration characteristics will immensely benefit the soil and water conservation planners in designing various engineering structures and execute the watershed management plans and watershed management activities.

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References

Baver, L.D., Gradner, W.H. and Gradner, W.R. 1972. *Soil Physics*, 4th Ed. Wiley & Sons, New York, NY.

Duley, F.L. 1939. Surface factors affecting the rate of intake of water by soils. *Soil Sciences Society Amer. Proceedings* 4.

Green, W.H. and Ampt, G. 1911. Studies of soil physics Part-1 - the flow of air and water through soils, *J. agricultural Science*, 4 : 1-24.

Hillel, D. 1971. Soil and Water - Physical Principles and Processes. *Academic Press*, New York, N.Y.

Holton, H.N. 1961. A concept for infiltration estimation in watershed Engineering. *USDA ARS Bull* 41-51, 25.

Holton, H.N. and Lopez, N.C. 1971. USDAHL-70 model of watershed hydrology. Tech. Bull. No. 1435., *USDA-ARS*.

Horton, R.E. 1940. An approach towards a physical interpretation of infiltration capacity. *Trans. Am. Geophys. Uninon*, Part IV, 693-694.

Kittredge, J. 1948. Forest influences. *McGraw Hill*, New York, p 394.

Kostiakov, A.N. 1932. On the dynamics of coefficient of water percolation in soils and on the necessity for studying from a dynamic point of view for purpose of amelioration. *Trans, 6th Comm. Intern. Soil Sci. Soc.*, Russian Part- A, 17-21.

Mathur, H.N. Soni, P. and Jain, N. 1982. Impact of burning on splashability and infiltration capacity of soils under Chir Pine plantation, *Proc. Symp. Trop. Pine*, Kraput, Orrisa.

Mein, R.G. and Larson, C.L. 1971. Modelling infiltration component of a rainfall-runoff process. Bull. 43, Water Resources Research Centre, *Uni. Of Minnesota Minneapolis* MN 72 PP.

Mein, R.G. and Larson, C.L. 1973. Modelling infiltration during a steady rain, *Water Resources Research* 9 (2): 384-394.

Mishra, A.K., Singh, R.K. and Stapathy, K.K. 2001. Modelling of infiltration in puddled acidic soils. *Indian J. Hill Framg.* **14** (2): 92-98.

Mistry, P.G. and Chatterjee, B.N. 1965. Infiltration capacity of soils in Ranchi, *J. of Soil and Water Conservation.* **13**: 43-47.

Morel-Seytouse, H.J. 1973. Two phase flows in porous medium. *Advances in Hydroscience*, **9**: 119-202.

Musgrave, G. 1955. How much of the rain enters the soil, *USA Year Book*, 151-159.

Phillips, J.R. 1957. The theory of infiltration 4. Sorptivity and algebraic infiltration equations. *Soil science*, **84**: 257-284.

Phillips, J.R. 1969. Theory of infiltration. *Advances in Hydrosciences* **5**: 215-296.

Richards, L.A. 1931. Capillary conduction through porous medium. *Physics*, **1**: 318-313.

Saha, B., Samra, J.S. and Mittal, S.P. 1995. Infiltration characterization of some established land use systems at Shivalik foot hills of North India. *Ind. Jr. of Soil Cons.* **23** (2): 98-102.

Slack, D.C. and Larson, C.L. 1981. Modelling infiltration: the key process in water management, runoff and erosion, In : Tropical Agricultural Hydrology, Russell, E. W. and R. Lal eds. *John Wiley & Sons Ltd.* Great Britain, 433 - 450.

Wood, H.B. 1977. Hydrologic difference between selected forested and agricultural soils in Hawai. *Soil Science Society America Journal* **41** (10): 132-136.