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Spatial Variability of Infiltration Rate in Inceptisol and Entisol Soils of Sahyadri Foothills of Western India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To characterize the spatial variability of infiltration in both Inceptisol and Entisol soils of irrigated farms of College of Agriculture, Pune.
Study Design: Ten GPS based locations each from Inceptisol and Entisol were selected randomly and infiltration rates were computed using double ring infiltrometer.
Place and Duration of Study: The research was conducted at irrigated farms of College of Agriculture, Pune, between January 2019- May 2019.

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Methods: Soil samples collected from these spots were analysed in lab for its physical and chemical properties and thus to arrives a correlation between infiltration rates and soil physico-chemical properties.

Results: Porosity (r =0.44*), per cent silt (0.58 **), per cent sand (0.57**) and hydraulic conductivity (0.53**) showed positive correlation with the cumulative infiltration rate, while the bulk density (r = -0.44*) and electrical conductivity (-0.84**) gave a negative correlation with the cumulative infiltration rate. Infiltration rates of soil varies with the spatial variability.

Keywords: Inceptisol; entisol; double ring infiltrometer; soil physico-chemical properties.

1. INTRODUCTION

Soil and water are the vital natural resources used in the crop production system. Efficient management of water is required for the effective control of infiltration into the soil. Soil Infiltration is the process of water penetration from the ground surface into the soil and is one of the major components of the hydrological cycle responsible for replenishing soil moisture and groundwater reservoirs [1]. Increased control of infiltration would help to solve several problems like upland flooding, pollution of surface and groundwater, declining water tables, inefficient irrigation of agricultural lands, and wastage of useful water [2]. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. Adequate knowledge of infiltration rate is essential for reliable prediction and control of soil and water related environmental hazards. Prediction of cumulative infiltration is important for the estimation of amount of water entering and its distribution in the soil. It is one of the most important soil parameters required in the design and evaluation of irrigation systems, watershed modelling and prediction of surface runoff [3]. Infiltration capacity varies in space and time due to soil heterogeneities, meteorological characteristics, clogging processes and temperature fluctuations, as well as other processes. The infiltration process is governed by two major factors *viz*. gravity which is a natural phenomenon and capillary action which is the ability of liquid to flow in narrow space [4].

The Basalt rock form more than 80% of the state Maharashtra. It composes the black soil and the black soil is present in large amount in the Maharashtra. In the East, the soil is heavier than the soil of west. The peppered saline soil is there in various districts like Sangali, Pune, Satara, Thane, Raigarh, Ahmednagar, Dhule and Solapur. According to that, the soil is classified into four groups. Soil of Upper Maharashtra, Soil of Lower Maharashtra, Soil of Konkan coast, and Soil of Western Ghats. In the region of Western Ghats, the severe erosion is highest, according to the soil profile. Regions such as the eastern part of Ratnagiri, the southern part of the Sahyadri Mountains, and the eastern part of the Sindhudurg have laterite type of soil. There exists spatial variability in the rate of infiltration between various soil types. The present study was carried out to elucidate and characterize the spatial variability in the infiltration rate in the Entisol and Inceptisol soils of the Sahyadri foothills of Western India.

2. MATERIALS AND METHODS

The field experiment on the characterization of infiltration was conducted during January 2019-May 2019 at College of Agriculture Farm, Pune. Twenty different locations were selected, ten each from Inceptisol and Entisol soils. The experimental set up used in the study comprised of a double ring infiltrometer.

For measuring the infiltration rate of the soil, the outer ring was filled with water which was immediately followed in the inner ring also to approximately 10 cm depth . To avoid the seepage of water from inner ring to outer and vice-versa, the water levels in both the cylinders were kept approximately same. After filling water, the infiltration depth in inner ring was determined with the help of a measuring scale as per time intervals. Water level in the inner ring as indicated on the measuring scale was measured starting with lesser time intervals. The infiltration rate was calculated using the formula:

$$\text{Infiltration rate}\left(\frac{\text{cm}}{\text{hr}}\right) = \frac{\text{Initial water depth (cm)} - \text{Final water depth (cm)}}{\text{Time required (hr)}} \quad (1)$$

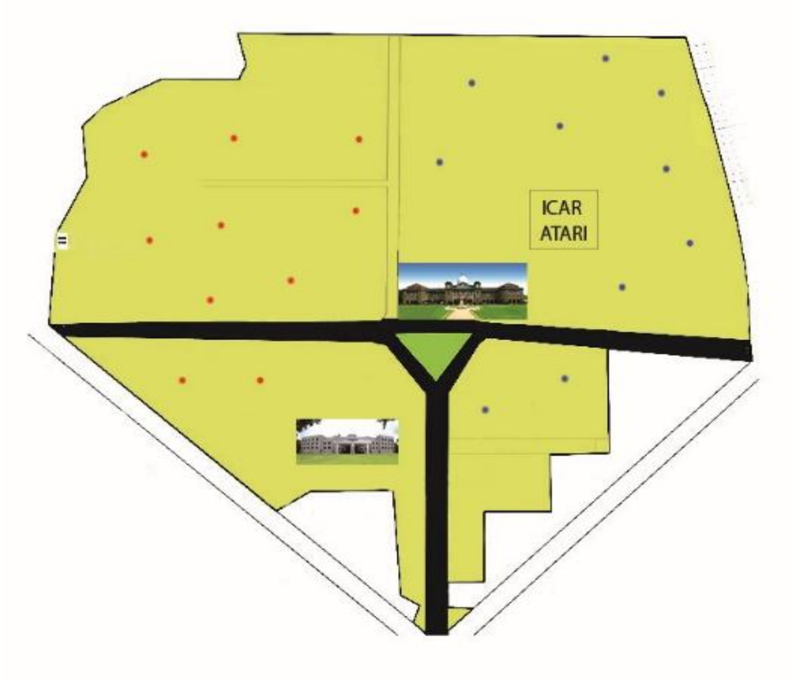

Fig. 1. Location map of the study area

Ten representative soil samples (0-15 cm) near the study area of infiltration spots in Inceptisol and Eentisol soils were collected, dried under shade, ground and was passed through 2 mm sieve. The soil samples were analyzed for physical and chemical parameters as per the standard methods. Soil parameters like bulk density was done by clod method [5], particle density using pycnometer, textural class by international pipette method and hydraulic conductivity by constant head method. Chemical parameters such as pH, EC (Potentiometry Conductometry), organic carbon (Walkley and Black rapid titration method), Available N (Alkaline potassium permanganate method), Available P (Bray No.1 extraction and estimation using spectrophotometer), Available K (Neutral normal ammonium acetate extraction and estimation using flame photometry by), Exchangeable Ca and Mg (Versanate titration method), available S ($CaCl_2$ extraction and estimation using spectrophotometer), B (Spectrophotometry - Azomethine-H method), available Fe, Mn, Cu, and Zn (0.1 N HCl extraction and estimation using atomic absorption spectrometry)

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Soil

Bulk density, varied between 1.20 to 1.46 and 1.34 to 1.75 for Inceptisol and Entisol, respectively (Table 1 and Table 2). However, the lowest mean value 1.33 Mg m^{-3} was observed in Inceptisol as compared with Entisol. Similar values of Inceptisol (clay to clay loam) and Entisol (sandy loam) have been reported by several research workers [6] and [7]. It might be because of higher clay content and lower values of sand and silt in Inceptisol. The percent porosity in Inceptisol was found to be higher as compared with Entisol. It is because of lower values of bulk density and higher values of organic matter than Entisol. The variation in porosity of soils have been observed among different types of soil. It may be attributed to differences in their texture and mineral composition. Due to lower clay content and less proportion of finer and swelling type of clay minerals, sand exhibited the lowest decrease in porosity and it has been reported by [8]. The textural class of Inceptisol was clay loam to clay and for Entisol it was sandy loam. The lowest mean value (3.19 cm h^{-1}) of hydraulic conductivity was recorded in Inceptisol than Entisol, which is because of the highest mean values of clay content (43.60 %) in Inceptisol. Intake rate of soil depends on the texture of soil, surface condition of the soil and time of pounding. Materials such as clay, polythene and mulch may seal the surface of soil so that infiltration rates are low [9].

There is no much difference in coefficient of variation in the values of hydraulic conductivity in every samples of either Inceptisol or Entisol. It attributes to the more or less similar textural class of soils used for analysis. Hydraulic properties are strongly influenced by texture and structure [10]. The Saturated hydraulic conductivity decreased with increase in soil bulk density due to reduction of non capillary pores [11].

A greater variability of infiltration parameters in sandy soils having high value of bulk density (1.87 Mg m^{-3}) was noticed [12]. They also reported that the clay, sand and bulk density influences the attributes in processes of water infiltration into the soil.

3.2 Chemical Properties of Soil

The data pertaining to the chemical properties of soil pH, EC, organic carbon, calcium carbonate and available nutrients of Inceptisol soils and Entisol region are given in Table 3 and Table 4 respectively. The mean data of chemical properties of soil revealed that Inceptisol soils showed higher values of pH, organic carbon, calcium carbonate, available nitrogen and phosphorus content over Entisol soils. However, Entisol soils observed the higher content of EC and available potassium. The pH values of Inceptisol soil showed similar range of values (<8) except soil samples number 1 and 2 which recorded the pH values above 8.0. The pH and EC values of Inceptisol ranged from 7.41 to 8.45 *i.e.* very slightly alkaline *to* medium alkaline and 0.09 to 0.25 dS m^{-1} respectively. The pH and EC for Entisol ranged from 7.02 to 7.71, very slightly alkaline to alkaline and 0.18 to 0.36 dS m^{-1}, respectively. The high values of pH in Inceptisol might be because of high base saturation and high amount of clay and organic carbon which is responsible for the retention or adsorption of exchangeable bases on clay complex.

The available nitrogen of Inceptisol ranged from 146.75 to 180.75 kg ha^{-1} and it was found higher than Entisol. The available phosphorus also recorded the higher values (21.28-29.27 kg ha^{-1}) in Inceptisol than Entisol (14.78-29.27 kg ha^{-1}). However, in general the higher mean values of available potassium was recorded in Entisol (282.12 kg ha^{-1}) than Inceptisol (258.16 kg ha^{-1}). This might be because of heavy intensity of crops grown in *Kharif* and *Rabi* in Inceptisol as compared with Entisol, which leads to the depletion of potassium in Inceptisol. From the data of descriptive statistics the lower values of coefficient of variation (< 10%) of pH, EC, organic carbon, available nitrogen, phosphorus and potassium were observed in Entisol as compared with Inceptisol. However, the higher values of variance were noticed in case of calcium carbonate under Entisol. The higher soil organic carbon content improved the water infiltration into the soil and water holding capacity of the soil which might be due to improved soil structure leading to better macro-porosity [13]. The soil organic matter is a key attribute of soil quality that impacts soil aggregation and water infiltration [14]. Application of $CaCO_3$ as agricultural lime increases the Infiltration rate [15]. At low organic carbon content up to one per cent, the sensitivity of water retention to changes in organic matter content was the highest in sandy soils .Increase in organic matter content led to increase of water retention in sandy soils and decrease of water retention in fine-textured soils [16].

3.3 Infiltration Rate and Cumulative Infiltration Rate of Soil

The measured infiltration rates and cumulative infiltration rates of soils under Inceptisol and Entisol are graphically depicted in Fig. 2. Infiltration studies were conducted at 10 spots of every Inceptisol and Entisol of College of Agriculture, Pune. At initial time (2 min) the infiltration rate of Inceptisol was 47.17 cm h^{-1} which was slightly higher than Entisol 45.30 cm h^{-1} and it progressively declined in both the types of soil up to constant infiltration rate. The 2.5 times decrease in infiltration rate was noticed within five minutes in case of Inceptisol. However, it was observed that the rate of infiltration decreased by 3.42 times in Entisol soils within an elapse of five minutes. A constant infiltration rate was observed at the end of 90 min. in Entisol soils and by 150 min in Inceptisol soils.

The high value of Infiltration rate and cumulative infiltration rate in Inceptisol is related to the relatively high matrix potential gradient of the initial dry soil. The basic infiltration rate of Inceptisol and Entisol were 1.94 and 1.80 cm h^{-1}. These values are in close agreement with the values reported by [17]. [18] observed constant infiltration rates of 3.6 and 2.4 cm h^{-1}under ploughed and unploughed condition of red soils respectively. The infiltration rate is also controlled by the swelling and dispersion of clay particles that may cause the sealing of soil pores which in turn lowers the infiltration rates of soils [19].The comparable values of standard error were observed in both the soils. Inceptisol recorded the slightly higher values of average infiltration rate than Entisol.

Table 1. Soil physical properties of Inceptisol region

Sample No	Soil type	Bulk density (Mg m^{-3})	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	Textural class	Hydraulic conductivity (cm h^{-1})
1	Inceptisol	1.20	46.90	30	20	50	Clay	3.17
2		1.23	47.21	39	21	40	clay loam	3.45
3		1.39	39.56	30	32	38	clay loam	2.75
4		1.46	40.16	35	31	34	clay loam	3.24
5		1.42	36.6	29	32	39	clay loam	3.17
6		1.45	37.76	29	32	39	clay loam	3.31
7		1.38	34.59	30	34	36	clay loam	3.17
8		1.23	46.28	21	39	40	clay loam	3.24
9		1.23	46.98	20	20	60	Clay	3.17
10		1.35	36.61	25	15	60	Clay	3.31
Mean		1.33	49.22	28.8	27.6	43.6		3.19
Standard Error		0.03	1.21	1.82	2.49	3.03		0.05
Standard deviation		0.10	3.82	5.76	7.87	9.59		0.18
Variance		0.01	14.65	33.28	62.04	92		0.03
Minimum		1.20	44.9	20	15	34		2.75
Maximum		1.46	54.71	39	39	60		3.45

Table 2. Soil physical properties of Entisol region

Sample No	Soil type	Bulk density (Mg m^{-3})	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	Textural class	Hydraulic conductivity (cm h^{-1})
1	Entisol	1.75	33.96	62.5	10.45	27.5	Sandy clay loam	7.41
2		1.62	38.86	71	6	23	Sandy clay loam	8.11
3		1.72	35.09	65	10	25	Sandy clay loam	7.9
4		1.58	40.37	72	12	16	Sandy loam	7.76
5		1.53	42.26	80	6	14	Sandy loam	8.11
6		1.34	49.43	78	10	12	Sandy loam	7.41
7		1.66	37.35	77	11	12	Sandy loam	8.46
8		1.43	46.03	73	10	17	Sandy loam	8.18
9		1.48	44.15	81	6	13	Sandy loam	8.11
10		1.37	48.30	70	7	23	Sandy loam	8.11
Mean		1.54	41.58	71.85	9.74	18.4		7.95
Standard Error		0.04	1.70	2.00	1.33	1.78		0.10
Standard deviation		0.14	5.38	6.34	4.22	5.62		0.3
Variance		0.02	28.94	40.22	17.83	31.69		0.11
Minimum		1.34	33.96	62.5	6	12		7.41
Maximum		1.75	49.43	81	20	27.5		8.46

Table 3. Soil chemical properties of Inceptisol region

Sample No	Soil type	pH(1:2.5)	E.C (dSm^{-1})	O.C (%)	$CaCO_3$	Available nutrients (kg ha^{-1})		
						N	P	K
1	Inceptisol	8.45	0.25	0.85	10	169.30	27.79	197.12
2		8.01	0.24	0.79	7.25	158.04	29.27	234.08
3		7.85	0.24	0.75	8	169.30	25.13	248.64
4		7.69	0.23	0.78	6.25	146.75	25.42	269.92
5		7.72	0.16	0.73	7	180.62	21.28	286.72
6		7.45	0.11	0.72	6.75	158.04	24.24	329.28
7		7.95	0.17	0.78	6.5	169.3	23.35	286.72
8		7.47	0.19	0.6	7.5	169.3	25.13	241.92
9		7.41	0.1	0.52	10.75	158.04	27.79	254.24
10		7.43	0.09	0.63	5.75	180.62	26.61	232.96
Mean		7.74	0.17	0.71	7.57	165.93	25.60	258.16
Standard Error		0.10	0.01	0.03	0.51	3.38	0.74	11.61
Standard deviation		0.33	0.06	0.10	1.61	10.70	2.36	36.72
Variance		0.11	0.003	0.01	2.61	114.62	5.56	1348.6
Minimum		7.41	0.09	0.52	5.75	146.75	21.28	197.12
Maximum		8.45	0.25	0.85	10.75	180.75	29.27	329.28

Table 4. Soil chemical properties of Entisol region

Sample No	Soil type	pH(1:2.5)	E.C (dSm^{-1})	O.C (%)	$CaCO_3$	Available nutrients (kg ha^{-1})		
						N	P	K
1	Entisol	7.35	0.36	0.68	7	158.04	26.31	286.72
2		7.39	0.33	0.71	4.5	169.3	22.47	305.76
3		7.29	0.30	0.73	6.25	169.3	21.58	293.44
4		7.40	0.35	0.7	6.75	146.75	14.78	347.20
5		7.21	0.29	0.69	9.25	158.04	23.65	334.88
6		7.02	0.23	0.62	10	169.3	29.27	290.08
7		7.31	0.19	0.6	5.25	146.75	20.4	225.12
8		7.23	0.21	0.71	6.5	169.3	24.24	246.4
9		7.52	0.18	0.63	5.5	158.04	23.35	249.76
10		7.71	0.22	0.52	4.5	158.04	23.06	241.92
Mean		7.34	0.26	0.65	6.55	160.28	22.91	282.12
Standard Error		0.05	0.02	0.02	0.58	2.81	1.19	12.90
Standard deviation		0.18	0.06	0.06	1.84	8.89	3.78	40.79
Variance		0.03	0.004	0.004	3.41	79.07	14.32	1664.2
Minimum		7.02	0.18	0.52	4.5	146.75	14.78	225.12
Maximum		7.71	0.36	0.73	10	169.3	29.27	347.20

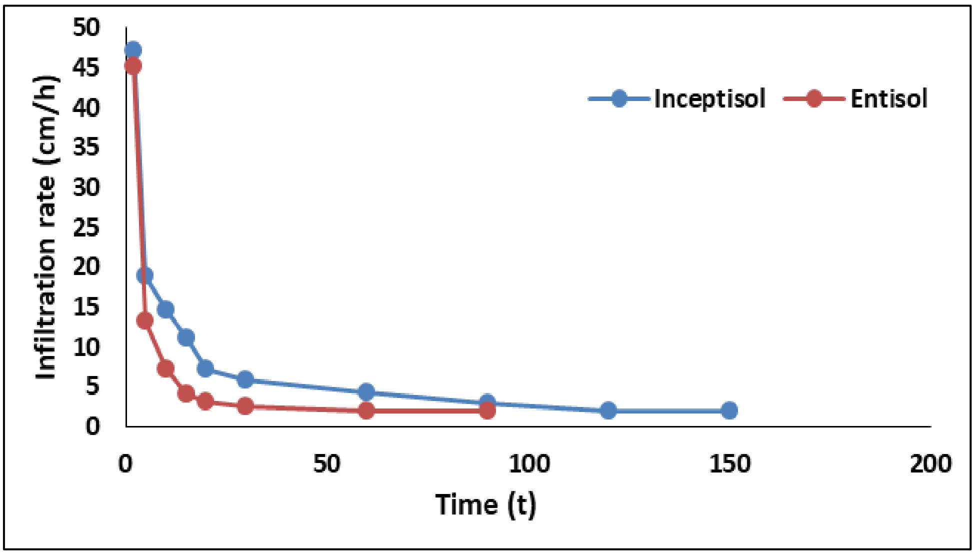

Fig. 2. Temporal variation in infiltration rate observed in Inceptisol and Entisol soils

From the data of infiltration rate with time non-linear regression equations for the Inceptisol and Entisol was carried out. These equations are as follows:

$$Y = 16.702\ e^{-0.017X} \quad (2)$$
(R^2= 0.7811Inceptisol

$$Y = 14.402\ e^{-0.044X} \quad (3)$$
(R^2= 0.6115)- Entisol

From the above equation it can be inferred that the more intercept and less decay constant have been obtained in Inceptisol as compared with Entisol. The results concluded that Inceptisol soils observed higher values of infiltration rate as compared with Entisol. A higher time period was required for attaining a constant infiltration rate in Inceptisol as compared with Entisol. The lower values of decay constant and higher values of coefficient of determination (R^2=0.7811) for infiltration rate was observed in Inceptisol over Entisol.

The correlation coefficient between soil physical properties and cumulative infiltration rate are given in Table 5. From the data it can be inferred that all the physical properties of soil analyzed *viz*., bulk density, porosity, per cent sand, silt and clay and hydraulic conductivity are significantly correlated to the cumulative infiltration rate. Porosity (r =0.44*), per cent silt (0.58**) per cent sand (0.57**) and hydraulic conductivity (0.55*) showed a positive correlation with the cumulative infiltration rate, while the bulk density (r = -0.44*) and per cent clay (-0.47*) gave a negative correlation with the cumulative infiltration rate. A similar negative correlation between bulk density and infiltration rate was found [20]. The results showed that there was no significant correlation between cumulative infiltration rate of soils with organic carbon, pH, calcium carbonate, available macronutrients and micronutrients content in the soil.

Table 5. Correlation coefficient between soil physico - chemical properties and cumulative infiltration rate

Soil properties	Correlation coefficient
Bulk density	-0.44*
Porosity	0.44*
% Sand	0.57**
% Silt	0.56**
% Clay	-0.47*
Hydraulic conductivity	0.53**
EC	-0.84**

4. CONCLUSION

From the above study it can be concluded that the different soil physico-chemical properties such as bulk density, soil texture, hydraulic conductivity, pH, EC, organic carbon, calcium carbonate, greatly influence the infiltration process. Considering the soil textural makeup of both the Entisol and Inceptisol soils, it is evident that soils having a higher per cent of sand exhibits higher infiltration rate as compared to soils with high clay content. It is amply clear from this study that the soil physical properties have greater impact on infiltration rate as compared to chemical properties.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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