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Characterization of Soil Water Movement in Reddish Brown Earth Soils (Alfisol)

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ABSTRACT: The three drainage associations of reddish brown earth soils namely well drained (WD), imperfectly drained (ID), and low humic gley (LHG) soils were characterized. The properties studied were: basic infiltration rate, saturated hydraulic conductivity, unsaturated hydraulic conductivity, and water retention characteristics.

The average steady infiltration rates of WD, ID, and LHG were 1.9, 0.6, and 0.3 cm/hr respectively. The mean saturated hydraulic conductivities of WD, ID, and LHG soil profiles were 2.1, 0.6 and 0.4 cm/hr respectively. Average field capacities of WD, ID, and LHG up to the depth of 0.6 m were 25.4, 27.2, and 27.4 cm/m respectively. The average permanent wilting points of WD, ID, and LHG were 17.3, 19.2 and 18.5 cm/m respectively. The unsaturated hydraulic conductivities reached an order of magnitude of 10^{-3} to 10^{-5} m/day at a moisture content little below the observed field capacities. The computer simulation model produced both graphic and tabular outputs which can be easily interpreted and used in irrigation scheduling.

INTRODUCTION

At present, it is a challenge for on farm water management researchers in Sri Lanka to determine the best combination of water application rate, duration of application, and frequency of application among the numerous alternate combinations available. This is mainly due to the fact that the information on soil hydraulic properties are not readily available and the process of soil water movement subsequent to irrigation is not fully understood.

Computer simulation models describing the movement of water in soils have become popular in developed countries in understanding the physical process occurring subsequent to irrigation. Though, field trials give more reliable information, its applicability is limited to the site where the study was conducted and also is expensive and time consuming. On the other hand computer simulation models could be used for various soils and for variety of treatments at the expense of few computer hours and with few easily obtainable basic field data. It also provides a mean of identifying and evaluating factors that are worthy of field experiments.

The association of Reddish Brown Earth (RBE) soils are found in most of the undulating as well as rolling landscape of the dry zone where the RBE soils occupy the upper aspect of the relief, the Yellowish Brown Earths occupy the middle aspect of the relief, and the Low Humic Gley (LHG) soils occupy the lower aspect of the relief which are well drained, imperfectly drained and poorly drained respectively (Panabokke, 1967). According to USDA taxonomy, these are classified as Rhodustalfs, Haplustalfs and Aqualfs respectively (Somasiri 1984, Figure 1).

The properties governing the soil processes such as infiltration, redistribution, deep percolation, drainage, and evaporation of water are collectively referred to as soil hydraulic properties (Klute and Derksen, 1986). Objective of the study was to characterize the soil water movement in the three drainage associations of RBE soils by measuring the soil hydraulic properties and by utilizing them in a soil water flow simulation model. The properties studied were; basic infiltration rate, saturated hydraulic conductivity, unsaturated hydraulic conductivity, and water retention characteristics. Mathematical models were fitted for unsaturated hydraulic conductivity and soil water retention, which were then utilized in computer simulation of soil water movement.

MATERIALS AND METHODS

The study was conducted at the catchment – C of the Regional Agricultural Research Station, Maha Illuppallama. Efforts were made to select areas that did have not have a history of puddling for at least one season prior to the experiment and the that were not ploughed prior to the experiment. Altogether three terraces were selected (one from each associate) and the measurements were replicated nine times at pre determined grids of nearly 5 m x 7 m. Hydraulic conductivity and water retention measurements were made to represent the three horizons as indicated in Table 1. Since the hydraulic properties except water

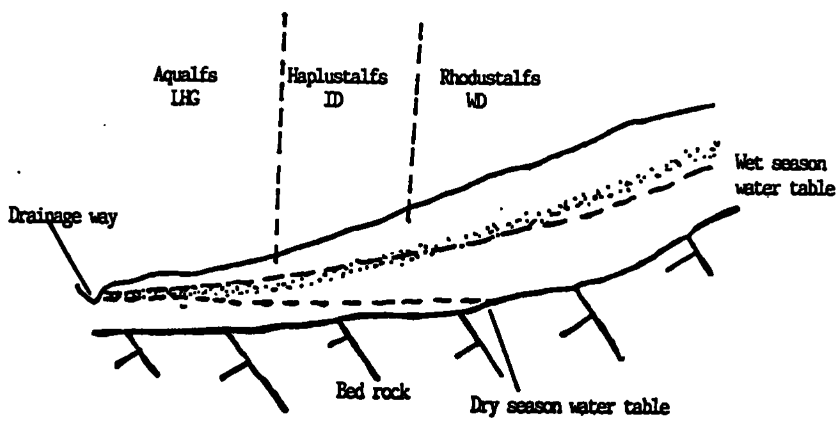

Fig. 1. Soil sequence in the catenary landscape in the RBE soils (Somasiri, 1984).

Table 1. The soil sampling depths and corresponding horizons for the three drainage classes.

Drainage classes	Horizon	Depth (cm)	Abbreviation
RBE Well Drained #	A (Surface)	0 - 15	WD-D1
Rhodustalfs *	AB(Subsurface)	15 - 30	WD-D2
	B (Gravelly)	30 - 60	WD-D3
RBE Imperfectly Drained #	A (Surface)	0 - 15	ID-D1
Haplustalfs *	AB(Subsurface)	15 - 30	ID-D2
	B (Gravelly)	30 - 60	ID-D3
RBE Poorly Drained #	A (Surface)	0 - 15	LHG-D1
(Low Humic Gley Soils)	AB(Subsurface)	15 - 30	LHG-D2
Tropaqualfs *	B (Gravelly)	30 - 60	LHG-D3

7th Approximation
* Soil Taxonomy (1975)

retention are log normally distributed, the data were transformed into log prior to statistical analysis and the geometric averages were used in discussion.

Double ring infiltrometers were used to measure the basic infiltration rates and saturated hydraulic conductivities as proposed by Ahuja *et al.* (1976). Simplified unsteady drainage flux method as described by Green *et al.* (1986) was adapted to determine the unsaturated hydraulic conductivity. Moisture characteristics were obtained in the laboratory using a pressure plate apparatus. Core sample were collected from the middle of the three horizons (Table 1) for this purpose.

A relatively simple model (Nofziger, 1985) was used to simulate two important processes namely water application and depletion which take place in an irrigated field. The mathematical functions adapted for hydraulic conductivity and water retention in this model are given in equations 1 and 2 respectively. The fitted parameters of the above equations are given in Table 2. The major drawback of this model is that it assumes the soil to be homogeneous.

$$K(h) = K(sat)\ A/\{A + [-h]^B\} \qquad \text{for } h < 0, \text{ and} \qquad (1)$$
$$K(h) = K(sat) \qquad \text{for } h >= 0$$

where, K(h) is conductivity (cm/min) at metric potential h.
K(sat) is saturated hydraulic conductivity (cm/min)
A & B are constants.

$$WC(h) = WC(res) + \{A\ [WC(sat) - WC(res)]\}/\{A + [\ln(-h)]^B\} \qquad (2)$$
$$\text{for } h < 0$$
$$WC(h) = WC(sat) \qquad \text{for } h >= 0$$

where, WC(h) is water content at metric potential h (m^3/m^3)
WC(res) is residual water content (m^3/m^3)
WC(sat) is water content at saturation (m^3/m^3)
A & B are constants

In the first instance, a soil profile of 0.6 m deep was considered. It was the entire profile to be initially at a moisture content corresponding to a matric suction of 300 kPa (*i.e.* 3000 cm water). Water was applied under flooded condition for five hours. Then the supply was terminated and allowed to redistribute under no evaporation for next 19 hours (*i.e.* flux at the upper boundary was zero cm/h). Zero flux was maintained at the lower boundary through out the simulation period (*i.e.* 24 hrs). The simulation was carried out in RBE well drained and imperfectly drained soils as these two drainage classes have great potential in the cultivation of other field crops under surface irrigation.

LHG was not included for simulation of water application as its suitability for surface irrigation method was marginal. However, the water depletion pattern from a wet LHG soil may be of interest to agronomists as it will have an impact on the paddy crop already established on these soils. Therefore, in the second instance, the moisture depletion pattern from a semi-finite profile of LHG soil which was initially at field capacity (*i.e.* 100 cm suction) was simulated.

RESULTS AND DISCUSSION

Infiltration is a soil process which is often studied in irrigated soils because of its crucial role in the selection, design, and management of irrigation systems. Basic infiltration rate is considered as a characteristic of the soil profile rather than of the surface alone. The mean steady infiltration rates of well drained (WD), imperfectly drained (ID), and low humic gley (LHG) soils were 1.9, 0.6, and 0.3 cm/hr and the average time taken for these drainage classes to attain the steady states were approximately 3, 7, and 7 hours respectively. According to the infiltration categories presented by Landon (1984), WD and ID posses moderately slow infiltration rates whereas LHG posses slow infiltration rate. Statistical analysis showed no significant difference between ID and LHG at 95% probability level while WD was significantly higher than both ID and LHG. The infiltration characteristics of WD is optimum for surface irrigation methods whereas the infiltration characteristics of ID and LHG are suitable and marginally suitable respectively.

Saturated hydraulic conductivity is a parameter which is important in drainage studies. The mean saturated hydraulic conductivity values obtained through in-situ measurements and the confidence intervals at 95% probability level are listed in Table 2. Statistical analysis for main effect indicated significant difference for both drainage classes and depths. The conductivity values of ID were more closer to LHG than

Table 2. The parameters of the equations accepted by the selected simulation model and the mean saturated hydraulic conductivities (Ks) and confidence interval at 95% probability level.

Model	Parameter	Well Drained			Imperfectly Drained			Low Humic Gley		
		Depth 1	Depth 2	Depth 3	Depth 1	Depth 2	Depth 3	Depth 1	Depth 2	Depth 3
Eq. (1)	A	0.0002	0.0006	0.0023	0.0008	0.0015	0.0089	0.0010	0.0133	0.0244
	B	1.622	1.701	1.620	1.755	1.605	1.783	1.590	1.706	1.974
Eq. (2)	A	22.55	14.77	4.40	11.34	13.45	10.18	11.91	37.16	1149.00
	B	1.417	1.159	1.066	1.411	1.188	1.001	1.388	1.566	2.978
Ks (m/day)		0.90	0.56	0.41	0.38	0.18	0.11	0.28	0.06	0.09
Ks at 95 % probability level		0.38 - 2.15	0.29 - 1.08	0.26 - 0.65	0.08 - 1.82	0.08 - 0.39	0.04 - 0.29	0.15 - 0.52	0.02 - 0.20	0.05 - 0.16

WD. Low hydraulic conductivity values of the bottom layers suggest possible impedance to water movement under saturation. The profile saturated hydraulic conductivities of WD, ID, and LHG soil were 2.1, 0.6, and 0.4 cm/hr (*i.e.* 0.51, 0.15, and 0.09 m/day) respectively. Except for WD, other two drainage classes fall into the category of slow to very slow hydraulic conductivity. The WD falls into the category of moderate hydraulic conductivity.

The unsaturated hydraulic conductivities were in an order of magnitude of 10^{-3} to 10^{-5} m/day at a moisture content little below the observed field capacities and it decreased below 10^{-9} m/day when the moisture content reached nearly 75% depletion of the available water. Such low values could be attributed to the sandy nature of the decomposing parent material whose unsaturated hydraulic conductivity become extremely low even at high moisture content (Joshua, 1988).

The trends of the moisture characteristic curves were similar for ID and LHG while they varied considerably from WD. Therefore, it is reasonable to assume that the soil properties such as field capacity, permanent wilting point, available water, field air capacity, micro porosity, and pore size distribution of ID to be similar to LHG than WD.

Volumetric moisture held at 10kPa and 1500 kPa suction are considered as field capacity (FC) and permanent wilting point (PWP) respectively. Average FCs of WD, ID, and LHG up to the depth of 0.6 m were 25.4, 27.2, and 27.4 cm/m respectively. The average PWPs of WD, ID, and LHG up to the depth of 0.6 m were 17.3, 19.2, and 18.5 cm/m respectively. Both FC and PWP of these soils were relatively high. As a result, the available water capacities were low for these soils and should be classified as "low available" for irrigated agriculture. Fifty percent depletion of available water occurred between 100 and 300 kPa while 75% depletion occurred between 300 and 500 kPa matric suction.

When the moisture characteristic curves were exploited to compute the pore size distribution as described by Vomocil, 1965, increasing trend in pore volume with decreasing pore radius was observed in all three associations and depths studied. It showed the presence of nearly 35 percent of pores having radius less than 9.72×10^{-6} cm.

The simulated results of the first instance are given in Figures 2 and 3. The results indicated a considerable amount of water movement

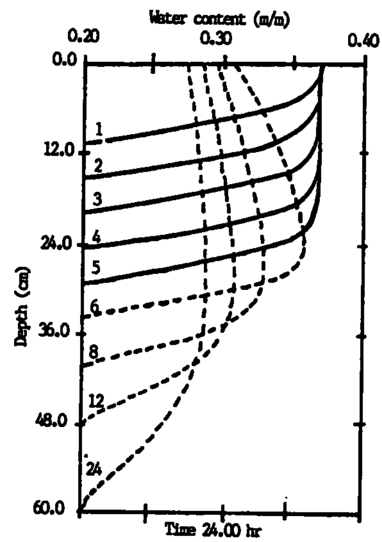

Fig. 2. Soil moisture profile during irrigation (wetting cycle) for RBE well drained soils. (The numbers represent the time in hours after irrigation started. The dotted lines indicate water application and the solid lines indicate redistribution).

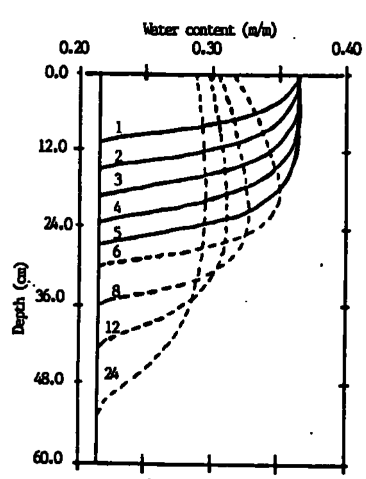

Fig. 3. Soil moisture profile during irrigation (wetting cycle) for RBE imperfectly drained soils (The numbers represent the time in hours after irrigation started. The dotted lines indicate water application and the solid lines indicate redistribution).

after the termination of water application. When the water application is terminated after five hours, the water front reached a depth of nearly 28 cm in well drained soils and 26 cm in imperfectly drained soils. However, redistribution continued and the water front reached 60 cm in WD and 54 cm ID after 24 hours from the beginning of the simulation (*i.e.* 19 hrs after termination of water application). This means if a 50 cm root zone is assumed, in both WD and LHG, water will begin moving below the root zone in nearly 12 hrs after termination of application. It indicates frequent, small applications are better for these soils. However, numerous alternatives could be simulated and the optimum application rate and duration of application as to avoid deep percolation losses below the root zone could be decided.

In the second instance, with the LHG profile, the simulation was carried out with an evaporation rate of 7 mm/day (0.03 cm/hr) at the upper boundary. The simulation, however, was not successful and automatically terminated in nearly 24 hours as the surface became very dry and the unsaturated hydraulic conductivity became extremely low before the effect could be transmitted to the lower part of the profile. However, in reality, similar result could be expected in any soil in the absence of well rooted plant cover.

Therefore, a mixed boundary condition of 7 mm/day evaporation (0.03 cm/hr) was maintained at the upper surface only until the matric suction reached 1000 kPa (*i.e.* 10000 cm of water). The results are plotted in Figure 4. It indicates the possibility of the prevalence of relatively wet soil beneath an extremely dry surface layer in LHG soils. In any case, the simulated results cannot be taken as representing the actual field condition where a crop factor also should be included.

CONCLUSIONS

According to the basic infiltration characteristics, well drained RBE soils showed optimum suitability for surface irrigation methods while imperfectly drained and LHG soils showed suitability and marginal suitability for surface irrigation methods respectively.

Except for WD, other two drainage classes fall into the category of slow to very slow hydraulic conductivity. The WD falls into the category of moderate hydraulic conductivity.

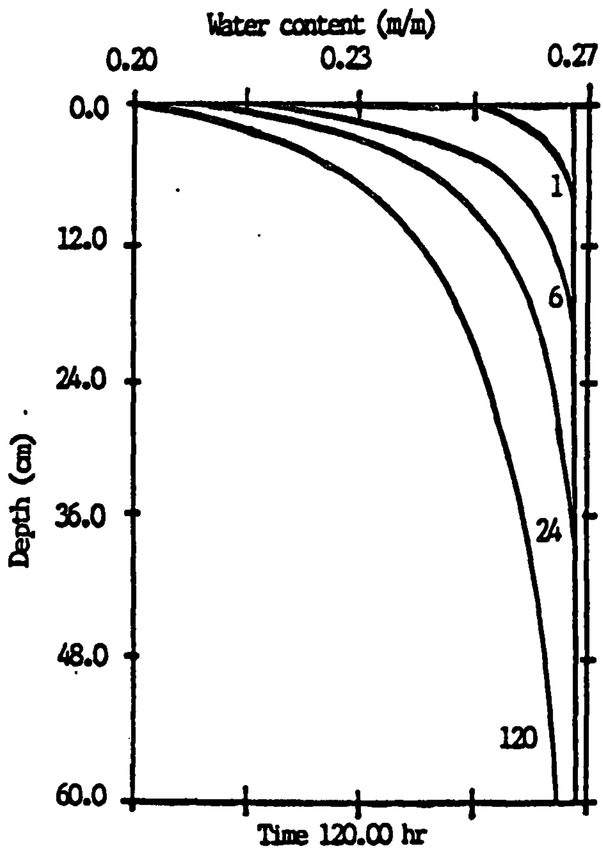

Fig. 4. Soil moisture profile during the drying cycle for LHG soils. (The numbers represent the time in hours after termination of irrigation).

Unsaturated hydraulic conductivities of RBE soils were very low and can be safely neglected for practical purposes. However, hydraulic conductivity as a function of volumetric moisture content or matric suction is very essential in adopting computer simulation models.

Available water capacity remained low for all three drainage classes and depths studied which varied between 7.1 and 9.9 cm/m. Seventyfive percent depletion occurred between 300 kPa and 500 kPa suction in RBE and LHG soils and not at 100 kPa as assumed previously.

Simulations of water movement using a mathematical model showed that small frequent applications will reduce the deep percolation losses in RBE soils. However, the understanding on soil water movement is incomplete with the local soils as far as the lower boundary of the root zone is concerned. Characterizing the water movement at the lower boundary by the conventional methods may require more expensive equipment and time. This could be over come by adopting computer simulations techniques. However, it should be born in mind that computer simulation cannot be a perfect substitute for valuable field observations.

REFERENCES

Ahuja, L. R., S. A. El-Swaify, and A. Rahman. 1976. Measuring hydraulic properties of soils with a double ring infiltrometer and multiple depth tensiometer. Soil Sci. Soc. Am. J. 40: 494-499.

Joshua, W. D. 1988. Physical properties of Reddish Brown Earth (Alfisols) and their relation to agriculture. J. Soil Sc. Soc. Sri Lanka. Vol. V: 1-42.

Klute, A. and Dirkson, L. 1986. Hydraulic conductivity and diffusivity: Laboratory methods. In A. Klute (Ed.). Methods of soil analysis. Part I. 2nd Ed. ASA Monograph 9: 687-732. Am. Soc. of Agronomy. Wisconsin, USA.

Landon, J. R. 1984. Booker tropical soil manual. Booker Agriculture International. 6: 58-102.

Nofziger, D. L. 1985. Interactive simulation of one-dimensional water movement in soils. Institute of Food and Agricultural Sciences, University of Florida.

Panabokke, C. R. 1967. Soils of Ceylon and use of fertilizers. Metro printers Ltd., 19, Austin Place, Colombo 8.

Somasiri, S. 1984. Wet alfisols of Sri Lanka. Paper presented at the Soil Sc. Socity of Sri Lanka. Annual meeting, 1984.

Vomocil, J. A. 1965. Porosity. In C. A. Black *et al.* (Ed). Method of soil analysis, Part I. Agronomy 9: 299-314. Am. Soc. of Agron., Medison, Wis.