EXPERIMENTAL STUDIES OF INFILTRATION IN CRACKING CLAY SOILS OF SUDAN - GEZIRA SCHEME

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Abstract

Double ring tests were conducted on the shrinking/swelling vertisols of the Gezira scheme in fallows and cotton fields, to analyze the influence of the infiltration on soil surface type. The well-defined of two phased cumulative infiltration curves was determined. Occurrence of the phase inflection point was found to be a function of the antecedent soil moisture content. The infiltration behaviour during the first phase was considered to represent flow of water through the soil macrospores in the drier upper soil layer and three-dimensional flow into soil peds while the soil swells sealing the macrospores during the transitional state. The second phase represented vertical flow of water into lower soil layers. The study recommended using the application depth and time as equal to those determined by the inflection point. It was therefore, advised to employ a high non-erosive inflow rate to the level basin fields and stop irrigation when the advance rate approaches the field end so as to avoid crop damage by excessive water pending and improve irrigation efficiency.

Keywords: Infiltration Rate, Hawasha, Infiltration Depth, Soil Condition.

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1. INTRODUCTION

Infiltration is generally defined as the process of water entry into the soil profile. The study of infiltration process is important for design, operation and evaluation purposes; because it is necessary to quantify the rate at which water enters the soil and the amount held in the soil profile before runoff starts. Characterization of infiltration is difficult due to its temporal and spatial variations. According to Dixon, (1996) and Skaggs, (1980) infiltration is described as an outcome of the physical interaction between capillarity, gravity and geometry of the soil. The postulation of quantifying filtration process via Darcy's law and the principle of conservation of mass was defeated by the non-homogenous soil condition in the field and by the non- rigid soil matrix leading to disequilibrium in capillary pressure.

As reported by Elliott, (1982) the factors affecting the decay process in the infiltration to include capillary gradient, surface sealing, soil settling, air entrapment, clay mineral hydration (soil swelling), eluviations and illuviation, water head dissipation macro porosity and cracking. However, the antecedent soil moisture content has a direct effect on infiltration because it defines the water holding capacity of the soil. Generally, wetted soil exhibits more rapid decrease of infiltration rate approaching some constant value equal to its saturated hydraulic conductivity. For a non-leaky infiltration system (high water table condition) infiltration involves the filling of a finite storage space and infiltration rate may approach zero with time. This decay process is most likely to occur in basins or borders when water is pounded over the surface. The effect is less significant in furrows. Soil textures, particularly the percentage of clay, influence infiltration rate significantly.

In case of vertisols, water movement into the crystalline structure of montmorillonite clay minerals causes physical instability of soil aggregates. This water movement causes the soil to expand on wetting and cracks on shrinking and drying, greatly influencing soil porosity and structure even during irrigation. After irrigation in hot dry climate like that of Gezira scheme drying can be rapid and intense resulting into a mosaic polygons cracks. The developed long meandering vertical cracks are important component of the soil process that is

vital to agricultural production in clay soils. Cracks constitute the pores that are essential for the flow of water and air to plants and for drainage of excess water Philip, (1969).
The initial entry of water into cracking soils is described as an open channel flow function of the amount of swelling clay and soil moisture content. This is in agreement with Ali, (1994) who used simple ring infiltro-meter to study infiltration in the Gezira scheme. Moreover, Bouma, (1998) described infiltration process to occur initially by water movement into the walls of soil peds at the sealed soil surface. As the infiltration rate into the peds decreased incipientponding occurred and water rapidly entered the cracks or macrospores between soil peds (termed short-circuiting). For free draining conditions (the case of Gezira soils) short- circuiting could continue with relatively little water infiltrating through soil the surface or via the vertical walls of soil peds. With restricted sub surface outflow (such as the case water ponding in basin irrigation and high water table), the cracks may be quickly filled with water and swelling of the soil would occur; the macrospores may swell and shut. The capacity of the soil microspores inside the soil peds would limit the infiltration rate, possibly causing effective sealing.
Many theoretical approaches were given to quantify infiltration rate on ordinary soils such as those of Clemmens,(1981), Kostiakov, (1932), Walker, (1987). And Elliott, (1982) many simple empirically based models were developed such as Skaggs, (1980), for ordinary soils. Two empirical infiltration equations have received widest use and acceptance. The first equation is the Kostiakov equation:

$$y(t) = a_1 t^{b1} \quad \text{-------------------------------(1)}$$

Where:
$y(t)$ = cumulative infiltration depth (L),
t = elapsed time,
a_1, b_1= empirical constants.
The second is the modified Kostiakov equation developed to account for constant intake at longer periods [12]:

$$y(t) = a_2 t^{b2} + ct \quad \text{--------------------------- (2)}$$

Where:
$y(t)$ = cumulative infiltration depth (L),
a_2, b_2 , c = empirical constants.
Infiltration rates can be obtained by taking the time derivatives of equations (1 and 2). Other empirical and approximate equations are reviewed and discussed by Walker, (1987).. All of the said models are made for ordinary soils. Somewhat surprisingly, modeling of infiltration process of cracking soils has scarcely been investigated. Therefore, the objective of this work was to study the general infiltration behavior in cracking clay soils under dry and wet conditions for the purpose of design and management of level basin irrigation system.

2. MATERIALS AND METHODES

Infiltration field data was collected from Elsuni Minor at Tyba Block in the Gezira Scheme. Fifty-four cylinder infiltro-meter tests in two field units (Number of 37.5 ha and 18 Hawashas) were conducted. One field was cotton cultivated (number 9) while the other was a fallow field (number 13). The double ring infiltro-meter and the field procedure described by Walker, (1987),are adopted. In each field unit twenty seven tests were carried out (three tests in each Hawasha at the head, mid and tail parts of the Hawasha) during actual irrigation on cotton fields and fallow land. This was made to reflect the effect of variations in the degree of tillage and antecedent soil moisture in the Gezira scheme. The tests in the fallow fields were made at the time just prior to the first irrigation in order to test the effect of soil drying and cracking on soil infiltration behavior. Tests in cotton fields were conducted during second and third irrigations so as to represent the general conditions of normal irrigations. Soil moisture data were taken at the time of each infiltration test using oven-dry gravimetric method at incremental soil depth of 30 cm to the total cyclic wetting depth of 60 crn Ali, (1994) and Farbrother, (1974). The double-ring infiltro-meter consisted of two concentric cylinders, 28 cm height and 0.25 cm thick fig (1). Measurement of water drop was taken in the inner 25 crn diameter cylinder using a point gauge.

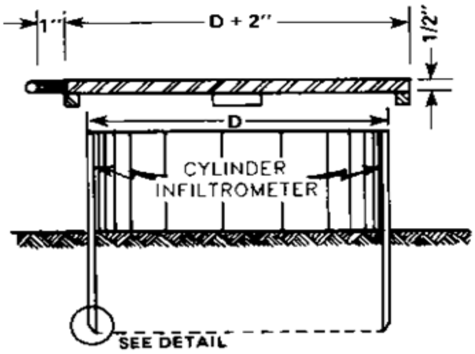

Fig (1) Double- ring infiltro-meter

The outer 55 cm in diameter cylinder formed a buffer pond. At one time the two cylinders were pressed firmly in the ground and hammered gently with the help of a wooden plate to a depth of 10 cm into the soil. A polythene sheet was laid in the bottom of the inner cylinder to prevent puddling and sealing of the soil surface. Water was added by a measuring cylinder into the inner ring. Likewise, the outer cylinder was filled with water to the same level as the inner one. Then, the polythene sheet was removed from the inner cylinder to record the starting time. Reading of the depth of ponded water in the inner cylinder was taken every five minutes and the test was run for approximately 60 hours. At the time of each reading the level of ponded water was restored back to its initial level by refilling with water throughout the test. The average of infiltration data of each Hawasha at the head, mid and tail part can be illustrated by the following figure.

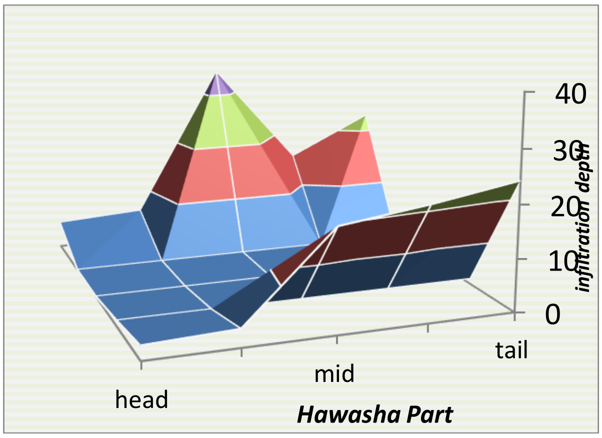

Fig (2) average of infiltration of Hawasha

3. RESULTS AND DISCUSSION

From each double cylinder test a data set of elapsed time (in minutes) and cumulative infiltrated depth (in millimeters) was obtained. Average time versus average depth plots for the data from each field unit were prepared on normal graph (Fig. 3) and on log-log graph (Fig. 4).

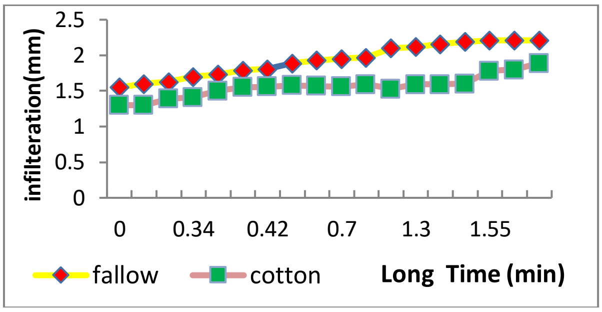

Fig (3) Cumulative in infiltration depth

Figure 3 clearly shows that infiltration depth in the dry fallow field unit (12% moisture) was faster than that of the cotton field unit (22% moisture). The log-log curve clearly showed two linear branches with distinctly different slopes on both fallow and cotton field units. This branched infiltration function is in agreement with Clemmens, (1981) and Holzapfel, (1988) who employed a branch function to account for transition infiltration from a power relation to a. long-term constant infiltration rate. The two-phase relationship may be used to describe transition from one set of active decay process to other. Hence, the inflection point may be determined by solving the simultaneous equations for the two phases:

$$t_0 = \left[\frac{a_2}{a_1}\right]^{(b_1-b_2)^{-1}} \text{---------------------------- (3)}$$

$$t_0 = \left[\frac{a_2}{a_1}\right]^{(b_1-b_2)^{-1}} \text{---------------------------- (4)}$$

Where:

a_1, b_l = coefficients of the equation of phase one, ($y(t) = [a_l\, t^{b1}]$).

a_2, b_2 =coefficients of the equation of phase two, ($y(t) = [a_2\, t^{b2}]$).

t_o= elapsed time at the inflection point (hours).

y_o= cumulative infiltrated depth at the inflection point (mm).

Figure 3 shows that initial soil water content (just prior to irrigation) has a significant effect on the soil infiltration depth .The effect of the initial water content is reflected by values of the constant at in the first phase in the fallow dry fields compared to that of the cotton wet fields. The value of the constant at decreases as the soil water content increases. Attributed this to a decreasing metric potential gradient. This indicates that the determination of soil infiltration at appropriate soil- water content is important in the design of irrigation methods and irrigation water management.

As given in figure 4 the phase change was gradual and the inflection point represented a short time interval during which the infiltration process moves from fast infiltration status described by the equation of the first phase to the status of slow infiltration as described by the equation of the second phase. The magnitudes of the parameters b, and b_2 indicate how well infiltration depth hold up with time. The phase change is expressed by the values of log to and log Y_o for cotton and fallow field units. [7]Reported a curvilinear relation between at and soil volumetric moisture content. He attributed the curvilinear relationship to be due to increase in macro porosity with decrease in soil moisture content. Similar trend can be observed in figure 3.

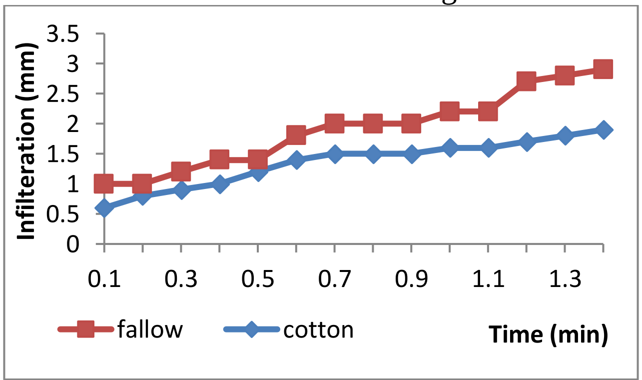

Fig (4) Log- LogCumulative in infiltration depth

Figure 4 also shows that change of infiltration depth with time in the second phase for the fallow field unit follows almost the same trend to that of the cotton field unit but with higher values of infiltration depth. However, Walker, (1987) reported that at 60 cm soil depth in the Gezira the soil is mostly wet with almost negligible change in its moisture content. Consequently, the matching of infiltration rate of the second phase in the fallow and cotton fields may be attributed to the presence of wet soil profile after filling the cracks with water during the first phase. The constants of the equation of infiltration depth for each phase and the point of inflection for fallow and cotton fields were determined using the two-point method suggested by Walker, (1987).

The average equations representing conditions during the first phase in fallow field is:

$y(t) = (61.9)t^{0.3750}$(t ≤ 6.6 hr) ------ (5)

And for cotton field in the first phase:

$y(t) = (38.8)t^{0.5529}$(t ≤5.0 hr) -------- (6)

The average infiltration equation describing the second phase for fallow field is:

$y(t) = (82.4)t^{0.223}$(t ≥ 6.6 hr) ------- (7)

Similarly for irrigation of cotton field the relevant equation is:

$y(t) = (61.2)t^{0.271}$(t ≥ 5.0 hr) ------- (8)

From the above discussion the infiltration process under the stated conditions could be described as:

- Initial vertical infiltration and flow into cracks occurring simultaneously in the upper soil layer during the first phase in both fields, but their magnitudes differ by the antecedent moisture content and extent of cracks.
- Three-dimensional flow of water into the soil peds occurring during the first phase.
- Soil expansion, closing the cracks partially or fully, eliminating cracks flow and reducing infiltration to vertical movement into the soil peds occurring during the transitional phase around point of inflection.
- Recession of surface water occurring at an infiltration rate of the second phase is limited by soil moisture content, micro porosity and storage capacity of the given soil profile. The infiltration behavior of the second phase represents constraints to effective management of basin irrigated fields. Rapid initial infiltration rate may prevent good water distribution in the field. Ponding of water may lead to excessive water application if the fields are not well leveled and have no good drainage system. Low-long term infiltration rates may lead to excessive inundation of soil surface,

creation of toxic anaerobic conditions and crop damage. As shown in figure 4 it thus advisable to apply amount of water equal to a depth less than or equal to the depth of the inflection and at a time before inflection point occurs.

4. CONCLUSIONS

The infiltration process of heavy clay soils, such as that of Gezira, proceeds in two phases each with distinct slope. The parameters for Kostiakov equation were determined for each phase and inflection point representing the phase change was obtained by solving simultaneous equations. The infiltration process is function of the antecedent moisture content and extent of cracks. The behavior of infiltration implies that improvement of water management in level basin can be achieved via using high inflow stream size to advance quickly to or near the field end in a time not more than the time of occurrence of the inflection point. This is recommended so as not to pond excessive water in the field. Proper land leveling and adequate surface drainage are strongly recommended to minimize crop damage due to prolonged ponding of the field surfaces in the Gezira Scheme.

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