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THE EFFECT OF LAND USE ON SOIL INFILTRATION RATE IN A HEAVY CLAY SOIL IN EGYPT

Effekten av landanvändning på infiltrationshastighet i egyptiska lerjordar

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Abstract

Double ring infiltrometers are usually used by engineers, agronomists, and other professionals to estimate the infiltration rate of different soil types. Measurement of surface infiltration rate is necessary for many purposes (describing the soil permeability). In this study, the effect of land use in heavy clayey soil on soil infiltration rate was investigated using double ring infiltrometers. Field experiments were carried out at three representative fields of different land use located in the El-Salam Canal command, Egypt. In all sites (cultivated, natural, and fish farm), the infiltration rate at the beginning was low and decreased to reach the steady (constant) value of 18, 60, and 12 mm h^{-1}, respectively. Based on the results, it appears that the initial infiltration rate depended mainly on the water content in heavy clayey soil. In addition, it was affected by the amount of cracks caused by the plant root, earth movement, and desiccation of clay.

Key words – Infiltration rate, Double ring infiltrometers, the El-Salam Canal command, Egypt

Sammanfattning

Dubbelringinfiltrometrar används av ingenjörer, agronomer och andra yrkesgrupper för att bestämma infiltrationskapaciteten för olika jordtyper. Mätningar av infiltrationskapacitet är viktiga för många olika tillämpningar. I denna artikel studeras effekten av landanvändning på infiltrationskapaciteten med hjälp av en dubbelring-infiltrometer. Fältmätningar gjordes på tre representativa fält nära El Salam kanalen, som är ett stort bevattningsprojekt i Egypten. Ett av de tre fälten var uppodlat, ett annat var orört medan det tredje hade varit använt till fiskodling. Infiltrationshastigheten var låg för alla fälten och nådde ett konstant värde på mellan 12 och 60 mm h^{-1}. Den initiella infiltrationshastigheten berodde på den initiella vattenhalten. Infiltrationskapaciteten styrdes också av andelen sprickor, rötter och landanvändning.

1 Introduction

Egypt is considered one of the water scarce countries, accompanied with high population growth rates. Therefore, the wise and efficient use of its available water is a must especially in agricultural practices. The higher population growth rates forced the country to extend its agricultural land to secure food needs. To avoid the profligate water use in agriculture, the investigation of land availability for cultivation should be done. It is well known that the availability of land for cultivation depends on its characteristics (e.g., infiltration rate, soil salinity, etc.). These are mainly influenced by the land use before cultivation that may affect soil infiltration rates (Ali, 2006; Hamed, 2007), thereby, affecting water use efficiency when the land is cultivated. Shang et al. (1998) stated that extensive fish farming rapidly exhausted the soil organic matter content. On the other hand, high soil toxicity and eutrophication were observed in rural Thailand by Flaherty et al. (1999) due to intensive use of fish farming.

Infiltration is the process by which water arriving at the soil surface enters the soil. This process affects surface runoff, soil erosion, and groundwater recharge (Gregory et al., 2005). Ring infiltrometers are commonly used for in situ determination of soil hydraulic properties (e.g., infiltration rate into the soil; Touma and Albergel, 1992). The measurement of water infiltration into the soil is an important indication in the regards of the efficiency of irrigation and drainage, optimizing the availability of water for plants, improving the yield of crops, minimizing erosion and describing the soil permeability.

Ring infiltrometer consist of a single metal cylinder that is driven partially into the soil (Gregory et al., 2005). The ring is filled with water and then the rate at which the water percolates into the soil is measured. The measurements are contained until an apparent steady rate of infiltration occurred which indicates that the saturated infiltration rate has been reached. Although the ring infiltrometers have been widely used to measure the infiltration rate of the soil (e.g., Olson and Swartzendruber, 1960; Johnson, 1963), there are many measurement errors accompanied with it. One of these errors related to the cylinder size. Tricker (1978) stated that a 15 and 50 cm diameter rings produce measurement errors of 30 and 20 % respectively compared to the infiltration rate that would be occurred with a ring of an infinite diameter. Single ring infiltrometer overestimate vertical infiltration rates (e.g., Gregory et al., 2005; Bouwer, 1986; Tricker, 1978). This is due to that the flow of water below the cylinder has two components, vertically and laterally. The lateral divergence is due to sorption and capillary forces of the surrounding dry and layers of low hydraulic conductivity below the cylinder (Ali, 2010). The lateral flow causes the steady infiltration rates that are quickly approached to be very much greater than the infiltration capacities or hydraulic conductivity values of the soils (Youngs, 1987). Another source of error is the leakage of water along the ring that occurs when driving the ring into the ground as a result of a poor connection between the ring wall and the soil. This leakage can be diminished by surrounding the inner ring by a larger ring and maintaining the water in a certain level in both rings (Bouwer, 1986).

Double ring infiltrometers is a development of the single infiltrometer method in which the error associated with the single ring method can be reduced because the water level in the outer ring forces vertical infiltration of water in the inner ring (ASTM, 2003). Double ring infiltrometers consists of two thin-walled steel tubes with varying inner and outer diameters. The size of these rings affects the accuracy of the measurements. Lai and Ren (2007) indicated that in case of high spatial variability soils, infiltrometers having a large inner ring are essential for reliable measurement. There are two operational techniques used with the double-ring infiltrometer for measuring infiltration rates (constant and falling head techniques). In the constant head technique, the water level in the inner ring is kept at a fixed level and the volume of water used to maintain this level is measured. In the falling head technique, on the other hand, the time taken for the water level to decrease in the inner ring is measured (Ali, 2010). In both constant and falling head techniques, the water level in the outer ring is kept at a constant level to force vertical infiltration from the inner ring and to eliminate leakage between rings. Numerical modeling has shown that falling head and constant head methods give very similar results for fine textured soils, but the falling head test underestimates infiltration rates for coarse textured soils (Wu et al., 1997).

In the view of the above, the aim of this work is to use double ring infiltrometer as a tool for reducing the potential error accompanied with single ring infiltrometer for investigating the effect of land use in heavy clayey soil on soil infiltration rate.

2 Materials and methods

2.1 Area description

Field experiments were carried out in 2006 at three sites located within the El-Salam Canal command, Egypt. The three sites are located west of Suez Canal, 18 km south of Port Said city. The first site has been used for cultivation since year 2000. Although rice was the desired crop for the farmer to cultivate, the high soil salinity forced the farmer to cultivate green fodder in the beginning and for two successive years. After that, the field had been leached and rice was cultivated. The irrigation method of this area was flooding irrigation. The second site represents the natural state of the land and was not used for cultivation until the time of experiment. The third site was used for fish farming since year 2000. Due to the unsatisfactory rice yield in this site during the cultivation attempts as a result of high soil salinity, the landholder used it as a fish farm. The fish farm was practiced where the land was flooded (to 60 cm water depth) for a certain period (3 to 5 months), after that the water was drained. These processes were repeated periodically (twice per year). Using the land as fish farm created a mud layer (from excess food and fish feces) on the surface to a depth equal to 7–10 cm. After draining the water, this layer dried up and formed desiccation cracks.

Soil bulk density and gravimetric water content were determined using undisturbed soil samples of 100 cm^3 collected from the top 20 cm soil layer at all the three

Table 1. *Soil properties for each site.*

Site No	Texture	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm^3)	Water content ($cm^3\ cm^{-3}$)	Land use
1	Heavy clay	4.00	30.80	65.2	1.778	0.505	Cultivated
2	Heavy clay	3.70	25.80	70.50	1.803	0.201	Natural
3	Heavy clay	3.19	32.71	64.10	1.974	0.455	Fish farm

different sites. The soil sample was weighted and oven dried in 105°C for 24 h and then weighed again to determine the gravimetric water content. Volumetric water content was estimated based on the gravimetric water content and soil bulk density. About 2 kg of soil samples from the different sites were collected for particle size distribution analysis. The particle size distribution was determined by using sieve analysis and the hydrometer method (Gee and Bauder, 1986). Soil properties of the different sites are described in Table 1. It is worth mentioning that all measurements conducted in the third site were done approximately two weeks after draining the water.

2.2 Experimental design

The measurements in this study were achieved using a double ring infiltrometer. The tools used in this experiments are a pair of stainless steel rings having diameters 30/60 cm with a height of 25 cm and a cutting edge, synthetic measuring bridge, measuring rod with float that moves freely up and down through a small tube in the measuring bridge, galvanized steel cross-shaped driving plate with a beating head in the middle, and a steel hammer (Figure 1). The purpose of the outer ring is to have the infiltrating water act as a buffer zone against infiltrating water straining away sideways from the inner ring. The measuring rod indicates the water level in the inner ring.

In this experiments the inner ring with the cutting edge was placed facing down on the ground and the small obstacles were removed then the driving plate was placed on the top of the inner ring and the impact absorbing hammer was used to insert the infiltration ring about 10 cm vertically into the soil. After that, the outer ring with the cutting edge was placed facing down around the inner ring and inserted vertically into the soil by using the driving plate and the impact absorbing hammer (Figure 2). The measuring bridge with measuring rod and float was placed on the top of the inner ring. Any vegetation that may hamper free movement of the float was removed without disturbing the soil structure. The outer ring was first filled with water, then the inner ring, to a depth of approximately 10 cm. To protect the

Figure 1. *Tools used during the infiltration experiment.*

Figure 2. *Driving the double ring infiltrometer into the soil.*

Figure 3. *Putting a 2 cm sand layer on the soil surface.*

Figure 4. *Infiltration rate measurements.*

ground surface when pouring the water, plastic foil and a 2 cm layer of sand was used (Figure 3). The measurements were done by noting the drop in the water level in the inner ring as indicated on the measuring rod during a certain interval (10 minutes) (Figure 4). This process was repeated and a plot of infiltration rate versus time is constructed. The measurements continued until the infiltration rate became steady or until it became equal to, or less than, a specified value. The same procedure was followed at all three sites. It worth mentioning that each experiment lasted approximately 2 hours (starting form experiment setup until ceasing the experiment) and all experiments were conducted in the same day during the daytime as an attempt to have same climatic conditions.

Results and discussions

The double ring infiltrometer is a way of measuring near-saturated hydraulic conductivity of the surface layer. The infiltration curves for the different sites (near-saturated hydraulic conductivity) as well as cumulative infiltration curves over a certain period are presented in figures 5 and 6.

In the first site (cultivated field), the infiltration rate at the beginning was low and decreased to reach the steady (constant) value of 18 mm/h. This low value is probably due to the soil composition and the initial high water content of the soil resulting from the water bonding for a long period during cultivation. In the second site (natural field), the infiltration rate at the beginning was high and decreased to reach the steady (constant) value of 60 mm/h. The infiltration rate was high in comparison with the first site. The high initial infiltration rate is due to the low initial water content of the soil and due to the presence of deep vertical cracks in the natural soil. In third site (fish farm field), the infiltration rate was determined for the undeveloped soil layer after removing the cracked layer (mud layer) lying at the top of the soil. Thickness of the mud layer ranges from 7 to 10 cm. The infiltration rate was low at the beginning and decreased to reach a constant value of 12 mm/h. This may be attributed to the water bonding of 60 cm for a long period and that some fine particles from the mud layer clogged the soil pores. Clogging could possibly also be a result from bacterial growth.

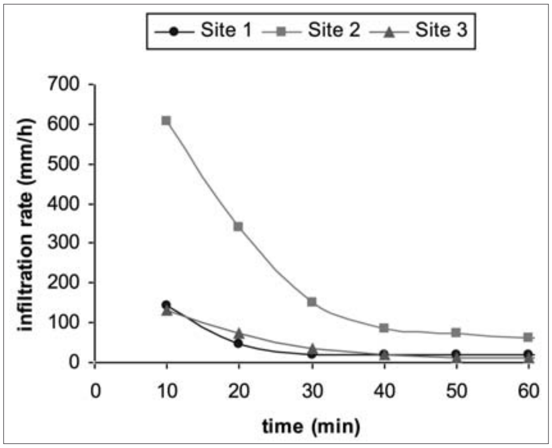

Figure 5. *Infiltration curves.*

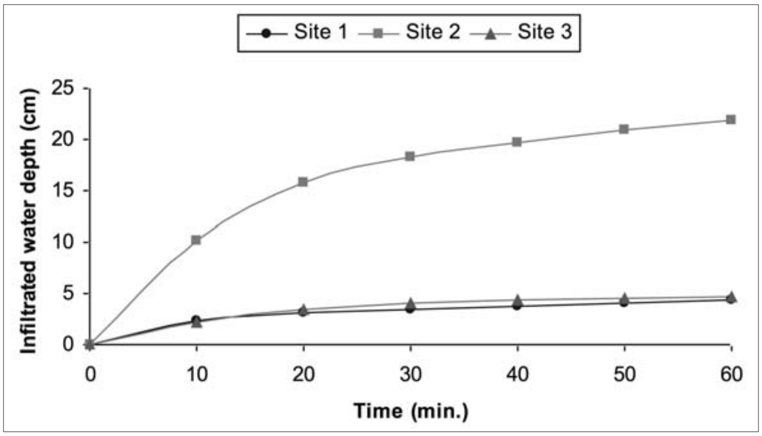

Figure 6. *Infiltrated water depth versus time.*

Conclusions

From this study, it was concluded that:

1. The initial infiltration rate depended mainly on the initial water content in heavy clayey soil.
2. The infiltration rate was affected by the amount of cracks caused by plant roots, earth movement and desiccation of clay.
3. The fish farm in heavy clayey soil did not increase the soil permeability accept the top layer (mud layer) due to the presence of large number of wide and deep cracks resulting from desiccation, but didn't improve the permeability of the undeveloped layer.
4. The natural soil had a high infiltration rate compared to the other fields due to the deep cracks in the soil and the low initial water content. This results concurring with the dye experiments conducted by the author in the same study area (Abou Lila et al., 2005). Average dye infiltration depth was 27, 36, and 17 cm for sites 1, 2, and 3, respectively.

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