Analysis on the Infiltration Character of Water Storage Pit

Ma Juanjuan and ***Sun Xihuan***

Taiyuan University of Technology, 030024, P.R.China
E-mail: sxhty@263.net

Abstract: Water storage pit irrigation method is a new method used suitably in orchard irrigation in arid or semi-arid area. The use of this method not only can make roots deeper to have the capacity of drought resistance, but also can storage rain water and reduce soil erosion. However, its theory must be studied further. The varying head infiltration in single storage pit of homogeneous soil was tested and analyzed in this paper. The mathematical model of the varying head infiltration in single storage pit of homogeneous soil was established, and the infiltration model characteristic was worked out by use of physical model experiment. The major effect factors on the varying head infiltration process were analyzed. This conclusion will be of important value for the further study on water storage pit irrigation.
Keywords: soil and water conservation, irrigation method, homogeneous soil, varying head, infiltration

1 Introduction

With the development of orchard area in agriculture plant structure in China, its technologies of water-saving irrigation have been concentrated on by many people. Water storage pit irrigation is a new method suitable for fruit tree irrigation in mountain and rolling area. This way belongs to middle-depth irrigation, in contrast to traditional surface irrigation. It not only can save irrigation water and benefits roots plunging into deeper soil to improve drought resistance, but also can storage rain water to decrease soil erosion. It is theoretical base of developing and applying this method that technical characteristic of water storage pit irrigation are decided. Water infiltration of this irrigation is undergone in varying head, complicated boundary condition. Water infiltration under conditions of constant water level and simple boundary were studied by former people, but reports with respect to the latter method were seldom. The variation law of water infiltration with time in varying head was studied in this paper, this work is the base of studying technical factors of water storage pit irrigation.

2 Test brief

The test was carried out indoor. Soil box of experiment was 30º fan shaped cylinder, its radius and height were 1.2 m and 1.5 m respectively. The box walls were made of organic glass plates to survey the water level in storage pit and the wet front in soil.

Test soil sample was disturbed loess taken from fruit tree experiment plant of Shanxi academy of agriculture sciences, stratified sampling was carried on in accord to plough horizon, plough bottom layer, substratum, meanwhile, undisturbed soil sample was taken by cutting ring, the buck density of plough horizon, plough bottom layer, substratum was 1.30 g/cm^3, 1.51 g/cm^3, 1.35 g/cm^3 respectively. Every layer soil sample was prepared by air-drying, pulverizing, sifting in 2 mm passing-screen size. In the test, the buck density of soil sample adopted was 1.35 g/cm^3, loading into box through weighing in layers.

The storage pit was in acute-angle part of the upper soil box, its radium and height were 16cm and 60cm respectively. Therefore the storage pit of this test was a fan-shaped cylinder to simulate actual storage water pit (its diameter was D, height is H_1, see Fig. 1). The pit bottom was made of organic glass plate, and the pit wall (radium director) consisted of arc organic glass pore plate to make water infiltrate into the soil. Pore size of arc plate was 2 mm, pores area was 50% of total arc plate area. Copper gauze was put between the arc plate and soil mass to prevent soil flowing into pit. Irrigation requirement was

defined and measured by graduated cylinder. Water was inflow into storage pit rapidly at the beginning of test, while stopwatch was set, infiltration time t and corresponding water level H_t were recorded.

3 The mathematical model of the varying head infiltration in storage pit of homogenous soil

Regard upper interface of soil column as reference plane, it was assumed that depth of pit was H_1 , pit diameter was D, water level varied from initial water stage H_0 to H_t after t minutes, seeing Fig. 1.

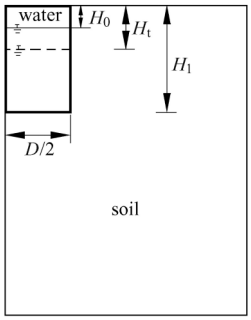

Fig. 1 The soil infiltration experiment of storage pit

Infiltration process of any point at infiltration plane can be described by KOSTIAKOV formula

$$i_t = i_1 t^{-\alpha} \tag{1}$$

where i_t is soil infiltration rate at t moment, i_1 is soil infiltration rate at end of the first unit time interval, α is an index.

If A_t is interface area of infiltration water in storage pit at t moment, then

$$A_t = \pi D(H_1 - H_t) \tag{2}$$

then the discharge of soil water inflow is given by the equation

$$q_t = A_t i_t = \pi D(H_1 - H_t) i_1 t^{-\alpha} \tag{3}$$

formula (3) is integrated, cumulative infiltration W_t during 0—t time interval is given by the equation

$$W_t = \int_0^t q_t \mathrm{d}t = \int_0^t \pi D(H_1 - H_t) i_1 t^{-\alpha} \mathrm{d}t \tag{4}$$

meanwhile

$$W_t = \frac{\pi}{4} D^2 (H_t - H_0) \tag{5}$$

so

$$\frac{\pi}{4} D^2 (H_t - H_0) = \int_0^t \pi D(H_1 - H_t) i_1 t^{-\alpha} \mathrm{d}t \tag{6}$$

making derivative for both sides of formula(6), then

$$\frac{\mathrm{d}H_t}{\mathrm{d}t} = \frac{4}{D}(H_1 - H_t) i_1 t^{-\alpha} \tag{7}$$

formula (7) is adapted as follow

$$\frac{\mathrm{d}H_t}{H_1 - H_t} = \frac{4}{D} i_1 t^{-\alpha} \mathrm{d}t \tag{8}$$

formula (8) is integrated, that is

$$-\int_{H_0}^{H_t} \frac{\mathrm{d}(H_1 - H_t)}{H_1 - H_t} = \int_0^t \frac{4}{D} i_1 t^{-\alpha} \mathrm{d}t \tag{9}$$

after integrated and arranged, the equation is given

$$\ln \frac{H_1 - H_t}{H_1 - H_0} = -\frac{4}{D(1-\alpha)} i_1 t^{1-\alpha} \tag{10}$$

Formula (10) is mathematical description of variable-water level infiltration in storage pit of homogeneous soil. When infiltration parameter i_1 and α is given, water level varying of infiltration in storage pit can be worked out by formula (10); When varying head is known by experiment, infiltration parameter i_1 and α in storage pit can be gotten.

4 Test analysis of varying head infiltration in storage pit of homogenous soil

4.1 Calculation of varying head infiltration parameter

Experiment was carried on by the above test soil box. Soil initial moisture content(volume percent) is 1.55%, pit depth H_1 is 60 cm, pit diameter D is 32 cm, water quality inflowing into storage pit was 3 liter, initial water level H_0 in pit was 15cm. 17 couples of data of t—H_t were known. According to the test data, infiltration parameters of varying head in storage pit of homogenous soil were calculated by formula (10).

Order $$Y_m = -\ln\frac{H_1 - H_t}{H_1 - H_0} \qquad a = \frac{4i_1}{D(1-\alpha)} \qquad b = 1-\alpha$$

So $$-Y_m = at^b \tag{11}$$

Taking logarithm from both sides of formula(11) $$\ln(-Y_m) = \ln a + b\ln t$$

Order once again $$\ln a = A \qquad \ln(-Y_m) = Y \qquad \ln t = X$$

So $$Y = A + bX \tag{12}$$

Number value of A and b can be calculated by using least square method to formula (12), so numeral values of α and i_1 were worked out.

$$\begin{aligned} \alpha &= 1-b \\ i_1 &= \frac{Db}{4}\mathrm{e}^A \end{aligned} \tag{13}$$

According to the test data and calculation, α is 0.3507, i_1 is 2.110 cm per minute.

4.2 Calculation of constant water level infiltration parameter

For the sake of comparing the differences in infiltration process between variable-water level and constant water level, infiltration experiment of horizontal earth pillar was done, test soil was the same as soil of varying head infiltration, the bulk density of soil was 1.35 g/cm^3, initial soil water-content coefficient θ was 1.97%(volume). Infiltration test was carried on in the condition that constant water head was 5cm. Measured data of infiltration were fit with KOSTIAKOV model so that α was 0.4598 and i_1 was 0.3040 cm per minute.

4.3 Analysis of effect factors on varying head infiltration

As known according to the above, comparing condition of that varying head(0 cm—45 cm), θ_0 was 1.55% to that of constant water head(5 cm), θ_0 was 1.97%, infiltration parameters in the conditions between the varying head and constant head were more different, and their infiltration processes were shown as Fig. 2.

It was known that soil water infiltration rate of varying head is always larger than that of constant water level at anytime, moreover, the infiltration rate of varying head at end of the first time interval was about six time bigger than that of constant water level. One hand, it is due to the difference of initial soil moisture content. The bigger is initial soil moisture content, the smaller is initial infiltration rate, vice versa. On the other hand, it is because of great effect of infiltration head on infiltration process. In general

constant water head, because its head was smaller and effect of pressure potential on infiltration was less, therefore the conclusion that the effect of storage depth on infiltration was less and even could be overlook was made by some scholar. But because initial water head in storage pit was higher(45 cm) and weight potential and pressure potential had great effect on soil water infiltration, so the phenomenon that initial infiltration rate of varying head was higher than that of constant water head occurred.

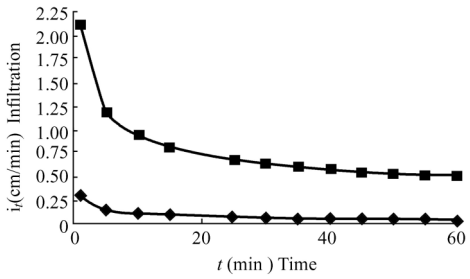

Fig 2 The difference in the soil moisture infiltration between varying head and constant head

Infiltration rate became smaller when infiltration time was prolonged, but that of varying head was reduced rapidly. It was because water level in storage pit fell with time extended, thus infiltration rate was decreased quickly.

Constant infiltration rate of variable-head infiltration was also bigger than that of constant head infiltration. There were two causes. One was soil initial percent moisture content of constant head infiltration was higher than that of varying head infiltration so that water potential gradient was different and had some effect on constant infiltration rate. The other was experiment of constant head infiltration was one-dimensional horizontal infiltration, while varying head was three-dimensional infiltration. The multi-directions infiltration made its constant infiltration rate bigger. It was the most important cause that the constant infiltration rate of variable-head infiltration was bigger than that of constant head infiltration.

In a word, effect factors on varying head infiltration process in storage pit included soil texture, soil structure, soil initial percent moisture content, variation of varying head and infiltration dimension. Therefore, the model parameters of varying head infiltration in storage pit could not be taken place by that of one-dimension constant head infiltration.

5 Conclusion

Based on KOSTIAKOV models, the mathematical model of the varying head infiltration in storage pit of homogenous soil was established by using principle of water balance in this paper. This model included the parameters reflecting soil physical characteristic and the variable character of inconstant water level in storage pit infiltration. Then corresponding infiltration parameters were worked out by experiment of physical model. Contrasting infiltration process of inconstant head in storage pit to that of constant head in condition of same soil, the major effect factors of storage pit infiltration process which were soil initial moisture content, range of varying head and infiltration dimension etc were analyzed, as a result the model parameters of varying head infiltration in storage pit could not be taken place by that of one-dimensional of constant head infiltration. This conclusion will be of important value for the further study on water storage pit irrigation.

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