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The effects of improved permeability on rainwater harvesting in irrigated fields

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Abstract
Infiltration phenomenon, has a direct impact on rainwater harvesting in fields under irrigation. In order to solve this problem (reduced infiltration and increased runoff), a few strategies can be suggested. Taking long-term decision for increasing the efficiency of irrigation should be strongly suggested. At the same time, ways in which customized irrigation is optimized must be studied. An old irrigation method has been used in large scale in Iranian furrow irrigation. Different design methods for furrow irrigation are offered; the most important ones are: 1- SCS (Soil Conservation Service) method; 2- FAO method; and 3- walker and Skogerbo method. The present study offers a design method that is suited according to environmental conditions and discusses the results obtained from this study. Attempts were made to identify the efficient length of furrow. A study field in Amirabad farm of college of Agriculture at Birjand University was selected. Preparation and leveling of the field was done, since furrow irrigation of the slope gradient for land leveling is very important. This research focused on soil infiltration (Double ring and input - output methods), advance time and recession time, and measuring furrow cross section in different steps during the study. Results showed the possibility of improving water use efficiency using furrow irrigation technique. Finally, it was concluded that using SCS is more consistent with methods of rain water harvesting and on-farm water efficiency.
***Keywords:** Rainwater harvesting, Irrigation Management, Soil Infiltration, Surface Irrigation*.

1. Introduction

Optimizing crop yield in arid zones considering unit area is only obtained at yield and water efficiency level. The most important factor in this regard is irrigation efficiency, which can be achieved by better design and change in irrigation system. This can be done by optimizing the irrigation system that best suits the climatic conditions of the specific area and meets the main required parameters for maximum yield while using minimum water. Overcoming this problem is feasible only by conducting continuous researches (Siyal and Skaggs, 2009).

Soil infiltration is the process of water entering the soil; the infiltration rate is defined as the velocity at which water penetrates the soil surface. Soils with low infiltration can be the cause of runoffs and flooding and can become saturated during rain events. This, in turn, decreases soil strength and increases erosion potential. It can also cause nutrient deficiencies in plants and generate anaerobic conditions. There are several factors that affect a soil's infiltration rate, including the type of soil, which is determined by the portions of sand, silt, and clay in the soil. Infiltration rates are generally measured in millimeters or inches per hour, in other words the given depth of a water layer entering the soil within one hour. Table 1 shows the average speed of penetration in different types of soils (Hillel, 1998).

Table 1. Average soil infiltration rates in different soils

Soil Type	Steady infiltration rate $(inch/hour)$
Sands	Soil Type
Sandy and silty soils	Sands
Loams	Sandy and silty soils
Clayey Soils	Loams
Sodium Clayey Soils	Clayey Soils
	Sodium Clayey Soils

Clay Soils

Clayey soils, generally included in the Natural Resource Conservation Service's (NRCS) hydrologic soil group D, tend to have a high potential for runoff and a very slow rate of infiltration when thoroughly wetted. Group D soils that have similar infiltration rates as clay include shallow soils over impervious materials and soils in areas with high water tables. The basic infiltration rate for clay, in millimeters per hour, is 1 to 5. Clay loam generally sees an infiltration rate between 5 and 10 millimeters per hour (Hillel, 1998).

Loams

Loamy soils can encompass a variety of infiltration speeds. The NRCS soil hydrologic group B includes sandy loam soils with moderate textures. This group's infiltration rate ranges from about 12 to 25 millimeters per hour. Group C soils are typically silty loam, with moderately fine to fine texture. These soils have an infiltration rate ranging from 4 to 7 millimeters per hour (Hillel, 1998).

Sandy Soils

Sandy or gravelly soils have a high infiltration rate and low runoff. The infiltration rate of especially sandy or gravelly soils can range from 25 to 200 millimeters per hour (Hillel, 1998)

Soils that are poor in terms of texture and structure, may be destroyed by splashing rain. As the permeability of these types of soils are severely decreased and runoff. Fig.1 shows an example of such soil.

Fig. 1. A thin surface crust caused by raindrop impact on a bare soil with poor structure.

2. Materials and Methods

2.1. The study area

The study area was agricultural research station of Birjand University at a distance of 5 km West of Birjand (Southern Khorasan province, Iran), with geographical latitude of: 32˚53’ N, and a geographical longitude of: 55˚13’ E, and altitude of: 1480 meters. The study was conducted during farming years 2010-2011. Fig.2 shows the location of the project area (Shahidi, 2012).

Fig. 2. Location of Southern Khorasan province, Iran.

In general, the area is warm and dry with cold winters and warm summers. During the last few years there has been little rain, therefore, a serious water crisis is rising. The water table in Birjand plain has been reduced by 73 cm in 2014 compared to the previous year, and this declining of water table level has continued during the last few years. Because of terracing and leveling of the soil since 1977, it is not a natural soil. Thus, due to fine texture and drainage conditions, this soil has had infiltration problems. In designing and evaluating the irrigation method, the problem of infiltration was carefully considered, therefore, after choosing the research site the importance of land leveling for furrow irrigation was kept in mind. The practice of land preparation and land leveling was carefully carried out in farming during years 2014-2015. Infiltration was measured in two ways:

- Double ring method (Fig.3)
- Input-output furrow method (Fig.4).

Fig. 3. Measuring the infiltrationby double-ring method

Fig. 4. Measuring the infiltrationbythe Input-output furrow method

Experiments: The following parameters was measured:

1- Soil infiltration. Infiltration parameters were calculated using the Kostiakov equation.
2- Cross section of furrow (Horst et al., 2005)
3- Advance and recession time in the furrow (Izadi and Wallender, 1985).

Based on this background, different furrow irrigation methods were introduced. Three conventional methods (FAO, Soil Conservation Service and Walker -Scogerboe methods) were studied in this research to compare water application efficiency.

A) FAO method: The principle of this method is based on required infiltration time for fulfillment of irrigation depth; in this method it is necessary to obtain water discharge, length of furrow, and the irrigation time. The furrow irrigation design is composed of the following steps:

1- Determination of kostiacove infiltration formula.
2- Determination of maximum water discharge
3- Determination of infiltration time based on required net irrigation depths.
4- Selection of different water discharges lower than the maximum water discharge design.
5- Determination of advancing water flow formula for furrow irrigation (when the delaying time for slop of > %0.4 was ignored and assumed to be 0.).

Election of the advancing time equal to about 1/4 of the required time for net irrigation depth.

B) SCS (Soil Conservation Service) method: The design used was cutback method after water arrival (initial discharge) to the end of furrow. The discharge was reduced to half and the irrigation continued up to the time when the end of furrow had enough water. Steps were as:

1- Determination of advancing time.
2- Calculation of the required time for infiltration of net irrigation depth at the end of furrow.

Total irrigation time (T_{ic}) is defined as the overall advancing time (Tt) plus the required time for net irrigation depth at the end of the furrow (T_{nc}).

$$T_{ic} = T_{nc} + T_t \quad \text{Eq (1)}$$

1- Determination of averageinfiltration time measuredalong the furrow with advance time (with the initial discharge).
2- Determination of gross irrigation depth (F_{gc}).
3- Calculation of average overall infiltration with cut back method equal to overall

infiltration at the advance time and infiltration at remaining irrigation time with secondary flow ($Q/2$).

4- Determination of surface runoff and deep percolation (Silva, 2007).

5- Calculate the irrigation efficiency (AE_c)

$$AE_c = 100\,\frac{F_n}{F_{gc}} \qquad \text{Eq (2)}$$

Where (F_n) = net irrigation depth (mm), (F_{gc})= Gross irrigation depth (mm).

Walker and Scogerboe method: in this method the Infiltration function is following:

$$Z_{req} = K.T_{req}^{a} + F_{0req} \qquad \text{Eq (3)}$$

where (Z_{req}) = total volume infiltrated for each furrow unit length. (T_{req}) = required infiltration time. (F_{0req}) = the basic intake rate in volume per meter for a time.

K = formula parameter in volume per meter for time. a = power of the formula.

The formula used for most surface irrigation is:

$$T_{req} = T_r - T_l \qquad \text{Eq (4)}$$

where (T_L) and (T_r) are advance and delaying times for initial and at the end of the field, respectively.

Applied efficiency of water (E_a in %) is defined as:

$$E_a = \frac{Z_{req} L}{Q_o T_{co}} \qquad \text{Eq (5)}$$

where (T_{co}) = irrigation cut off time (min), (Q_0) = input water discharge (m^3/s),

L = furrow length (m).

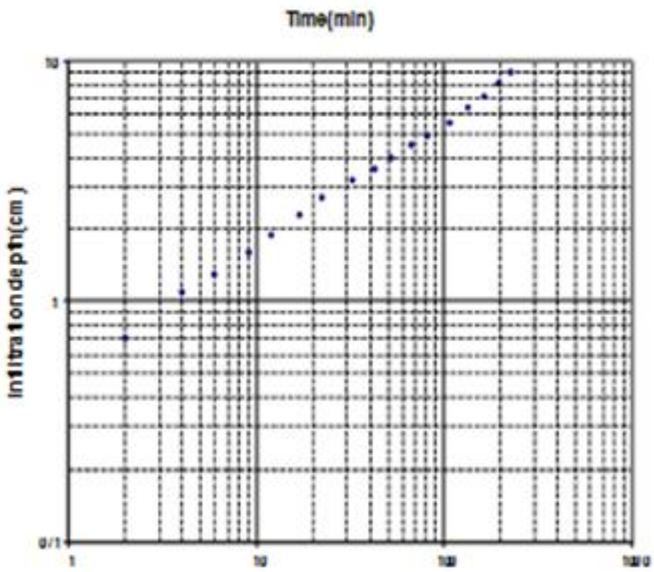

Fig. 4. Double ring curve

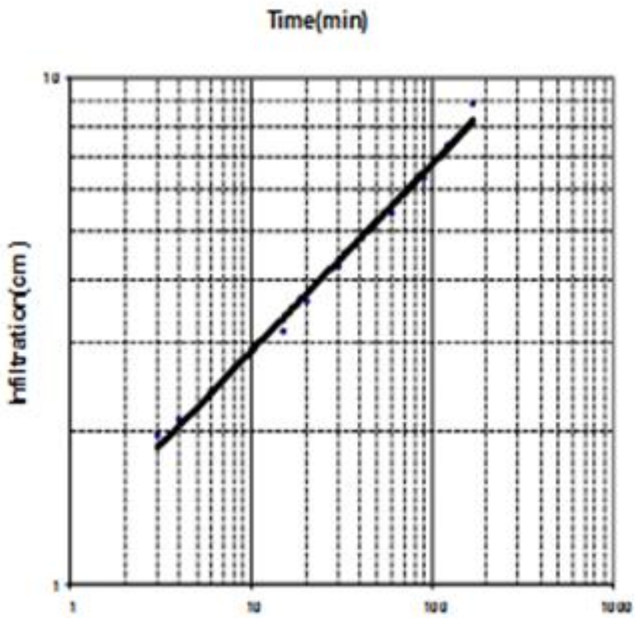

Fig. 5. Input-Output method curve

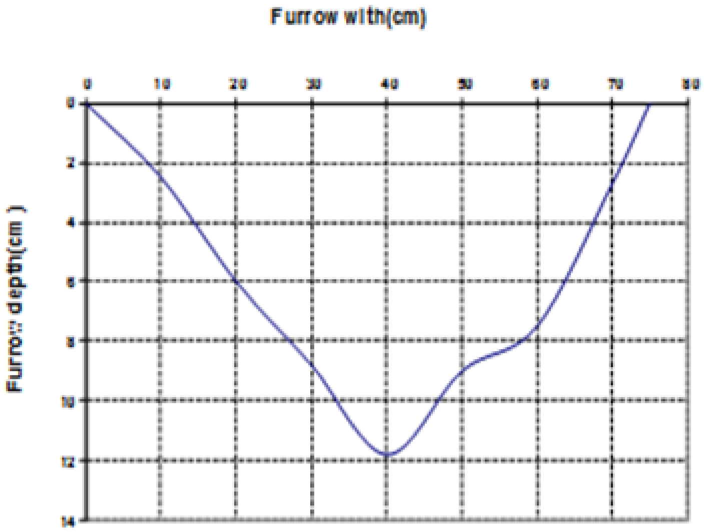

Fig. 6. Furrow Cross Section

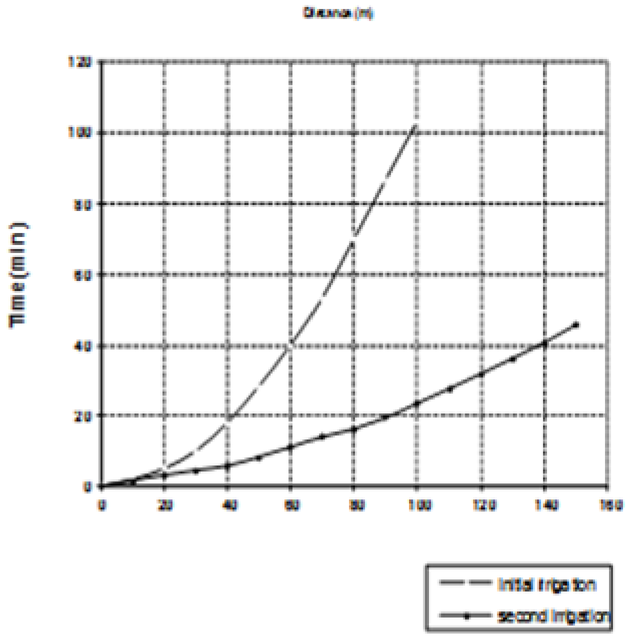

Fig. 7. Advacing Curve

The calculations have been carried out in Table 2.

Table 2. Calculated values of infiltration by the Kostiakove equation for input-output furrow lines.

T (min)	**Q(out)** (lit/s)	**Q(out)** (lit/s)	**Q(in)** (lit/s)	**Q** (lit/s)	**T** (sec)	**V** (lit)	**Zi** (mm)	**Z** (mm)
0	0.00					52.5	2.33	
		0.125	1	0.875	60			2.33
1	0.25					81.0	3.60	
		0.325	1	0.975	120			19.60
3	0.40					34.5	1.53	
		0.425	1	0.575	60			21.13
4	0.45					63.6	2.83	
		0.470	1	0.530	120			23.96
6	0.49					59.4	2.64	
		0.505	1	0.495	120			26.60
8	0.52					55.2	2.45	
		0.540	1	0.460	120			29.05
10	0.56					123.0	5.47	
		0.590	1	0.410	300			31.52
15	0.62					103.5	4.60	
		0.655	1	0.345	300			36.12
20	0.69					144.0	6.4	
		0.760	1	0.240	600			42.52
30	0.83					261.0	11.6	
		0.855	1	0.145	1800			54.12
60	0.88					216.0	9.6	

T (min)	**$Q_{(out)}$** (lit/s)	**$Q_{(out)}$** (lit/s)	**$Q_{(in)}$** (lit/s)	**Q** (lit/s)	**T** (sec)	**V** (lit)	**Zi** (mm)	**Z** (mm)
		0.880	1	0.120	1800			63.72
90	0.88					216.0	9.6	
		0.880	1	0.120	1800			73.32
120	0.88					360.0	16.0	
		0.880	1	0.120	3000			89.32
170	0.88							

Table 2 depicts an infiltration calculating table for input-output method by the Kostiakove equation.

- The first column shows times on minutes.
- The forth column shows average output discharge and the fifth column shows average input discharge to furrows.
- The sixth column shows difference between input and output discharge with equal infiltration volume on (lit/sec).
- The last column shows total infiltration depth on mm per unit area.

3. Results

The following results were obtained:

1- According to the infiltration studies it was noted that the mean infiltration of double ring group IF (Infiltration Family) =1 whereas the mean for input-output group came out to be as IF=1.5, the differences among the group could be due to: A) The surface infiltration area for input-output method was more than that of the double ring method. B) Double ring method only considered vertical infiltration, whereas, permeability and capillary are also considered in the input-output method. C) The related soils contained layers whose top layer was heavy texture and the subsoil was light texture, and because in input-output method the surface layer was disturbed (because in this way the soil surface is scratched), therefore, the subsoil had the most infiltration. Thus, the obtained results showed that the input-output method is a more reliable method.

2- In initial irrigation, water flow in the furrow is slow, because the soil pores have not yet been closed by small soil particles, and there is also a soil roughness resistance.

3-The calculated input discharge was 0.925 (liter/sec), which was tested for 1, 1.5 & 2 (liter/sec). Results showed that 1.5 & 2 (liter/sec) caused erosion.

4- After evaluating different tested designs it was concluded that S.C.S method of furrow with the optimum length of 130 (m) had a better efficiency than any of the other methods. Since the effect of the soil on the width of the furrow was not considered in the F.A.O method, a factor which was considered in the S.C.S method. The obtained result also showed that Walker and Skogerboe method have the efficiency between F.A.O and S.C.S. Finally, it was concluded that using SCS is more consistent with the methods of rain water harvesting and on-farm water efficiency.

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