Australian Journal of Agricultural Engineering AJAE

AJAE 1(2):29-37(2010) ISSN:1836-9448

The comparison of erosion of meandering and standard furrow irrigation under different field slopes

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Abstract

The Gholam-gardeshi irrigation (meandering furrow irrigation) is a modified form of standard furrow irrigation, which to date, there is no study about the effects of slopes on erosion of this method of irrigation. To measure the erosion of this method of irrigation and to compare the results with standard furrow irrigation, two experimental fields with different soil textures and field slopes were used to collect data such as furrow inflow hydrograph, furrow outflow hydrograph, advance and erosion. The experiment was laid out with a randomized factorial design with three replications. In both methods, the developed second order polynomial equation for the erosion, and advance equation were able to interpolate the field data with coefficient of determination of more than 94 %. The results showed that the velocity of advance, runoff and erosion are lower significantly at 5% probability level for the meandering furrow irrigation as compared to the standard furrow irrigation. As the slope of the field increased, erosion and runoff in both irrigation methods increased significantly.

Key words: Modified furrow; irrigation; runoff, soil loss.

Introduction

Surface irrigation is most widely used over the world because of its simplicity and low capital costs. Furrow irrigation is one of the oldest methods of surface irrigation. Meandering furrow irrigation (locally called Gholam-gardeshi irrigation) is a modified form of furrow irrigation, which has being used for some farmlands and gardens in Iran traditionally for a long time. In this method of irrigation the hydraulic behavior is different as compared to the standard furrow irrigation because water moves in snake-shaped furrows with lower velocity of advance in the direction of field slope. The Gholam-gardeshi irrigation is inexpensive and can be used as an alternative choice for more expensive methods of irrigation such as sprinkler or trickle systems especially for fields with high slopes where the ordinary furrow irrigation has low efficiency and high soil erosion. The study by Mostafazadeh-Fard and Moravejalahkami (2006) showed that for the same field and furrow conditions as the furrow slope increases the efficiency of furrow irrigation decreases while the efficiency of Gholam-gardeshi irrigation increases. Sepaskhah and Shaabani (2007) applied standard methods to Gholam-gardeshi irrigation and developed Kostiakove-Lewis infiltration equation and furrow hydraulic and geometric parameters for this method of irrigation.

The improvement in furrow irrigation performance and reduction of soil erosion due to furrow irrigation erosion are the main goal of many researchers. The efficient application and distribution of water by furrow irrigation is dependent on parameters such as furrow inflow rate, soil texture, field slope, soil infiltration, plant coverage, roughness coefficient and irrigation management. Different studies on furrow irrigation such as runoff recovery, cutback technology, cablegation and surge irrigation have been carried out to reduce water losses (Younts et al., 2003; Gaton, 1966; Walker and Skogerboe, 1987; Walker, 1989; Mintesiont et al., 2004). Researchers studied different irrigation manage- ments and techniques to reduce erosion and to relate furrow irrigation erosion to the parameters such as furrow stream size, field slope, furrow length, soil type, plant coverage and soil density (Goodson et al., 2006; Leib et al., 2005; Szögi et al., 2007; Silva, 2006; Evans et al., 1995;

Table 1. Soil characteristics for the experimental fields

Field	Bulk density (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Texture	Soil moisture (%)
Khazaneh	1.2	21	31	48	Clay	2.9
University	1.25	39	29	32	Clay loam	3.2

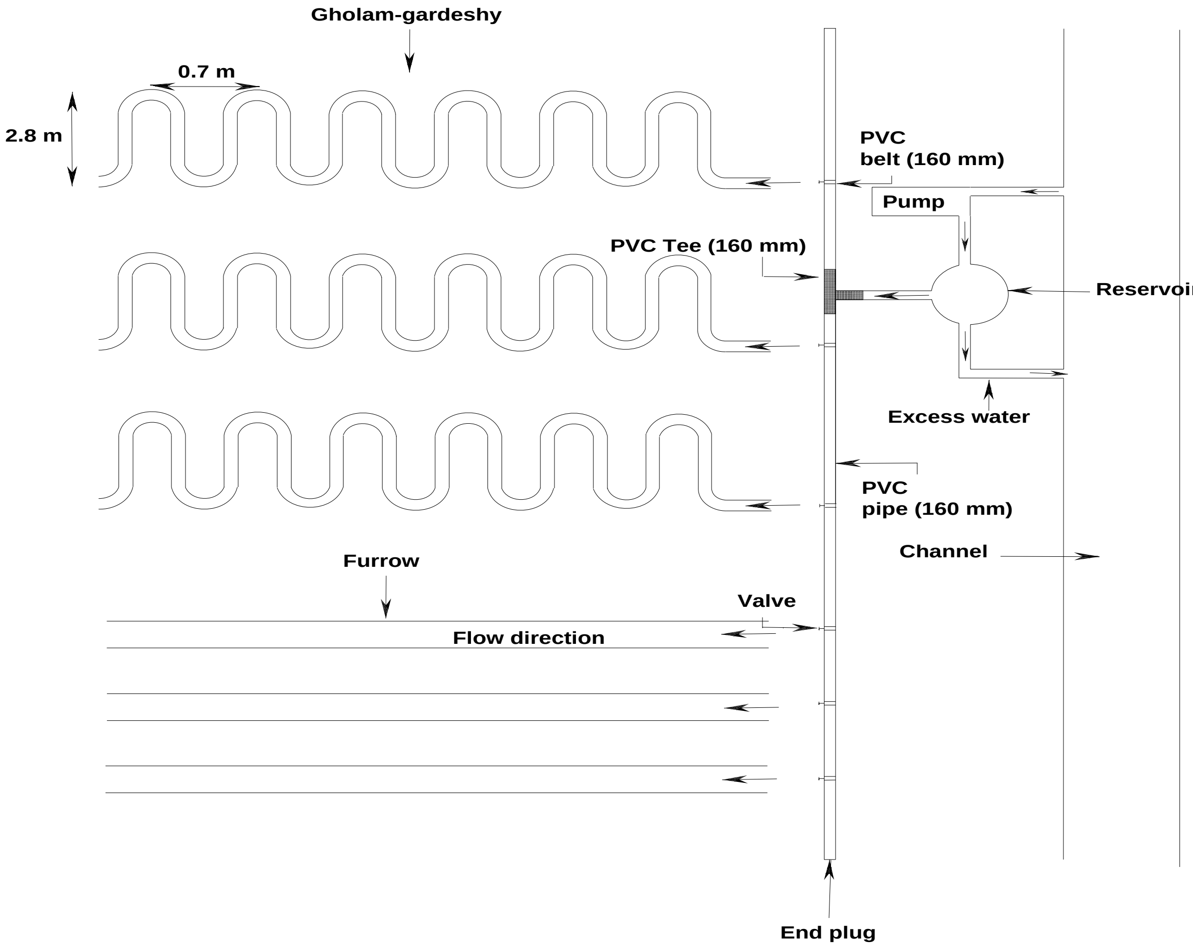

Fig 1. Schematic of constant head water delivery system to the furrows

Trout, 1995; Carter, 1993). The major factors affecting soil erosion are climate, soil erodibility, slope gradient and length, and surface and vegetative conditions. Controlling soil erosion on furrow irrigated fields is essential to maintain productivity and reduce off-site impacts of eroded sediment (Bjorneberg and Sojka, 2008). Eroding the topsoil from the inflow ends of furrow irrigated fields can reduce crop yield 25% (Carter et al. 1985). The study by Koluvek et al. (1993) shows that about 60% of the soil removed from the fields by erosion are not returnable and causes the soils to lose their fertility.

No works have been done previously about erosion of Gholam-gardeshi furrow irrigation. The objective of this study was to investigate the erosion and runoff of Gholam-gardeshi irrigation and to compare the results with standard furrow irrigation method.

Materials and methods

Two experimental fields, Khazaneh and University belonged to Isfahan University of Technology, Isfahan, Iran, were used to collect field data during summer 2007 for both meandering and standard furrow irrigation. The Isfahan (32°37′N, 51°39′E) with elevation of about 1550 m above mean sea level is located in central part of Iran with dry climate condition, low annual rainfall (<125 mm), high annual evapotranspiration demand (>1500 mm) and average annual temperature of about 16 degrees centigrade.

Table 2. Characteristics of the experimental plots for Khazaneh field

Plot	Irrigation method	Inflow discharge (lit/s)	Slope (%)	Advance time (min)	Inflow (lit)	Outflow (lit)	Average erosion (g/lit)	Erosion (g)
1	Furrow	1.06	0.4	8.3^{el}	3816	1542.1^{e}	0.86^{d}	1230.3^{e}
	Gholam-gardeshi			22.1^{a}	3816	683.8^{h}	0.47^{e}	321.5^{g}
2	Furrow	1.06	1	8.1^{f}	3816	2211.45^{c}	1.73^{c}	3823.6^{c}
	Gholam-gardeshi			15.5^{b}	3816	1034.1^{g}	0.64^{d}	655.6^{fg}
3	Furrow	1.06	1.3	5.7^{g}	3816	2627.1^{b}	2.15^{b}	5648.9^{b}
	Gholam-gardeshi			13.8^{c}	3816	1268.2^{f}	1.75^{c}	2220.3^{d}
4	Furrow	1.06	2	5.1^{h}	3816	3140.4^{a}	3.15^{a}	9881.2^{a}
	Gholam-gardeshi			9.2^{d}	3816	1678.9^{d}	2.32^{b}	3885.3^{c}

1- Means within a column that are followed by the same letter are not significantly different at the 5% level.

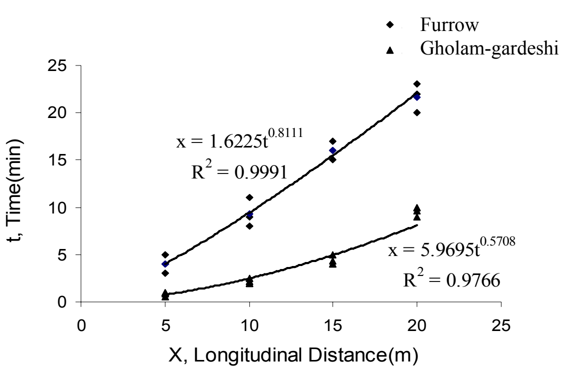

Fig 2. Advance curves for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 1

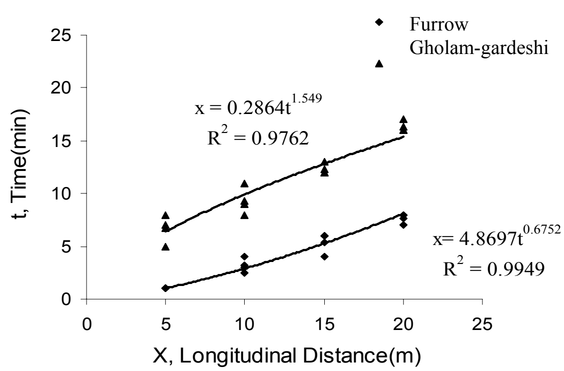

Fig 3. Advance curves for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 2

At Khazaneh field, four plots with different slopes were obtained. The experiment utilized a randomized factorial design with three replications. To compare the results of Khazaneh field with another field with different soil texture, another experimental field was conducted at University field for the same selected field slope and furrow inflow rate as plot 1 of the Khazaneh field. The soil and field characteristics for the experimental fields and experimental plots are shown in Tables 1 and 2. Soil moisture given in Table 1 is based on dry mass which is the average of three samples taken from depth of zero to 30 cm before irrigation. A constant head water delivery system to the furrows was installed at the upstream end of each experimental field and was used to irrigate the experimental plots. The schematic drawing of constant head water delivery system and experimental fields are shown in Fig 1. Overflow of water from reservoir guaranteed the constant head. The constant flow rates to the furrows were provided by control valves connected to the pipe. Control valves were adjusted to the desired levels before the experiment. Inflow and outflow of each furrow were measured by calibrated WSC flumes. The scale attached to the flume was used to record the water level in the flume and then it was used to determine the furrow discharge using the calibrated equation that was developed with high accuracy for the flume. Furrow spacing was the same for both methods and was equal to 0.7 m and furrow shape was nearly triangular. A profilometer (Mostafazadeh-Fard and Walker 1987) was used to measure furrow cross-section before and after irrigation at different stations for both methods and to determine furrow geometry parameters. But the comparison of furrow cross-section data for before and after irrigation was not used to determine net soil loss due to soil consolidation. For Gholam-gardeshi method the distance between two turning points of water was 2.5 m as shown in Fig. 1. Each experimental field had slope in longitudinal direction but the slope in the lateral direction was zero. The fields were irrigated for the first time with no plants. The tests started with non erosive inflow rate and were continued until constant outflow hydrograph was achieved. The irrigation time was 60 minutes and the outflow flume was set at distance of 20 m (in direction of field slope) from the inflow flume for both methods. To determine the advance equation, advance times were measured at different stations

Table 3. The Comparison of erosion and runoff for the University field

Irrigation method	Inflow (lit)	Outflow (lit)	Average erosion (g/lit)	Erosion (g)
Furrow	3827	1089[a1]	1.973[a]	2148.59[a]
Gholam-gardeshi	3827	446[b]	1.645[b]	733.67[b]

1- Means within a column that are followed by the same letter are not significantly different at the 5% level.

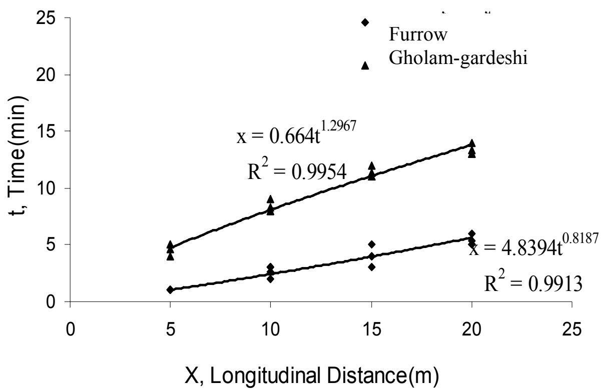

Fig 4. Advance curves for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 3

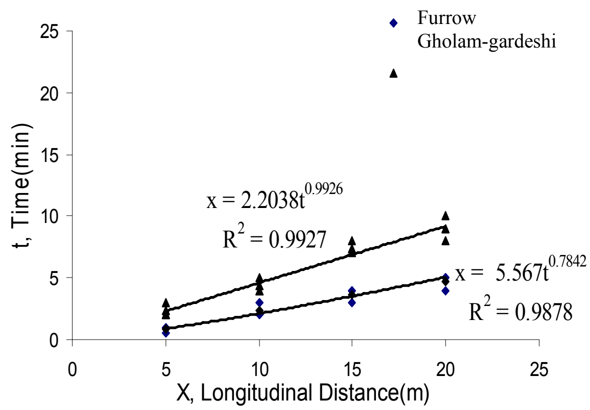

Fig 5. Advance curves for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 4

along the field for both irrigation methods until water reached the end of the furrow. Inflow, outflow, advance and erosion were measured for both irrigation methods and inflow and outflow hydrographs were determined. To determine furrow erosion (net furrow soil loss) for both methods, after runoff started, samples from runoff water were taken at different time intervals at the outflow station using plastic containers. Then, the samples were taken to the laboratory to determine total soil losses from each furrow. The total erosion of each furrow was calculated by multiplying the average furrow erosion to the volume of furrow runoff. The average furrow erosion was calculated by integration of the erosion equation in time interval between the beginning of runoff and the end of runoff and dividing it by the above time interval.

Results and discussion

Advance

The advance curves and equations were determined for both methods for each of the experimental fields which these results for Khazaneh field are shown in Figs. 2 to 5. For both methods the velocity of advance was determined in longitudinal direction (in field slope direction). These figures and their related equations show that for the same furrow inflow discharge, field slope and irrigation time the velocity of advance is higher for furrow irrigation as compared to the Gholam-gardeshi irrigation. The comparison of Fig. 2 with Fig. 5 show as the slope of the field increases the advance distance and the difference between both methods increases. For each experimental plot, the difference between two methods for longitudinal advance was significant at 5 % level (Table 2). In both methods the determined advance equations were able to predict the field data with coefficient of determination of more than 95 %. Similar results were obtained for the University field as shown in Fig. 6. For University field the advance time for water to reach the end of the furrow was 23.5 and 11 minutes for Gholam-gardeshi and furrow irrigation methods, respectively, witch the difference was significant at 5% level. In furrow irrigation, advance phase is important because it influences other hydraulic parameters such as deep percolation, uniformity of distribution of water along furrow, efficiency, runoff and erosion or soil water loss as the erosion and runoff are discussed below.

Erosion

For the Khazaneh field, the inflow hydrograph, the outflow hydrograph and erosion for furrow irrigation and for the Gholam-gardeshi irrigation were determined which the results for four experimental plots are shown in Figs. 7 to 10. The scales in these figures are the same so the comparison between any of the two experimental plots can be made easily. In Figs. 7 to 10, the comparison of Gholam-gardeshi irrigation with furrow irrigation shows that the erosion starts with delay for Gholam-gardeshi irrigation, and for both methods, at the beginning of the runoff the rate of erosion is

Table 4. Furrow geometry parameters for Khazaneh field for before irrigation

a_1	a_2	σ_1	σ_2	γ_1	γ_2
0.3	0.28	0.234	1.28	1.233	0.4756

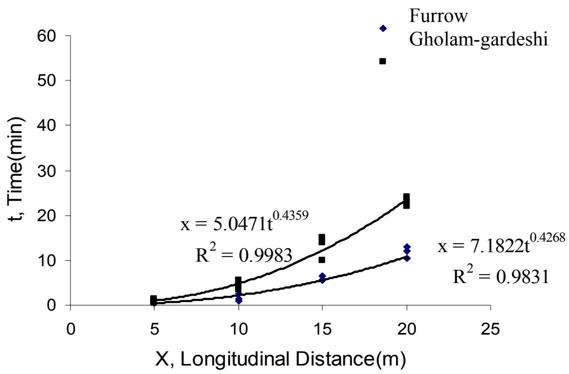

Fig 6. Advance curves for furrow and Gholam-gardeshy irrigation for University field (For the same conditions as plot 1 of Khazaneh field)

high and then starts to decrease until it reaches zero when the outflow stops. The comparison of Figs. 7 to 10 shows that as the slope of the field increases the initial sediment concentration increases due to increase in flow velocity. These figures also show that the initial sediment concentration is higher for furrow irrigation as compared to the Gholam-gardeshi irrigation because in Gholam-gardeshi irrigation the actual slope is decreased due to snake-shaped furrows. The computations from Manning's equation show that as the slope increases the flow depth at the up-stream ends decreases which causes higher flow velocity. For instance for Khazaneh field plot 1 the flow depth at the up-stream end for furrow was 0.062 m and for Gholam-gardeshi was 0.087 m and these values for plot 4 for furrow was 0.04 m and for Gholam-gardeshi was 0.056 m. The actual slopes for Gholam-gardeshi irrigation for plots 1 to 4 where 0.12, 0.3, 0.39 and 0.6%, respectively. As the field slope increases the difference between the initial sediment concentration of furrow and Gholam-gardeshi irrigation increases. At lower field slope (Fig. 7), the rate that erosion decreases is nearly linear and the difference between the two methods is small. At higher field slope (Fig. 8), the rate that erosion decreases is nearly nonlinear and the difference between the two methods becomes higher at a critical time of about 40 minutes from the start of irrigation. Fig. 8 also shows that in Gholam-gardeshi irrigation most of the eroded soil from the upstream end is sediment in the furrow before reaching the end of the furrow. Figs. 9 and 10 shows as the field slope increases, after the inflow cut off time, the erosion rate of both methods reaches close to each other with higher erosion for furrow irrigation as compared to the Gholam-gardeshi irrigation. The results showed that for the same irrigation time, slope, soil texture and discharge the tail water runoff and erosion are lower significantly at 5% level for Gholam-gardeshi irrigation as compared to the furrow irrigation method (Table 2). The comparison of four experimental plots shows as the field slope increases the erosion increases significantly for both methods (Table 2). The developed second order polynomial equation for the erosion also is given in each figure which shows that the equation is able to interpolate the erosion field data with coefficient of determination of more than 95%. Fig. 11 shows the overall relationship between field slope and soil erosion for both furrow and Gholam-gardeshi irrigation methods for Khazaneh field. This figure also shows as the field slope increases the erosion increases significantly for both methods and the difference between the two methods are significant at 5% level (Table 2). In Fig. 11, the developed second order polynomial equation for erosion shows that equation is able to interpolate the field erosion with coefficient of determination of more than 95 %. Similar results were obtained for the University field as shown in Fig. 12 and Table 3. The comparison of Fig. 7 from the Khazaneh field with Fig. 12 from the University field show that the furrow erosion in University field is higher than the furrow erosion of the Khazaneh field for both methods because the soil texture of University field is clay loam which is more erosion able as compared to the soil of Khazaneh field which is clay.

Based on furrow cross-section measurements, the furrow geometry equations parameters ($T = a_1 y^{a_2}$, $A = \delta_1 y^{\delta_2}$ and $WP = \gamma_1 y^{\gamma_2}$) for top width (T, m), area (A, in m^2) and wetted perimeter (WP, in m) as function of furrow depth (y in m) were developed for before irrigation for Khazaneh field which the results are given in Table 4. For the University field the furrow geometry parameters for before irrigation where the same as Khazaneh field. Figure 13 shows an example of furrow cross-section measurements for Khazaneh field for before irrigation. In Gholam-gardeshi irrigation the actual slope is decreased due to snake-shaped furrows and causes the potential for erosion to decrease. For the actual length of the flow the actual slope was calculated and applied to the Manning's equation using the furrow geometry equations parameters of Table 4 and an assumed n value of 0.03 and the flow depth at the up-stream end were calculated for

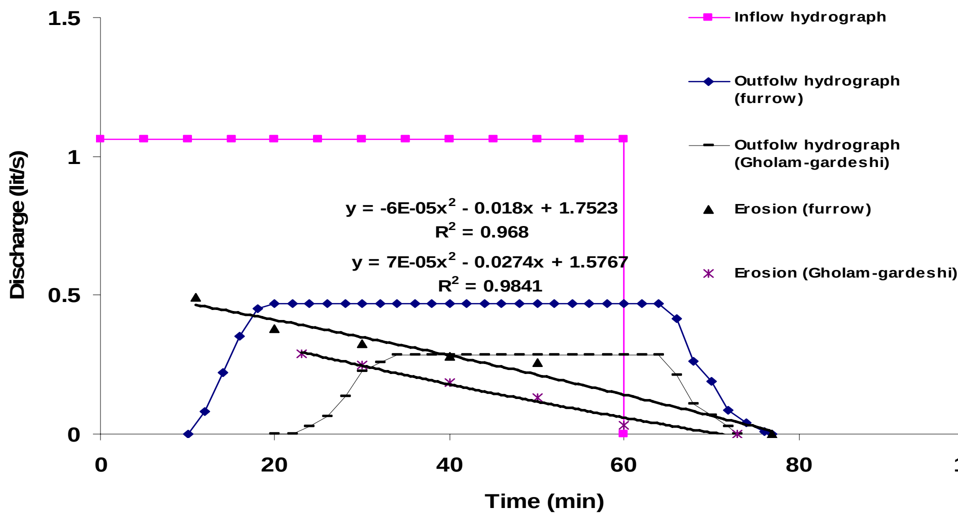

Fig 7. Inflow-outflow hydrographs and erosion for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 1

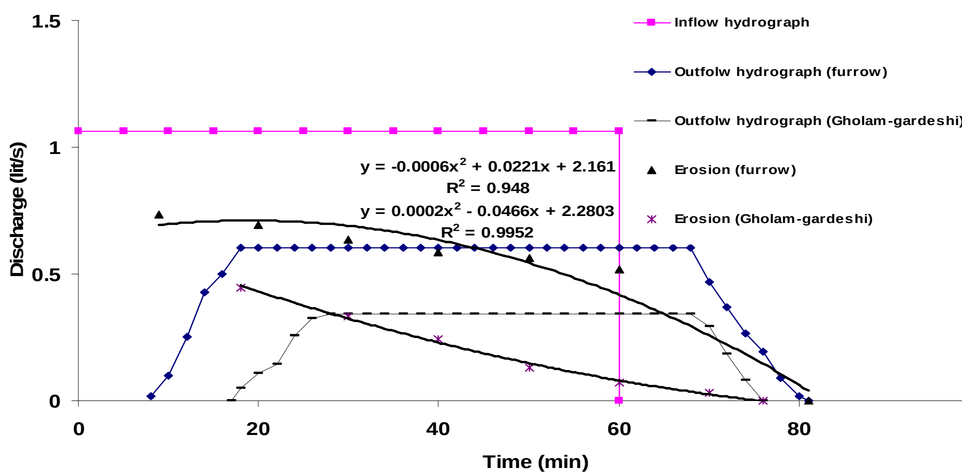

Fig 8. Inflow-outflow hydrographs and erosion for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 2

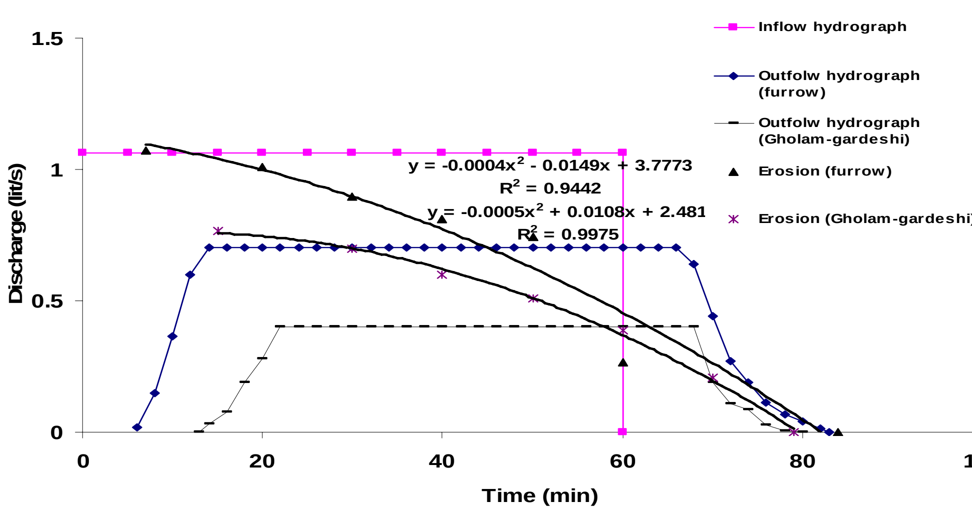

Fig 9. Inflow-outflow hydrographs and erosion for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 3

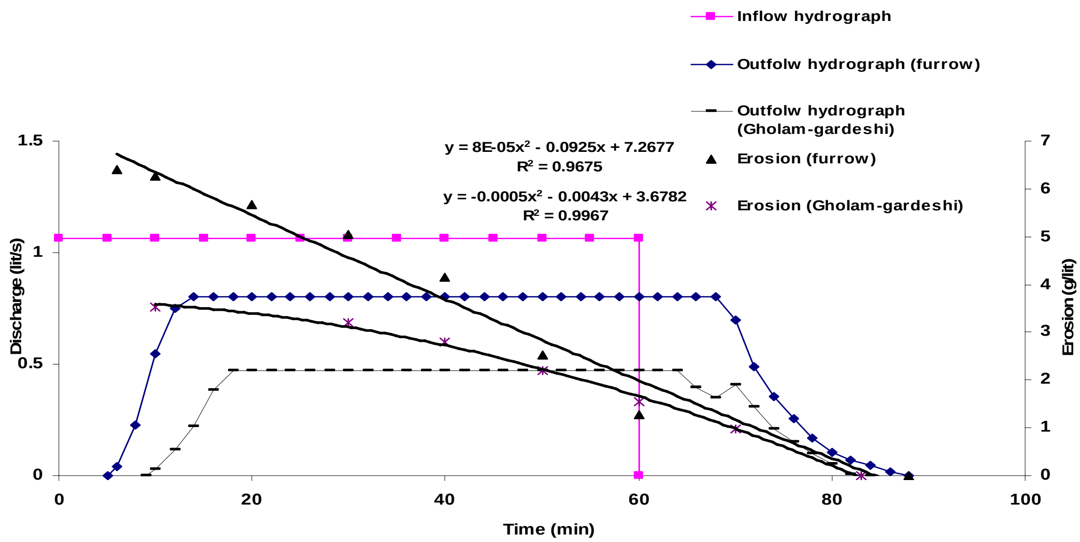

Fig 10. Inflow-outflow hydrographs and erosion for furrow and Gholam-gardeshy irrigation for Khazaneh field plot 4

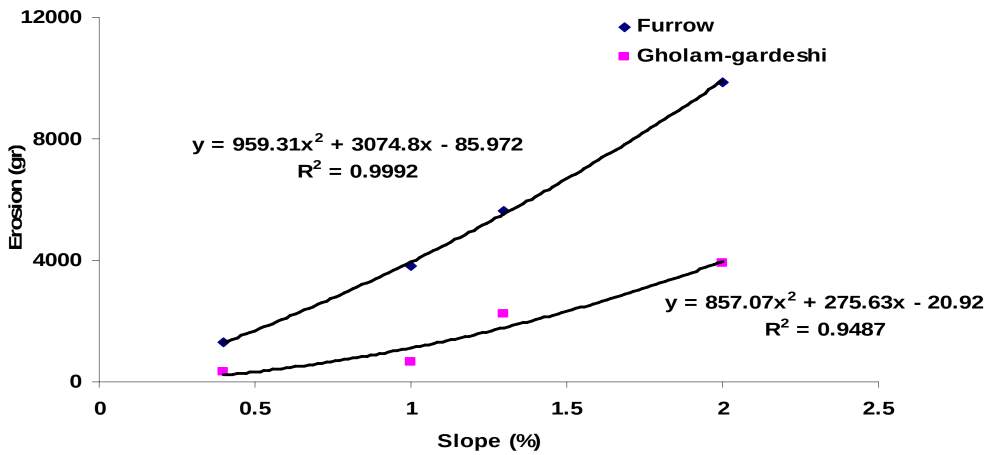

Fig 11. Furrow and Gholam-gardeshy irrigation erosion as affected by slope for Khazaneh field

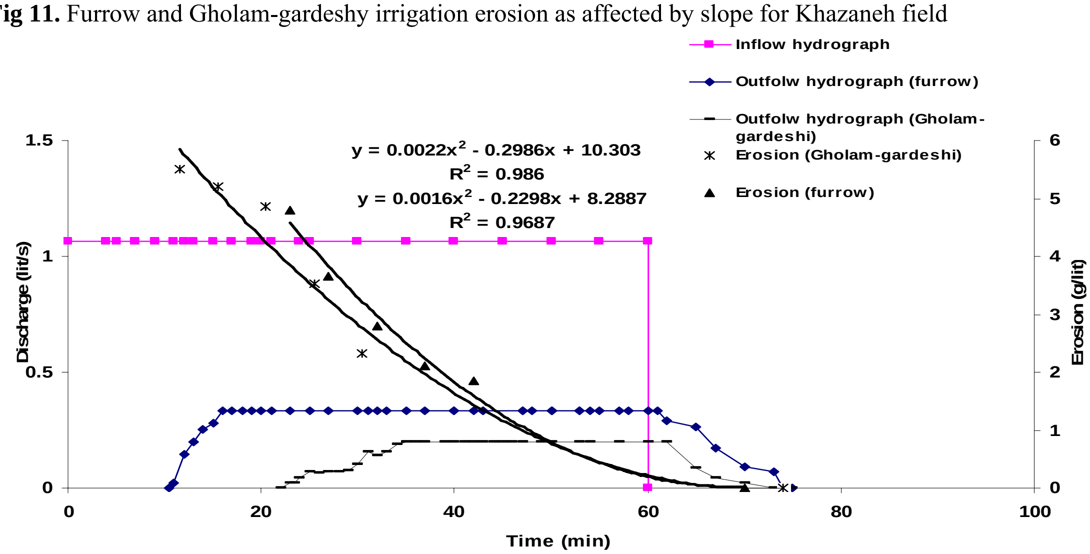

Fig 12. Inflow and outflow hydrographs and erosion for furrow and Gholam-gardeshy irrigation for University field. For the same conditions as plot 1 of Khazaneh field

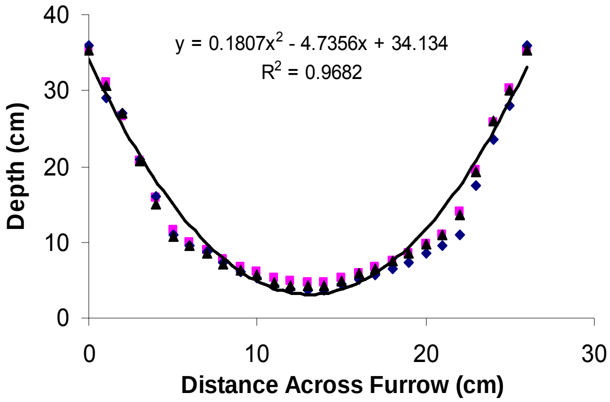

Fig 13. Furrow cross-section measurements for Khazaneh field for before irrigation

both methods. The results for the first experimental plot of Khazaneh field showed that for the same inflow rate, the flow depth at the up-stream end increases by about 28% for Gholam-gardeshy irrigation as compare to the furrow irrigation. This might results in higher deep percolation. For design purpose, to overcome this problem, since the actual slope is decreased due to meandering furrows and causes the potential for erosion to decrease, a higher non erosive discharge or a higher actual slope can be applied for the Gholam-gardeshy irrigation in order to have higher uniformity of distribution of water along the furrow and better irrigation performance with lower erosion. This shows that even fields with higher slopes than expected can be irrigated with Gholam-gardeshy irrigation with less soil loss.

Conclusions

From the study it was observed that the Gholam-gardeshy irrigation reduces furrow erosion significantly as compared to the common furrow irrigation method. For soils with higher potential for erosion, the Gholam-gardeshi irrigation has good capability to reduce furrow erosion. Especially, at higher field slopes, the use of Gholam-gardeshi irrigation can reduce erosion and reduce the need for more expensive irrigation systems such as sprinkler or trickle irrigation. In Gholam-gardeshi irrigation the actual slope is decreased due to meandering furrows which cause the potential for erosion to decrease. This allows a higher non erosive discharge to be applied to the furrow in order to improve the uniformity of distribution of water along the furrow. The above method of irrigation can be an effective watershed management for steep area to reduce soil losses.

Acknowledgements

This research was funded by Isfahan University of Technology. This assistance is gratefully acknowledged.

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