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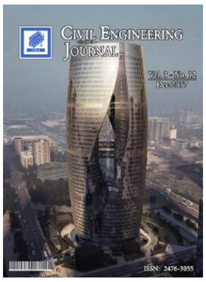

Changing Furrow Irrigation to Increase Efficiency and Feasibility Study of Reusing Surface Runoff

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Abstract

To improve irrigation techniques and the utilization of available water resources in Iran, a first steps re evaluation of traditional irrigation methods. To assess the efficiency of furrow irrigation, a 4-ha plot (87 furrows) cultivated with sugarcane was evaluated in Khuzestan Province. The quantities of inflow, outflow runoff, soil moisture before irrigation, depth of root development and depth of water infiltration were measured and thus the values of water use efficiency, uniformity coefficient, and distribution uniformity were determined for the selected plot. Using Geographical Information System, in ArcView, the irrigation efficiency of its levels were analyzed using two furrow irrigation methods: open and closed-end. The results showed that the irrigation efficiency, uniformity coefficient and distribution uniformity for the open-end than the closed-end method. The prevention of deep infiltration losses (approximately 30% lower than for closed-end) and allowing outflow of end runoff, and depending on water quality, the riffle can be considered ideal for irrigating other surfaces.

Keywords: ArcView GIS Software; Closed-End Furrow Irrigation; Open-End Furrow Irrigation; Tail Water Quality.

1. Introduction

Water scarcity in most developing countries imposes a large economic burden on governments, and efficient use of irrigation water is considered a top priority to conserve this resource. Due to the limited atmospheric precipitation and lack of appropriate spatial and temporal distribution, is classified as an arid and semi-arid country. However, a rapidly growing population, urbanization, and development of both economic and agricultural areas have increased demands for water resources. One of the most important elements of water resources management is predicting future availability of these resources [1].

In Iran, the gap between supply and demand for water is increasing with time. By considering this major challenge, the rational utilization of available water resources in all applications is particularly important for agriculture as the major consumer of water (92%). Therefore, the government must adopt policies focused on the economical utilization of water and persuade farmers to consume water as efficiently as possible. Increasing the efficiency of irrigation is considered an efficient solution to the current problem and also leads to enhancement of the irrigated farming area.

Due to having the most suitable soil and water resources, Khuzestan Province has the potential for cultivating both tropical and sub-tropical plants. Sugarcane was one of the first crops widely cultivated in this province. Now, in addition to Haft Tappeh Sugarcane Agro-Industry Co, Karun and MianAb, other companies are actively engaging in producing

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sugarcane through seven projects, two in the north of the province and the others south of Ahvaz. Accounting for the level of fallow, sugarcane is grown annually on 100000 ha. The sugarcane water requirements in the Khuzestan climate, assuming an efficiency of transmission and distribution of nearly 85%, is 29539 m3 annually [2].

According to available statistics, 8.7 million hectares are under irrigated cultivation in Iran. Surface irrigation is one of the most common methods of irrigation, in which water flows by gravity on the soil surface [3]. This method is popular due to low investment costs, a ready energy supply, and ease of operation, and maintenance, and many studies on increasing its efficiency have been conducted [4]. For sugarcane, furrow and flood irrigation are the most widely used [5]. Sugarcane in the USA was studied in 20 adjacent furrows with three irrigation states continuous flow, reduced flow, and spate irrigation and resulted in water use efficiency of 40- 60% [6]. Two years of study on a number of farms in Colorado USA showed water use efficiency in therange of 7 - 67 %. In general, water use efficiency is between 40-60%, whereas theoretically efficiency of 70-80 % is possible [7]. In cotton fields in Australia, irrigation efficiency ranged between 50 and 90%, and randomly between 30 and 85% over the season, resulting from lessening the degree of deep losses of irrigation water [8]. In a study on cotton in Australia, water use efficiency on average was 48% and the amount of deep losses to drainage was 42.5 mm on average [9].

Furrow irrigation is widely used, demands a huge primary investment, and requires uniform distribution; however, its water use efficiency never exceeds 60- 70% with an average of 50-55% and is influenced by such factors as furrow geometric parameters (lengths, slope, and cross-section), flow rate, plant age, and soil texture and structure [10]. In many regions, the furrow system has a low efficiency. Studies conducted on irrigation efficiency in sugarcane fields in Karun (Khuzestan Province, Iran) found irrigation efficiency of 50%. Unskilled irrigators, leaving water uncontrolled and night irrigation are regarded as major problems [11]. One study on sugar beet conducted in three farms in the areas Shahreiar, Hashtgerd and Kamalabad (Tehran Province, Iran) revealed water use efficiencies of 11, 57 and 41%, respectively [12]. However, using optimal management of furrow irrigation and adequate design, it is possible to achieve water use efficiency of 90% [13].

By changing the amount of inflow for furrow irrigation in Bundaberg, Australia the application efficiencyincreased by 45- 90% and the efficiency of distribution uniformity *(DU)* by more than 90% [14]. Rezaei and Sabouri [15] examined the impact of irrigation management on the water use efficiency of sugarcane in Khuzestan Province. In this study, soil moisture samples were taken before and after irrigation. In addition, input flows furrow, water advance time and water recession time were measured. Then, using the method proposed by Adamala et al [16], evaluation , including water use efficiency and the volume of water used, in two irrigation methods (controlled and uncontrolled) were calculated. The water use efficiency for the uncontrolled method was 34% and 52% for the controlled method on average. This shows that the existing irrigation system will operate relatively well with proper management. An accurate control of water distribution and reuse of runoff can increase irrigation efficiency by 70-85% [17].

Studies on irrigation efficiency in farm are gradually decreasing and more attention is paid to water management. On one hand, overall efficiency is dependent on the efficiency of agricultural water utilization and on the other hand is affected by changes during penetration. The current study was performed to evaluate the furrow irrigation system.

2. Materials and Methods

2.1. Study Area and Field Measurements

This research was conducted in a 4-ha (87 furrows) area of an experimental field cultivated with sugarcane in Khuzestan Province (Figure1). Furrow irrigation with the open-end and closed-end methods was evaluated, and simultaneously we qualitatively evaluated residual water for use in downstream irrigation.

Figure 1. Project location in map

2.2. Soil Physical Properties

To determine tissue type by hydrometer, soil texture compound samples were prepared from various depths of 0-100 cm. The overall soil texture type was silt loam. Bulk density (*bp*) was measured by sampling using metal rings of a certain volume. A hole was drilled to a depth of 1.5 m and a width of 1 m and four samples from depths of 0-25, 25-50, 50-75 and 75-100 cm were prepared and then transferred to the laboratory where samples were dried in an oven at 105°C. The *bp* of soil was defined using the modified Equation 1:

$$b\rho = Ws/Vs \tag{1}$$

Where Ws is dry weight soil and Vs is volume of soil (Table 1).

Table 1. Initial moisture of the points before irrigation and their physical characteristics

Number station	X	Y	weighted moisture before irrigation(open-end)	weighted moisture before irrigation(closed-end)	Soil bulk density (g/cm3)	moisture FC%
1	257015	3426992	20.5	20.65	1.6	25.45
2	256975	3426992	19.8	19.5	1.6	25.45
3	256935	3426992	20	19.85	1.6	25.45
4	256895	3426992	19.7	19.8	1.6	25.45
5	256855	3426992	20.25	20.175	1.6	25.45
6	257015	3426952	20.65	20.67	1.6	25.45
7	256975	3426952	20.12	21.6	1.6	25.45
8	256935	3426952	20	19.7	1.6	25.45
9	256895	3426952	20.4	20.32	1.6	25.45
10	256855	3426952	20.45	21.25	1.6	25.45
11	257015	3426912	20.125	20.3	1.6	25.45
12	256975	3426912	19.4	19.8	1.6	25.45
13	256935	3426912	21.3	22.05	1.6	25.45
14	256895	3426912	22.1	23.2	1.6	25.45
15	256855	3426912	21.3	23.07	1.6	25.45
16	257015	3426872	19.8	19.55	1.6	25.45
17	256975	3426872	20.87	20.82	1.6	25.45
18	256935	3426872	21.37	22.1	1.6	25.45
19	256895	3426872	20.47	20.97	1.6	25.45
20	256855	3426872	19.72	18.75	1.6	25.45
21	257015	3426832	20.65	20.67	1.6	25.45
22	256975	3426832	20.12	21.6	1.6	25.45
23	256935	3426832	20.8	19.7	1.6	25.45
24	256895	3426832	20.4	20.32	1.6	25.45
25	256855	3426832	20.45	21.25	1.6	25.45
26	257015	3426792	20.125	20.3	1.6	25.45
27	256975	3426792	19.42	19.8	1.6	25.45
28	256935	3426792	21.475	220.5	1.6	25.45
29	256895	3426792	22.17	23.2	1.6	25.45
30	256855	3426792	21.3	23.07	1.6	25.45
31	257015	3426752	19.82	19.55	1.6	25.45
32	256975	3426752	20.87	20.82	1.6	25.45
33	256935	3426752	21.37	22.1	1.6	25.45
34	256895	3426752	20.45	20.97	1.6	25.45
35	256855	3426752	19.72	18.75	1.6	25.45

2.3. Soil Moisture Surveys

Before each irrigation, soil moisture for each station besides spatial data as descriptive information for second layer input was prepared. Measurements of sugarcane roots were performed in the depth of 0-100 cm, and for each station before irrigation the moisture averages were considered for four layer 0-25, 25-50, 50-75 and 75-100 cm. In each evaluation, 140 samples before irrigation were sent to the laboratory to determine soil moisture by weighing each sample before and after drying in an oven at 105°C for 24 h. Then, soil moisture content was calculated using Equation 2 (Table 1):

$$Weight\ moisture = \frac{weight\ of\ wet\ soil - weight\ of\ dried\ soil}{weight\ of\ dried\ soil} \tag{2}$$

The difference between the moisture content before and after irrigation, and *bp* in the rooting depth, were used to determine the net irrigation depth (*In*):

$$In = bp \times MAD \times D_{rz}(\phi_{fc} - \phi) \quad (3)$$

In the above equation, *In* is in (cm), $Ø_{fc}$ is moisture weight at soil field capacity (decimal), *Ø* is moisture weight before irrigation *(decimal)*, D_{rz} is rooting depth (cm), *MAD* is permissible moisture depletion (0.65 as recommended by the Food and Agriculture Organization of the United Nations), and *bp* is ing/cm^3. Since the final goal in all irrigation systems is to raise soil moisture content to the desired amount, the field method was used to determine soil gravimetric moisture content in the study area at field capacity. To do this, the surface of part of the tested furrows (a length of 1.5-2 m) was covered with black plastic and consecutive samples taken after irrigation once every 12 h to determine the moisture content of the covered part until it became constant. The mean gravimetric moisture percentage at field capacity for the study area was 25, 45%.

2.4. Irrigation Operation

Irrigation operation was applied using the hydroflume irrigation system and through a 15-inch diameter polyethylene pipe, with outlet valves (2 inches in diameter) for each furrow (Figure2). The volume of water from outlet ports delivered into each furrow in each replicate was recorded. At the beginning of each experimental furrow, the inlet flow directly from the mouth of the hydroflume pipe was recorded at different times. An inlet flow hydrograph was constructed according to the time (h) and water flow (L/s) (Figure 3).

After irrigation in closed-end furrows, the same steps were repeated for open-end furrows. Following this operation, inlet flow to the furrow and runoff outlet at the end of the furrow were measured using the volumetric method and a hydrograph was drawn (Figure 4). Furthermore, according to the Wilcox chart, for classification for inlet water and tail water, three samples for analysis of water quality from input water and tail water during the experiment were taken: beginning, middle and end.

Figure 2. Hydro-flume with Adjustable out-let valves

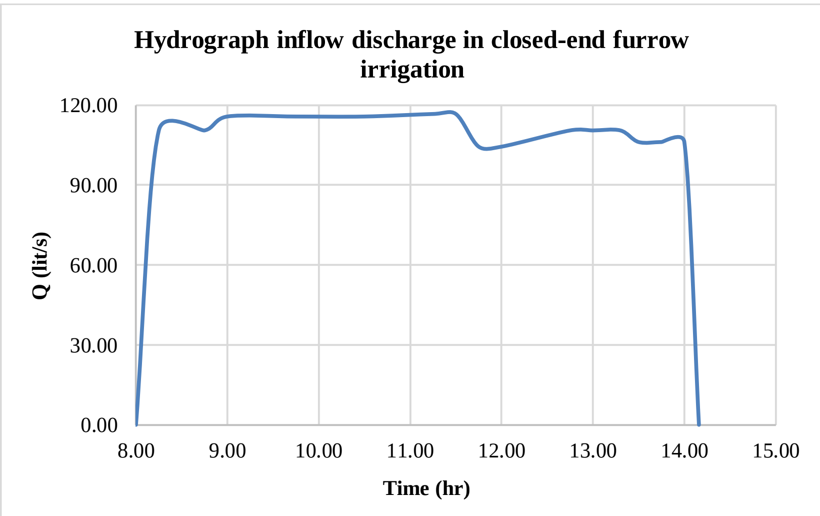

Figure 3. Hydrograph of inflow discharge for closed-end furrow irrigation

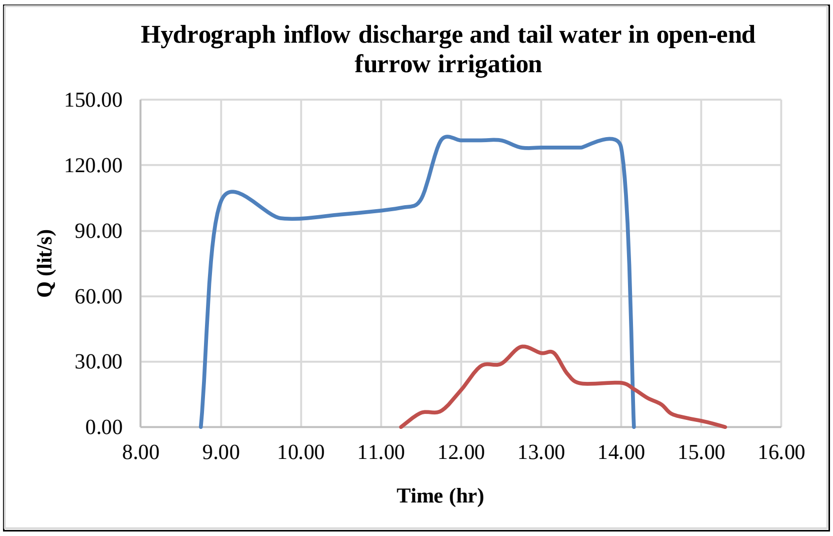

Figure 4. Hydrograph of inflow discharge and tail water for open-end furrow irrigation

Results of the following calculations show 12 percent of surface runoff left the study area at the end of the furrows because tail water was allowed to leave the field. In equation 3, I_{RO} is the depth of tail water that is obtained by dividing the area under the tail water curve by the surface area of the land under study.

According to the final tail water hydrograph (Figure 4), the percentage final tail water was calculated using the following equation:

$$I_{RO} = \frac{Area\ under\ the\ tail\ water\ curve}{Area\ of\ the\ land\ under}, I_{RO} = \frac{253.1}{38453.17} = 0.658\ cm \quad (4)$$

Where, I_{RO} is the depth of tail water, obtained by dividing the area under the tail water curve by the surface area of the land under study.

$$TWR = \frac{Depth\ of\ tail\ runoff}{Depth\ of\ inflow} = \frac{0.658}{5.5} \times 100 = 12\% \quad (5)$$

Where, *TWR* is the tail water runoff, obtained by dividing the depth of tail runoff by the depth of inflow study.

2.5. Assessment Indicators

Using the collected data, assessment indicators including irrigation efficiency (*Ea*), deep percolation ratio (*DPR*), coefficient uniformity (*CU*), and distribution uniformity (*DU*) were calculated.

$$Ea = \frac{In}{Ig} \quad (6)$$

Where, *Ig* is irrigation gross depth.

$$DPR = \frac{(Ig - In)}{Ig} \quad (7)$$

$$CU = 100 - [1 - \frac{sum\ of\ absolute\ differences\ between\ observed\ values\ and\ the\ mean}{sum\ of\ percolation\ values\ in\ all\ of\ the\ points}] \quad (8)$$

$$DU = 100 - 1.59(100 - CU) \quad (9)$$

$$TWR = 100 - Ea - DPR \quad (10)$$

2.6. Assessment by ArcView

As the areas under irrigation were small, the results of models used for assess furrow irrigation systems have always been viewed with skepticism, and assessment indicators have not always been accurate. However, using ArcGIS spatial analysis, geographic information system (GIS) users can create, query, map, and analyze cell-based raster data; perform integrated raster/vector analysis; derive new information from existing data; query information across multiple data layers; and fully integrate cell-based raster data with traditional vector data sources.

The 87 furrows of the field (160 m in width and 240 m in length), covering approximately 4 ha, were selected to evaluate open and closed-end furrow irrigation systems. Then, the examined area was surveyed and the map was designed using AutoCAD software, and finally an output DXF file imported as the first layer in the ArcView software for further examination (Figure 5).

40*40 networks were designed, 35 points inside the study area were marked, and the geographical coordinates of each point determined using a Garmin GPS device. These points were prepared as a spatial layer with UTM coordinates and DBF file in the Excel software (Figure 5).

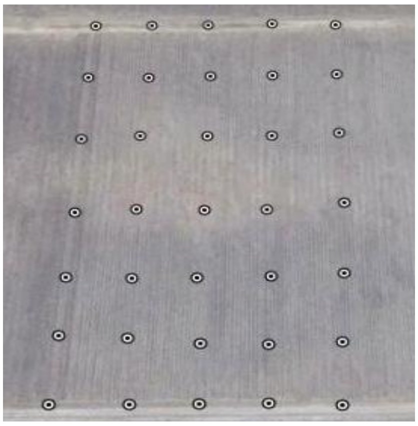

Figure 5. Location of the stations in the study area

3. Results and Discussion

3.1. Zoning Moisture Distribution for the Two Irrigation Methods

Results of zoning moisture distribution before irrigation showed similar moisture conditions for the two methods (Figures 6 and 7). The maximum area of moisture distribution for the open-end furrow method was in the interval 20.2-20.7% with a weighted mean of 21.06%, and correspondingly for the closed-end furrow was 20.256-21.142% and 21.65%. The reason behind higher values for the closed-end compared to the open-end method was the longer duration of water accumulation in furrows. It is noteworthy that soil moisture before irrigation greatly affects infiltrability: the greater the soil moisture before irrigation the less the infiltrability, and infiltrability increases with reductions in soil moisture. This point was very clearly observed for both irrigation methods.

3.2. Zoning Net Irrigation Depth (*In*)

The *In* before irrigation was almost the same for both methods and, in regard to percentage areas (Figures 8 and 9), the soil deficient moisture at the depth of 100 cm prior to irrigation was 3.99 cm and 3.38 cm in the open-end and closed-end methods, respectively Zoning indicated that's In was greater in the open-end compared to the closed-end method because in the former the water moisture content was lower due to the water having less time to infiltrate into soil and, hence, soil water requirement was greater.

3.3. Zoning Irrigation Application Efficiency

Figure 10 shows the white part at the start of the furrow, the yellow part, and the green part with irrigation efficiencies in the intervals of 0.828-0.985, 0.67-0.828, and 0.512-0.67 covered 29.16, 26.99, and 43.85 % of the studied area of the field for the open-end method, respectively; irrigation efficiency was within 0.512-0.985 with a weighted mean of 68% (Figure 10). Figure 11 indicates the white part at the start of the furrow, the yellow part, and the green part with irrigation efficiencies in the intervals of 0.741-0.9811, 0.472-0.741, and 0.203-0.472 covered 27.61, 41.13, and 31.26% of the studied area of the field for the closed-end method, respectively; irrigation efficiency was with in 0.203-0.9811 with a weighted mean of 48%. Thus, irrigation efficiency was 20% higher for the open-end, compared with the closed-end method. These results are in agreement with those obtained by Izadi et al [6], who studied irrigation efficiency in three plots, each with 20 adjacent furrows in a sugarcane field in the USA using continuous irrigation, reducing furrow flow rate, and surge irrigation. They reported efficiencies in the range of 40- 60%.

3.4. Zoning Deep Percolation Ratio (*DPR*)

Considering the *In* and *Ig* calculated above, the values of deep percolation in the two experiments were calculated and then, by repeating macro scripting in the ArcView software, DPR was obtained using equation 7. Figure 12 shows the white, the yellow, and the green part with the *DPR*s in the intervals of 0.33-0.488, 0.172-0.33, and 0.015-0.172 covered 43.76, 27.17, and 29.07 % of the area of the studied field for the open-end method, respectively; DPRs were in the 0.015-0.488 interval with a weighted mean of 20.2 %. Moreover, Figure 13 indicates the white part, the yellow part, and the green part with DPRs in the intervals of 0.528-0.797, 0.259-0.528, and 0.011-0.259 covered 31.31, 41.15, and

27.54 % of the studied field for the closed-end method, respectively; DPRs were within 0.011-0.797 and had a weighted mean of 52 %.

Considering the calculations and zoning above, the following relationship was established. The difference of DPR in the two techniques shows that a good irrigation practice results in decreased deep losses and also leads to increased irrigation efficiency. Our results are supported by those of Dalton [8], who increased irrigation efficiency from 50 to 90 % by decreasing deep losses.

3.5. Zoning Coefficient of Uniformity (*CU*)

Deep percolation values at every point in the two experiments were calculated considering the *In* and Ig calculated above, and then equation 8 was used by repeating macro scripting in the ArcView GIS environment to determine *CU*.

Figure 14 shows the white, the brown, the yellow, the light green, and the deep green parts with *CU* sin the intervals of 96.303-99.376, 93.236-96.306, 90.166-93.236, 87.096-90.166, and 84.026-87.096 covered 10.65, 34.46, 23.87, 27.84, and 3.18 % of the studied field for the open-end method, respectively; *CU* was within 84.026-99.376 with a weighted mean of 89.06 %. Figure 15 shows the white, brown, yellow, light green, and deep green parts with *CU* in the intervals of 83.339-98.934, 67.745-83.339, 52.15-67.745, 36.555-52.15, and 20.961- 36.555 covered 12.31, 48.25, 14.05, 18.94, and 6.45 % of the studied field, respectively; *CU* was within 20.961-98.934 with a weighted mean of 72.09 %.

3.6. Zoning Distribution Uniformity (*DU*)

The *DU* was obtained from equation 9 by considering the *CU* values in the previous section and by repeating macro scripting in the ArcView GIS software.

In Figure 14, the white, the brown, the yellow, the light green, and the dark green parts with *DU*s distribution uniformities in the intervals of 95.157-99.182, 91.132-95.157, 87.107-91.132, 83.082-87.107 and 79.057-83.082 covered 10.64, 34.47, 23.87, 27.84 and 3.18 % of the studied field for the open-end method, respectively; *DU* was within 79.057-99.182 with a weighted mean of 88.92 %. Figure 15 indicates the white, the brown, the yellow, the light green, and the dark green parts with distribution uniformities in the intervals of 83.339-98.934, 67.745-83.339, 52.15-67.745, 36.555-52.15, and 20.961-36.555 covered 7.13, 45.59, 18.25, 22.1, and 6.93 % of the studied area for the closed-end method, respectively; *DU* was within 20.961-98.934 with a weighted mean of 68.11 %. This almost 20 % superiority confirmed one point that is one of the factors involved in promoting the use efficiency and increased *DU*. In the study of Baillie [14], changing the amount of inflow to furrow increased the application efficiency by 45- 90% and resulted in a *DU* of more than 90%.

3.7. Qualitative Analysis of the Tail Runoff and Inflow Discharge

Results showed that water quality did not change and was of class S_2C_4 in the inflow and in the tail runoff. This result and those from section 3, indicate that, the open-end furrow method increased irrigation efficiency, due to the exit of tail runoff from the field, and preserved the water quality (as shown in the Wilcox diagram). Therefore, the tail runoff could be reused for irrigating other land, which would further increase productivity of the tail runoff.

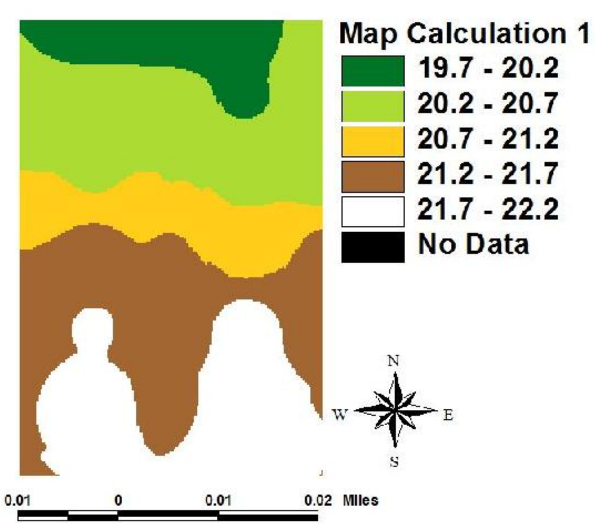

Figure 6. Moisture distribution in open-end furrows

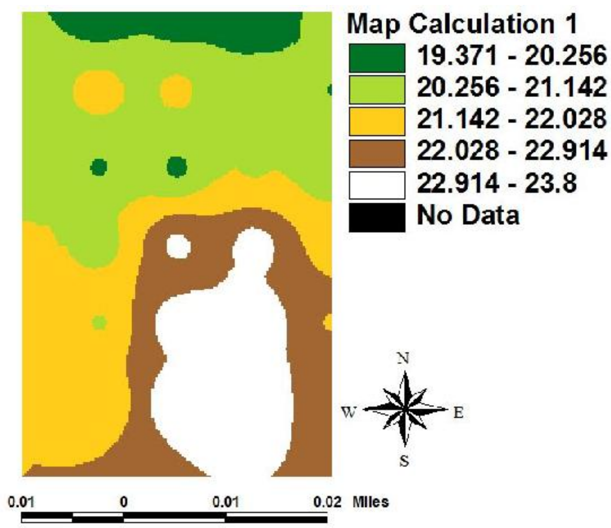

Figure 7. Moisture distribution in closed-end furrows

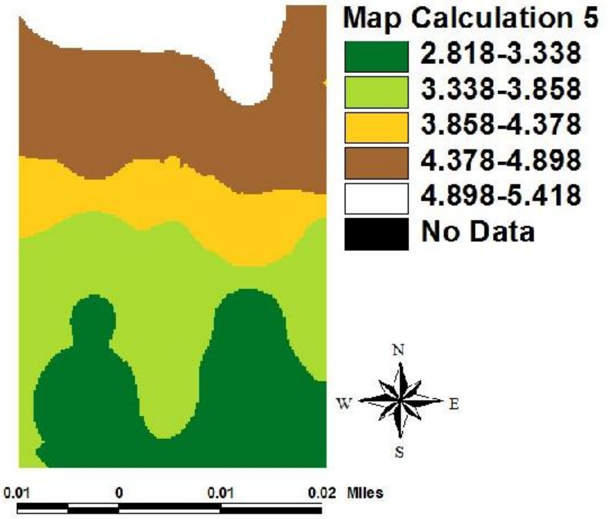

Figure 8. Distribution of net irrigation depth in open-end

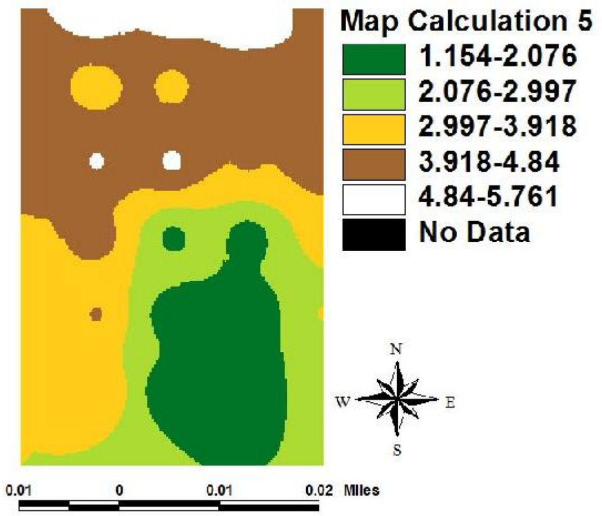

Figure 9. Distribution of net irrigation depth in closed-end

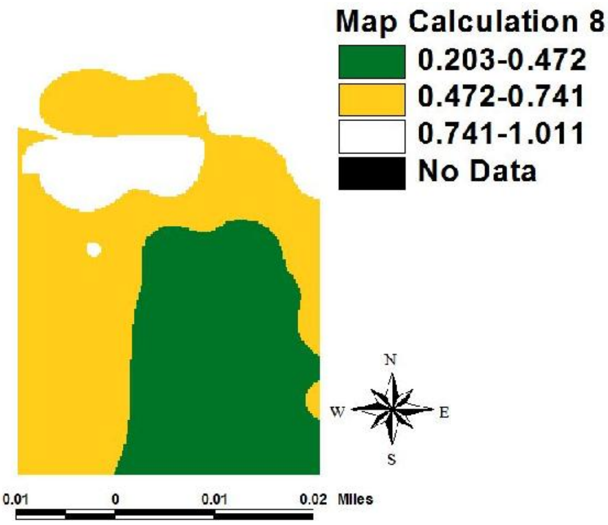

Figure10. Irrigation efficiency distribution in open-end

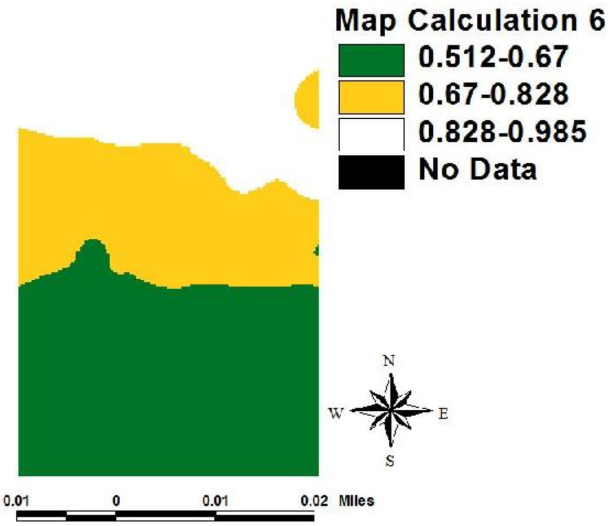

Figure11. Irrigation efficiency distribution in closed-end

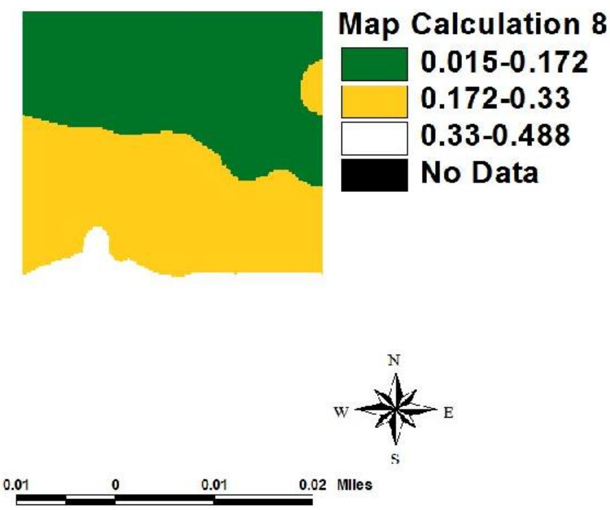

Figure12. Deep percolation in the open-end

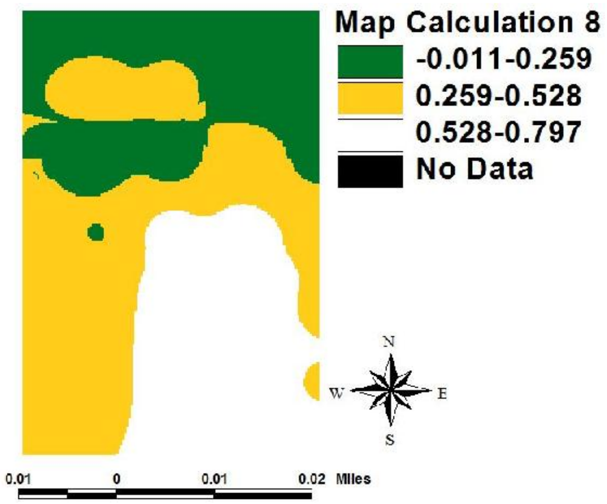

Figure 13. Deep percolation in closed-end

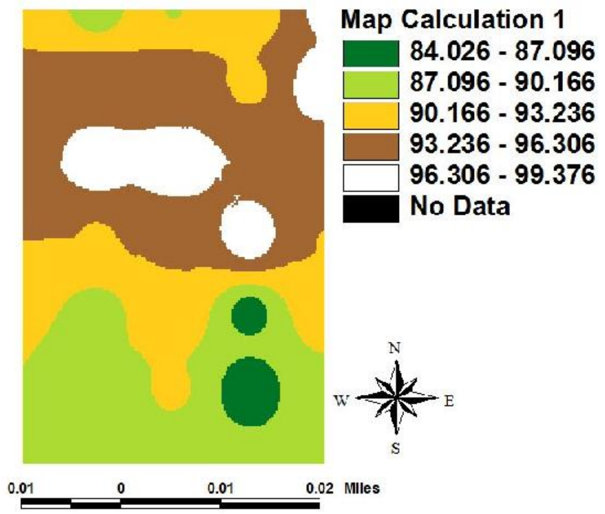

Figure 14. Distribution of uniformity and uniformity coefficient in open-end

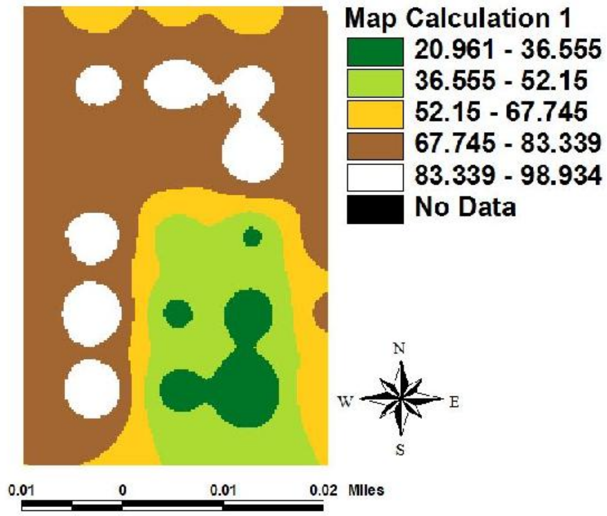

Figure 15. Distribution of uniformity and uniformity coefficient in closed-end

4. Conclusion

Irrigation of the furrow surface using the open-end method was more efficient (68 %) than the closed-end method (48%). This resulted in the open-end method having 73% of the total area with efficiency of 47 %, while 68 % of the closed-end area had efficiency above 67% (Figures 10 and 11). The closed-end of the furrow caused accumulation of water in the end of the field, increased the deep losses, and reduced irrigation efficiency. Our calculation showed that the amount of runoff from furrows was 12 % and this value with the value of tail water measured in the open end of quite equal. This data classification accuracy of this model also confirmed the accuracy of field data. *DPR* in the 44% of the total area in the open-end was in the range of 33 - 48 % and 31% of the total area in the closed-end was within 53 - 80 %. This data represents increased deep losses for the closed-end method. With water entering into the deep soil, water quality changes and drainage water causes high costs from environment pollution and river salinization. For the open-end method the *CU* had a weighted average of 89.06 %, but that for the closed-end was 72.09%, which represented 20% improvement and confirmed that the correct implementation of irrigation reduced runoff and increased efficiency of irrigation. For the open-end method *DU* had a weighted average of 92.88 % and 68.11% for the closed-end, this difference showed that the influence of *DU* between the deep infiltration and the efficiency. It should be noted that the lack of tangible change in water quality class at the downstream (for the open-end) means that the runoff could be used for other surface irrigation. In this regard, the reduction of deep losses with the open-end method made it more effective than the existing closed-end method**.**

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