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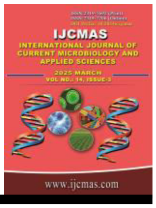

Original Research Article

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Comparison of Amount of Water Percolation and Evaporation in Sprinkler and Surface Irrigation Systems

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ABSTRACT

Increasing demand for water consumption and tensions resulting from negative balances in water basins have doubled the need for optimal water consumption. This project assessed the efficiency of water application, water use efficiency indices, and water losses in sprinkler and surface irrigation systems to enhance water utilization. Two lysimeters with under-cultivating alfalfa were investigated for water losses within the irrigation systems. The water balance equation method was applied to compare the water budget components in the irrigation systems. The results showed that the average water use efficiency and field water application efficiency in sprinkler and surface irrigation systems were 5.91 and 2.06 kg/m³ and 83 and 45 percent, respectively. The average deep percolation compared to the irrigation water in sprinkler and surface irrigation systems was 35.15 and 53.50 percent, respectively, while the evaporation rates were 61.1 and 45.7 percent. Water consumption in the sprinkler irrigation system was 12.2 percent less than that of the surface irrigation system. However, deep percolation in surface irrigation was 42.2 percent greater than in sprinkler irrigation, and evaporation was 15.4 percent higher in sprinkler irrigation. When comparing water use efficiency in sprinkler and surface irrigation systems at a 5 percent significance level using a t-test, a significant difference was observed, while no significant difference was found between dry and wet yields.

Keywords

Components of water balance, sprinkler and surface irrigation systems, water use efficiency, losses in irrigation water

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Introduction

As water demands increase and the negative water balance affects more regions of Iran, discussing and studying the optimization and sustainable use of water resources is essential. Surface and subsurface water resources were limited due to seasonal flows and runoff. However, the implemented controls, advancements in technology, and increased activities have minimized changes and climate confusion. Over time, the agricultural sector's ability to harvest water for community food production has consistently faced serious challenges. Water in the agricultural sector is one of the main factors of production that should be guided and distributed by irrigation systems at the farm and available for the area of plants' roots. Shortage of water resources and increasing water demands are among the factors that affect no equilibrium of water balance in each region (Alimohammadi, 2017). One of the objectives of sprinkler irrigation systems is to increase water use efficiency and reduce the amount of water extracted from water resources and to strengthen those water resources. Sprinkler irrigation systems spray water into the air by sprinklers, and the arrival of water sprayed on the surface of the plant and the soil until it is absorbed by the plant, have need to go through different stages and spend time. At this time interval, such factors as solar radiation, temperature, airflow, plant type, soil structure & texture will convert a percentage of the output water from sprinklers to water losses (evaporation, wind drift, and deep percolation). Depending on the soil and plant characteristics, a percentage of water reaches the soil and plant surface. In some cases, a percentage of that exits from the plant availability by deep percolation or runoff. But in surface irrigation, the amount of evaporation is less than in the sprinkler irrigation system. Deep percolation and runoff losses in surface irrigation are more than those in sprinkler irrigation. The volume of water deep percolated is continuously added to groundwater and to be improved the reservoir water aquifers (Howell, 2003 and Tanji and Kielen, 2002; Howell and Event, 2005). These waters are not water losses because they can be reused. Sammis, in a study at the University of New Mexico, compared yield and water use efficiency among current irrigation systems and confirmed that the Surface irrigation method has less water use efficiency than the sprinkler irrigation system; this was due to more water consumption (Sammis, 1980). Deep percolation did not cause water losses because it added to groundwater resources and included water return flow. This volume of water is added to water resources (Kang and Park, 2014). In an analysis of the factors affecting evapotranspiration, yield, and economic performance of corn that they did under different irrigation conditions concluded, the low irrigation option had higher water productivity (Paredes *et al.,* 2014). The evaporation rate in sprinkler irrigation is dependent on complex parameters, including meteorological parameters and soil plant water status. The energy issue in this process was very important, and energy transfer can be done from adjacent areas that are dry or wet and to be effective in amount of evaporation (Hancock *et al.,* 2015). They approved that water losses play an important role in optimizing water consumption in sprinkler irrigation systems. To predict and estimate the exact amount of water losses in sprinkler irrigation systems was the aim of the artificial neural network and multiple linear regression models. The results showed that the model of artificial neural networks for the prediction of water losses was better than multiple linear regression (R = 0.943) (Al-Ghobari *et al.,* 2018). Yazar, by doing research in Nebraska University, stated that Irrigation water losses in sprinkler water irrigation systems were respectively include evaporation and wind drift loss. The amount of water loss was equivalent to 30.7 percent of applied water (Yazar, 1984). During the research on yield crop and water use efficiency of sugar beet in furrow and sprinkler irrigation methods in Kamalabad, Karaj, Iran, by applying treatments of irrigation water based on farmer's custom and water requirement by Penman-Monteith method. They concluded that Sprinkler irrigation has a 31 percent reduction in irrigation water consumption and a 55 percent increase in water use efficiency (Haghayeghi *et al.,* 2005). In Khorasan province, operation of pressurized irrigation methods determined that the average of irrigation efficiency in under conduit irrigation systems was 55.5 percent. However, due to the limited amount of water available, a high-efficiency irrigation system in the area is necessary (Ebrahimi, 2006). A few researchers calculated the parameters of the Kostiakov and Kostiakov-Lewis penetration equations for surface irrigation systems, and the results indicated the high accuracy of the corresponding equations. So that, the volume of water infiltrated with the Kostiakov and Kostiakov-Lewis equations compared to the inlet and outlet hydrographs flows to the furrow were 2.9 and 7.6 percent, respectively (Kefayati1 *et al.,* 2008). In Jiroft, Iran, it was confirmed that the highest water use efficiency for alfalfa was 2 kg per cubic meter, and water use efficiency was reduced by applying water stress. However, due to the problems and limitations of water resources in the region, if alfalfa was not irrigated in August, there was no significant difference in yield. And water use efficiency was also improved (Afsharmanesh *et al.,* 2008). In a nationwide study, it was calculated for products such as wheat, sugar beet, potatoes, forage corn, and alfalfa (dry). The results were 0.73, 4.56, 2.18, 5.58, and 1.46 kilograms of crop production in exchange for every cubic meter of water consumption, respectively, and an average of water use efficiency throughout Iran was estimated to be 1.38 kg / m3 (Heydari, 2012). In Mahabad, West Azerbaijan, Iran, they concluded in the evaluation that the average loss due to evaporation and wind drift loss was 12.3 percent, deep penetration was 13.4 percent, and total losses were 25.7 percent. The uniformity coefficient of Christiansen and the distribution uniformity were estimated to be 66.4 and 52.2 percent, respectively (Sivase Mardeh and Bayazidi, 2011). In evaluating the operation of the sprinkler irrigation system (GAN), it was approved that the water uniformity coefficient, water use efficiency, and evaporation with wind drift losses were 65.1, 48.8, and 2.5 percent (Doust Mohammadi *et al.,* 2014). The sprinkler irrigation systems would help improve groundwater resources if they do not extend the cultivating surfaces area, otherwise, groundwater resources would be sharply reduced (Alizadeh *et al.,* 2014). The average Water spray losses and deep infiltration in sprinkler irrigation systems in the Khorramabad region were 13.2 and 30.1 percent, respectively (Mikhak Beiranvand *et al.,* 2015). By assessing the effects of increasing irrigation efficiency in conditions without increasing the area under cultivation and development cultivation area, water consumption can be saved up to 43 percent (Batoukhteh *et al.,* 2016). In the comparison of Water use efficiency and yield indexes in sprinkler and furrow irrigation systems, it was concluded that water use efficiency in a sprinkler irrigation system was more than surface irrigation system (30 percent) and deep percolation in surface irrigation was higher. Crop yield in sprinkler irrigation was 64.5 percent more than surface irrigation system (Al- jamal, 2001). The sprinkler irrigation systems have a significant effect on lowering air temperature and air pressure in the region, also, the amount of evapotranspiration measured in surface irrigation was more than the sprinkler irrigation system (Liu and Kang, 2006). In the dry and semi-dry regions, optimization of water supply-demand management could save up to 42 percent in water consumption (Moghaddasi *et al.,* 2010).

By investigating the Effect of sprinkler Irrigation Management in the Spanish Reguero Basin using the water balance method and the calculation of inlet, outlet, actual evapotranspiration, wind drift losses, and evaporation losses, it was concluded that water use efficiency for alfalfa was 81 percent (Zahiri and Echmi, 2012). In the trajectory of transferring water from sprinklers to the canopy, amounts of that water are converted to evaporation. And after irrigation, the residual water on the canopy converted to evaporate again, and this difference was Significant (Uddin *et al.,* 2013). The water use efficiency index for wheat and saffron in the surface irrigation method were calculated, and the results were 0.36 and 0.002 kg / m3, respectively. Much of the water used has been spent for evaporation and deep percolation. The performance of optimal consumption and sustainable water management was necessary to achieve increasing the water use efficiency and water saving (Yaghoubi *et al.,* 2016). A few researchers in northwest of China confirmed that changing the irrigation method from traditional to modern dropped the amount of evapotranspiration and had significant effects on consumption and water saving (Han *et al.,* 2017). To cope with water scarcity in northeastern Syria, a comparison of surface and sprinkler irrigation systems for wheat production was done by multi-criteria analysis. That economic efficiency index in sprinkler irrigation systems was more than surface irrigation systems (Darouich *et al.,* 2017). We could improve somewhat of water use efficiency by deficit irrigation management (Li and Su, 2017). According to studies conducted, water use efficiency in sprinkler irrigation systems has been more than surface irrigation systems. Therefore, to evaluate water consumption in sprinkler and surface irrigation systems, in this research, water losses (deep percolation, wind drift, and evaporation) in both systems were investigated with a more detailed analysis.

Materials and Methods

This research has been carried out in the Chahartakhteh Research Station, Shahrekord, Iran, from 2012 for three years. The station was located at 50°, 56 ' E longitude and 32°, 18 ' N latitude at an altitude 2073 meters above sea level. According to the Gaussian method, this region has a cold steppe climate, and according to the Amberjeh method, it was an arid region. The average annual precipitation was 295 mm, the warmest month's temperature reached a maximum of 39 °C, and the coldest month reached a minimum of -27.8 °C. The dry period is more than six months old, and the average relative humidity and the evaporation rate in this station were 27.5 percent and 1709.9 mm per year, respectively.

Samples were taken from different layers in the soil laboratory of the research center to determine soil texture, field capacity, wilting point, and available water, and they were analyzed for the required parameters in the soil laboratory of the research center. In this project, two gravitation Lysimeters, soil properties of Lysimeter no. 1, with field capacity, wilting point, and bulk density were 19.5, 10.8 percent, and 1.6 gr/cm3, respectively. In lysimeter No. 2, the values were 13.6, 8.1 percent, and 1.36 gr/cm3. Volumetric soil water content (WC) was measured at different depths in access tubes (0-30, 30-60, 60- 90, 90- 120, and 120- 150, (cm) one day after irrigation. There were four sprinklers at four corners of each plot (25×24 meters), for determining the amount of water amount reached on the ground surface (canopy) used of the network include 64 plastic catch cans. During the irrigation period, the operating time of the system was measured. The system operating pressure was 6 atmospheres, and the sprinkler type was Ambo with discharge 2.625 lit/s. After every irrigation, the volume of water inside the plastic cans was measured and recorded. The height of the water sprayed by the sprinklers was calculated by considering the spraying time, discharge, spray rotation radius, number of sprinklers, and ground area.

The water heights reached on the ground surface by converting the water volume into the cans to the water height and averaging them. With the Use of the Kristiansen method, the distribution uniformity coefficient in the field.

Water Application Efficiency (AE)

The Water Application Efficiency indicates the water use efficiency in the field. The water volume stored in the root zone used by the plants is less than the amount of water entering the farm, and Water Application Efficiency was calculated from the ratio of these values (Shirazi *et al.,* 2011).

$$AE = \frac{d}{d_r} \times 100 \quad \text{.....(1)}$$

d Average depth of water stored in the root zone (mm),

d_r Average depth of water applied in the field (mm).

Water Distribution Uniformity (DU)

The uniformity coefficient of water distribution is the expression of its numerical value in the field, and that is suitable criteria for determining the uniform distribution of water in the field. The amount of that is relative and usually should be above 67 percent, if its value will be lower than 67 percent, it is unacceptable. The low value of the uniformity coefficient of water distribution indicates low water use efficiency and water losses as percolation (Christiansen, 1942; Merriam and Keller, 1978).

Where: dq is the average of the lowest 25 percent of applied depths.

$$DU = \frac{d_q}{d} \times 100 \quad \text{....(2)}$$

The amount of evapotranspiration based on soil water balance was measured (all units are in millimeters) (Pruitt and Angus, 1960; Sammis, 1980; Andreja, 1957; Kuzin, 1970; Sokolovski, 1968; Ridder and Boonstra, 1994). Water balance for the lysimeter was used in the following equation (3).

$$ET = P + I - Dp \pm \Delta S \ \text{...(3)}$$

Where ET is evapotranspiration, P is precipitation, I is Irrigation water, Dp is water drainage from Lysimeter, ΔS is a change in soil water storage inside the lysimeter.

The water losses of evaporation and wind drift (WDEL, %) were calculated from the following equation (4).

$$WDEL = \frac{D_N - \bar{D}}{D_N} \times 100 \ \text{...(4)}$$

Where D_N is the average depth of outflow rate from sprinklers (nozzles), $\bar{D}$ is the average water depth reached on the ground surface.

The amounts of measured evaporation (class A pan) in duration of project performance were 2115, 2015 and 2113 millimeter per year, respectively. And for converting these data to potential evapotranspiration, use of class A pan coefficient (Doorenbos and Pruitt, 1977). In the surface irrigation system, the length and width of each Furrow was 115 and 0.6 meters. A few parameters, including irrigation water height, drainage water height, and soil moisture at different depths, were measured before and after each irrigation at lysimeters. The volumes of inflow, outflow, and infiltration at each furrow were calculated with monitoring of inlet flow rate, outflow rate, and flow duration by use of hydrographs (Walker and Skogerboe, 1987; Skogerboe, 1969).

$$V_i = \sum_{i=1}^{n} Q_i \times \Delta t_i \ \text{...(5)}$$

$$V_o = \sum_{o=1}^{n} Q_o \times \Delta t_o \ \text{...(6)}$$

$$V_f = V_i - V_o \ \text{...(7)}$$

$$Q_i = 0.0037 \times H^{2.646} \ \text{...(8)}$$

Where V_i Input volume to furrow, V_o outlet volume of each furrow (liters), V_f volume of infiltration water per each furrow (liter), Q_i inlet flow rate to furrow (l/s), Q_o outlet discharge from each furrow (l/s), Δt_i Duration of inlet flow rates, seconds, Δt_o Duration of outlet flow rates, seconds, Q_I Flow rate measured by flume type I, H water height in flume (cm).

The basis for calculating the water requirement of the plant was the Penman-Monteith equation (Allen *et al.,* 1998), irrigation water amount and interval were used of customary laws in the region for both systems. Furrows have the same geometric dimensions. Each furrow was individually irrigated using a WSC (Washington State College) type I flume, and the volume of water required was calculated by considering the soil moisture deficiency and the cross-sectional area of the furrow. Soil moisture depletion coefficient was considered according to the type of plant (Alfalfa) and soil texture (55 percent). (Iranian National Committee on Irrigation and Drainage, 2003). The outflow runoff of the furrows was measured by type I flume. Soil moisture content was measured by TDR (Time Domain Reflectrometry) at different depths (0- 30, 30- 60, 60- 90, 90- 120 cm). The water balance equation was used in equation 9, for the surface irrigation system (Sokolov and Chapman, 1974):

$$V_i = V_s + V_f + V_o \quad \text{.... (9)}$$

Where Vs is the Surface water storage volume (cubic meter), inflow water volume was calculated using input hydrograph area from inlet flow time since cutting flow (t) using trapezoidal rule numerical integration method, outflow water volume was calculated same as inlet water volume using the output hydrograph.

Water application efficiency

The field application efficiency used of the ratio of the water consumed by the plant to water delivered to the field, equation 10 (Irrigation Association of Australia (IAA), 1998; Jensen, 1967; Burman *et al.,* 1981 and Jensen, 2007). The most important factors affecting the field water application efficiency in surface irrigation systems were including; root zone depth, dimensions of borders, inlet flow rate and termination of the irrigation time. The, appropriate selection of these parameters is very effective in calculating the field water application efficiency (Gillies *et al.,* 2008).

$$E_a = \frac{V_m}{V_f} \times 100 \ \dots (10)$$

Where E_a is field water application efficiency (percent), V_m is crop water requirements (m^3), and V_f is water delivered to the field (m^3).

Water use efficiency

Water use efficiency (WUE, kg/m3) is the ratio of the crop yields (Y, kg) to the volume of irrigation water consumed (V, m3) used in Equation (11).

$$\mathrm{WUE} = \frac{Y}{V} \ \dots (11)$$

Data were analyzed by SPSS software and t-test.

Results and Discussion

The alfalfa water requirement was estimated at 877 mm from mid-April to November. According to the calculated indices for sprinkler irrigation systems in Table 1, the mean water reached at the ground surface was 67.90 mm, but sprayed water depth on the field surface was 76.42 mm, which an average of 8.52 mm or 11.15 percent was water losses at the dropped trajectory. The average distribution coefficient of uniformity was calculated to equal 71.5 percent, and the difference between the average depth of the minimum quarter intake of plastic cans and to the average depth of water received on the ground surface was 67.29 percent (Table 1).

The amounts of Applied water, evaporation, and deep percolation in both irrigation systems (Lysimeter No. 1, sprinkler irrigation and Lysimeter No. 2, furrow irrigation) were presented in Table 2. The results showed that, in the first year, the irrigation water depth in lysimeter I was 1096/18 mm, including evapotranspiration 738.73 mm, 77.27 mm was used for increasing soil moisture, and 280.18 mm due of deep percolation.

The drained water (deep percolation) than to irrigation water in Lysimeter No. 1 during three years of project implementation were 25.5, 23.2 and 49.9 percent, and in surface irrigation were 52, 57 and 51 percent. If taken as a weighted average of the drained water in sprinkler irrigation (Lysimeter 1), then to the amount of applied water during the implementation of the project was 35 percent. In surface irrigation (Lysimeter 2) was 54 percent and the results indicated the deep percolation in surface irrigation was more than sprinkler irrigation (Figures 1 and 2).

The depth of water consumed (Reached on the ground surface) in the sprinkler irrigation at the first, second, and third years were 1096, 1138, and 1645.73 cubic meters per hectare, and the quantities of applied water were always more than the calculated evapotranspiration. The infiltrated water volume than to the water volume of inlet flow in the surface irrigation were in the first year, 52, second year 57 and in the third year of project implementation was 51 percent (Figure 2). The water amount of deep percolation was a function of the input flow to each furrow. The average of infiltration water volume to the volume of inflow in the duration of the performance project was 53.5 percent. The average of water use efficiency for dry forage production in sprinkler irrigation systems that to surface irrigation systems was 2.49 times. The average of water application efficiency during the three years of project implementation in the sprinkler irrigation system was 81.2 percent, and in the surface irrigation system (furrow), it was 45.2 percent. In general, water use efficiency in sprinkler irrigation was more than surface irrigation system. The water use efficiency in sprinkler irrigation system than to the surface irrigation systems was 1.79 times. The results of water use efficiency in sprinkler and surface irrigation systems were presented in Table (3) for dry and wet crop production. Water use efficiency for sprinkler irrigation was 6/6, 6/39 and 4/76 kg wet forage production, for the first, second and third years of project implementation respectively, with an average of 5.91 kg/m3. But for the production of dry forage were respectively, 2.75, 1.85, 1.14 and 1.9 kilogram per cubic meters. Water use efficiency in surface irrigation system were 2.48, 2.89 and 2.43 with average was equal 2.6 kg (wet)/m^3 and 0.85, 0.91 and 0.54 with average 0.76 kilogram of dry crop production for each cubic meter water consumption.

The results showed that water use efficiency in sprinkler irrigation systems was more than surface irrigation system (furrow). In such a way that water use efficiency in sprinkler irrigation systems than to surface irrigation systems were 2.85, 2.21 and 1.96 times in the first, second and third years respectively. Average of water use efficiency in sprinkler irrigation systems was 5.91 kilograms per cubic meter (wet forage production). In surface irrigation systems, average water use efficiency was 2.60 kg / m3. These values were 1.90 and 0.76 kg / m3 for crop dry yield in sprinkler irrigation and furrow irrigation systems. This, average of water use efficiency was 2.5 times, for dry forage production in sprinkler irrigation systems than to surface irrigation systems.

Water application efficiency for sprinkler irrigation system was 0.97, 0.85, and 0.62, and in surface irrigation were 0.65, 0.33, and 0.38 respectively, years of project implementation (Table 4). In the comparison of water use efficiency average in sprinkler irrigation and surface irrigation systems, there was a significant difference at 5 percent level with t-test. There were a few differences between the wet and dry yields, but there were no significant differences between them. Water use efficiency showed a significant difference at the level of 5 percent of T the test in dry and wet yields of alfalfa in sprinkler and surface irrigation systems (Table 5).

By optimizing water usage in exchange for higher yield and crop production, water use productivity can be enhanced. To ensure optimal water use, any loss of water, whether from deep infiltration or evaporation, should be avoided. In this context, this project compared two irrigation methods: rainfall and flood irrigation. The results showed that the water use efficiency index in sprinkler systems was 2.8 compared to surface irrigation. And the water use efficiency in the field also shows a twofold increase in sprinkler irrigation compared to surface irrigation. This is consistent with the studies of Afsharmanesh *et al.,* (2008) and Al-Ghobari *et al.,* (2018). The depth percolation in surface irrigation was 1.5 times that of sprinkler irrigation, but the evaporation rate in the sprinkler irrigation system was 1.3 times that of the surface irrigation system. The results are consistent with those of other researchers (Al-Ghobari *et al.,* 2018; Ebrahimi, 2006; Al-Jamal *et al.,* 2001 and Rana *et al.,* 2006).

This project was implemented to analyze accurately the components of the water balance equation in lysimeters using two irrigation methods: sprinkler and surface. Irrigation was carried out according to the traditional practices of local farmers. The amount of evapotranspiration was somewhat dependent on the volume of water applied. In the case of sprinkler irrigation, water loss amounted to 11.23 percent, and deep percolation relative to the applied water was 35 percent, whereas in the surface irrigation system, it was 54 percent. This indicates that deep percolation in surface irrigation was greater than in the sprinkler irrigation system.

Table.1 Sprinkler irrigation systems assessment indexes

Years	D (mm)	DU (%)	Dr (mm)
first	60.15	70.56	69.72
second	64.97	68.26	73.28
Third	78.59	74.34	86.27
Average	67.90	71.05	76.42

Table.2 Amount of irrigation water and drainage in lysimeters (furrow and sprinkler irrigation)

Years	Lysimeter 1 (sprinkler irrigation) mm				Lysimeter 2 (furrow irrigation) mm			
	Irrigation water	Drained water	evaporation	Change moisture	Irrigation water	Drained water	evaporation	Soil moisture change
2011- 12	1096.2	280.2	738.73	77.27	981.37	510.22	470.64	00.51
2012- 13	1147.4	265.9	814.01	67.40	1567.47	894.01	673.16	00.30
2013- 14	1645.7	822.1	821.92	01.60	1881.03	965.54	883.09	32.40
Mean	1296.4	456.0	791.60	48.80	1476.60	789.90	675.60	11.07

Table.3 Water use efficiency in sprinkler and surface irrigation systems.

Year	Sprinkler irrigation system (kg/m^3)		Surface irrigation system (kg/m^3)	
	wet	dry	wet	dry
first	6.58	2.75	2.48	0.85
second	6.39	1.82	2.89	0.91
Third	4.76	1.14	2.43	0.54
Average	5.91	1.90	2.60	0.76

Table.4 Water Application Efficiency in sprinkler and furrow irrigation systems.

Years	Sprinkler irrigation system (m^3/m^3)	Furrow irrigation system (m^3/m^3)
first	0.970	0.653
second	0.847	0.325
Third	0.620	0.378
Average	0.812	0.452

Table.5 Comparison of the means of water application, water use efficiency and Crop yield in different irrigation systems.

Irrigation systems	Water Application Efficiency (m^3/m^3)	Water Use Efficiency (kg/m^3)		Yield (kg/ha)	
		dry	wet	dry	wet
sprinkler	0.930^{a}	2.714^{c}	7.390^{e}	8762^{a}	29202^{b}
surface	0.755^{b}	0.981^{d}	3.060^{f}	9008^{a}	26509^{b}

Figure.1 Various amounts of water balance components in lysimeters 1 and 2.

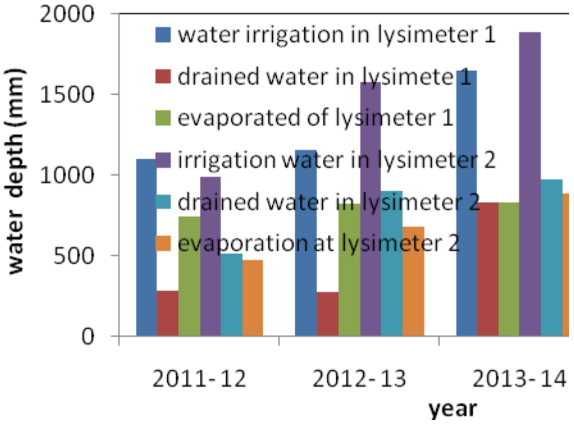
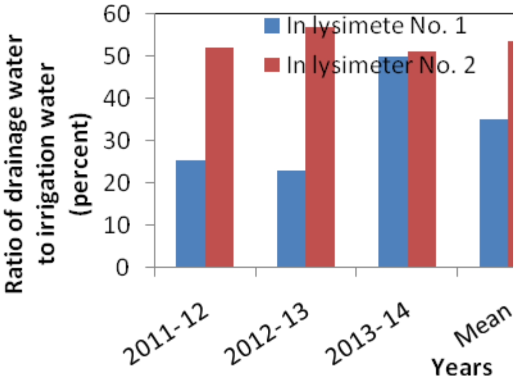


Figure.2 The amount of drained water (deep penetration) compared to irrigation water in lysimeters 1 and 2.



The amount of irrigation water applied and deep percolation in surface irrigation were 12.2% and 42.2% higher than in the sprinkler irrigation system. Water use efficiency in the sprinkler and surface irrigation systems was 5.91 and 2.60 kilograms per cubic meter, respectively (2.27 times for wet forage production and 2.5 times for dry forage production). In the sprinkler irrigation system, the water use efficiency for wet crops compared to the water use efficiency index for dry crops was 3.11, while in surface irrigation systems, it was 3.42. Water application efficiency in the sprinkler and surface irrigation systems was 83% and 45%, respectively. Water application efficiency in a sprinkler irrigation system is greater than that of a surface irrigation system, with a value of 1.48.

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Author Contributions

Rahim Alimohammadi Nafchi: Investigation, formal analysis, writing—original draft.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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