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THE EFFECT OF SUBSURFACE DRIP IRRIGATION DESIGN ON WATER USING EFFICIENCY AND THE ALFALFA YIELD IN SOUTHERN IRAQ DESERT REGION

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Abstract

A field experiment was carried out during the agricultural season 2018-2019 in a desert soil located in the southwest of Al-Diwaniyah Governorate, southern Iraq, to study the effect of distances and depths of subsurface drip lines on water use efficiency and alfalfa yield. The experiment was designed according to the Nested design method with three replicates, the experiment included the distances of drip lines (50, 75 and 100 cm), and the depth of drip lines (20 and 40 cm) in addition to the comparison treatment (surface irrigation treatment). An evaluation of the irrigation system was carried out before planting for calculating the discharge rate, uniformity coefficient, and discharge variations, while the Alfalfa seeds a local variety were planted on 29/10/2018 in the form of lines and the distance between them 20 cm.
The results indicated an increase in the values of uniformity coefficient with the increase in the operating pressure, where the uniformity coefficient reached 96.23, 95.33 and 97.78% for the distances 50, 75 and 100 cm for the pressure of 60 Kpa. Furthermore, the results indicated that the yield of dry matter and green forage decreased with increasing distance between the drip lines, and the highest water use efficiency for dry matter and the green forage yield at the treatment of distance 50 cm and depth of 20 cm reached 0.0066 and 0.0198 ton ha^{-1} mm^{-1}, respectively. Finally, the use of a subsurface drip irrigation system resulted in the provision of irrigation water at a rate of 18.23% compared to the surface irrigation system.
Keywords: Subsurface drip irrigation system, Uniformity coefficient, Water use efficiency, Alfalfa yield

Introduction

The central and southern regions of Iraq lies within the conditions of the dry environment, as the rate of rainfall does not exceed 400 mm annually, it is among the lands covered by desertification. However, more than 90% of the Iraqi lands are affected to one degree or another by one of the desertification operations to varying degrees, for several reasons, including climate change, low rainfall, and misuse of natural pastures. As well as, the overgrazing and urban sprawl at the expense of agricultural lands, the use of unsustainable farming methods and poor irrigation operations, low levels of surface water flowing into the Iraqi rivers. (National Action Program to Combat Desertification in Iraq, 2018). The lack of irrigation water is one of the most important factors that affect crop productivity, at the same time; there is an increasing demand from humankind for water resources, especially in arid and semi-arid regions. Irrigation agriculture is the largest consumer of water especially that adopts surface irrigation, which is characterized by low irrigation efficiency, inhomogeneous water distribution, loss of irrigation water as surface runoff and deep leakage. The use of water and energy-saving irrigation systems, reduced water losses, environmental pollution and an increase in the outcome, therefore it is a reliable alternative (Sezen *et al.*, 2019; Sezen *et al.*, 2017). Moreover, the use of drip irrigation systems and the use of modern methods in agricultural irrigation management help to reduce water waste and improve production and achieving maximum efficiency in water and fertilizer use (Sarkar *et al.*, 2018). Lamm and Camp (2007) defined Sub-surface drip irrigation (SDI) as the addition of water under the soil surface employing micro-irrigation emitters with a discharge of less than 7.5 L h^{-1}, meaning that adding water in small quantities and with high frequency in specific areas in the field has few water losses and high irrigation efficiency. The subsurface drip irrigation system is suitable in arid and semi-arid regions due to its lack of evaporation, surface runoff, and deep permeation. Furthermore, it has been used for large areas in the United States of America for several types of economic crops such as wheat, maize, and forage crops such as alfalfa compared to other irrigation systems such as sprinkler irrigation and surface irrigation (Alam *et al.*, 2002). Ambitious experiments were carried out in the last decade of the last century in the states of California and Kansas to apply the subsurface drip irrigation to irrigate field crops with dense growth such as alfalfa and maize (Lamm *et al.*, 1995 and Lamm *et al.*, 1997 and Alam *et al.*, 2002). The results were encouraging to expand scientific research to apply subsurface irrigation systems for irrigating the alfalfa and wheat in order to improve irrigation management methods, the root growth environment, increase yields with less water consumption, rationing the crop water needs and permanently eliminate surface water losses for large areas (Kandelous *et al.*, 2012). The most important of all these advantages is to increase the yield significantly, by using less water (Lamm *et al.*, 2012a). The distance between the drip lines and their depth in the subsurface drip irrigation system depending on the movement of water in the soil, soil type, architecture of the root, crop type, growth stage, and some other plant factors. Generally, the depth ranges between 5-30 cm (Lamm and Camp, 2007), where, the ideal depth for burring subsurface drip irrigation (SDI) pipes depends on the discharge rate of the emitters, the distance between the emitters. As we as, the type of soil, the root distribution, the pipes should be buried to the appropriate depth so that they do not expose to damage when performing agricultural operations. It is preferable to place the drip pipes under the surface in the soils with a coarse texture on a little depth while in the fine soils should increase the depth (Evans *et al.*, 2007). Three depths of SDI pipes were tested in a loamy sand soil of 5, 20 and 35 cm and was found that the depth 35 cm was the best and gave the highest irrigation efficiency and moisture distribution uniformity and the highest yield (Douh *et al.*, 2013). Moreover, Lamm *et al.* (1997) obtained the highest yield of maize and the highest efficiency of using irrigation water at the spacing of drip lines 1.5 m by a depth 40 - 45 cm. In addition, they indicated that increasing the distance between the drip lines results in an irregular horizontal distribution of soil moisture, which caused a decrease in the yield with an increase in the horizontal distance of drip lines. Wang *et al.* (2018) confirmed that the depth between 10 - 20 cm and the distance between drip lines 60 cm was appropriate, as it gave the highest yield of dry matter for alfalfa and the highest water use efficiency. Additionally, Ismail and Almarshadi (2013) obtained the highest yield of dry and wet matter for alfalfa and reached 3.36 and 12.6 ton.ha^{-1} respectively. The highest water use efficiency when using a distance between drip lines 40 cm and a depth of 10 cm in the soil of sandy clay loam and the subsurface drip irrigation in the alfalfa gave an increase in the yield due to the ability to adding irrigation water even at the harvesting time. The water use efficiency reflects the need of the plant to use added water that can be expressed based on the dry matter of the total vegetative part (biological yield) to the total amount of water used as water depth, volume or mass. Furthermore, the production is expressed as either total production, net production, or dry matter production, this depends on the type of crop used (Howell, 2003). Whereas, the water use efficiency is expressed as a mass of dry matter or the fresh matter yield for a unit area of a depth unit for the used water (Marais *et al.*, 2002). Alfalfa is a crop that requires large quantities of water compared to other crops. Therefore, high-efficiency irrigation systems such as a subsurface drip irrigation system can be used to reduce the amount of added water, and the yield quality can be improved with the other irrigation systems as well as the ability to continue irrigation until harvesting (Lamm *et al.*, 2012b). Zaccaria *et al.*, (2017) obtained an increase in the alfalfa dry matter yield by 10-30%, and provide an amount of irrigation water by 20-30% compared to a surface irrigation system, and achieved one to three additional cutting using the same amount of irrigation water used in the surface irrigation system. In order to investigate the possibility of agricultural investment in desert lands of Iraq, especially in the southern regions, and to cultivate them with forage crops to provide green forage, hay, fence, or to provide green areas for animal grazing. The current research was conducted to evaluate a subsurface irrigation system designed with different distances and depths between the drip lines and its effect on the alfalfa yield and in the efficiency of using irrigation water.

Materials and Methods

A field experiment was carried out in the Al-Shanafiyah district, Al-Khasif area in the southwest of Al-Diwaniyah governorate in southern Iraq, 100 km from the center of Al-Diwaniyah city in desert soil. The site is located at a latitude of (33° 38' 22.3" N, 44° 24' 17.7" E) and at an altitude of 28 m above sea level. Moreover, the field soils are classified as sedimentary soils with sandy loam texture; medium moderate, Typic, Torri fluevents, according to Soil Survey Staff (2012). Field soil samples are taken randomly and collected in the form of a composite sample and for depths 0.00 - 0.20 and 0.20 - 0.40 m. The samples were air-dried, crushed and then passed through a sieve with a diameter of 2 mm openings, then physical and chemical analyzes were conducted on it (Klute *et al.*, 1986; Page *et al.*, 1982) as shown in Table 1. A subsurface drip irrigation system was used to irrigate the alfalfa plant, where the water was equipped from a well at the site of the experiment, and samples of this water were taken to determine the chemical properties of water according to the food and agriculture organization classification (FAO) of irrigation water (Phocaides, 2001). Table 2 shows the chemical properties of irrigation water, the water class, and sodium adsorption ratio.

Table 1 : Some physical and chemical properties of field soils before planting

Property	Value
Sand (g kg^{-1})	743
Silt (g kg^{-1})	133
Clay (g kg^{-1})	124
Soil texture	Sandy loam
Bulk density (Mg m^{-3})	1.400
Volume moisture content at 10 kPa (cm^{3}cm^{-3})	0.290
Volume moisture content at 1500 kPa (cm^{3}cm^{-3})	0.062
Available water (cm^3 cm^{-3})	0.288
Organic matter (g kg^{-1})	11.8
Electrical conductivity (ds m^{-1})	3.75
pH	7.2
Carbonate minerals (g kg^{-1})	271

Table 2 : Chemical properties of well water used for the alfalfa irrigation

Water Source	EC	pH	Na^+	K^+	Ca^{++}	Mg^{++}	NO_3^-	B	SAR	Class
	dSm^{-1}		meL^{-1}				mgL^{-1}			
Well	5.03	7.86	27.60	0.82	29.00	21.00	33.00	2.10	5.53	C_4S_2

A field experiment was carried out to test the effect of distances and depths of subsurface drip lines in the growth and yield of the alfalfa, as it included distances of 50, 75 and 100 cm and depths of drip lines 20 and 40 cm, in addition to the comparison treatment, which represented the surface irrigation system. The experiment was designed according to the nested design method with three replicates, where the data were statistically analyzed and the averages were compared at the least significant difference test (LSD), at the probability level 5% using GenStat commercial program. A specified subsurface drip irrigation pipes used in the form of striped pipes class XFS Dripline from the US company Rain Bird and equipped with a copper shield technology that protects the emitters from penetrating the roots and is enhanced with a self-cleaning ability with water and constant discharge of 3.5 L h^{-1}. The distance between the emitter and another 30.5 cm. Alfalfa seeds of a local variety were planted with a seeding rate of 20 kg ha^{-1} on lines and the distance between them 20 cm on 29/10/2018, five cutting took when 10% flowering was completed in each cutting. The yield of the green forage (kg ha^{-1}) was calculated from the harvest of one square meter for each experimental unit after each cutting. The green matter was weighed with a sensitive balance and then converted to kg ha^{-1},and the dry forage yield was calculated after drying the square meter and converting it to kg ha^{-1}. Furthermore, the soil moisture content was evaluated using the gravimetric method by measuring the soil moisture and monitoring the moisture changes in the soil to determine the irrigation time and the depth of added water. As the depth of water added of the subsurface drip irrigation system was reached 2760.5 mm, and for the treatment of surface, irrigation reached 3264 mm. Emitters discharge was measured from the following equation (Hachem and Yaseen, 1992):

$$q = \frac{v}{t} \qquad ...(1)$$

Where:

q = The emitter discharge (L h^{-1}).

v = Volume of water received in the volumetric unit (liters).

t = Operating time (hours).

The uniformity coefficient was calculated from the following equation (Christiansen, 1942):

$$UC = \left(1 - \frac{\sum |x_i|}{m \times n}\right) \times 100 \qquad ...(2)$$

Where:

UC = Coefficient of uniformity percentage.

□Xi = Sum of deviations from the discharge rate (L h^{-1}).

m = Average emitters discharge (L h^{-1}).

n = the number of emitters.

Moreover, the discharge variations in the emitters discharge q_{var} was calculated from applying the equation mentioned in (Camp *et al.*, 1997) which is:

$$q_{var} = \frac{q_{max} \times q_{min}}{q_{max}} \times 100 \qquad ...(3)$$

Where:

q_{var} = The discharge variations of emitters (L h^{-1}).

q_{max} = The highest discharge of emitters (L h^{-1}).

q_{min} = The lowest discharge of emitters (L h^{-1}).

Finally, the field water using efficiency was calculated according to the following equation (Howell, 2003)

$$WEE_f = \frac{yiedl}{water\ applied} \qquad ...(4)$$

Where:

WUE_f is the field water use efficiencies (kg ha^{-1} mm^{-1}).

Yield is the total yield (kg ha^{-1})

Water applied as the water depth (mm).

Results and Discussion

Uniformity coefficient and discharge variations

The results of Table 3 indicated an increase in the values of uniformity coefficient with an increase in the operating pressure, where the uniformity coefficient gave the highest values at a pressure of 60 Kpa by 96.23, 95.33 and 97.78% for the distances between the subsurface drip lines 50, 75 and 100 cm, respectively. Whereas, the lowest values of the uniformity coefficient at a pressure of 40 Kpa by 88.98, 90.06 and 91.32% for the same distances of the drip lines above. These results confirm that the irrigation system was highly efficient in distributing irrigation water homogeneously, as (Arya *et al.*, 2017) observed that the drip irrigation system is very efficient as the uniformity coefficient was not less than 85%. The reason behind the uniformity coefficient increasing may be attributed to an increase in the operating pressure, which increased the speed of water flow within the pipes and relatively reduced friction losses. This result was consistent with (Ahmed *et al.*, 1999; Sah *et al.*, 2010; Jamrey and Nigam 2018) where they attributed the difference in the uniformity of water distribution to the difference in operating pressure due to the loss by friction. Table 3 also indicates the discharge variations relationship with the operating pressure, and it was observed that there was a decrease in the discharge variations with increasing the operating pressure. As the operating pressure, 60 Kpa gave the lowest discharge variations amounted to 16.17, 18.44 and 7.40% for the distances between the subsurface drip lines 50, 75 and 100 cm respectively, while the operating pressure 40 Kpa gave the highest discharge variations was 36.02, 38.05 and 40.63% for the distances between the drip lines as above. Increasing operating pressure reduces the friction effect of water molecules with the pipe walls with each other because of an increase in the water flow speed, which reduces the chance of discharge variations of the emitters, as indicated by (Sah *et al.*, 2010 and Sarker *et al.*, 2019).

Table 3 : Uniformity coefficient and discharge variations under different operating pressures

Distance between drip lines (cm)	Uniformity coefficient %			Discharge variations %		
	operating pressures (kpa)					
	40	50	60	40	50	60
50	88.98	94.27	96.23	36.02	19.54	16.17
75	90.06	91.88	95.33	38.05	27.94	18.44

100	91.32	95.28	97.78	40.63	20.00	7.40

The yield of dry matter and green forage for alfalfa

The results of Table 4 showed the effect of distance between the subsurface drip lines and their depths on the dry matter yield for alfalfa. As the results showed a decrease in the dry matter yield for alfalfa with the increase in the distance between the subsurface drip lines and reached 17.03, 14.51 and 10.80 ton ha^{-1} for the distances 50, 75 and 100 cm, respectively. The reason behind the dry matter yield decreasing with an increase in the distance between the subsurface drip lines is due to the moisture content decreasing between the drip lines and the increase in the distance between them. It was negatively reflected in the alfalfa yield, and this is what (Alam *et al.*, 2002; Ismail and Almarshadi, 2013; Lamm *et al.*, 2012) findings. The results of statistical analysis showed that there were no significant differences in the effect of the subsurface drip lines depth in the alfalfa yield. It reached about 14.26 and 13.98 ton ha^{-1} for the depths 20 and 40 cm respectively, and this is consistent with (Alam *et al.*, 2002). Also, the results of the statistical analysis indicated a significant interaction of the distances and depths effect of the subsurface drip lines in the dry matter yield for alfalfa. Since the treatment of distance 50 cm and a depth of 20 cm gave the highest yield of the dry matter for alfalfa reached 18.24 ton ha^{-1}, and the lowest yield reached 10.32 ton ha^{-1} in treatment of distance 100 cm and a depth of 20 cm, while the treatment of surface irrigation gave a dry matter yield of 18.02 ton ha^{-1}.

Table 4 : Effect of the distance and depths of the subsurface drip lines on the dry matter yield for alfalfa (ton ha^{-1})

Distance between the drip lines (cm)	Depth of the drip lines (cm)		Average
	20	40	
50	18.24	15.83	17.03
75	14.21	14.82	14.51
100	10.32	11.28	10.80
LSD	0.80		0.57
Average depth	14.26	13.98	
LSD	NS		
Surface irrigation treatment	18.02		
LSD	0.756		

The results of Table 5 showed the effect of distance between the subsurface drip lines and their depths in the green forage yield for alfalfa, where the yield reached 52.91, 44.95 and 33.02 ton ha^{-1} for distances 50, 75 and 100 cm, respectively, while the surface irrigation treatment gave a yield of 49.3 ton ha^{-1}. The statistical analysis showed that the interaction of distance and depth had a significant effect on the yield of green forage for alfalfa. Whereas, the treatment of distance 50 cm and depth 20 cm gave the highest yield of green forage reached 54.51 ton ha^{-1}, and the lowest yield reached 32.06 ton ha^{-1} for the treatment of distance 100 cm and depth 20 cm. The distance increase between the subsurface drip lines leads to a decrease in the irrigation water supply to the plant, thus, the plant was exposed to water stress, which is reflected negatively on the yield, and this was confirmed by (Wang *et al.*, 2018; Lamm *et al.*, 1997; Lamm 2016). The results of statistical analysis indicated that there were no significant differences for the depths of subsurface drip lines in the yield of green forage, as the yield reached 44.11 and 43.14 ton ha^{-1} for depth 20 and 40 cm, respectively.

Table 5 : Effect of the distance and depths of the subsurface drip lines on the green forage yield for alfalfa (ton ha^{-1})

Distance between the drip lines (cm)	Depth of the drip lines (cm)		Average
	20	40	
50	54.51	51.30	52.91
75	45.76	44.13	44.95
100	32.06	33.98	33.02
LSD	4.35		4.34
Average depth	44.11	43.14	
LSD	NS		
Surface irrigation treatment	49.3		
LSD	3.94		

The efficiency of field water use (ton ha^{-1} mm^{-1}) for dry and wet weight

Table 6 showed the field water using the efficiency of the alfalfa dry weight under the effect of distances and depths of subsurface drip lines. The results showed a decrease in the field water using efficiency with an increase in the distance between subsurface drip lines and reached 0.0062, 0.0053 and 0.0039 ton ha^{-1} mm^{-1} for distances between the subsurface drip lines 50, 75 and 100 cm, respectively. Whereas the results of the interaction of distances and depths between the subsurface drip lines showed a significant difference. As the treatment of distance 50 cm and depth 20 cm gave the highest water use efficiency of 0.0066 ton ha^{-1} mm^{-1}, while the lowest efficiency was recorded for the treatment of distance 100 cm and depth 20 cm reached 0.0037 ton ha^{-1} mm^{-1}. The reason behind the field water using efficiency decreasing with an increase in the distance between subsurface drips lines is due to decrease in the dry matter yield as shown in Table 4. As well as the stability of the water added amount of the subsurface drip irrigation system of 2760.5 mm, compared to the surface irrigation treatment, which amounted to 3264.0 mm, the field water using efficiency was recorded 0.0055 ton ha^{-1} mm^{-1}. The results also showed that there were no significant differences in the depth of subsurface drip lines, as it reached 0.0052 and 0.0051 ton ha^{-1} mm^{-1} for depth 20 and 40 cm, respectively.

Table 6 : Effect of the distance and depths of the subsurface drip lines on the field water use efficiency for the alfalfa dry weight (ton ha^{-1} mm^{-1})

Distance between the drip lines (cm)	**Depth of the drip lines (cm)**		**Average**
	20	**40**	
50	0.0066	0.0057	0.0062
75	0.0051	0.0054	0.0053
100	0.0037	0.0041	0.0039
LSD	0.0003		0.0002
Average depth	0.0052	0.0051	
LSD	NS		
Surface irrigation treatment	0.0055		
LSD	0.0002		

Table 7 showed the effect of distances and depths of the subsurface drip lines in the field water use efficiency for the alfalfa wet weight, as it reached 0.0192, 0.0163 and 0.0120 ton ha^{-1} mm^{-1} for the distances of subsurface drip lines 50, 75 and 100 cm, respectively, while the field water use efficiency for the surface irrigation treatment reached 0.0151 ton ha^{-1} mm^{-1}. The results also indicated that there were no significant differences for the depths in-field water using efficiency, as it reached 0.0160 and 0.0156 ton ha^{-1} mm^{-1} for depth 20 and 40 cm, respectively.

Table 7 : Effect of the distance and depths of the subsurface drip lines on the field water use efficiency for the alfalfa wet weight (ton ha^{-1} mm^{-1})

Distance between the drip lines (cm)	**Depth of the drip lines (cm)**		**Average**
	20	**40**	
50	0.0198	0.0186	0.0192
75	0.0166	0.0160	0.0163
100	0.0116	0.0123	0.0120
LSD	0.0015		0.0011
Average depth	0.0160	0.0156	
LSD	NS		
Surface irrigation treatment	0.0151		
LSD	0.0014		

It was observed from the above that the subsurface drip irrigation system in the treatment of distance of 50 cm has exceeded the surface irrigation treatment in the field water use efficiency for the alfalfa dry weight. Furthermore, the two treatment of distance 50 and 75 cm exceeded the surface irrigation treatment in the field water use efficiency for the alfalfa wet weight, and if the amount of added irrigation water is equal in drip irrigation treatments, this means that the treatment of distance 50 cm as shown in Table 6. Besides, the treatments of 50 and 75 cm as shown in Table 7, which was given the highest alfalfa yield with less water amount than the surface irrigation treatment as shown in Tables 4 and 5. The difference in the used water amount represents the amount of extra available water, as the percentage of available water is 18.23%, which is a very important amount of water because it can be used at another site or to irrigate another crop or use it later.

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