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RESEARCH ARTICLE

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Effect of Moisture Depletion Rate and Irrigation Water Depth on the Productivity and Water Use Efficiency of Soybean Crop (*Glycine max* L.) Merr. under Drip Irrigation and Fixed Sprinkler Irrigation Systems

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ABSTRACT

Background: Water management and its appropriate use are priorities in arid and semi-arid areas across the globe.

Methods: A field experiment was carried out at Hisar in Al-Tunkopry district, Kirkuk Governorate, during 2023 summer season. Split-split plot design was adopted to implement the experiment, using randomized complete blocks design (RCBD). The main plots included irrigation method factor (sprinkler and drip) and the moisture depletion rate was placed in the sub plots (60 and 70% of the available water) while varing irrigation depth were placed in the sub-sub plots (50, 75 and 100)% of the net irrigation depth.

Result: Results of the study revealed that the water requirement of the soybean crop under the sprinkler irrigation system reached 1275.9 and 1272.9 mm season^{-1} at 100% of net irrigation depth and at moisture depletion rates of 60 and 70%, respectively and in drip irrigation system it reached 1170.6 and 1201 mm season^{-1} for an irrigation level of 100% of the net irrigation depth and at a moisture depletion rate of 60 and 70%, respectively. The yield coefficient values (0.52, 0.90, 1.01, 0.90) and (0.44, 0.85, 0.96, 0.52) at a moisture depletion of 60% for the two methods (drip and sprinkler irrigation). The highest seed yield was 4.094 Mg ha^{-1} for the sprinkler irrigation treatment with a moisture depletion rate of 60% and an irrigation water level of 50% of the net irrigation depth, while the lowest yield was 2.41800 Mg ha^{-1} for the drip irrigation treatment with a moisture depletion rate of 60 and a level of 75% of the net depth. The drip irrigation achieved the highest water use efficiency 0.607072 kg m^{-3}, in comparison to the sprinkler irrigation 0.362063 kg m^{-3}.

Key words: Drip irrigation, Moisture depletion, Net irrigation depth, Soybeans, Sprinkler irrigation.

INTRODUCTION

Water management and its appropriate use are priorities in arid and semi-arid areas. Cropping system of the farmers all over the country, because this crop fits well in the crop rotation. Agriculture is the main consumer of fresh water all over the world. Accounting to 70% of water consumption is by (Jensen and Allen, 2016) and with 85% in Iraq (Al-Ansari, 2021). There has been a need to use modern methods of irrigation without wasting water, while adopting moisture limits appropriate to the type of soil and the crop grown in order to achieve optimal use of water. Therefore, it has become necessary to adopt and use modern methods in order to regulate water consumption by reducing the depths of used water and appropriate moisture depletion rates that do not cause stress to the plant (Al-Mehmdy and Al-Dulaimy, 2018; Al-Hafoudi and Khalaf, 2004).

Sprinkler irrigation method is defined as adding water to the surface of the soil in the form of a spray. The effect of wind on water distribution patterns in the sprinkler irrigation system greatly reduces its efficiency and to overcome these problems, it is necessary to use low-pressure sprinklers (Chen *et al*., 2019). Sprinkler irrigation conserve water up to 50% and can irrigate 2 to 3 times area compared to surface irrigation (Sheikhesmaeili *et al*., 2016). Irrigation scheduling is considered a good management method for controlling the amount of water given in each irrigation and the number of irrigations, according to the soil capacity to water retention and the requirements at the different stages of crop growth to reach the highest productivity (Spellman, 2020).

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Al-Aqabi, 2015 found an increase in the soil moisture content in treatments irrigated in 50% of the available water was exhausted as compared to treatments irrigated with 75% of the available water was exhaustion. Water use efficiency is an important parameter in arid and semi-arid regions, due to the increase in irrigated areas and high-water requirement of crops. These problems can be reduced by increasing the efficiency of water use, as improving the efficiency of water use becomes a major goal for agriculture (Kalamartzis *et al*., 2020).

The aim of the study is to investigate the effect of irrigation methods, moisture depletion and varying irrigation depth on the productivity and water use efficiency of soybean crop.

MATERIALS AND METHODS

A field experiment was carried out in Kirkuk university, Iraq during 2023 summer season. Samples of the soil of the study site were taken at a depth of ($0^{-3}0$) cm before planting to determine physio-chemical properties. The EC in the extract (1:1) = ds m^{-1} 2.3, PH = 7.44, organic matter, gypsum, lime, sand, silt and clay reached (9.5, 3, 215, 40, 44, 16) g kg^{-1}, soil texture is mixed, volumetric soil moisture at field capacity and permanent wilting point is (0.28, 0.09) cm^{-3}, respectively and the bulk density is 1.31 gm cm^{-3}. The experiment was implemented in split-split plot system within randomized completely blocks design (RCBD). The main plot included the irrigation method (spraying and dripping) and the moisture depletion rate (60 and 70% of the available water) was set in the split plot, while the irrigation depth levels, (50, 75 and 100% of the net irrigations′ depth was placed in the split-split. The land was plowed using a rotary plow and divided into three blocks (36 m width × 190.5 m length), leaving a 10 m wide guard area between each block and another. A 10 m interval was also left between the experimental units of the sprinkler irrigation system to ensure that this would not occur. Interference of the sprinkler water with each other, as every two lines, which represents four sprinklers, was considered an experimental unit and a 12 meter interval between the lines was followed and a distance of 12 meters was followed between one sprinkler and another within one line (Al-Izawee, 2020) Regarding to drip irrigation, strip drip tubes with a discharge of 3 liters per $hour^{-1}$ were used, with a distance of 0.25 m between drippers. Soybean seeds of Shaima variety was planted on 1st May 2023, Nitrogen fertilizers were added at a rate of 160 kg N ha^{-1} using urea fertilizer (46%N), Phosphate fertilizers were added at a rate of 80 kg P_2O_5 ha^{-1} in the form of calcium superphosphate at planting date (Ali, 2012) Hydraulic calibration of the drip irrigation system was performed determining the most appropriate pressure, which is 100 kilopascals, as mentioned by (Tahir and Ameen, 2019).

Several tests were conducted to evaluate the sprinkler discharge and the consistency of water distribution under the sprinkler irrigation system and the appropriate pressure was determined as 2.5 bar, which gave a discharge of 1.7 m^3 h^{-1} for one sprinkler. All study treatments were irrigated during the first two weeks of planting in equal quantities and after the appearance of 4 complete leaves on 15 May the study coefficients were applied for the two moisture depletions (60 and 70) % of the available water according to the following:

The irrigation water depth was added to both moisture depletions (60 and 70%) of the total available water depth, by applying the mathematical equation:

$$d = (\theta FC - \theta i)\, D \qquad ...(1)$$

d = Depth of water to be added (mm).
θfc = Soil moisture at field capacity (cm^3 cm^{-3}).
θi = Soil moisture before irrigation (cm^3 cm^{-3}).
D = Depth of root zone (mm).
dp= The percentage of moisture depletion applied in this study is (60 and 70%).
θAW = Available water cm^3 cm^{-3} (calculated from the difference between the volumetric soil moisture at field capacity and the volumetric soil moisture at the permanent wilting point).

$$Aw = \theta fc - \theta wp \qquad ...(2)$$

θwp = Volumetric moisture content at permanent wilting point (cm^3 cm^{-3})

The total depth of irrigation for the drip irrigation system calculated based on the irrigation efficiency 0.90 (Sabah *et al*., 2023) and for the sprinkler irrigation system 0.8498 (Jasam, 2023) and according to the following equation:

$$GDI = \frac{d}{Ea} \qquad ...(3)$$

GDI = Total irrigation depth (mm)
Ea = Addition efficiency (%).

The amount of water added was calculated from the following equation (Connellan, 2002).

$$Wn = \frac{d}{1000} \times \frac{Aw}{1000} \qquad ...(4)$$

Wn = Amount of water added (m^3)

The time required for irrigation was calculated from the following equation:

$$Q \times T = a \times d \qquad ...(5)$$

Q= Discharge (m^3 min^{-1}).
T= Perfusion time (minutes).
a= Irrigated area (m^2).
d= Depth of added water (m).
Where (a × d) is the same as Wn (m^3) calculated in equation (5).

The yield coefficient for the stages of plant growth was calculated according to the climatic data of the study area.

$$Kc = \frac{ETc}{ETO} \qquad ...(6)$$

After crop maturity was completed, the harvesting process was carried out on 11/15/2023 and the grain yield (Mg ha^{-1}) was calculated according to the following equation:

$$\text{Yield} = \frac{\text{Yield of experimental unit}}{\text{Area of experimental unit}} \times 10000 \quad ...(7)$$

Field water use efficiency was calculated by applying the following equation (Hasanuzzaman, 2019).

$$\text{WUEf} = \frac{\text{Yield}}{\text{Water applied}} \quad ...(8)$$

WUEf = Field water uses efficiency (kg m^{-3}).
Yield = Total yield (kg ha^{-1}).
Water applied= Volume of water added during the season (m^3 ha^{-1}).

The data were analyzed statistically according to the design followed using the SAS2000 program and the means of the were compared according to the Duncan multiple tests at the probability level of 0.05.

RESULTS AND DISCUSSION

Added field water requirements (mm) for soybean crop irrigated with a drip irrigation system Table 1 showed the depths of water added according to study factors, in general the highest depth of added water was at flowering stage, which accounted to 620.2 and 619.2 mm for the 60 and 70% moisture depletion and 100% net irrigation depth, respectively. When the irrigation level was reduced to 75 and 50% of the net irrigation depth and the moisture depletion rate was 60%, the depths reached 465.15 and 310.1 mm, respectively. While at 70% depletion, the depths added to the irrigation water were 464.4 and 309.6 mm for levels of 75 and 50% of the total net irrigation depth, respectively. It is clear from the results that water consumption values were high during the branching and flowering stages compared to the vegetative growth and maturity stages, as the branching stage represents the stage of growth reflected in higher dry matter accumulation within a consequent higher water and nutrient requirement. This was reflected in the rates of evaporation and transpiration in these stages (branching, flowering and pod formation), as a result of the deeper and wide spreading of the roots, thus increasing their efficiency in absorbing water and increasing the leaf area, which increased the water lost from the plant through transpiration (Jasam, 2023), in addition to the high temperature rates during July, August and September months. The rate of evapotranspiration of the soybean crop increases with plant age and the influence of climatic factors (temperatures and wind speed), according to data issued by the weather station in the study area. The lowest stage of water depth, was the vegetative growth which reached 95, 71.25 and 47.5 mm at 60% moisture depletion at irrigation level of 100, 75 and 50% and it decreased to 88.4, 66.3 and 44.2 mm when the depletion rate was 70% and the irrigation level is 100, 75 and 50%, respectively.

The reason for this may be due to the decrease in the plant's requirements for water due to the mature and drying of plant parts (Al-Shamary *et al.*, 2021). The total depth of water added during the growing season for drip irrigation for 60% moisture depletion reached 1170.6, 877.95 and 585.3 mm season^{-1} for irrigation levels of 100, 75 and 50%, respectively. While applying 70% depletion rate slightly increased the total water depth, reaching 1201.2, 900.9 and 600.6 mm season^{-1}.

Added water requirements (mm) for soybean crop irrigated with fixed sprinkler irrigation system

The data in Table 2 showed that the total water depths added during the season at 60% moisture depletion reached 1275.9, 956.925 and 637.95 mm season^{-1} for 100, 75 and 50% levels of the net irrigation depth, respectively.

Table 1: Depth of water added (mm) during the growing season of irrigated soybean crop under drip irrigation system.

Growth stage	Additive water depths (mm) at 60% water exhaustion			Additive water depths (mm) at 70% water exhaustion		
	100%	75%	50%	100%	75%	50%
Vegetative growth 6/10-5/15	95	71.25	47.5	88.4	66.3	44.2
Tilling 7/15- 6/11	284.4	213.3	142.2	294.4	220.8	147.2
Flowering 9/15-7/16	620.2	465.15	310.1	619.2	464.4	309.6
Maturity 11/15-9/16	171	128.25	85.5	199.2	149.4	99.6
Total	1170.6	877.95	585.3	1201.2	900.9	600.6

Table 2: Depth of water added (mm) during the growing season of irrigated soybean crop under constant sprinkler irrigation system.

Growth stage	Additive water depths (mm) at 60% water exhaustion			Additive water depths (mm) at 70% water exhaustion		
	100%	75%	50%	100%	75%	50%
Vegetative growth 6/10-5/15	100.0	75.0	50.0	93.6	70.2	46.8
Tillering 11/6-15/7	301.5	226.125	150.75	312	234	156
flowering 16/7-15/9	694.4	520.8	347.2	656.4	492.3	328.2
Maturity 16/9-15/11	180	135	90	210.9	158.175	105.45
Total	1275.9	956.925	637.95	1272.9	954.675	636.45

At 70% depletion, it reached 1272.9, 954.675 and 636.45 mm season^{-1} for 100, 75 and 50% levels, respectively.

The amounts of irrigation water added during the vegetative growth stage, at 60% moisture depletion recorded 100, 75 and 50 mm for the levels of 100, 75 and 50% of the net irrigation depth, respectively. The vegetative growth stage took 26 days with 5 irrigations. When applying 70% moisture depletion, the depth of the added water reached 93.6, 70.2 and 46.8 mm for the levels of 100, 75 and 50% of the net irrigation depth, respectively. The depth of added water increased during the flowering stage, as it reached 694.4, 520.8 and 347.2 mm at 60% moisture depletion for the levels of 100, 75 and 50% of the net irrigation depth, respectively. The flowering stage took 60 days with 14 irrigations. When applying 70% moisture depletion, the depth of the added water reached 656.4, 492.3 and 328.2 mm for the levels of 100, 75 and 50%, respectively, with 12 irrigations during this stage. Higher values of the added water depth during the flowering stage were due to the prolonged period of this stage. It was found that the seasonal water requirement increases with growth. This could be attributed to the increase in the plant's water needs owing to increase in root depth and spread, thus increasing its efficiency in absorbing water and assimilatory surface with a resultant increase in leaves and transpiration. These results are in line with findings of (Al-Shamary *et al*., 2021).

The depth of added water decreased during the maturity stage. When the moisture depletion was 60%, it reached 180, 135 and 90 mm for 100, 75 and 50% levels, respectively. However, when the moisture depletion was 70%, it reached 210.9, 158.175 and 105.45 mm for 100, 75 and 50% levels, respectively. It could be ascribed to water requirement of crop.

Table 3: Values of soybean crop index (kc) for growth stages and by study treatments.

Growth stage	Drip		Sprinkler	
	60%	70%	60%	70%
Vegetative growth	0.52	0.43	0.44	0.41
Tillering	0.9	0.93	0.85	0.88
Flowering	1.01	1.01	0.96	0.96
Maturity	0.55	0.64	0.52	0.60

Yield coefficient

Data in Table 3 revealed that the yield coefficient when applying drip irrigation system, s reached 0.52 and 0.43, at vegetative growth stage, 0.9 and 0.93, at branching stage, 1.01 and 1.01, at flowering stage, 0.55 and 0.64, at maturity stage, for 60% and 70% moisture depletion respectively.

When applying the sprinkler irrigation system, the yield coefficient values decreased compared to applying the drip irrigation system, as the values for the vegetative growth stage 0.44 and 0.41, for the branching stage 0.85 and 0.88, for flowering stage d 0.96 and 0.96, for maturity stage 0.52 and 0.60, for the moisture depletion 60 and 70%. It is evident from the results that the yield coefficient values increased at the flowering stage, reaching the highest value due to the formation of new initiation sites in the plant and the increase in the activity of biological prosses. This could be due to the increase in the value of the actual and reference water requirement at flowering stage due to the high rates of temperature that it leads to an increase in evaporation rates and an increase in the values of reference and actual water consumption, so the plant's need to consume water and nutrition has increased (Tetteh *et al*., 2020; Al-Mosawy, 2021, Jasam, 2023). The results also showed a decrease in yield coefficient values at the end of the season due to plant maturity, which causes a decrease in actual water consumption, as well as a decrease in evapotranspiration rates in September and October as a result of lower temperatures and humidity increased during the day and night hours.

Seeds yield (Mg ha^{-1})

Table 4 revealed that the irrigation method has a significant effect on the seeds yield, as the highest grain yield 3.18141 Mg ha^{-1} at sprinkler irrigation compared to 2.53619 Mg ha^{-1}

Table 4: Effect of moisture depletion ratio and irrigation water depth on soybean yield (Mg ha^{-1}) under drip irrigation and constant sprinkler irrigation systems.

Irrigation method (I)	Water depletion ratio (M)	Irrigation water levels (V)			I × M	I	M
		100%	75%	50%			
Drip (D)	60%	2.94083 e	2.14800 h	2.28327 g	2.45737 d	2.53619 b	2.98066 a
	70%	2.40133 f	3.08223 d	2.36150 gf	2.61502 c		2.73695 b
Sprinkler (S)	60%	2.42550 f	3.99147 b	4.09487 a	3.50394 a	3.18141 a	
	70%	3.34653 c	3.08137 d	2.14873 h	2.85888 b		
I×V	D	2.67108 d	2.61512 d	2.32238 e			
	S	2.88602 c	3.53642 a	3.12180 b			
M×V	60%	2.68317 d	3.06973 b	3.18907 a			
	70%	2.87393 c	3.08180 b	2.25512 e			
V		2.77855 b	3.07577 a	2.72209 c			

Table 5: Effect of study parameters on field water use efficiency (kg m^{-3}) and quantity of saved water.

Irrigation method	Water depletion ratio	Irrigation water depth%	Seeds yield Mg ha^{-1}	Applied water depth m^3 ha^{-1}	Water use efficiency m^3 ha^{-1}	Irrigation water saved m^3 ha^{-1}	Land area (ha)	Additional yield ratio Mg ha^{-1} depending on the best yield treatment
Drip	60%	100	2.94083	5853	0.5024	0	0	0.00
		75	2.14800	4389.75	0.4893	1463.25	0.25	0.735
		50	2.28327	2926.5	0.7802	2926.5	0.5	1.470
	70%	100	2.40133	6006	0.3998	0	0	0.00
		75	3.08223	4504.5	0.6842	1501.5	0.25	0.770
		50	2.36150	3002.5	0.7865	3002.5	0.5	1.541
Sprinkler	60%	100	2.42550	12759	0.1901	0	0	0.00
		75	3.99147	9569.25	0.4171	3189.75	0.25	1.0237
		50	4.09487	6379.5	0.6418	6379.5	0.5	2.0474
	70%	100	3.34653	12729	0.2629	0	0	0.00
		75	3.08137	9546.75	0.3227	3182.25	0.25	0.8366
		50	2.14873	6364.5	0.3376	6364.5	0.5	1.6732

at drip irrigation with an increase of 25.44% and that may be attributed to the lack of blockage of the sprinklers compared to the drippers that were subject to blockage as a result of mud deposits and other impurities in the irrigation water. Which led to a decrease in the drainage of drippings and thus the plant did not obtain sufficient water requirements. In addition, sprinkler irrigation moisturizes the atmosphere and soil surrounding the crop, which creates more suitable environmental conditions for plant growth.

It is also clear from Table 4 that the moisture depletion rate has a significant effect on grain yield, as the highest yield 2.98066 Mg ha^{-1} at 60% moisture depletion compared to 2.73695 Mg ha^{-1} at a 70% depletion rate. The reason for the decrease in grain yield at 70% may be attributed to exposed the plant to water stress (Jaybhay *et al*. 2019 and Al-Shamary *et al*., 2021).

The results in Table 4 showed that irrigation levels had a significant effect on seed yield, as the treatment with 75% irrigation depth gave the highest yield 3.07577 Mg ha^{-1} compared to the treatment 100 and 50% levels, which gave 2.77855 and 2.72209 Mg ha^{-1}. The reason for the increase at 75% level may be that the amount of water added to the soil at this level that push out the salts and keep them away from the root zone, which gives the roots the opportunity to grow and develop, which is reflected positively in the absorption of Nutrients, (Al-Nuaymy, 2009), while reducing irrigation level to 50% limits the spread of roots and make the plant in stress, which decreased the yield.

Water use efficiency (kg m^{-3})

Table 5 showed that the highest water use efficiency reached 0.7865 kg m^{-3} for the drip irrigation at 70% moisture depletion and 50% of the net irrigation depth, while the lowest value was 0.1901 kg m^{-3} for the sprinkler irrigation, at a 60% moisture depletion and 100% of the net irrigation depth. This is due to the role of drip irrigation in reduction the amount of water added and this is consistent with the findings of (Oudeh, 2016) that the drip irrigation method gave the highest water use efficiency compared to other irrigation methods.

It is also noted from Table 5 that the water uses efficiency increases with a decrease in irrigation water depth and for any percentage of moisture depletion. When applying the drip irrigation system with 70% moisture depletion the water uses efficiency values reached 0.3998, 0.6842 and 0.7865 kg m^{-3} for irrigation water levels of 100, 75 and 50%, respectively. The reason for this is the reduction in the amount of water added and the slight increase in seed yield (Al-Nuaymy, 2009, Al-Shareef, *et al*. 2018).

CONCLUSION

From this study it can be concluded that adding water at 75 and 50% of the water depth and for any percentage of moisture depletion, in drip and sprinkler irrigation methods, led to saving irrigation water at a rate of 25 and 50% for irrigating other cultivation area. The highest yield values (4.09487 Mg ha^{-1}) were from the triple interaction treatment (sprinkler irrigation with a moisture depletion 60% at 50% of the net irrigation depth). The drip irrigation treatment, at a moisture depletion 70% and with an irrigation water level of 50% of the net irrigation depth, achieved the highest water use efficiency (0.7865 kg m^{-3}).

Conflict of interest

There is no conflict of interest.

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