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Optimizing Water Use Efficiency and Cabbage Yield Under Surface and Subsurface Drip Irrigation with Bio-Fertilizer WSG

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ABSTRACT

The current research aims to optimize water consumption in the cabbage crop to contribute to sustainable development in the agricultural sector. A field experiment was conducted in the Heet district, Anbar Governorate, during the autumn season of 2023–2024. The objective was to study the effects of irrigation deficit and bio-fertilizer application on the growth and yield of the cabbage crop under surface and subsurface irrigation systems. A split-split plot design with three replicates was used to distribute the experimental treatments. The main plots consisted of surface and subsurface drip irrigation treatments. The subplots included irrigation water levels, while the sub-subplots involved the application of bio-fertilizer (WSG). The total water applied during the growing season was 345.6 mm and 172.8 mm/season for surface drip irrigation at 100% and 50% levels, respectively, and 232.7 mm and 116.35 mm/season for subsurface drip irrigation at the same respective levels. Subsurface drip irrigation at the 50% level with the addition of 10 kg/ha of bio-fertilizer resulted in the highest recorded values for yield (28.6 Mg/ha), field water use efficiency (36.58 kg/m³), plant height (34.93 cm), leaf area (267.33 dm²), and head diameter (23.6 cm). In contrast, surface drip irrigation at the 50% level without bio-fertilizer application recorded the lowest values for yield (7 Mg/ha), plant height (15 cm), leaf area (120.2 dm²), and head diameter (7 cm). The lowest water use efficiency was observed under surface drip irrigation at the 100% level without bio-fertilizer application, with a value of 5.18 kg/m³.

1. INTRODUCTION

Efficient irrigation water management is essential for reducing water consumption in the agricultural sector, particularly in arid and semi-arid regions. It helps minimize water losses through evaporation, deep percolation, and surface runoff. Researchers and farmers aim to improve crop yields, mitigate the effects of drought, and reduce the increasing demand for water resources. Therefore, it is essential to adopt effective water management practices by optimizing irrigation application technologies and monitoring water content and distribution in the root zone [1, 2]. SSoil properties influence irrigation decisions, water requirements, and water loss through evapotranspiration, as they affect water movement within the soil, which in turn determines plant water uptake [3]. As a result, the adoption of modern irrigation systems has increased in water-scarce regions due to their efficient water use capabilities [4]. Study [5] mentioned that drip irrigation is a globally recognized irrigation system that is characterized by a high degree of irrigation efficiency and water utilization, it is also effective in providing water and fertilizer allocation, as it is simple to add chemical fertilizers to the soil in the form of solutions that are mixed with the irrigation water and directly applied to the plant's roots, this enables the potential for holding and preventing manure from being spread through the soil to be exceeded, as well as the high efficiency in transporting and distributing irrigation water using pipes without the need to make irrigation channels or waterways, water is added by surface drip method to the soil surface in an amount equivalent to evapotranspiration [6]. Subsurface drip irrigation (SDI) is a system in which water flows slowly and continuously into or below the soil surface through emitters, either as discrete droplets or as a minimal flow. This system is also referred to as a low-flow irrigation method due to its minimal and precise water application. Marine algae extracts are considered important organic inputs in agricultural production. They complement, rather than replace, traditional fertilizers by stimulating plant physiological functions. This is attributed to their content of macro- and micronutrients, growth-promoting substances such as cytokinins, amino acids, organic acids, and various vitamins [7]. The use of organic materials such as humic acid and Bactrian fertilizer has been reported to positively affect soil health and enhance broccoli productivity under open field conditions with drip irrigation [8]. Bio-fertilizers enhance chlorophyll synthesis by activating key enzymes and reducing catabolic processes. They also increase nitrogen content in plant tissues due to the presence of nitrogen-fixing bacteria. Approximately 70% of the leaf nitrogen is incorporated into plastids, which store nearly half of the plant's nitrogen content [9]. Cabbage is a common winter vegetable crop in Iraq. It is nutritionally valuable, containing vitamins A, B1, B2, and C, amino acids, proteins, and minerals such as calcium, iron, and phosphorus. Its high fiber content also aids digestion. The edible part of the plant is the head, composed of tightly wrapped leaves. Every 100 g of cabbage leaves contains approximately 94% water, 1 g of protein, and 14 calories [10]. The objectives of this research are to maximize irrigation water savings, promote sustainable agricultural development, and evaluate the effects of irrigation deficit and bio-fertilizer application on the growth and yield of cabbage under surface and subsurface drip irrigation systems.

2. MATERIALS AND METHODS

A field experiment was carried out in Anbar Governorate, Heet District, during the autumn season of 2023-2024 in sandy loam soil for the period from 1/11/2023 to 20/2/2024. The physical and chemical soil properties of the soil of the study site are shown in Table 1. The land slope gradient was specified to implement this experiment. The Split Plot Design of three replicates was used, in which the study treatments were distributed. The main plots included surface and subsurface drip irrigation treatments (independent variable), while the secondary plots included the treatments of the level of irrigation water quantity (50 and 100)% of the net irrigation depth (independent variable), in the sub-secondary plots (Bio-fertilizer WSG) treatments were placed with levels of (0, 5 and 10) kg ha^{-1}. Bio-fertilizer WSG treatments (independent variable) were added two weeks after seedling with irrigation water (fertigation) and in three batches, between one batch and another, 20 days. Table 2 shows the components of Bio-fertilizer WSG. The seedlings, which are 8-10 cm long, were transferred to the permanent field on 1/11/2023 after preparing the field for ploughing, levelling, and fining it and establishing three terraces for each of the study treatments with a length of 15 m and a width of 50 cm and the distance between one terrace and another 60 cm with a space of 1.5 m between one treatment and another Di Ammonium Phosphate (DAP) fertilizer and potassium sulphate were added at a rate of 150 kg P_2O_5 and K_2O ha^{-1}, respectively, while urea fertilizer was added at a rate of 150 kg N ha^{-1} after 20 days seedling by the method of scattering above the soil surface [11].

Table 1. Some physical and chemical properties of field soil

Soil Properties		Units	Values
Potential of hydrogen (pH)		-	7.6
Electrical conductivity (EC) 1:1		dS.m^{-1}	1.4
Available nutrients	Nitrogen	mg.kg^{-1}	57.3
	Phosphorus		13.4
	Potassium		146.5
Organic matter		g.kg^{-1}	10.5
$CaSO_4$			Nil
$CaCO_3$			184
Soil separates	Sand		600
	Silt		284
	Clay		116
Soil texture			Sandy loam
Field capacity		%	36
Permanent wilting point		%	16
Bulk density		Mg.m^{-3}	1.34

Table 2. The components of Bio-fertilizer WSG

Material	Value
Trichoderma harizanum	10%
Bacillus subtilis	10%
Humic acid	75%
Marine algae	5%
Moisture	10 – 12%
Organic matter	65%
Potassium dissolved in water (K_2O)	11%
Cation exchangeable capacity	400 mg/100 g soil
Boron	15 mg/ kg
Percentage of insoluble substances in water with alkaline properties	Less than 0.1%

The surface and subsurface drip irrigation system was used to irrigate the plants. GR drip pipes (with 4 litres h^{-1}) with a distance of 40 cm between one drip and another were used. The depth of the irrigation pie was 15 cm below the soil surface. hydraulic calibration was performed for the drip irrigation system, and the most appropriate pressure was determined, which is 100 kPa as mentioned [12, 13]. The first irrigation was given after the sapling on 1/11/2023, and the soil moisture was delivered to the field capacity limits. Irrigation for all experiment treatments was scheduled at a moisture depletion rate of 40% of the ready water, according to the depth of water added, according to the formula [14].

$$d = (\theta fc - \theta I) \times D \tag{1}$$

where, d=Applied water depth (mm); θfc=Volumetric moisture content at field capacity (cm^3 cm^{-3}); θI=Volumetric moisture content before the irrigation operation; D=Total depth of roots (cm).

The time required for irrigation was calculated from the equation given in study [15].

$$T = \frac{Ae \times GDI}{Q} \tag{2}$$

where, T=the time required for irrigation (hour); GDI=Total irrigation depth (m); Q=Discharge is given for the sum of drippers operating simultaneously (m^3 h^{-1}); Ae=Wetting area for all test lines (m^2).

The irrigation time was determined by estimating the actual residual moisture by the gravimetric method. This process was repeated until 40% of the available water for the plant was exhausted.

The following growth indicators and the outcome were studied at the end of the season (dependent variable) by taking five random plants.

1. Plant height (cm): Plant height was determined after measuring the height of five randomly selected plants using a ruler from soil level to the top of the head, and then calculating the average [16].

2. Head diameter (cm): Measured from the widest area of the head by ruler [17].

3. Leaf area (dcm^2): The leaf area was determined in Eq. (3) [18].

$$A = \frac{W \times As}{Ws} \quad (3)$$

where, A is the leaf area (dcm^2), W is the weight of the piece of trace leaf on which the leaf is drawn (g); As is the area of geometric shape, Ws is the weight of the piece of trace leaf on which the geometric shape is drawn (g).

1. Total yield ($Mg\ m^{-3}$):

The total marketable yield was calculated from the plant density product of 41.66 plants per hectare.

2. Field water use efficiency ($kg\ m^{-3}$):

The efficiency of using field water was calculated according to the following equation:

$$WUEf = \frac{Yield}{Water\ applied} \quad (4)$$

The results were analysed statistically using the SAS 2000 software according to the experimental design used. The arithmetic means of the treatments were compared according to the Dunkin' polynomial test at a probability level of 0.05.

3. RESULTS AND DISCUSSION

3.1 Water requirements of the cabbage crop

Table 3 shows that the values of total water requirements for cabbage crop during the growing season and surface drip irrigation treatment were 345.6 and 172.8 mm $season^{-1}$ and irrigation water levels of 100% and 50% respectively, while the values of water requirements during the growing season for subsurface drip irrigation treatments were 232.7 and 116.35 mm $season^{-1}$ and irrigation water levels of 100% and 50% respectively. The occurrence of rainfall with a depth of 40 mm during the growing season in the study area has helped to reduce the water requirements of the cabbages crop, as active rain must be taken into account in the calculations of the water requirement of the crop to rationalize the use of irrigation water and thus raise the efficiency of water use. These findings are consistent with the findings of studies [18, 19].

Table 3. Water depths (mm) added to cabbage crop during the growing season (mm $season^{-1}$)

No.	Growth Stage	Additive Water Depth (mm)				Depth of the Root Zone (cm)	Rainfall Depth (cm)
		Surface drip irrigation		Subsurface drip irrigation			
		100%	50%	100%	50%		
1	Vegetative growth (1-11 to 1-12)	88.4	44.2	63.3	31.65	10-15	-----
2	Head formation and elongation (2-12 to 1-1)	199.5	99.75	114.3	57.15	15-25	33
3	Maturity (2-1 to 15-2)	57.7	28.85	55.1	27.55	25-35	7
	Total	345.6	172.8	232.7	116.35		40

The highest added water depth was in the stage of head formation and elongation, as the values of the added water depths for surface drip irrigation treatments were 199.5 and 99.75 mm for irrigation water levels of 100% and 50%, respectively. The added water depth values for subsurface drip irrigation coefficients were 114.3 and 57.15 mm for irrigation water levels of 100% and 50%, respectively. The reason for the increase in water depths added during the stage of head formation and elongation is due to the increase in the effective root steaming of the crop and the increase in water absorption, as this stage is sensitive to water deficiency, and any water stress on the plant will reduce the yield. The depth of irrigation water added to subsurface drip irrigation treatment decreased compared to surface drip irrigation treatment for the same growth stage (head formation and elongation), with added water depth values of 114.3 and 57.15 mm for irrigation water levels of 100 and 50%, respectively. Subsurface Drip Irrigation (SDI) adds water directly to the root zone. Water losses caused by evaporation and deep percolation are reduced and almost non-existent, thus reducing the number of irrigations required to irrigate the crop [20].

3.2 Plant height

The results in Table 4 and Figure 1 demonstrated the effects of the treatments on the average plant height; the subsurface drip irrigation treatment had the highest average plant height of 25.15 cm $plant^{-1}$, with a significant difference from the surface drip irrigation treatment, the average plant height was 22.60 cm $plant^{-1}$. The cause of the average plant's superiority is attributed to the uniformity of the water distribution in the root area, as well as the supply of irrigation water via the creation of a good water balance at the appropriate depth in the root area, in addition to the fact that the surface irrigation system is less effective than the subsurface system because of the water's waste, in addition to that the growth of some weeds constrain the stem expansion, and thus the reduction of plant height [21].

The irrigation water levels significantly affected the average plant height, as the highest average plant height was 26.78 cm $plant^{-1}$ in an irrigation treatment of 100%, while the irrigation treatment of 50% gave the lowest average plant height of 20.97 cm $plant^{-1}$. These findings are consistent with findings [22]. It was found that conducting the process of deficit irrigation leads to a significant decrease in plant height at the vegetative growth stage compared to full irrigation, and this was because the vegetative growth stage is an active stage for the growth and expansion of cells and their division, which is affected by water shortage potential. Exposure of plants to water stress in the early stages of growth lowers their height, while the same stress in the late stages of growth does not affect plant height [23].

Table 4. The effect of study treatment on plant height (cm plant^{-1})

Drip Irrigation Style (D)	Irrigation Water Level (I)	Bio-Fertilizer Levels (kg ha^{-1}) (H)			D×I Interaction	D	I
		0	5	10			
Surface	100%	17.90 gh	28.36 cd	30.16 cb	25.47 b	22.60 b	26.78 a
	50%	15.00 i	19.16 g	25.00 e	19.72 d		20.97 b
Subsurface	100%	18.33 gh	31.00 b	34.93 a	28.08 a	25.15 a	
	50%	17.00 h	23.00 f	26.66 de	22.22 c		
D×H	surface	16.45 d	23.76 c	27.58 b			
	Subsurface	17.66 d	27.00 b	30.80 a			
I×H	100%	18.11 e	29.68 b	32.55 a			
	50%	16.00 f	21.08 d	25.83 c			
H		17.05 c	25.38 b	29.19 a			

Different letters indicate statistically significant differences ($p < 0.05$), while the same letters indicate no significant difference.

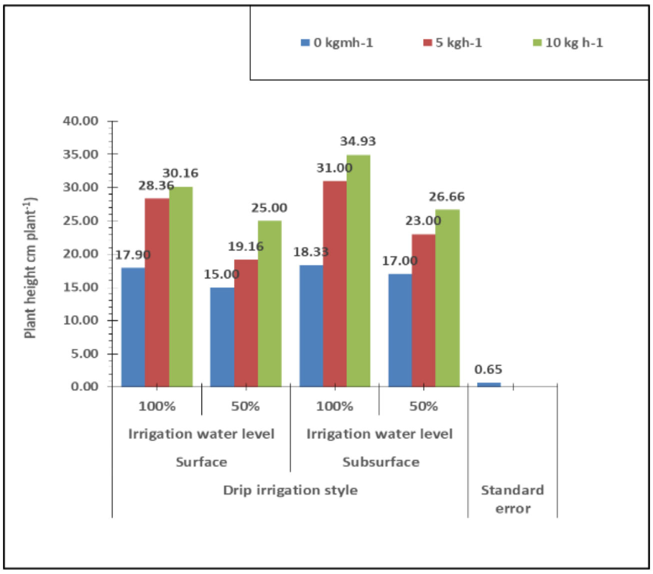

Figure 1. The effect of the drip irrigation method and irrigation water and bio health levels on plant height (Plant cm^{-1})

Figure 1 shows that the addition of bio-fertilizer significantly affected the average plant height, as the level of 10 tons ha^{-1} revealed the highest plant height of 29.19 cm plant^{-1}, while the lowest plant height rate was 17.05 cm plant^{-1} at the treatment of zero-addition of bio-fertilizer. The reason for this may be because the hormonal nature of Bio-fertilizer led to its significant superiority, as the presence of organic matter, humic acids and some other elements in Bio-fertilizer led to stimulating the formation of hormones and increasing their concentration within the plant and that this increase reflected positively on vegetative growth, where hormones interact physiologically, leading to increased cell division and its role in the strength of the growth of the root system and thus elongation [24].

3.3 Leaf area (dcm^2 plant^{-1})

The results in Table 5 and Figure 2 showed the effect of the treatments on the average leaf area, the subsurface drip irrigation treatment had the highest average area of 203.95 dcm^2 plants^{-1}, followed by the surface drip irrigation treatment with significant differences, the average leaf area was 193.60 dcm^2 plants^{-1}, the reason for the superiority of the average leaf area in the subsurface drip irrigation system is attributed to the beneficial effects of the water on the plants, the water is not evaporated by the sun and does not have a significant impact on the groundwater table. Additionally, the motion of nutrients is spherical and larger in volume around the subsurface dripper, while in the case of surface one, the motion is hemispherical below the dripper only [25].

The irrigation water levels have significantly affected the average leaf area, as the highest average leaf area was 220.90 dcm^2 plant^{-1} in the treatment of 100% irrigation water level. The lowest leaf area average was 176.66 dcm^2 plants^{-1} in the irrigation treatment level of 50%. These discrepancies in the area of the leaf in the cabbage plant's studied treatments can be attributed to the influence of the moisture content of the soil (MCA) at different stages of plant growth, this will consequently affect the physiological processes of the plant, and then the area of the leaf will be affected.

This may be caused by the lack of amino acid creation, which decreases the rate of protein creation of these acids, as well as increased degradation due to the alteration of these physiological processes in the plant, which was manifested in the average leaf area. This is in line with the [26] study. A decrease in the water content of the leaf relative to the other leaves results in a decrease in the size and number of cells, which decreases the rate of expansion of the leaf [27].

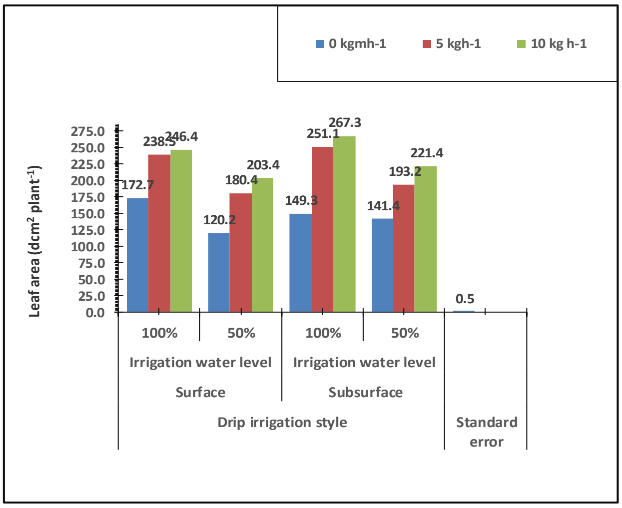

Figure 2. The effect of the drip irrigation method and irrigation water, and bio health levels on leaf area (dcm^2 plant^{-1})

The addition of bio-fertilizer significantly affected the leaf area, as the level 10 tons ha^{-1} revealed the highest leaf area of 234.62 dcm^2 plant^{-1}, while the lowest plant's leaf area was 145.91 dcm^2 plant^{-1} for the treatment of bio-fertilizer zero addition (Figure 2).

Table 5. The effect of study treatments on leaf area (dcm^2 plant^{-1})

Drip Irrigation Style (D)	Irrigation Water Level (I)	Bio-Fertilizer Levels (kg ha^{-1}) (H)			D×I	D	I
		0	5	10			
Surface	100%	172.73 i	238.53 d	246.36 c	219.21 b	193.60 b	220.90 a
	50%	120.20 l	180.40 h	203.40 f	168.00 d		176.66 b
Subsurface	100%	149.33 j	251.10 b	267.33 a	222.58 a	203.95 a	
	50%	141.40 k	193.16 g	221.40 e	185.32 c		
D×H	Surface	146.46 e	209.46 d	224.88 b			
	Subsurface	145.36 e	222.133 c	244.36 a			
I×H	100%	161.03 e	244.81 b	256.85 a			
	50%	130.80 f	186.78 d	212.40 c			
H		145.91 c	215.80 b	234.62 a			

The bio-fertilizer content of marine algae and humic acids may reduce the hydrogen potential (pH) of the soil in addition to irrigation water, leading to an increase in mineral availability for plant growth as well as improved physical properties, and this is consistent with [28]. Also, the marine extract led to an increase in the content of green matter, vegetation, and leaf area. There was a significant increase when fertilizing with bio-fertilizer for the foliar area by increasing the added fertilizer concentrations [29].

3.4 Cabbage head diameter (cm)

The results in Table 6 and Figure 3 demonstrated the effects of the treatments on the average plant head diameter, the subsurface drip irrigation treatment had the highest average head diameter of 14.83 cm, followed by the surface drip irrigation treatment, which is different from it, and in this treatment, the average head diameter of the plant was 12.46 cm.

The average head diameter of the subsurface irrigation system is superior to the surface system because of the uniform distribution of moisture in the root area and the provision of water from the soil; both of these factors contribute to the efficiency of the subsurface system. Additionally, the system is less prone to the growth of weeds, which causes the stem to grow longer and then decreases the height of the plant in comparison to the treatment of subsurface irrigation [21].

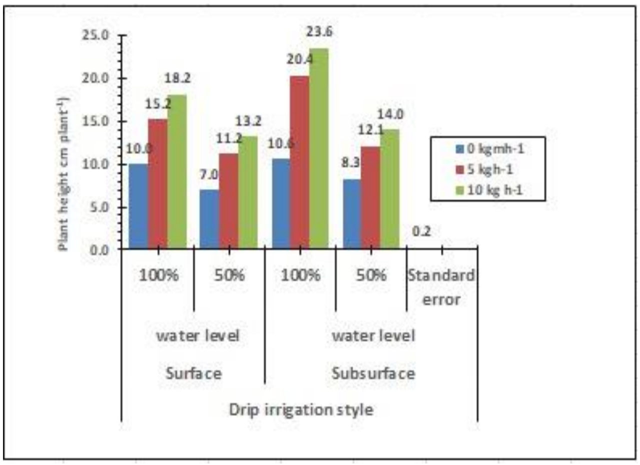

Figure 3. The effect of the drip irrigation method and irrigation water, and bio health levels on head diameter (cm)

Table 6. The effect of study treatments on the head's diameter (cm)

Drip Irrigation Style (D)	Irrigation Water Level (I)	Bio-Fertilizer Levels (kg ha^{-1}) (H)			D×I	D	I
		0	5	10			
Surface	100%	10.00 i	15.20 d	18.16 c	14.45 b	12.46 b	16.32 a
	50%	7.00 k	11.20 h	13.20 f	10.46 d		10.97 b
Subsurface	100%	10.60 hi	20.36 b	23.60 a	18.18 a	14.83 a	
	50%	8.30 j	12.13 g	14.00 e	11.47 c		
D×H	Surface	8.50 f	13.20 d	15.68 c			
	Subsurface	9.45 e	16.25 b	18.80 a			
I×H	100%	10.30 e	17.78 b	20.88 a			
	50%	7.65 f	11.66 d	13.60 c			
H		8.97 c	14.72 b	17.24 a			

Table 7. The effect of the study treatment on total yield (Mg ha^{-1})

Drip Irrigation Style (D)	Irrigation Water Level (I)	Bio-Fertilizer Levels (kg ha^{-1}) (H)			D×I	D	I
		0	5	10			
Surface	100%	11.10 fg	21.10 c	24.50 b	18.90 b	16.01 a	20.80 a
	50%	7.00 h	14.40 e	18.00 d	13.13 c		14.06 b
Subsurface	100%	13.00 of	26.50 b	28.60 a	22.70 a	18.85 a	
	50%	10.00 g	15.00 e	20.00 cd	15.00 c		
D×H	Surface	9.05 e	17.75 c	21.25 b			
	Subsurface	11.50 d	20.75 b	24.30 a			
I×H	100%	12.05 e	23.80 b	26.55 a			
	50%	8.50 f	14.70 d	19.00 c			
H		10.27 c	19.25 b	22.77 a			

3.5 Total yield (Mg ha^{-1})

The results in Table 7 and Figure 4 showed the effect of the experimental treatments on the average total yield, as the subsurface drip irrigation treatment gave the highest average total yield of 18.85 Mg ha^{-1}, followed by the surface drip irrigation treatment, which differed from it significantly, where the average total yield was 16.01 Mg ha^{-1}, which can be attributed to the higher average yield in the subsurface drip irrigation system because it allows water to move faster in the horizontal direction resulting in a greater wetting diameter compared to surface irrigation [30].

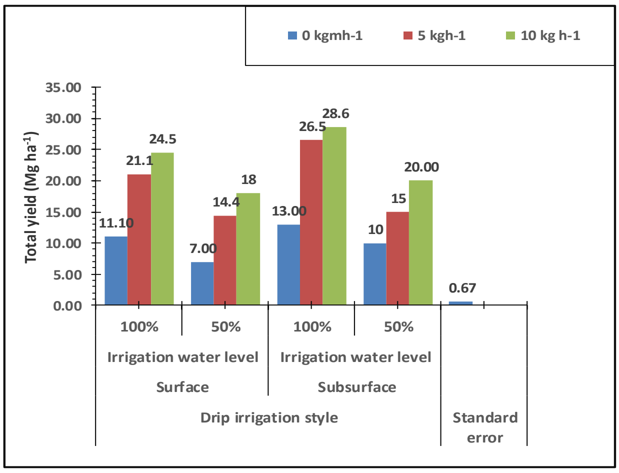

Figure 4. The effect of the drip irrigation method and irrigation water, and bio health levels on total yield (Mg ha^{-1})

3.6 Field water use efficiency (kg m^{-3})

The results in Table 8 and Figure 5 showed the effect of irrigation treatment on the average efficiency of water use, as the subsurface drip irrigation treatment gave the highest average water use efficiency of 17.27 kg m^{-3}, followed by surface drip irrigation treatment, which differed with it significantly and the average efficiency of water use was 14.06 kg m^{-3}, the reason for exceeding the average efficiency of water use in the subsurface drip irrigation system can be attributed as it is clear that it has contributed significantly to reducing evaporation from the soil surface and this reflected on the amount of water used and affected the total water consumption (Table 3), as it increased the growth and penetration of roots, secured moisture suitable for growth and nutrients in the active root zone, and increased the efficiency of consuming the water content stored in the soil [22].

The irrigation water levels significantly affected the average water use efficiency, as the highest average water use efficiency in an irrigation treatment was at 100% at 21.09 kg m^{-3}, while the irrigation treatment at the level of 50% gave the lowest efficiency of water use at 10.24 kg m^{-3}, The study finds significant differences in water use efficiency between different irrigation intervals and locations [31].

The addition of bio-fertilizer had a significant effect on the efficiency of water use; the highest yield was achieved when the level of 10 tons ha^{-1} was used, which was 24.01 kg m^{-3}, while the lowest yield was achieved when the level of 8.5 tons ha^{-1} was used, which was 8.87 kg m^{-3}. The results of the statistical analysis showed that the interaction between the percentage of bio-fertilizer and the method of irrigation was significant; the highest yield was achieved when the method of irrigation was 100%, and the addition of 10 kg of bio-fertilizer led to an increase in the yield of 27.69 kg m^{-3}. The low yield was 5.88 kg m^{-3}. The results of the statistical analysis also showed that the interaction between the level of irrigation water and the percentage of bio-fertilizer was significant; the highest yield was achieved when the level of irrigation was 100%, and the addition of 10 kg of bio-fertilizer led to an increase in the yield of 33.96 kg m^{-3}. The low yield was 5.88 kg m^{-3}. (Irrigation level 50% and without the addition of bio-fertilizer).

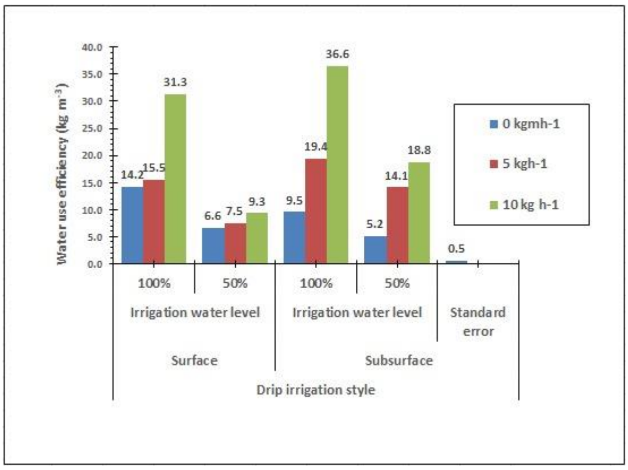

Figure 5. The effect of the drip irrigation method and irrigation water, and bio health levels on water use efficiency (kg m^{-3})

Bio-fertilizer WSG may increase yield by activating root growth, stimulating hormone synthesis, and other mechanisms; the differences between the water and nutrient utilization pathways of underground drip irrigation systems and surface drip irrigation.

Table 8. The effect of study treatment on water use efficiency (kg m^{-3})

Drip Irrigation Style (D)	Irrigation Water Level (I)	Bio-Fertilizer Levels (kg ha^{-1}) H			D×I	D	I
		0	5	10			
Surface	100%	14.20 d	15.47 d	31.34 b	20.33 a	14.06 a	21.09 a
	50%	6.58 fg	7.470 f	9.33 e	7.79 c		10.24 b
Subsurface	100%	9.53 e	19.43 c	36.58 a	21.85 a	17.27 a	
	50%	5.18 g	14.10 d	18.80 c	12.69 b		
D×H	Surface	10.39 d	11.47 d	20.33 b			
	Subsurface	7.36 e	16.76 c	27.69 a			
I×H	100%	11.86 d	17.45 b	33.96 a			
	50%	5.88 e	10.78 d	14.06 c			
H		8.87 c	14.12 b	24.01 a			

3.7 Interaction between WUE and the addition levels of water and bio-fertilizer

Figure 6 shows the relationship between WUE for the cabbages crop and the levels of addition of bio fertilizer and irrigation water levels, as the highest efficiency of water use was 33.96 kg m^{-3} at the treatment (irrigation level at 100% and the addition of 10 kg bio health) and the lowest efficiency for water use is 5.88 kg m^{-3} at the treatment (irrigation level at the level of 50% and without the addition of Bio Health). With a determination factor (R^2) of 0.483 and 1 for the levels of fertilizer and irrigation water, respectively, and this explains that the relationship is directly weak between the levels of bio fertilizer and the efficiency of water use, meaning that 48% of the changes in the efficiency of water use is due to the impact of bio fertilizer levels, and the reason for this may be because the efficiency of water use is affected by several other factors and bio fertilizer is one of these factors, As for the relationship between the efficiency of irrigation water use and levels, the relationship is strong linear (R^2 = 1), which means that irrigation water levels have a strong impact on the WUE for the cabbages crop.

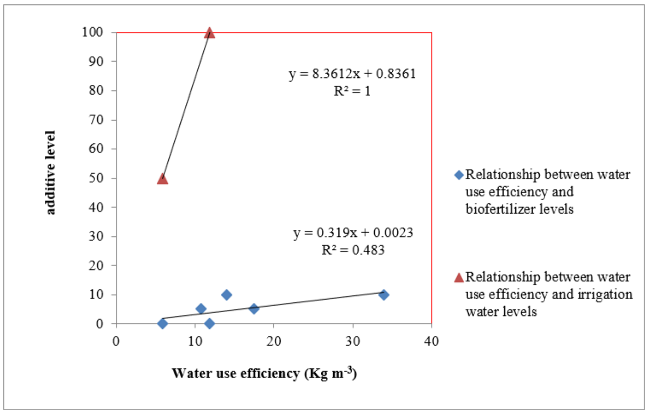

Figure 6. The relationship between the water use efficiency of the cabbages crop and the levels of both the bio fertilizer and the irrigation water levels

4. CONCLUSIONS

Subsurface drip irrigation at 50% water level combined with 10 kg ha^{-1} Bio-fertilizer WSG was optimal for yield and WUE. Growth indicators were reduced under 50% irrigation compared to full irrigation at 100%. The water requirements of the cabbage crop (345.6 and 232.7) mm season^{-1} reached the level of 100% irrigation for surface and subsurface drip irrigation treatments, respectively.

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