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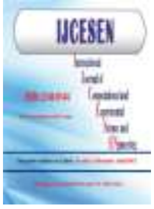

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Hydraulic Performance Analysis for Drip Irrigation Systems Efficiency and Water Productivity

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Abstract:

As competition for water demand increases in all life sections, the agricultural sector has observed a gradual decrease in water consumption. To sustain or enhance agricultural productivity, innovative irrigation methods, like surface and subsurface drip irrigation systems, enhance the efficiency of water utilization compared to conventional systems. In this study investigates the impact of operating pressure and emitter spacing on the uniformity coefficient (UC), distribution uniformity (DU), and application efficiency (EA) of a surface drip irrigation system. Data revealed a nuanced relationship between these variables, with the UC achieving a peak of 92% at 150 kPa, while lower pressures (100 and 200 kPa) resulted in decreased UC values of 88% and 92%, respectively, for both 20 cm and 40 cm emitter spacing. The distribution homogeneity for the lowest quartile decreased with increasing pressure, indicating that optimal pressure is crucial for maintaining uniform water distribution. Additionally, EA reached 90% to 93% across varying pressures, highlighting an inverse relationship between drainage rate and efficiency at higher pressures. Consumptive water use for lettuce crops varied significantly across irrigation methods, with surface irrigation consuming up to 380 mm compared to 223 mm for subsurface methods, underscoring the influence of irrigation design on water management and crop efficiency. Overall, these findings suggest that careful calibration of operating pressure and emitter spacing is essential for optimizing water distribution in drip irrigation systems.

1. Introduction

The scarcity of water resources and the severe drought conditions threaten food production in arid and semi-arid regions. They limit the growth of further crops and do not possess the ability to provide water requirements of plants at the present. The term climatic change is therefore defined as the slow and steady shift in weather conditions over a long period of time that characterized by change in rainfall patterns and increased incidences in different types of weather and climatic events including heat waves. Drought is expected to disturb the balance of rainfall and evaporation, increase water demand, and pose the need for water management as the central approach to reducing the impacts of climate change [1-7]. Sustainable control of irrigation water and other issues associated with this water is required to allow proper utilization at the correct rates. Efficient utilization productivity of cultivated crops is one of the areas of emphasis in agricultural practices, particularly in the arid and semi-arid areas such as Iraq.

Water conservation at each level starts with crop production and this forms the basic principle of modern irrigation methods. Relative to this concept, it is more significant to the specialists in irrigation water management. The modern irrigation enables the user to have a good understanding of how water is transported from the soil to the plants in order to better utilize water. Some of the factors that control the efficiency of water transfer through the root zone of plants include the type of soil, the type of plants, climate, limited funds and, water refill. Conventional irrigation practices cause a lot of waste of water. As a result, numerous works have attempted to find new strategies for scheduling irrigation and, thereby, define the quantum of water which should be incorporated and the ideal time for irrigation. Therefore, it has become necessary for agriculture to adopt the use of modern irrigation machinery that are simple to operate. Because of water deficiency several measures have been developed to irrigate crops. Drip irrigation system works by means of weak solution of the nutrient to the root zone at a slow method. It means that the water supply in the root area is maintained within the field capacity so that the plant can get water needed without much of it draining through the root or running on the soil surface. Drip irrigation is preferred most of the time because of its low water use efficiency, which ranges from 90- 95%.

The uniformity of water distribution in a drip irrigation system depends on some factors; these include the performing pressure of the pump, the drain facility, the characteristics of the pipes, the length of the pipes used for water conveyance and distribution and the pattern of the drip lines. These factors are the number of drip lines that has the number of drippers and the irrigation frequency. The selection of the most suitable parameters constitutes the other important steps and contributes highly to the design of the drip irrigation system for the best efficiency. To determine the appropriate discharge for the dripper it is recommended to look into factors like water demand by the crop being grown, the running time of the dripper, and nature of the soil. Spacing of plants, size of wet soil, and distance of drippers and drip lines controls the drainage of the drippers. However, the time between two triangle irrigations, triangle irrigation time and cost of irrigation also deserve some consideration. This means that detailed studies on evaluation criteria and system elements are needed for Drip irrigation. Surface drip irrigation, a water-saving method of irrigation, exists where water is incorporated in the active portions of the root of crops by the method of sufficiency and consistency by small openings referred to as drippers. Therefore, water is applied on the soil surface as equal amount of evapotranspiration loss. Drip irrigation basically involves the electronics foggers which add water at a slower rate than it seeps into the ground, thus, the drip irrigation system mainly feeds water to the root zone, it laterally and vertically in the soil bed without any losses in the form of deep infiltration, losses in surface run off way With drip irrigation, the fertilizer and irrigation water both are well calculated and well supplied at the slowing rate in the root zone so Such accuracy means that plants receive just enough water for their needs, yet the process is water wise, eliminating leaching and runoff.

In Iraq, drip irrigation was used selectively in guidelines for irrigation agriculture open and sheltered. The authors found that overall, utilization of drip irrigation in Iraqi scenarios was near to 80% effective when contrasted to even more standard methods like irrigation. It is possible to obtain several advantages with the help of a drip irrigation system. It is a technique of water storage for irrigation. It has been estimated that 1966% of water is saved compared to irrigation, and as much shrub as is possible is avoided. It also avoids the contraction of the disease, and it equally helps to halt soil erosion; the quad does not hinder some of the crucial agricultural care practices such as hoeing, removing shrubs, and spraying of pesticides.

This study aims to evaluate the relationships between operating pressure, emitter spacing, and key performance indicators of a surface drip irrigation system, specifically the uniformity coefficient (UC), distribution uniformity (DU), and application efficiency (EA). By analyzing the effects of varying pressures (100, 150, and 200 kPa) and distances between emitters (20 cm and 40 cm), the research seeks to determine optimal conditions for water distribution and efficiency in crop irrigation. The study also investigates how these factors influence water consumption in crops, using lettuce as a case study, to assess the impact of irrigation methods on water use and efficiency. Ultimately, the findings aim to provide insights for improving irrigation practices and optimizing water management strategies in agricultural systems.

2. Material and Methods

2.1 Experimental Site

The experiment was carried out in the Mazloum District, which is situated in the Middle Euphrates region of the Republic of Iraq, west of Najaf Governorate. The settlement of Al-Nour serves as the district's urban core. The district's administrative code is 28015. Specifically, one of the fields owned by farmers is situated at longitude 31° 53′ 59.56″N and longitude 44° 13′ 38.81″E. For the winter season of 2023. The irrigation system contains the water drawn from a well using a gasoline-powered water pump connected to the pump. The main transport pipe

Figure 1. *Site of a field experiment in the Mazloum district west of Najaf governorate, Iraq.*

then connects the secondary and branch pipes to the main transport pipe. It contains valves to control the opening and closing of the pipes. They control the water drainage, in addition to a pressure measuring device and a water filter, so the irrigation system is equipped with pure water free of impurities as follows: Plugs and drippers The irrigation system consists of a drop pipe and a pipe that draws water from the well and the sump to a main transfer pipe with a diameter of 1.5 inches that transports the water to the experimental site. It branches from the main pipe, especially the branch from the secondary pipes; the diameter of the secondary pipe is 1.5 inches .There are four side branches that branch off from the main pipe, with each branch consisting of two experimental units. The dimensions of each unit are 10 * 5, and there is a distance of 3 meters between each pair of experimental units. Additionally, each side pipe has nine drip pipes, with each drip pipe measuring 5 meters in length. The distance between each drip pipe is 70 cm. In the first experimental unit, surface drip irrigation pipes were installed along the plant line. In the second experimental unit, holes were dug 10 cm deep below the soil and drip irrigation pipes were installed at this depth. The same process was carried out by digging holes 20 cm and 30 cm deep below the ground and installing and extending the pipes along the designated plant line. Figure 1 is the site of a field experiment in the Mazloum district west of Najaf governorate, Iraq.

2.2 Laboratory Experiments

The laboratory experiments on loam soil (23% clay, 35%silt, and 42% sand) in certified lab. Figure 2 shows different operating pressures (1bar ,1.5 bar ,2 bar) to evaluate the drainage of the drippers of the surface drip irrigation system and the uniformity of water distribution. Figure 3 is the process of evaluate the discharge of the drippers of the surface drip irrigation system. Figure 4 is the measuring the wetness diameter of the wetting area.

Table 1. *Chemical and physical characteristics of the land soil before planting*

Location in Najaf		
Characteristics	**Unite**	**Depth(0-.30)m**
sand	g. kg^{-1} soil	420
clay	g. kg^{-1} soil	230
silt	g. kg^{-1} soil	350
texture	Loam	
Bulk density	$Mg.m^{-3}$	1.27
particle density	$Mg.m^{-3}$	2.65
porosity	%	50
PH	-	7.49
EC	Ds/m	4.73

2.3 Evaluate the hydraulic parameters for surface drip irrigation system

A variety of experiments were carried out for evaluating the discharge of the drippers in the SDI system and the frequency of water distribution. One of the pipes was chosen from the replicates treated with surface drip irrigation. Twenty-five cans with a diameter of 0.15 m and a high of 0.10 m were placed below the drippers of the pipes to collect the flowing water as a means of operating the system. The tests were conducted at Different operating pressures were chosen, as three operating pressures were chosen: 100, 150, and 200 kPa, and a mechanical pressure gauge was used for recording the pressure, and the drip irrigation system was calibrated at the chosen operating pressure,

1. Emitters discharge
2. Emitter uniformity coefficient
3. Variability percent of emitters discharge coefficient
4. According to equation Christiansen (1942) [8]:
5.
6. $Cu = 100\left[1 - \frac{\sum x}{Mn}\right]$ (1)
7.
8. Cu% = Uniformity coefficient as a percentage
9. $\sum x$ = Total deviations from the discharge rate (L $/h^{-1}$)
10. M = Average discharge dipper (L/h^{-1})
11. n = Number of dippers

Figure 2. *Different operating pressures (1bar ,1.5 bar ,2 bar) to evaluate the drainage of the drippers of the surface drip irrigation system and the uniformity of water distribution.*

Figure 3. *Process of evaluate the discharge of the drippers of the surface drip irrigation system.*

2.4 Calculate The Volume of Water

The available water was calculated according to equation Klute (1986) [4]

$$Aw = \theta fc - \theta wp \qquad (3)$$

AW :Available water content in the soil (cm^3 / cm^3)
θfc : Volumetric moisture at field capacity (cm^3 / cm^3)
θwp :Volumetric moisture at permanent wilting point (cm^3 / cm^3)

The volume application water of drip irrigation was calculated according the following equation

$$NDI = RZD \times WHC \times Pd \times pw \qquad (4)$$

NDI = Net Depth Irrigation
RZD =Root Zone Depth
WHC = Water Holding Capacity (mm of water cm^{-1}) = F.C—W. P
Pd = Percent of depletion
Pw =Percent of wetting

The volume application water of irrigation was calculated according to following equation Kovda & al. (1973) [6]:

$$d = (\theta_{FC} - \theta_w)D \qquad (5)$$

d =irrigation depth (mm)
θ_{FC} = Volumetric moisture at field capacity

Figure 4. *Measuring the wetness diameter of the wetting area*

θ_W =Volumetric moisture before re-irrigation (depletion 50- 55% of available water)
D = effective root depth (mm)

2.5 The Time Required for Irrigation

The time required for irrigation (T) in minutes was calculated

$$T = \frac{Ae \times d}{Q} \qquad (6)$$

Since:
d = depth of added water (cm), which is represented by the net irrigation depth (NDI).
Q = dripper discharge, which amounted to 4 liters per hour-1 for one dripper.
Ae =The wettability area of one dripper (m), which was calculated from the following equation:
Ae = 0.8 $(SW)^2$ (7)

2.6 Measuring The Wet Area of The Dripper.

Calculating the diameter of the wetted circle obtained from the field line drippers using a tape measure.
Since:

$$At = \pi r^2 \qquad (7)$$

AT: total wetting area
r: is half the radius of the wetting circle

2.7 Irrigation Scheduling

Irrigation of germination was given after planting. Irrigation was performed when 50% of the available water was depleted.

1. The depth of irrigation water to be added at each irrigation was calculated according to the equation no. (12) mentioned by (Kovda et al, 1973) [6].

$$d = (\theta_{fc} - \theta_w) * D \qquad (8)$$

where:
d = water depth(cm).
ϴfc= Volumetric field capacity ($cm^3\ cm^{-3}$).
ϴw= Volumetric Water Content before irrigation ($cm^3\ cm^{-3}$).
D = soil depth (cm).

2. The actual water consumption of lettuce was calculated by using the water balance equation (Allen et al., 1998) [9]

$$(I+P+C) - (ET_a+D+R) = \Delta S \qquad (9)$$

where:
I = depth of added irrigation water (mm).
P = rainwater depth (mm).
C = height of water in capillary property (mm), assuming it was zero, because groundwater is deep.
ETa = actual transpiration evaporation (mm).
D = the puncture water depth (mm), assuming zero because the losses for deep leaching were 0
R= Runoff (mm) assumed equal to 0.
ΔS = change in soil moisture storage between beginning and end of season.
3- The modified Monteith-Penman equation from the Food and Agriculture Organization (FAO) was used to estimate the evapotranspiration reference transpiration ET_o (Allen et al., 1998) [9] using the Aqua Crop program.

$$ET_\circ = \frac{\left(0.408 \times \Delta(R_n - G) + \gamma\left(\frac{900}{T+273} U_2 (e_a - e_d)\right)\right)}{\Delta + \gamma(1 + 0.34\, U_2)} \qquad (10)$$

Where:
ET_o = evaporation transpiration reference (mm Day^{-1}).
Rn = net irradiance at the crop surface (MJ m^{-2} $days^{-1}$).
G = heat flux at the soil surface (MJ m^{-2} day^{-1}).
T = average daily air temperature at an altitude of 1.5 - 2.5 m (º m).
U_2 = wind speed measured at a height of 2 m (m s^{-1}).
e_a = saturated vapour pressure at 1.5-2 m (kPa) altitude.
e_d = true vapour pressure at 1.5-2 m (kPa) altitude.
e_a-e_d = decrease in vapour pressure (kPa).
Δ = slope of the vapour pressure curve (kPa / o m).
γ = psychometric constant (kPa / oM).
900 = conversion constant

2.8 The Yield

Factor of lettuce during the growth stages was calculated using the following equation (Allen et al., 1998) [9]

$$Kc = \frac{ETa}{ETo} \qquad (11)$$

were
Kc = yield factor (without units)
ETa = actual transpiration evaporation (mm)
ETo = Refractory transpiration evaporation (mm)

2.9 Water Productivity

Was calculated according to the equation mentioned in (Allen et al., 1998) [9].

$$Water\ Productivity = \frac{Yield\ (kg\ h^{-1})}{water\ applied\ (mm)} \qquad (12)$$

Where:
Water productivity = water productivity (kg ha^{-1} mm).
Yield = total yield (kg ha^{-1}).

2.10 Estimate The Efficient Use Of Field And Crop Water:

The efficiency of field water use was calculated according to the following equation (Cracium, 1996) [10].

$$WUEf = \frac{Y}{WA} \qquad (13)$$

Where:
WUE$_f$= Efficient use of field water (kg m^{-3}).
Y= grain yield (kg).
WA= The amount of water added in the irrigation process (m^{3}season^{-1}).

3. Results and Discussion

3.1 Analysis Of Hydraulic Variables For Surface Drip Systems For Irrigation

Figure 5, illustrates the operating pressure and the uniformity coefficient of irrigation water distribution for the surface drip irrigation system. The link between them changed when the uniformity coefficient declined by 100,200 Kpa. The greatest homogeneity coefficient achieved was 92% at a pressure of 150 kPa. At operating pressures of 100 kPa to 200 kPa, the homogeneity coefficients were 88%, 92%, and 88%, respectively, for 20 cm between emitters, and 88%, 92%, and 89%, respectively, for a distance of 40 cm between emitters. These results are consistent with what was found by [11,12] noted that the homogeneity coefficient when the operating pressure increased because the drippers used in the evaluation process were designed to operate at low operating pressures, and that high pressures cause irregular flow of water distribution.

The results of Figure 6 also illustrate the uniformity of the distribution for the operating pressure, indicating a reverse correlation at a distance of 40 cm between emitters, where the uniformity diminishes as the operating pressure escalates. It attained 93%, 90%, and 85% at operating pressures of 100, 150, and 200 kPa, respectively, at 40 cm between emitters. Furthermore, distribution homogeneity attained 89%, 92%, and 87% at working pressures of 100, 150, and 200 kPa, respectively, for 20 cm between emitters. The reduction in distribution uniformity values can be ascribed to the influence of discharge and operating pressure, as well as their interaction. As distribution uniformity values grow markedly, water distribution in the field becomes uniform, as distribution uniformity is the ratio of discharge rate to drainage rate. Regarding the total drippers [13].

Figure 6, illustrates that the irrigation addition efficiency attained 90%, 93%, and 88% for operational pressures of 100, 150, and 200 kPa, correspondingly, at 20 cm between emitters. For 40 cm between emitters, the irrigation addition efficiency reached 89%, 93%, and 89% for the same that operate pressures. Increasing the actual drainage rate by elevating the operating pressure results in a reduction of irrigation efficiency at 200 Kpa for both 20 and 40 cm. This is due to the variable relationship between irrigation efficiency and actual drainage rate, which explains the decline in addition uniformity at 100 Kpa (Table 1). Table 2 is hydraulic parameters for surface drip irrigation (CU, DU,EA) with different distance between emitters (20,40) cm.

3.2 Consumptive Use and Applied Water

The volume of water utilized by a crop is influenced by its categorization, growing season,

Table 2. *Hydraulic parameters for surface drip irrigation (CU, DU,EA) with different distance between emitters (20,40) cm.*

Operating Pressure (kPa)	**CU (%)**		**DU (%)**		**EA (%)**	
	40 cm	20 cm	40 cm	20 cm	40 cm	20 cm
100	88	88	93	89	89	90
150	92	92	90	92	93	93
200	89	88	85	87	89	88

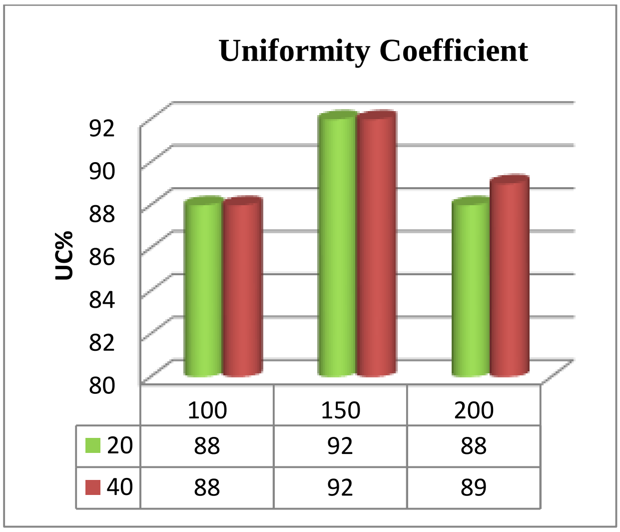

Figure 5. *Uniformity coefficient vs operating pressure for surface drip irrigation with different distance between emitters (20,40) cm.*

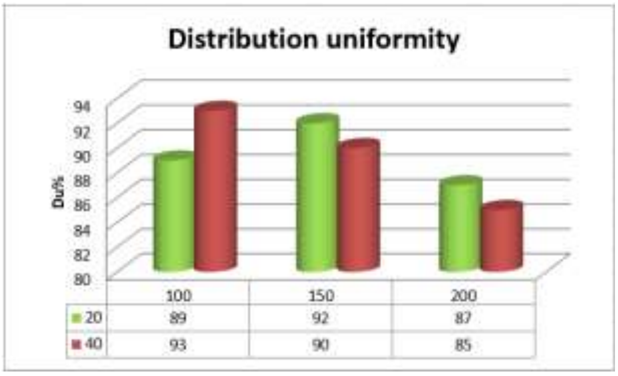

Figure 6. *Distribution uniformity vs operating pressure for surface drip irrigation with different distance between emitters (20,40) cm.*

Figure 7. *Application efficiency vs operating pressure for surface drip irrigation with different distance between emitters (20,40) cm.*

climate, management practices, soil type, and irrigation system. The water balance equation was employed to ascertain the consumptive usage values for the lettuce crop, which were subsequently changed according to the irrigation technique utilized. The maximum consumptive usage occurred in the surface irrigation treatments (D1), ranging from 380 mm to 358 mm per season at emitter distances of 40 cm and 20 cm, respectively. The minimal consumptive use for subsurface drip irrigation treatments occurred at an emitter depth of 30 cm (D4), measuring 223 mm and 210 mm for emitter distances of 40 cm and 20 cm, respectively. with a reduction of 23 to 25% in comparison to surface irrigation treatment. The decrease was attributed to the irrigation method employed at the effective rhizosphere, where the wet area was defined by the soil surrounding the emitters beneath the surface, and the moisture volume and wetting in subsurface drip irrigation occurred within the soil without saturating the surface layer. Consequently, evaporation from the soil surface reduced extended irrigation intervals, which resulted in reduced water consumption by the plant. Furthermore, minimal deep percolation occurred without surface runoff, as supported by [14] and [15].

Due to the application of irrigation water in varying places based on the moisture distribution pattern beneath the emitter and the volume and efficiency of the irrigation water utilized, the consumptive use in treatment D2 was lower than in treatment D1.The consumptive usage is contingent upon the volume of water supplied and the quantity of rainfall during the growing season, as the water provided to the soil is influenced by its moisture retention capacity and the extent of soil moisture depletion, which is further determined by the irrigation scheduling system.

The largest volume of water utilized was for surface irrigation treatment D1, totaling 380 mm and 358 mm each season for emitter distances of 40 cm and 20 cm, respectively. Furthermore, the minimum volume of water utilized occurred in the subsurface drip irrigation treatment with drippers positioned at a depth of 30 cm, with measurements of 292 mm and 265 mm for emitter spacings of 40 cm and 20 cm, respectively, during season one. The increase in water application for surface irrigation treatment D1 resulted from inadequate control over moisture distribution in the rhizosphere, particularly as the wet region expanded outside the rhizosphere. Furthermore, the exposure of the saturated soil surface to solar radiation escalates in tandem with evaporation, leading to water losses from surface runoff and deep percolation, compounded by the low efficiency of the application. This underscores the necessity to augment water input to achieve the soil moisture levels required for field capacity and plant needs.

Prior research has demonstrated that subsurface drip irrigation decreases water application by 30 to 60% relative to conventional techniques. Subsurface drip irrigation benefits from protection against direct sunlight and is distinguished by its direct interaction with the rhizosphere, facilitating water distribution in both vertical and horizontal directions by capillary action. This enhances the likelihood of water dispersing throughout the rhizosphere. The impact of the evaporation process is diminished. Moreover, the influence of diverse soil pores and particles is amplified throughout the growing season due to elevated temperatures. This also resulted in enhanced water evaporation from the soil surface, as evidenced by the varying consumptive usage estimates for the 2023 season. The results were corroborated by [16-20]. Figure 7 is application efficiency vs operating pressure for surface drip irrigation with different distance between emitters (20,40) cm.

3.3 The Effect of The Distance Between Emitters on Moisture Distribution for Drip Irrigation Systems in The Field (Wetting Diameter)

Surface drip irrigation tends to produce a larger wetting diameter because water spreads laterally along the soil surface before seeping deeper. This is why a surface dripper has a larger wetting diameter (35 cm) compared to subsurface depths. When the drippers are spaced closer (20 cm apart), the wetting areas from adjacent drippers overlap, forming a rectangular pattern. This occurs because the wetting fronts from adjacent drippers meet, increasing the horizontal wetting range. Subsurface drip irrigation at increasing depths (10 cm, 20 cm, 30 cm) shows a decrease in wetting diameter. This reduction occurs because water infiltrates deeper into the soil profile, leading to less lateral spread on the surface. As depth increases, the vertical component of water movement becomes more dominant, with less lateral dispersion. For instance, when the dripper is placed at 10 cm, the wetting diameter is 31 cm, but at 20 cm depth, it decreases to 26 cm, and at 30 cm depth, it further reduces to 25 cm. This decline occurs because the deeper of the dripper, the more constrained the water movement becomes, especially in the upward direction due to soil resistance and gravity (Figure 8). At a 40 cm spacing between drippers, the wetting circles generally do not intersect. This means that the wetting patterns remain isolated, and each dripper creates its own distinct wetting area without overlapping with adjacent areas. The diameters for different depths also vary, with surface drip showing a wetting diameter of 37 cm, while subsurface drippers at depths of 10 cm, 20 cm, and 30 cm have wetting diameters of 33 cm, 29 cm, and 27 cm respectively. The lack of overlap between wetting areas suggests that the spacing is too large to create continuous hydration along the soil surface (Figure 9).

The reduction in wetting diameter as dripper depth increases can also be attributed to the hydraulic conductivity of the soil. At deeper levels, water must overcome greater resistance to spread horizontally and is instead drawn downward by gravity. Additionally, water progress in different directions diminishes with depth. In shallow layers, water can move upward and laterally with ease, but as depth increases, upward movement becomes restricted, leading to a smaller surface wetting area. Table 3 is the number of irrigations, depth of water and water consumption. The volume of water added at deeper dripper levels is absorbed more quickly into the deeper soil layers, which limits its horizontal spread. Thus, for subsurface drip systems, more precise placement of drippers is required to ensure that plants receive adequate water, especially if the root zone is shallow. Deeper drippers lead to a more focused and smaller wetting pattern due to reduced lateral spread and the greater influence of gravity pulling water downward. Thus tighter spacing of the dripper provide a larger overlapping effect on the wetting areas thus provide a larger and even hydration area. To achieve efficient irrigation, the depth of installation of the drippers as well as the spacings between drip lines have to be right. There is prior empirical evidence and theoretical frameworks of modeling soil wetting patterns under drip irrigation [21].

3.4 Yield of Crop

Table 4 shows the effect of depth and distance between the surface and subsurface irrigation on the total yield of lettuce. The variation between the

Table 3. *The number of irrigations, depth of water and water consumption*

Irrigation System	Distance Between Emitters	Num. of Irrigation	Depth Of Water (mm)	Water Consumption
Surface (D1)	20	18	358	358
	40	19	380	380
Subsurface 10 (D2)	20	16	305	275
	40	17	322	298
Subsurface 20 (D3)	20	12	238	220
	40	15	287	249
Subsurface 30 (D4)	20	14	265	210
	40	16	292	223

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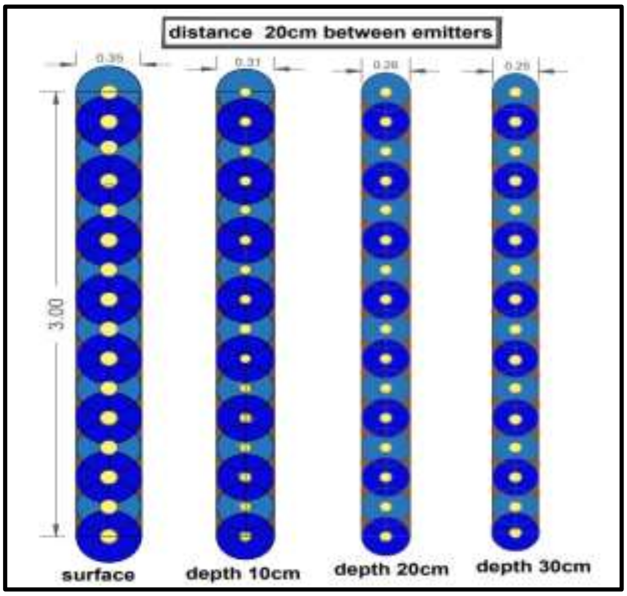

Figure 8. *Wetting diameter for drip irrigation with distance 20 cm between emitters*

distances of the drips and the depths of the different irrigation tubes has a significant impact on the productivity of lettuce. The parameter S1D3 is the higher yield of lettuce that is 118 mg. ha-1. There is also significant impact between the distance (S1, S2) in the same depth, and the parameter S2D3 which has productivity of lettuce about 106 mg. ha-1.

The possible explanation is that the plant line or density of the plant is higher in distance S1 compared to S2. This results in an increased number of plant branches per unit of area.

The results also showed that there was a difference between the depths D1, D2, D3, D4, where the parameter S1D1 was 75 mg. ha-1and for the parameterS2D1 for the same depth was 66 mg. ha-1. For the depth D2 the parameter S1D2 produced 89 mg. ha-1and for S2D2 It was 79 mg. ha-1, while, as have noted above, the depth D3 at distance S1 was the largest productivity of lettuce it was 118 mg. ha-1 and at parameter S2D3 the yield was 106 mg. ha-1.where the productivity of lettuce in the parameter S1D4 was about 93 mg. ha-1and at the second parameterS2D4 for the same depth was about 85 mg. ha-1. Have been concluded that the largest yield obtained at depth D3 is because the distribution of balanced water at the depth of D3, water can spread better and cover the root area of lettuce more efficiently. This balanced distribution helps to achieve better growth of plants compared to other depths. And Avoiding surface evaporation: Under-surface irrigation at D3 cm lowers water loss due to evaporation compared to surface drip. This means that plants get more water directly at their roots. Enhancement of radical aeration: Plants can get optimal root aeration when they are at an adequate depth. Shallow depths, such as D3, can lead to higher humidity and limited air flow, which can have a damaging impact on root growth. The moisture-heat balance within a D3 depth of soil helps maintain a consistent temperature, creating a stable environment for root growth. The shallow regions, such as those within D2 of the surface, see significant variations in temperature, which can have an impact on the growth of plants. and Minimizing disease risk: Subsurface drip irrigation decreases leaf wetness and soil surface moisture, hence minimizing the probability of growing genetic and bacterial infections in wet environments. Optimal nutrition: Performing irrigation at a depth of D3 can enhance the efficiency of nutrient dispersion in water, resulting in improved accessibility to the root zone and ultimately enhancing plant growth and productivity.

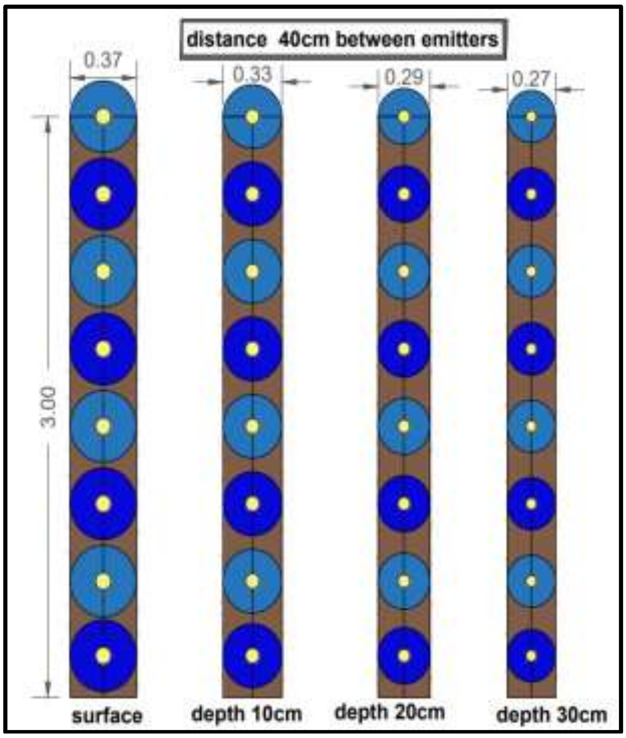

Figure 9. *Wetting diameter for drip irrigation with distance 40 cm between emitters*

Table 4. *The yield and water productivity*

Parameter	**Water Consumption**	**Yield mg. ha^{-1}**	**Water Productivity (kg.m^{-3})**
S1D1	358	75	20.9
S2D1	380	66	17.36
S1D2	275	89	32.36
S2D2	298	79	26.51
S1D3	220	118	53.63
S2D3	249	106	43.08
S1D4	210	93	39.52
S2D4	223	85	33.63

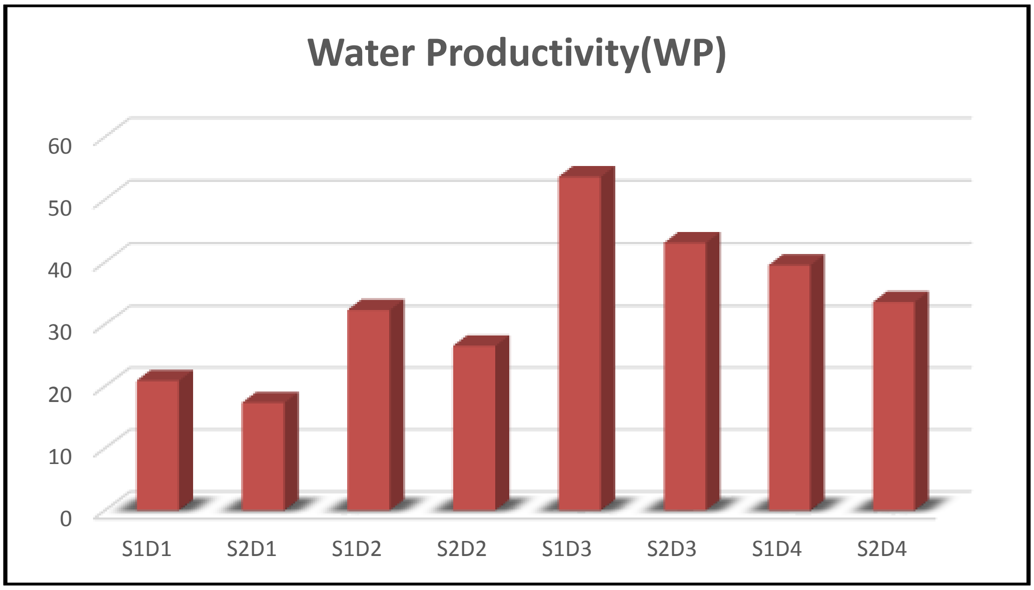

Figure 10. *The water productivity for depths (0,10,20,30)cm and two spaces between emitters (20,40)cm*

3.5 Water productivity (WP)

Figure 10 illustrates the results of various treatments because of water productivity through the utilization of irrigation water. The statistical analysis indicates significant variations in the average values of the transactions under study. water production for treatment S1D3 indicates that the maximum value recorded is 53.63 kg.m^{-3}, while the lowest value for water productivity is approximately 17.36 kg.m^{-3} in treatment S2D1. This is because plants heavily utilize the additional irrigation water, leading to increased productivity and positively impacting the overall efficiency of irrigation water That matches the findings obtained from [22]. The results were impacted by the distance between the drip lines and the depth of the tube. Table 4 illustrates the water production for treatment S1D1 about equal to 20.9 kg.m-3. The treatment S2D1 was 17.36 kg.m^{-3}. When the depth changed to D2, the water productivity at treatment S1D2 was 32.36 kg.m^{-3}, and at the treatment S2D2 it was 26.51 kg.m^{-3}. At the depth D3, the productivity at the treatment S1D3 was 53.63 kg.m^{-3}. At the same depth, for the treatment S2D3 was about 43.08 kg.m^{-3}. At the final depth D4, the water productivity of the treatment S1D4 was 39.52 kg.m^{-3} and for the treatment S2D4 was 33.63 kg.m^{-3}.

There are many reasons why the depth is greater than D3 by water productivity: The distribution of water at a depth of D3is more uniformly and widely spread throughout the root area compared to depths of D2 and D4. A depth of D2 can be too shallow, which leads to rapid evaporation, while a depth of D4 may cause water to be missed outside the active root area, minimizing evaporation at a depth of D3 decreases the amount of water lost by evaporation, which mostly happens during surface irrigation or at shallow depths, such as D2. This increases the amount of available water for plants.

Adequate aeration of the D3 deep roots creates an optimal environment for root airflow, hence enhancing root growth. A soil depth of D2 may subject the roots to high moisture levels and limited airflow, whilst a depth of D4 may be excessively deep, resulting in oxygen deprivation. The temperature remains constant at a depth of D3, and the soil is less affected by temperature fluctuations compared to shallower levels. This makes it possible to provide a better stable and thermal conditions for root development thus improving on plants growth. Enhancing water conservation. The drip irrigation regime situated at the depth of D3 further augments water productivity since water is issued directly to the root area. This cuts wastage and offers the best chances of plants getting the irrigated water they need. The ideal interval spacing of D3 is suggested for the application of proper water droplet distribution on the root zone. This makes the coverage of the cultivated area complete and it also helps to avoid formation of areas where the water accumulate.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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