The Effect of Water Stress Under Drip Irrigation System on Different Textured Soils in the Values of Available Water (TAW and RAW) on yellow corn crop Zea mays L

Noor N. Al-Saigh[1], Faris A. Al-Wazzan [2]

[1]Soil Science and Water Resources Dep., College of Agriculture and Forestry, University of Mosul/ Iraq

[2]Soil Science and Water Resources Dep., College of Agriculture and Forestry, University of Mosul/ Iraq

noor.21agp41@student.uomosul.edu.iq Dr.farisakram@uomosul.edu.iq

Abstract

The study aims to know the effect of soil texture and available water levels under drip irrigation system on Zea mays L Crop . The results showed that the values of both RAW and TAW increased with the advancement of the growth stage. At the beginning of the season, for the forest site, the values were 1.26 and 0.765 mm, respectively, while for the Al-Ghofran site, they were 1.425 and 0.872 mm. By the end of the season, for the forest site, the values were 276.10 and 201.82 mm, and for the Al-Ghofran site, they were 313.50 and 224.75 mm, respectively, for maize under both drip irrigation systems. The total available water under the subsurface drip irrigation system was higher than under the surface system throughout the growth period, which resulted in greater moisture retention efficiency and better water use efficiency for the subsurface system. This was in addition to the effect of soil texture, which changed with depth, becoming finer with an increased clay fraction, thereby enhancing the soil's ability to retain moisture at its maximum capacity. The variation in soil texture between the two study sites led to different values, with lower values observed at the forest site compared to the Al-Ghofran site due to the change in soil particle size. The results indicated that the amount of water available for consumption by the maize crop (RAW) was lower than the total available water (TAW) in general for all treatments under both surface and subsurface drip irrigation systems at the Al-Ghofran site compared to the forest site. This was due to the effect of soil texture. As the growing season progressed, deeper maize roots increased the soil's ability to absorb water, raising the RAW percentage.

.**Keywords:** Soil texture, Drip irrigation, Water consumption, Soil infiltration, maize yield

Introduction

The sustainability and development of strategic crops such as maize are crucial at present due to their economic importance for food security (Jiyad, 2020). To achieve development goals and ensure the sustainability of maize production while maximizing yield, it is essential to focus on modern irrigation systems, especially in arid regions suffering from severe water shortages (Thaher, 2024).

Water resources are a crucial determinant for agricultural development programs and are considered one of their main pillars. They also play an essential role in defining the investment patterns for agricultural lands and their potential for both vertical and horizontal expansion. The Tigris and Euphrates Rivers are the primary sources of water resources in Iraq, with rainfall playing a secondary role in meeting water demand, particularly for agricultural purposes. Groundwater occupies a third rank, contributing a small proportion of the total water usage, primarily for drinking in desert areas and irrigation in agricultural regions (Al-Badri & Nasser, 2012).

Water resources play a vital role in agricultural and economic development programs in many countries, serving as a crucial resource for crop cultivation and animal husbandry, thereby increasing agricultural production and improving product quality. Water is used in various irrigation systems, particularly in areas with low rainfall, and it plays a key role in improving soil and land quality through proper irrigation.

Soil texture significantly affects drip irrigation efficiency and water consumption. Sandy soils, with coarse texture, are characterized by fast water drainage and low moisture retention capacity, which necessitates more frequent irrigation with smaller amounts to meet plant needs. In contrast, clay soils, with fine texture, retain water for longer periods but suffer from slow drainage, requiring longer irrigation periods and larger amounts of water to avoid soil saturation and ensure proper root aeration. Mixed soils, which possess intermediate properties between sand and clay, offer a better balance between water retention and drainage, facilitating more efficient irrigation management. As noted by Al-Wazzan (2022), sandy soils require more frequent but smaller irrigation amounts, while clay soils need less frequent irrigation but with larger volumes due to their better water retention capacity. Other studies have shown that fine-textured soils, such as clay, retain water better but may experience slow drainage, which affects water use efficiency under different irrigation systems.

Tilled soils and agricultural practices have led to an increase in soil compaction, which slows water infiltration and increases mechanical resistance, hindering root growth due to higher bulk density, thus restricting the spread of maize roots (Al-Shami, 2018). Umair et al. (2019) tested three irrigation systems, including conventional flooding irrigation, surface drip irrigation, and subsurface drip irrigation. They found that subsurface drip irrigation reduced actual water consumption by 26% and 15% compared to the conventional and surface drip irrigation systems, respectively, resulting in lower crop coefficient values for the subsurface drip system.

Wang et al. (2020) indicated that drip irrigation is an effective method for reducing water consumption and increasing maize yield, thereby improving water use efficiency compared to conventional flooding irrigation. Water use efficiency values were 1.84 and 2.09 $kg.m^{-3}$ for conventional irrigation and drip irrigation, respectively. Wang et al. (2020) also reported that maize yields of 3.6 tons per hectare consumed 3730 m^3 of water per hectare under subsurface drip irrigation, with a water use efficiency of 3.93 $kg.m^{-3}$, outperforming both surface drip and conventional irrigation systems, which had water use efficiencies of 3.25 and 2.84 $kg.m^{-3}$, respectively. This is attributed to the higher efficiency of subsurface drip irrigation in supplying the root zone with adequate water

ISSN 2072-3857

and minimizing surface evaporation or deep percolation.

Zhang et al. (2021) compared different irrigation methods for improving maize yield, water productivity, and economic benefits in a dry region. They concluded that drip irrigation outperformed surface irrigation in water productivity, with field water use efficiency values of 2.52 and 3.84 $kg.m^{-3}$ and crop water use efficiency values of 2.46 and 3.23 $kg.m^{-3}$ for surface and drip irrigation, respectively.

Thamer et al. (2021) also highlighted the superiority of subsurface drip irrigation in terms of water use efficiency over both surface and traditional (flood) irrigation systems in consecutive seasons. The values of water use efficiency were 1.21 and 1.12, 1.26 and 1.14, and 2.99 and 2.71 $kg.m^{-3}$ for the respective irrigation systems. Drip irrigation systems, particularly subsurface drip irrigation, impact soil structure due to their contribution to water and air movement within the soil. This has led to better seed germination, seedling emergence, and root spread within the soil. Thus, soil structure is a determining factor in several water-related properties, such as water retention, air exchange, and root extension in the porous medium (Rai et al., 2017).

Material and Methods

Study Site:

Surface soil samples were collected, both disturbed and undisturbed, from two soil depths: the first from 0-15 cm and the second from 15-40 cm. The soil textures varied from clayey to sandy loam Soil separations were estimated by mechanical analysis using a hydrometer. The first site is located in the forest field at latitude 36.385593° N and longitude 43.123843° E.

The second site is located in the fields of the Nineveh Agriculture Directorate (Al-Ghofran district), situated at latitude 36.32778° N and longitude 43.16848° E, with an elevation of 222 meters above sea level. This site is classified as part of the dry and semi-arid regions of northern Iraq. The soil is calcareous, and its major classification according to the American Soil Taxonomy is Calciorthids (Figure 1).

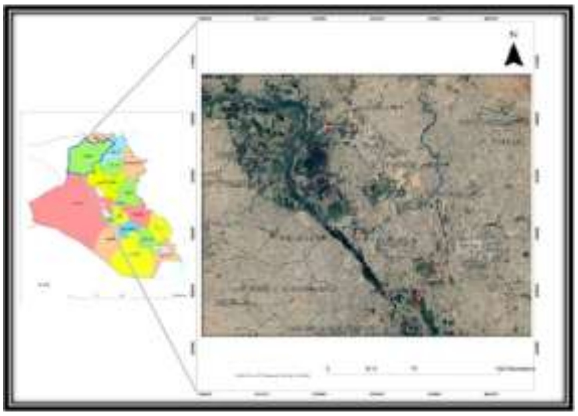

Figure 1: A map showing the study sites.

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Preparation of Study Sites

The study soil was plowed multiple times using a triple-bottom plow on July 30, 2023. The soil was then leveled and smoothed with disc harrows to prepare it for the study. Plant residues, stones, and gravel were removed from the soil. Afterward, soil samples were randomly collected from both the surface and subsurface layers. These samples were air-dried, crushed with a wooden hammer, and sieved through a mesh with 2 mm openings, and a composite sample was taken from the field for chemical, physical, and fertility analysis before planting. The results of these analyses are presented in Tables 1 and 2.

Drip Irrigation:

A drip irrigation system was used as it is one of the most water-efficient methods, especially in dry and semi-arid regions due to the scarcity of rainfall and water resources. The study utilized a drip irrigation system with both surface and subsurface pipes of 0.5-inch diameter made from PVC material. The system operates based on low-pressure water flow, has self-cleaning capabilities, and the distance between each pipe is 1 meter. Each treatment line had 7 emitters per pipe, with 3 lines per treatment, making a total of 21 emitters per treatment. The distance between emitters was 0.5 meters.

The drip pipes were connected to a secondary pipe with a 1-inch diameter, equipped with a control valve at the beginning for regulating water quantity and irrigation time. There was also a cleaning valve at the end and water meters to measure the amount of water used, as shown in the diagram in Figure 2.

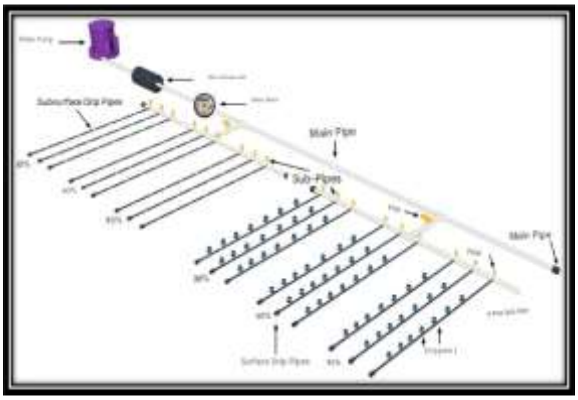

Figure 2: A diagram of the irrigation system.

Evaluation of Irrigation System:

The drip irrigation system was evaluated to determine the effectiveness of the network, test its efficiency, and ensure there were no malfunctions or blockages in the emitters. Tests were conducted to assess the irrigation system for the study site, including surface and subsurface drip irrigation treatments for both sites. The water discharge (Q) was measured, and the uniformity coefficient of water distribution (uc) under the emitters was calculated.

One drip pipe was selected from each replicate of the experimental treatments, and fifteen cylindrical containers were placed beneath the emitters of these pipes to collect the water flowing from them during the operation of the drip irrigation system. The

ISSN 2072-3857

tests were conducted at different operating pressures, selecting three discharge rates representing 30%, 60%, and 90% of the available water, depending on the saturated moisture content (θs) and the residual moisture content (θr).

The duration of the irrigation system evaluation was ten minutes, during which the collected water in each container was measured to determine the emitter discharge rate during the operation. The discharge was expressed in milliliters per minute ($mL.min^{-1}$) based on Darcy's equation, as referenced by Hajem and Yassin (1992).

The formula for calculating the emitter discharge is:

$$Q = \frac{V}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

Q = Emitter discharge (milliliters per minute, $mL.min^{-1}$)

V = Volume of water collected in each container (milliliters)

t = Operation time (minutes)

The uniformity coefficient (UC) under the emitters was calculated using the following formula (Christiansen, 1942):

$$UC = \left(1 - \frac{\sum|Xi|}{Mn}\right) \times 100 \ \ldots\ldots\ldots \quad (2)$$

Where:
UC = Uniformity coefficient (percentage)
Xi = The numerical deviation of the discharges from the average discharge (milliliters per minute, $mL.min^{-1}$)
M = Average discharge of the emitters (milliliters per minute, $mL.min^{-1}$)
n = Number of emitters

The Emission Uniformity (EU) index was used to evaluate the performance of the drip irrigation system, and it is expressed by the following formula, as stated in Ortega et al. (2002):

$$EU = \frac{\bar{q}_{25\%}}{\bar{q}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (3)$$

Where:
EU = Emission Uniformity (percentage)
$\bar{q}_{25\%}$= Average discharge rate of the lowest quartile (liters per hour, L/h)
$\bar{q}$ = = Average discharge rate of the emitters (liters per hour, L/h)
The coefficient of variation (CV) was calculated using the following formula, as stated by Wu and Gitlin (1974):

$$q_{Var} = \left(\frac{q_{Max.} - q_{Min.}}{\overline{q_{Max.}}}\right) \ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

Where:
qVar = Coefficient of Variation (percentage)

q_{Max} = Maximum discharge rate of the emitters (liters per hour, L/h)

q_{Min} = = Average discharge rate of the emitters (liters per hour, L/h)

The pressure was maintained during the operation of both the surface and subsurface drip irrigation systems throughout the duration of the research.

The readily available water (RAW) and total available water (TAW) were calculated using the following equations:

The equation for RAW (Readily Available Water), which represents the amount of water available to the plant before it starts to experience water stress, is calculated as follows:

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$$p \times TAW = RAW \quad \text{……… (5)}$$

Where:

RAW = Readily Available Water (mm)
TAW = Total Available Water (mm)
p = Depletion Factor or the proportion of readily available water (dimensionless)

The TAW (Total Available Water) is calculated using the following equation:

$$_{r}Z \times (\theta_{w}p - {}_{f}\theta) = TAW \quad \text{………… (6)}$$

Where:
fθ = Field capacity (the water content at field capacity)
θ wp = Wilting point (the water content at wilting point)
Z_r = Effective root zone depth (m)

Planting

Yellow corn seeds (Zea mays L.) of a hybrid variety from the Spanish company (Sagunto Fito) were planted on 30-7-2023. The seeds were sown in rows within plots oriented from south to north. Each plot contained three rows, with a distance of 1 meter between rows and 0.50 meters between each planting hole. Each row had seven planting holes, with a total of 21 planting holes per plot for the experimental treatments. Four seeds were placed in each hole at a depth of 30 cm, and thinning was done to two plants per hole two weeks after germination to achieve the desired plant density. The corn stalk borer (Sesamia criteca) was controlled using the chlorpyrifos pesticide at a concentration of 0.05%, with three applications: the first on 12-8-2023, the second on 23-9-2023, and the third and final one on 13-10-2023. Crop management practices, including weeding and manual removal of weeds, were carried out throughout the duration of the experiment.

Fertilizers Used and Application Methods

Mineral fertilizers were added for nitrogen (N), phosphorus (P), and potassium (K). Urea fertilizer $CO(NH_2)_2$ (46%) was used as a nitrogen (N) source, K_2O was applied at 52 kg as a potassium source, and P_2O_5 was added at 50 kg for phosphorus. The fertilizers were applied in two doses: the first at the vegetative growth stage, 17 days after germination, and the second at the male flower formation stage, 44 days after the first dose. The fertilizers were applied near the emitters, 10 cm away from the planting hole and 5 cm deep, manually.

Harvesting

The yellow corn crop was harvested on 22/11/2023, with the growing season lasting 115 days. The harvest was done manually and sequentially for each experimental unit, with measurements and readings taken accurately for each treatment.

Physical and Chemical Properties

Electrical conductivity (EC) was measured in a 1:1 soil extract using an EC meter, while the soil pH was measured in a 1:1 extract using a pH meter. Cations (K, Na, Mg, Ca) and total carbonates were estimated as outlined by Page et al. (1982). The soil moisture content was also measured to study soil moisture changes during the 115-day growing period. Soil samples were continuously taken at two depths, surface and subsurface, to observe moisture changes at different depths within the root zone throughout the plant's vegetative growth and

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root extension. The moisture front movement under both surface and subsurface irrigation systems and its impact on vegetative growth were also monitored. Soil samples were collected using soil augers, weighed directly in the field, then dried in the lab at 105°C for 24 hours. The moisture content difference, representing the soil moisture at the required depth and growth period, was calculated following Allen et al. (1998). An equation was used to calculate the depth of water to be added to compensate for depleted moisture.

Results and Discussion

1. Soil Particles Size Distribution

The mechanical analysis results of the soil samples from the study sites, shown in the table, revealed variations in the distribution of soil particle sizes. The highest clay content was observed at the subsurface depth at the Al-Ghafran site (310 $g.kg^{-1}$), while the lowest was at the surface depth of the same site (220 $g.kg^{-1}$). In contrast, the clay content at the forest site was similar for both surface and subsurface layers, ranging between (249.5-260) $g.kg^{-1}$. This similarity is attributed to the deep tree roots' impact, which caused the clay fractions in the surface and subsurface layers to converge, with a slight increase in the subsurface horizon due to the downward movement of fine clay particles. This trend supports the findings of Al-Mousa (2020), who noted the effect of forest tree roots in the downward movement of clay particles.

For silt, the highest content was recorded at the subsurface depth at the forest site (520 $g.kg^{-1}$), while the lowest was at the surface depth of the same site (240 $g.kg^{-1}$). The differences at the Al-Ghafran site for both surface and subsurface layers were small, ranging between (450-460) $g.kg^{-1}$. These variations depend on the distribution and movement of soil particles influenced by agricultural practices and equipment. Regarding sand content, the lowest was found at the subsurface depth of the forest site (220 $g.kg^{-1}$), while the highest was at the surface depth of the same site (510.5 $g.kg^{-1}$). In contrast, the sand content at the second site was higher at the surface (320 $g.kg^{-1}$) and lower at the subsurface (240 $g.kg^{-1}$).

The results showed clear increases in the clay fractions at subsurface depths across all study sites. However, Al-Ghafran exhibited more noticeable movement of clay particles from the surface depth (220 $g.kg^{-1}$) to the subsurface (310 $g.kg^{-1}$). This movement was influenced by factors like soil formation processes, plowing, and irrigation methods, which caused the movement of these particles. Climatic factors, such as the amount of rainfall, may have also played a role in the clay particle movement at this site. On the other hand, at the forest site, the movement of clay particles between the surface and subsurface layers was minimal.

The behavior of the silt fraction was similar to that of the clay in terms of distribution between the surface and subsurface depths, while the distribution of the sand fraction differed from the clay and silt in terms of increase and decrease.

The change in soil texture at the study sites and its variation with depth had a clear impact on the soil’s water characteristics. This, in turn, affected corn yield and growth during the growing season, depending on the soil texture and its ability to retain moisture, which influenced vegetative growth and root extension in the soil.

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Initial Soil Moisture Content

The initial soil moisture content (θ_0) is a function of the soil condition, its moisture content, and its capacity to retain maximum moisture over different time periods. The results revealed variation in the initial moisture content between the study sites with different soil textures. The values were (19.6% and 11.3%) for the forest and Al-Ghafran sites, respectively. This variation can be attributed to the nature of the soil texture and structure, which significantly influences the initial moisture content and its organic matter content. The organic matter contributes to enhancing the soil's ability to retain moisture for a longer time. This effect was more pronounced at the forest site for the surface depth. At the subsurface depth, the same behavior was observed, with moisture content values of (19.6% and 13.3%) for the forest and Al-Ghafran sites, respectively, for the same reason. Therefore, the soil at the forest site has a higher initial moisture content, which provides a good start for crop growth and reduces water consumption. Thus, the forest soil is more suitable for crops that require good aeration and faster drainage, such as certain vegetables or trees that tolerate rapid drainage. On the other hand, the soil at the Al-Ghafran site is characterized by its ability to retain water, making it suitable for crops that require sustained moisture.

Table (1) Some physical properties of the study soil.

Location	Fertilization	Depth	Soil Fractions g.kg^{-1}			Organic Matter	Bulk Density	Total Porosity	Saturated Hydraulic Conductivity	Initial Volumetric Water Content	Texture
			Clay	Silt	Sand	g.kg^{-1}	Mg.m^{-3}	%	cm.hour^{-1}	%	
Forests	Unfertilized	Surface	149.5	240	510.5	0.67	1.14	56.98	0.378	16.7	Sand Clay Loamy
		Subsurface	260	520	220	0.614	1.33	49.85	0.242	19.6	Silty Loam
	Fertilized	Surface	149.5	240	510.5	0.67	1.14	56.98	0.378	16.9	Sand Clay Loamy
		Subsurface	260	520	220	0.632	1.38	50.94	0.258	19.3	Silty Loam
Alghafran	Unfertilized	Surface	220	460	320	1.652	1.23	53.58	0.172	11.3	Loam
		Subsurface	310	450	240	1.03	1.45	45.28	0.145	13.3	Clay Loamy
	Fertilized	Surface	220	460	320	1.651	1.22	53.96	0.188	13.2	Loam
		Subsurface	330	430	240	1.622	1.43	46.03	0.167	13.5	Clay Loamy

Physical and Chemical Properties of the Study Soils:

Soil pH

The pH values of the soil samples in the study showed close values, ranging between (7.3-7.8). It is observed that there was no significant variation in the pH values across the different soil samples and depths. This could be due to the dynamic equilibrium between the carbonate roots in the soil solution and the basic ions in calcareous soils. This balance is described by Lindsay (1979) and Sposito (2008), who determined the pH to be around (pH = 7.82) (Table 2).

Electrical Conductivity (EC)

The results of measuring electrical conductivity (EC) in the soil extracts (1:1) showed a noticeable variation in conductivity values at the forest site. The electrical conductivity was higher in the fertilized subsurface soil, with the highest values recorded at (0.508) dS.m^{-1} in the depth range of (15-30 cm). The reason for the higher conductivity values could be due to agricultural practices, as the area is used for vegetable crops. At the Al-Ghafran site, however, a different pattern was observed. The electrical conductivity increased with depth in the soil, with the highest values recorded in the fertilized soil (1.810) dS.m^{-1}. This increase could be attributed to the

ISSN 2072-3857

movement of salts and their accumulation in the deeper soil layers.

Table (2): Some chemical properties of the study soils.

Location	Fertilization	Depth	pH	Ec	K^+	Na^+	Ca^{++}	Mg^{++}	$SO_4^=$	$CO_3^=$	HCO_3^-	Cl^-	Total Carbonates
				$dS.m^{-1}$	$meq.L^{-1}$								$g.kg^{-1}$
Forests	Unfertilized	Surface	7.8	0.354	1.282	0.789	2.16	0.126	2.101	NIL	1.23	1.48	252
		Subsurface	7.4	0.398	1.261	0.794	2.22	0.128	2.105	NIL	1.38	1.50	264
	Fertilized	Surface	7.6	0.441	1.230	0.819	2.28	0.147	2.104	NIL	1.72	1.44	254
		Subsurface	7.6	0.508	1.218	0.834	2.37	0.151	2.107	NIL	1.91	1.47	280
Alghafran	Unfertilized	Surface	7.73	1.482	1.025	1.271	10.11	3.30	2.245	NIL	11.70	1.36	287
		Subsurface	7.75	1.620	1.017	1.290	10.52	3.42	2.251	NIL	12.23	1.41	290
	Fertilized	Surface	7.30	1.547	1.057	1.311	10.63	3.47	2.254	NIL	12.88	1.38	278
		Subsurface	7.53	1.810	1.040	1.345	11.01	3.71	2.265	NIL	13.13	1.45	294

Soluble Ions

The cations and anions in the soil solution were measured for the study sites. The results generally showed higher calcium values in the soil at the Al-Ghafran site, both in the surface and subsurface layers, with values ranging between (10.11 - 11.01) $meq.L^{-1}$. This is likely due to the calcareous nature of the soils and their higher base content. In contrast, the forest site showed calcium values ranging between (2.16 - 2.37) $meq.L^{-1}$. The variation in the cation and anion concentrations across the study sites and soil depths is influenced by the soil's chemical and physical properties, as well as its fertility, as shown in Table (2).

Total Carbonate

Laboratory analysis results showed a significant increase in total carbonate values across all study areas. The highest values were observed at the Al-Ghafran site, reaching (294) $g.kg^{-1}$in the subsurface layer, while the forest site recorded the lowest values, ranging from (252 - 280) $g.kg^{-1}$ for both surface and subsurface layers. There was a slight increase in carbonate content with depth, which can be attributed to the leaching process and its downward movement, as noted by Mustafa and Al-Wazzan (2022).

Soil Moisture characteristicCurves

Table (3) and Figure (3) show the volumetric moisture content at different moisture potentials for the forest site at both the surface and subsurface layers under fertilized and non-fertilized treatments. The results revealed higher moisture content in the subsurface layer at all moisture potentials compared to the surface layer. This difference was particularly noticeable at low potentials (33, 100 kPa), where the subsurface layer recorded (0.437 and 0.317), compared to the surface layer, which recorded (0.334 and 0.214) for the same potentials. However, the results were similar at higher potentials (300, 500, 700 kPa). This difference in moisture retention between the surface and subsurface layers is likely due to the change in soil texture, with the subsurface soil transitioning from a silty clay loam to a loam texture, which gave the finer soil particles a greater capacity to retain water, as indicated by Wallender and Singh (2011).

The results also showed variation in moisture retention capacity and changes in the shape of the soil moisture descriptive curve between fertilized and non-fertilized treatments. Fertilized soils exhibited higher moisture content at all moisture potentials, which can be attributed to the impact of the NPK fertilizer in improving soil's ability to retain water by dispersing soil particles and enhancing the formation of water retention

ISSN 2072-3857

layers. However, this effect was temporary, as it ceased once the fertilizer dissolved and spread through the soil, as suggested by Brady and Weil (2016) , Al-Wazzan and Abdulrahman(2025) .

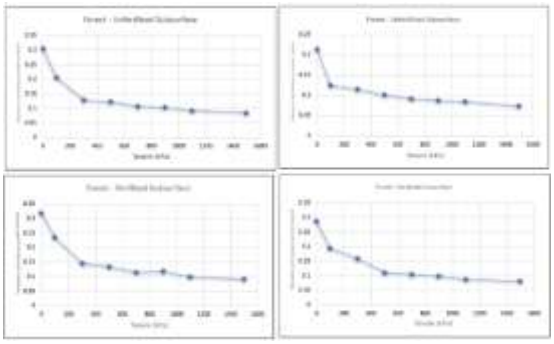
When comparing the soil moisture retention curves for the Al-Ghafran and forest sites, the results indicated that the volumetric moisture content for Al-Ghafran was higher at all moisture potentials for both surface and subsurface layers, as well as for both fertilized and non-fertilized treatments. This difference is due to the soil texture at the Al-Ghafran site, which is a loam in the surface layer (with a clay content of 220 $g.kg^{-1}$) and a clay loam in the subsurface layer (with a clay content of 310 $g.kg^{-1}$). These textures allow the soil at Al-Ghafran to retain moisture more effectively compared to the forest site, which has sandy clay loam in the surface layer and a silty loam in the subsurface layer. Therefore, soil texture, particularly the clay content, is the primary factor determining the soil's ability to retain water at various moisture potentials. This finding is in agreement with Harbawi (2025) and Al-Wazzan (2025), who highlighted the influence of soil texture on moisture retention.

Table (3): Relationship between volumetric moisture content and moisture potentials for the forest site.

Tension (kPa)		33	100	300	500	700	900	1100	1500
Surface Unfertilized	Volumetric Water Content (cm^3/cm^3)	0.334	0.214	0.135	0.124	0.100	0.091	0.086	0.083
Subsurface Unfertilized		0.425	0.305	0.204	0.144	0.126	0.111	0.107	0.092
Surface fertilized		0.406	0.286	0.194	0.160	0.119	0.104	0.098	0.087
Subsurface fertilized		0.437	0.317	0.234	0.188	0.140	0.115	0.107	0.101

Table (4): Relationship Between Volumetric Water Content and Suction for Al-Ghufran Site.

Tension (kPa)		33	100	300	500	700	900	1100	1500
Surface Unfertilized	Volumetric Water Content (cm^3/cm^3)	0.370	0.250	0.149	0.124	0.102	0.095	0.090	0.085
Subsurface Unfertilized		0.442	0.322	0.211	0.148	0.130	0.124	0.118	0.110
Surface fertilized		0.402	0.282	0.158	0.143	0.132	0.122	0.104	0.100
Subsurface fertilized		0.451	0.331	0.278	0.161	0.141	0.132	0.118	0.108



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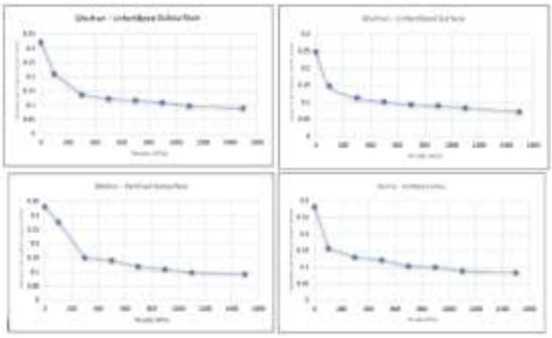

Figure (3): The Relationship Between Water Content and Suction

Water Consumption:

The water consumption of yellow corn during the growing season was calculated for both study sites under surface and subsurface drip irrigation systems at different soil moisture levels (30%, 60%, 90% of available water). Actual measured soil moisture content throughout the growth period was used as a basis to determine the increase or decrease in moisture content and the water consumption rate of the plants as the growth progressed, with root development and elongation of the green mass. These results were compared with predicted water consumption values using the Penman-Monteith equation to determine the degree of match or discrepancy between the actual and predicted values.

Total Available Water (TAW):

The results presented in Tables (5 and 6) for calculating the total available water for the plants showed an increase in the values during the growth phase for both the surface and subsurface drip irrigation systems, both for fertilized and non-fertilized treatments. At the beginning of the planting season, before the corn seeds germinated, the values were low, with (1.26) mm for the non-fertilized surface layer, and (1.06) mm for the same fertilized layer. In contrast, for the subsurface drip irrigation system, the values were higher: (1.67) mm for the non-fertilized treatment and (1.68) mm for the fertilized treatment. These values started off low because the roots were just forming fine root hairs. Over time, the main root and lateral roots developed and extended deeper into the soil, which affected the values calculated in the equations estimating the total water available for the plant (Equation No. (), Abdul Razzaq et al., 2016).

Tables (6) show that the total available water for the "Al-Ghafran" site was higher under subsurface drip irrigation than surface drip irrigation throughout the growing season. This is because the subsurface layer has a greater ability to retain moisture compared to the surface layer, which is exposed to harsher climatic conditions and higher temperatures. Consequently, the total available water was higher in the subsurface layer under the subsurface drip irrigation system. It was noted that the values ranged between (1.26 and 1.60) mm for the surface layer with sandy clay loam texture (fertilized and non-fertilized) at the beginning of the planting season, and became (276.10 and 350.90) mm at the end of the growing season (Said et al., 2023). The increase is attributed to the extension of the roots into the soil's pore space. This root growth deepened over time, which resulted in changes in the calculations and estimations of

TAW. Furthermore, the fertilized treatments showed higher values than the non-fertilized ones from the beginning of planting to harvest. This is likely due to the effect of the added fertilizer, which enhanced root growth more than in the non-fertilized treatment, leading to a higher TAW value as the root system developed to its maximum length. As for the TAW values for the subsurface layer with silty clay texture, they ranged from (1.67 and 1.68) mm at the start of the season, becoming (366.30 and 369.60) mm for the non-fertilized and fertilized treatments, respectively. These values were notably higher than the surface layer values at the same site, due to the influence of soil texture, which became finer with a higher proportion of clay and a lower percentage of sand, thus improving the soil’s ability to retain moisture at its maximum capacity. Additionally, subsurface drip irrigation is more effective at delivering water to the root zone, confirming that this irrigation system is more economical and efficient in saving water for the crop throughout the growing season.

Results for the "Al-Ghafran" site, with a loamy texture, showed consistent values with those of the "Al-Ghafran" site. The values showed an increase, as observed in the "Al-Ghafran" site, ranging from (1.425 and 1.510) mm at the beginning of the season to 313.5 and 332.2) mm for the surface layer under the non-fertilized and fertilized treatments, respectively. For the subsurface layer at a depth of 15 cm, with loamy clay texture, the values ranged from (1.660 and 1.715) mm at the start of the season, becoming (365.2 and 377.30) mm at the end of the season for the non-fertilized and fertilized treatments, respectively. The highest values were observed in the subsurface layer with loamy clay texture, which had the most noticeable increase due to the change in soil texture from the surface to the subsurface layer and its transition toward a finer texture. This clearly indicates that changes in the soil particle fraction and an increase in clay content led to an increase in the total available water for the plants. The highest recorded value was (377.30) mm, which is consistent with the findings of Al-Wazan (2017), who indicated that clay particles have a high capacity to hold water molecules, forming water films around soil particles, thus providing higher water retention and sustaining plant moisture for a longer period.

Consumable Water Quantity for Plants in Soil (RAW)

The results presented in Tables (5 and 6) show that the consumable water quantity for plants (RAW) at the forest site was lower than the total available water (TAW) across all treatments for both surface and subsurface drip irrigation systems. This mainly indicates that not all available water is accessible for absorption by plant roots. This is due to several factors, the most important being the plant's age, root extension, and the soil's specific conditions, such as its texture, water movement within the porous medium, and the soil's ability to form capillary bundles that contribute to the movement and transfer of water and salts to the plant for utilization. Additionally, it was observed that the values ranged from (0.765 to 0.972) mm at the beginning of the growing season and increased to (201.82 to 256.50) mm at the end of the growing season for the surface drip irrigation system, with fertilized and non-fertilized treatments, respectively (Zawawi et al., 2022). The significant change in values from the beginning to the end of the season and the

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large increase were attributed to the corn crop's growing need for moisture as the season progressed, along with the deepening of roots in the soil, which increased the (RAW) until it reached its maximum at harvest. It was also noted that the values ranged from (1.01 to 1.02) mm at the beginning of planting and increased to (267.76 to 270.17) mm at the end of the growing season for the subsurface drip irrigation system for the non-fertilized and fertilized treatments, respectively, at the forest site. This agrees with the findings of (Saleh, 2010), who indicated that as the growing season progresses, corn roots penetrate deeper into the soil, increasing their ability to absorb water from greater depths. This leads to an increase in the consumable water quantity (RAW) over time. The distribution of corn roots was found to be influenced by the amount of water applied, which in turn affects water use efficiency. The results also indicated that the change in values for the subsurface irrigation system was lower for both fertilized and non-fertilized treatments compared to the surface drip irrigation system. This was because the addition of fertilizer to the surface layer led to the absorption of higher amounts of water compared to the non-fertilized treatments to dissolve the fertilizer present on the soil surface. This was confirmed by (Abdul Razzaq et al., 2016), who stated that fertilizer application affects water consumption, especially in surface drip irrigation systems, where adding fertilizer to the surface layer requires the plant to absorb more water to dissolve and take up the fertilizer. This results in an increase in water consumption compared to non-fertilized treatments. The results showed that water use efficiency increased by 3.3% when using subsurface irrigation, indicating that this system might be more water-efficient while minimizing the effect of fertilizer addition on water consumption.

Moreover, the calculated values of consumable water under the surface drip irrigation system were higher, and the amount of water added and the change in soil moisture content were higher due to its direct exposure to atmospheric conditions, which increased the added water amount. This affected the calculation and estimation of both the total amount of water added (TAW) and the consumable water quantity (RAW). No significant differences were observed in the subsurface drip irrigation system between fertilized and non-fertilized treatments, as the fertilizer was applied to the surface layer, at least 15 cm away from the drip tubes, and these moisture content values in this system were less affected by atmospheric conditions, especially temperature. Therefore, the consumable water quantity under the subsurface drip irrigation system was similar for both fertilized and non-fertilized treatments (Mohammed, 2022).

The results presented in Tables (5 and 6) for the Ghafran site showed that the consumable water quantity for plants (RAW) was lower than the total amount of water applied (TAW) for both surface and subsurface drip irrigation systems across all treatments. These values were generally higher than those observed at the forest site, likely due to the direct impact of soil texture at this site, which had a finer texture compared to the forest site, both at the surface and subsurface depths. The (RAW) values for the surface drip irrigation system ranged from (0.872 to 0.924) mm at the beginning of the season and increased to (224.75 to 238.15) mm at the end of the season for non-fertilized

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and fertilized treatments, respectively, over a 115-day period. In contrast, the (RAW) values for the subsurface drip irrigation system ranged from (1.016 to 1.050) mm at the beginning of planting and increased to (261.81 to 270.49) mm for non-fertilized and fertilized treatments, respectively. The results also indicated that the consumable water quantity (RAW) at this site, as a proportion of the total available water (TAW) applied to the plants, was higher compared to the forest site, influenced by the soil texture. Thus, soil texture is a key factor in choosing the drip irrigation system, whether surface or subsurface, and in determining the total water applied (TAW) and the consumable water quantity (RAW), which is consistent with the findings of (Al-Daraji, 2019).

Table 5: Total Available Water (TAW) and Consumable Water Quantity (RAW) for the Forest Site

Date	TAW	TAW	TAW	TAW	RAW	RAW	RAW	RAW
Type	A	B	C	D	A	B	C	D
7/30	1.26	1.67	1.60	1.68	0.765	1.015	0.972	1.024
7/31	3.77	5.00	4.79	5.04	2.350	3.118	2.987	3.146
8/1	5.77	7.66	7.34	7.73	3.635	4.823	4.620	4.866
8/6	10.54	13.99	13.40	14.11	6.781	8.996	8.618	9.077
8/7	11.55	15.32	14.67	15.46	7.339	9.737	9.328	9.825
8/13	22.59	29.97	28.71	30.24	14.054	18.645	17.861	18.813
8/14	25.10	33.30	31.90	33.60	15.098	20.031	19.189	20.212
8/20	40.16	53.28	51.04	53.76	26.075	34.594	33.139	34.905
8/21	42.67	56.61	54.23	57.12	27.323	36.249	34.725	36.576
8/28	60.24	79.92	76.56	80.64	38.038	50.464	48.343	50.919
8/29	62.75	83.25	79.75	84.00	39.914	52.954	50.728	53.431
9/5	80.32	106.56	102.08	107.52	40.554	53.803	51.541	54.288
9/6	82.83	109.89	105.27	110.88	40.261	53.414	51.169	53.896
9/13	100.40	133.20	127.60	134.40	49.429	65.578	62.821	66.168
9/14	102.91	136.53	130.79	137.76	54.309	72.052	69.022	72.701
9/21	120.48	159.84	153.12	161.28	68.363	90.697	86.884	91.514
9/22	122.99	163.17	156.31	164.64	72.470	96.146	92.104	97.012
9/29	140.56	186.48	178.64	188.16	75.238	99.818	95.622	100.717
9/30	143.07	189.81	181.83	191.52	83.471	110.740	106.084	111.738
10/7	160.64	213.12	204.16	215.04	94.894	125.896	120.603	127.030
10/8	163.15	216.45	207.35	218.40	99.782	132.380	126.814	133.572
10/15	180.72	239.76	229.68	241.92	106.234	140.940	135.014	142.210
10/16	183.23	243.09	232.87	245.28	110.008	145.947	139.812	147.262
10/23	200.80	266.40	255.20	268.80	124.247	164.838	157.908	166.323
10/24	203.31	269.73	258.39	272.16	118.254	156.886	150.291	158.300
10/30	218.37	289.71	277.53	292.32	130.166	172.690	165.430	174.245
10/31	220.88	293.04	280.72	295.68	99.539	132.058	126.506	133.248
11/7	238.45	316.35	303.05	319.20	169.377	224.711	215.264	226.736
11/8	240.96	319.68	306.24	322.56	171.445	227.455	217.893	229.504
11/15	258.53	342.99	328.57	346.08	183.041	242.839	232.630	245.027
11/16	261.04	346.32	331.76	349.44	187.335	248.536	238.087	250.775
11/21	273.59	362.97	347.71	366.24	198.454	263.287	252.218	265.659
11/22	276.10	366.30	350.90	369.60	201.829	267.765	256.508	270.178

A= "non-fertilized surface"
B= "non-fertilized subsurface"
C= "Fertilized surface"
D= "Fertilized subsurface"

Table 6: Total Available Water (TAW) and Consumable Water Quantity (RAW) for the Ghafran Site

Date	TAW	TAW	TAW	TAW	RAW	RAW	RAW	RAW
Type	A	B	C	D	A	B	C	D
7/30	1.425	1.660	1.510	1.715	0.872	1.016	0.924	1.050
7/31	4.275	4.980	4.530	5.145	2.679	3.121	2.839	3.224
8/6	11.970	13.944	12.684	14.406	7.695	8.964	8.154	9.261
8/7	13.110	15.272	13.892	15.778	8.329	9.703	8.826	10.024
8/13	25.650	29.880	27.180	30.870	15.948	18.579	16.900	19.194
8/14	28.500	33.200	30.200	34.300	15.667	18.251	16.602	18.856
8/20	45.600	53.120	48.320	54.880	28.530	33.235	30.231	34.336
8/21	48.450	56.440	51.340	58.310	29.451	34.308	31.208	35.445
8/28	68.400	79.680	72.480	82.320	40.148	46.769	42.543	48.319
8/29	71.250	83.000	75.500	85.750	42.230	49.194	44.749	50.824
9/5	91.200	106.240	96.640	109.760	44.563	51.912	47.221	53.632
9/6	94.050	109.560	99.660	113.190	43.018	50.112	45.584	51.773
9/13	114.000	132.800	120.800	137.200	54.309	63.265	57.549	65.361
9/14	116.850	136.120	123.820	140.630	60.350	70.302	63.949	72.631
9/21	136.800	159.360	144.960	164.640	76.579	89.207	81.147	92.163
9/22	139.650	162.680	147.980	168.070	82.123	95.666	87.022	98.836
9/29	159.600	185.920	169.120	192.080	80.973	94.327	85.803	97.452
9/30	162.450	189.240	172.140	195.510	92.582	107.850	98.104	111.423
10/7	182.400	212.480	193.280	219.520	92.659	107.939	98.186	111.516
10/8	185.250	215.800	196.300	222.950	99.924	116.402	105.884	120.259
10/15	205.200	239.040	217.440	246.960	103.297	120.332	109.459	124.319
10/16	208.050	242.360	220.460	250.390	108.826	126.772	115.317	130.972
10/23	228.000	265.600	241.600	274.400	128.850	150.099	136.536	155.072
10/24	230.850	268.920	244.620	277.830	115.182	134.177	122.063	138.623
10/30	247.950	288.840	262.740	298.410	126.953	147.889	134.525	152.789
10/31	250.800	292.160	265.760	301.840	77.720	90.537	82.356	93.537
11/7	270.750	315.400	286.900	325.850	183.732	214.031	194.691	221.123
11/8	273.600	318.720	289.920	329.280	186.098	216.788	197.199	223.971
11/15	293.550	341.960	311.060	353.290	197.579	230.162	209.364	237.788
11/16	296.400	345.280	314.080	356.720	204.841	238.621	217.059	246.528
11/21	310.650	361.880	329.180	373.870	219.755	255.995	232.863	264.477
11/22	313.500	365.200	332.200	377.300	224.752	261.817	238.159	270.491

ISSN 2072-3857

hoot length (cm)

Results in table (1) showed that Zark cultivar had a significant effect on shoot length (225.78cm). The same table clearly shows that girdling process and spraying cultivars with10 g.L^{-1} of phosphorus significantly affected shoot length where the highest values were 242.89 and 272.75 cm, respectively. The interaction of Zark cultivar + girdling and Kamali cultivar + girdling significantly differed in shoot length from either cultivar+Non-girdling. Kamali cultivar treated with 10g.L^{-1} Phosphorus gave the highest value which surpassed significantly to the lowest value (Table1).

Chlorophyll content:

The combination of girdling/Phosphorus also showed significant effect on shoot length of grapevine, since the maximum value was obtained from combination treatment of girdling/10g.L^{-1} Phosphorus. Results also showed that the interactions of the three factors differed significantly; the maximum shoot length value (308.33 cm) was recorded from interaction of Kamali cultivar/ girdling/10 g.L^{-1} Phosphorus compared with the minimum value (150 cm) resulted from Kamali cultivar/ Non-girdling/0 g.L^{-1} Phosphorus.

Conclusion

1- The use of the subsurface drip irrigation system is more effective in the soil's ability to retain and absorb moisture during the growing season of maize compared to the surface drip irrigation system.
2- The impact of changes in soil texture on its water consumption capacity, with variations in both RAW and TAW values, depended on the fineness of the soil particles.
3- The gradual increase in water consumption values and the need for water as the maize plant progresses through its growth stages is significantly influenced by soil texture, which plays a crucial role in moisture retention.
4- RAW values were consistently lower than TAW under different irrigation systems, with the irrigation
5- system used and the distribution of soil particle sizes being the key influencing factors.

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