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EFFECT OF MODERN IRRIGATION SYSTEMS ON MAIZE PLANT IN CLAY SOIL AT MENOUFIA, EGYPT

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ABSTRACT: Due to the growing challenges concerning water resources, notably in Egypt, many farmers have turned to modern irrigation systems to optimize water use, especially in clay soils. This study aims to evaluate various irrigation systems applied to clay soil in Menoufia Governorate, Egypt. To achieve this goal, three different irrigation systems were tested: flood irrigation, surface drip irrigation, and subsurface drip irrigation, all used for cultivating maize, a summer crop. The results showed that the water consumption in flood irrigation was significantly higher compared to the other systems, namely surface and subsurface drip irrigation. Among the drip irrigation methods, subsurface drip irrigation resulted in higher plant height than both surface drip and flood irrigation. However, maize grain output was maximized with surface drip irrigation in comparison to both flood and subsurface drip irrigation. Furthermore, surface drip irrigation significantly enhanced the biological yield of maize in comparison to both flood and subsurface drip irrigation systems. Surface drip irrigation saved 594.6 m³ per feddan, a 21.43% reduction compared to flood irrigation. Subsurface drip irrigation saved 614.42 m³ per feddan, resulting in a 22.14% reduction in water use against flood irrigation.

These findings highlight the significant water-saving potential of drip irrigation systems, as well as their positive impact on maize growth and yield in clay soils, demonstrating their effectiveness in addressing water scarcity challenges in Egypt.

Keywords: Irrigation systems, flood irrigation, surface drip irrigation, subsurface drip irrigation, maize, water using efficiency, yield.

INTRODUCTION

Egypt's agriculture is severely constrained by limited water resources, particularly affecting newly reclaimed lands due to the high agricultural demands in the Nile Delta and valley regions. The agricultural sector consumes over 84% of available water, with irrigation practices accounting for 70-80% of the total water usage *(El-Beltagy and Abo-Hadeed, 2008; Abd El-Halim, 2015)*. This reliance on irrigation poses significant challenges to sustainable crop production, necessitating enhanced water use efficiency amid a growing population and various socio-economic pressures. Innovative techniques such as laser land leveling and modern irrigation systems have shown promise in improving water productivity *(Eid and Negm, 2019)*. Additionally, the shift from traditional surface furrow irrigation, which has low efficiency and high water losses, to more efficient systems is critical for optimizing water resource utilization *(Mitchell et al., 1995; Raine and Bakker, 1996; El-Kader et al., 2010; Abd El-Halim, 2015)*.

Drip irrigation is an efficient method that delivers water directly to the root zone of plants, enhancing water distribution and reducing plant disease risks by keeping foliage dry *(Okasha et al., 2020; Tian et al., 2022)* reported a 57.58% increase in water productivity for winter wheat

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*Corresponding author: mohamedhelmy200167@gmail.com compared to border irrigation, while *Darouich et al., (2014)* noted a rise in water productivity from 0.43 kg/m³ to 0.61 kg/m³ for various crops, indicating cost-effectiveness. The effectiveness of drip irrigation relies on both water availability and its efficient utilization, leading to improved plant growth and nutrient uptake while lowering application costs *(Nofal et al.,* 2019). When combined with proper fertilization, it can achieve up to 90% efficiency in increasing crop yields *(Camp et al., 2000; Fernandez-Galvez and Simmonds, 2006)* noticed that drip irrigation significantly enhances crop yields, optimizes resource use, and minimizes pollution risks. Additionally, it has been shown to boost yields in crops like watermelon, cotton, and maize compared to other irrigation systems *(Liu et al., 2022; Moursy et al., 2023).*

Subsurface drip irrigation (SSDI) efficiently delivers water directly to the root zone, minimizing evaporation and runoff while enhancing water use efficiency. It is particularly advantageous in arid regions and can be adapted to various cropping systems. However, successful implementation requires collaboration among water managers, designers, and end-users to address unique challenges (Lamm, 2009). Studies show mixed performance among irrigation systems; for example, while SSDI reduced water use by 5.5% compared to surface drip irrigation, it increased water productivity by 17.11% in open fields *(Moursy et al., 2023).* Conversely, SSDI yielded lower onion yields and WUE than surface drip systems *(Soliman et al., (2020)*, highlighting the need for careful consideration of system selection based on specific conditions.

Maize *(Zea mays)* is a crucial crop in Egypt, serving important roles in food production, animal feed, and industrial applications. It flourishes in the Nile Delta and Valley, where it benefits from irrigation sourced from the Nile River. However, successful maize cultivation requires efficient irrigation practices and modern agricultural techniques to overcome water constraints and optimize yields. This study aimed to assess the effects of modern irrigation systems on soil properties, as well as maize growth and yield, in the clayey soils of Menoufia Governorate, Egypt, an area predominantly dependent on flood irrigation. The response of crop yields was evaluated in test plots located within the study region.

MATERIALS AND METHODS

This study was carried out in the greenhouse of the Soil Science Department of the Faculty of Agriculture, Menoufia University, Egypt, situated at latitude 30° 33' 30.2" N and longitude 31° 00' 50.1" E.

This field experiment was conducted in randomized block design with three irrigation systems: flood irrigation (FI), surface drip irrigation (SDI), SSDI, and three replications. The plot area was 5 m x 6 m (width x length). To prevent potential side effects from infiltration after irrigation, a 2.0 m non-irrigated buffer zone was left between the parcels, with 3.0 m between the blocks. Fig. (1) shows the layout of the experiment. Irrigation water was sourced from the Nile in the research area.

The surface and subsurface drip irrigation systems consisted of a pump, screen filter, manometers, pressure regulator, main valve, control valves for each parcel, water meters, manifold pipelines, and lateral pipelines with in-line drippers. In both systems, lateral pipes with a 16 mm (GR) diameter and 25 cm dripper spacing were used. For the subsurface drip irrigation system, laterals were installed 15 cm below the soil surface according to *Gültekin and Ertek, (2022),* with one lateral per plant row (*Lamm and Trooien, 2003*). The GR pipes were connected to a 50 mm diameter uPVC pipe. The emitters had a flow rate of 6 l/h and a working pressure of 100 kPa.

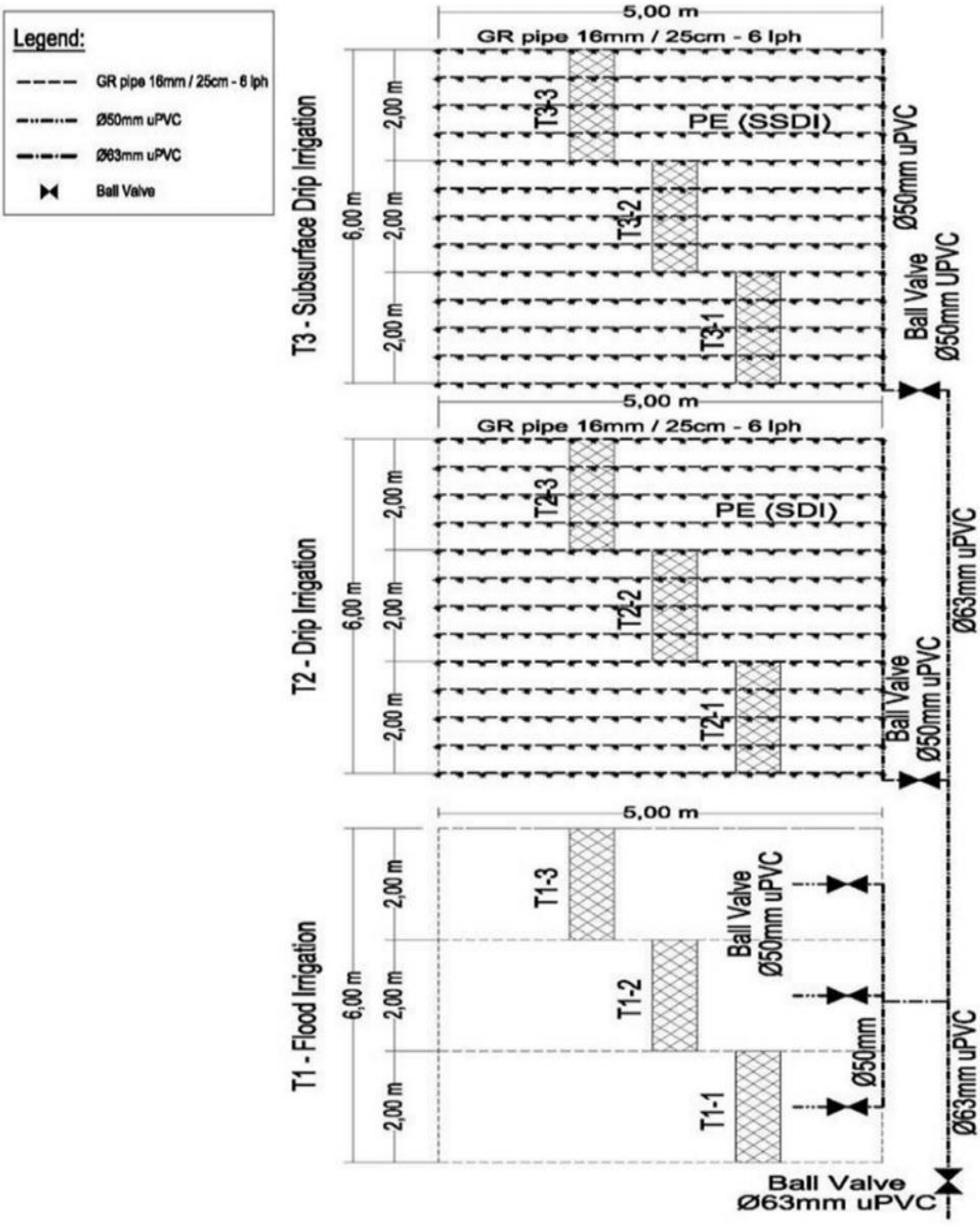

Fig. (1): Design the studied irrigation systems.

The seeds utilized in this investigation were the Single Hybrid Giza 130 type of Zea mays. The seeds were acquired from the Administration of Seeds, Agricultural Research Center, Ministry of Agriculture and Land Reclamation. Maize grains were manually sown in hills spaced 25 cm apart and rows 70 cm apart on May 15, 2021, at the advised rate of 12 kg per feddan, in accordance with the Ministry of Agriculture's recommendations. The study plants were monitored throughout the summer growing season to implement fertilization, irrigation, and pest control programs as per the Ministry's recommendations. Harvesting took place on August 29th, 2021, 105 days after sowing. Yield components and plant chemical composition were assessed, and maturity data were also collected.

Measurements and calculation

Soil

Before planting, disturbed and undisturbed soil samples were taken from the experimental soil at (0–20, 20–40, and 40–60) cm depths. These samples were analyzed for some physical and chemical properties following the procedures described by *Page et al. (1982)* and *Kuite and Page (1986)*, respectively as shown in (Tables 1, 2, and 3). As well as after harvesting, additional soil samples from each experimental unit were taken at soil depths of (0–20, 20–40, and 40–60) cm to assess any changes in the physical and chemical characteristics as shown in (Tables 4, 5, and 6). Soil physical properties were determined according to *Dane and Topp (2020)*, while chemical analysis of both soil extracts and plants followed the methods of Page *et al.* (1982). The main physical and chemical properties of the soil were measured both in the field and in the laboratory at the beginning of the trial.

Table (1): Initial physical properties of the experimental soil before planting.

Irrigation systems	Depth (cm)	Sand	Silt	Clay	Texture	B.D Mgm^{-3}	T.P %	H.C cmh^{-1}
FI	0 – 20	23.23	35.17	41.60	Clay	1.28	56.39	4.30
	20 – 40	24.23	37.35	38.43	Clay loam	1.45	55.36	4.15
	40 – 60	24.31	38.42	37.27	Clay loam	1.54	54.39	4.06
SDI	0 – 20	23.41	34.32	42.27	Clay	1.27	56.50	4.32
	20 – 40	25.33	37.24	37.43	Clay loam	1.46	55.52	4.15
	40 – 60	25.28	38.22	36.50	Clay loam	1.56	54.38	4.07
SSDI	0 – 20	23.24	35.22	41.55	Clay	1.28	56.37	4.31
	20 – 40	24.30	37.40	38.30	Clay loam	1.46	55.49	4.15
	40 – 60	25.29	38.23	36.48	Clay loam	1.55	54.45	4.07
LSD at 0.05		**0.07**	**0.03**	**0.05**		**0.03**	**0.10**	**0.04**

FI = flood irrigation, SDI = surface drip irrigation, SSDI = subsurface drip irrigation. B.D = bulk density, T.P = total porosity, H.C = hydraulic conductivity, and $Mg.m^{-3}$ = mega gram per cubic meter.

Table (2): Chemical properties of the experimental soil before planting.

Irrigation systems	Depth (cm)	pH (1:2.5)	EC dSm^{-1}	OM %	$CaCO^3$ %	CEC $c.molekg^{-1}$
FI	0 – 20	7.75	1.54	0.40	3.54	29.13
	20 – 40	7.69	1.63	0.35	4.15	27.11
	40 – 60	7.63	1.65	0.31	3.91	24.65
SDI	0 – 20	7.73	1.33	0.35	3.44	29.04
	20 – 40	7.64	1.28	0.30	4.12	27.10
	40 – 60	7.57	1.17	0.25	3.89	23.93
SSDI	0 – 20	7.75	1.75	0.37	3.48	30.43
	20 – 40	7.69	1.65	0.34	4.06	28.95
	40 – 60	7.62	1.51	0.27	3.74	27.82
LSD at 0.05		**0.03**	**0.03**	**0.02**	**0.04**	**0.03**

Table (3): The studied soil content of available macro-nutrients (N, P, and K) and of available micro- nutrients (Fe, Mn, Zn, and Cu) at mg kg^{-1} before planting.

Irrigation systems	Depth (cm)	N	P	K	Fe	Zn	Mn	Cu
FI	0 – 20	35.63	12.14	343.91	3.22	1.33	2.34	0.45
	20 – 40	34.30	11.53	331.49	3.12	1.11	2.25	0.32
	40 – 60	33.44	10.27	319.09	2.99	1.01	2.14	0.22
SDI	0 – 20	38.35	13.45	350.72	3.21	1.52	2.33	0.56
	20 – 40	37.22	12.14	342.51	3.10	1.32	2.15	0.41
	40 – 60	36.04	11.11	335.32	2.91	1.20	2.07	0.32
SSDI	0 – 20	34.43	10.35	330.57	2.82	1.23	1.42	0.35
	20 – 40	33.36	9.96	321.48	2.62	1.16	1.33	0.23
	40 – 60	32.05	9.25	316.23	2.30	1.08	1.21	0.13
LSD at 0.05		**0.08**	**0.08**	**0.06**	**0.03**	**0.03**	**0.04**	**0.03**

Crops

A known part of the harvested plants was taken separately. Plant samples were collected in the middle of the season and at harvest. The first set into grains and straw weighed separately air-dried at 70 °C for 42-hour weight, ground, and prepared for chemical analysis after that 0.5 g of oven-dried plant materials was digested by 10 ml of a concentrated mixture of H_2SO_4 + $HCIO_4$ (5:0.5) according to Chapman and Pratt (1961). Various growth parameters of the maize plants were measured. Forty-five days after planting, random plant samples from each subplot were collected to study vegetative growth parameters, including the number of leaves and plant height. At harvest, biological yield, yield components, and seed yield for each plot were recorded, and the total seed yield was determined. Key quality traits of maize, such as cob length and weight, were also assessed.

The plant materials were subjected to determine N by kjeldahl distillation method and P by the molybdenum blue method as well as K by flam photometer method *(Jackson, 1967)*. While Fe, Mn, Zn, and Cu were determined using atomic adsorption plasma - ULTIMA 2-ICP- OES (Inductively Coupled Plasma Optical. Emission Spectrometry). The approximate percentage of protein content was calculated using Official Analytical Chemists techniques (AOAC, 1990). Protein content was determined as (protein% = N% in grain × 5.75).

The harvest index is an indicator that represents the efficiency of the system in converting the fraction of dry matter weight into grain yield. It is the ratio of grain yield to dry matter weight and was calculated by the following:

$$\text{Harvest index (\%)} = \frac{\text{Grains yield (Kg/fed)} \times 100}{\text{Biologicl yiled (Kg/fed)}}$$

Water relation

1- Amount of water applied:

The irrigation water applied was calculated using the application CropWat software version 8, and the crop coefficient was figured out based on the crop and soil type in the study area. The irrigation efficiency within the program was 60% for flood irrigation, 90% for surface drip irrigation, and 91% for subsurface drip irrigation.

2- Water use efficiency

Water use efficiency (WUE) was used to assess the treatments that achieved the highest yield per unit of water consumed or applied. WUE, is defined as the yield weight in kg/m^3 of water transpired and evaporated during the growing season. WUE was calculated to evaluate water management practices. The water depth for drip irrigation was determined based on irrigation schedules developed using CropWat (version 8.0) software. To calculate the volume of irrigation water, the total irrigation time was multiplied by the system's flow rate (*C*hauhdary *et al* 2017). Crop yield WUE was measured following the methods outlined by *Jensen (1983) and James (1988)* as follows:

$$\mathrm{WUE} = \frac{y}{AW} = \mathrm{kg/m^3}$$

Where:

WUE = water use efficiency (kg/m^3).
y = total grain yield (kg/fed).
AW = total applied water (m^3/fed).

3- Water saving

The water saving per treatment was calculated by the following:

Where:
AW(FI) = applied water for flood irrigation systems (m^3/fed).
AW (SDI or SSDI) = applied water for surface drip irrigation or subsurface drip irrigation systems (m^3/fed)

Statistical analysis: The results were subjected to the standard analysis of variance procedure. Collected data were analyzed according to *Gomez and Gomez (1984).*

RESULTS AND DISCUSSION

Soil characteristics

Soil physical properties before and after maize plant harvesting.

The physical properties of soil irrigated with the three irrigation systems were evaluated before and after the experiment. The data presented in (Tables 1 and 4) show that the soil texture at three depths (0–20 cm, 20–40 cm, and 40–60 cm) consisted of clay, clay loam, and clay loam, respectively. Higher clay percentages were observed in the surface layers of the soil. Soil bulk density ranged from 1.28 to 1.56 Mg·m^{-3} for flood irrigation, 1.29 to 1.56 Mg·m^{-3} for surface drip irrigation, and 1.29 to 1.56 Mg·m^{-3} for subsurface drip irrigation. Total porosity ranged from 54.44% to 56.43% for flood irrigation, 54.48% to 56.44% for surface drip irrigation, and 54.44% to 57.67% for subsurface drip irrigation. Hydraulic conductivity ranged from 4.05 to 4.31 cm/h for flood irrigation, 4.06 to 4.29 cm/h for surface drip irrigation, and 4.07 to 4.29 cm/h for subsurface drip irrigation. The analysis indicates that the physical properties of the soil are suitable for plant growth. With the increase in soil depth, B.D was increased while both T.P and H.C were decreased. Regarding the values of B.D, T.P, and H.C concerning the supplying irrigation systems the data in (Tables 1 and 4) show a low increase in soil B.D well as a slight decrease in both T.P and H.C. These results agree with those obtained by *Blake, and Hartage (1986).*

Table (4): Effect of using modern irrigation systems on some physical properties of clay soil after maize plant harvesting.

Irrigation systems	Depth (cm)	Sand	Silt	Clay	Texture	B.D Mgm^{-3}	T.P %	H.C cm h^{-1}
FI	0 – 20	23.40	34.18	42.42	Clay	1.28	56.43	4.31
	20 – 40	24.18	37.53	38.29	Clay loam	1.44	55.45	4.14
	40 – 60	24.34	38.44	37.22	Clay loam	1.56	54.44	4.05
SDI	0 – 20	23.43	35.21	41.35	Clay	1.29	56.44	4.29
	20 – 40	25.21	37.24	37.55	Clay loam	1.44	55.44	4.16
	40 – 60	25.18	38.21	36.61	Clay loam	1.56	54.48	4.06
SSDI	0 – 20	23.13	34.35	42.45	Clay	1.29	56.67	4.29
	20 – 40	24.13	37.58	38.29	Clay loam	1.48	55.83	4.15
	40 – 60	25.38	38.25	36.34	Clay loam	1.56	54.44	4.07
LSD at 0.05		**0.11**	**0.15**	**0.13**		**0.03**	**0.13**	**0.04**

FI = flood irrigation, SDI = surface drip irrigation, SSDI = subsurface drip irrigation, B.D = bulk density, T.P = total porosity, H.C =hydraulic conductivity, and Mg.m^{-3} = mega gram per cubic meter.

The data in Tables 1, 2, 4, and 5 show that bulk density is inversely linked with total porosity, clay, pH, organic matter, and CEC, consistent with findings by *Tadele et al. (2021).* Low bulk density of surface soil as compared to sub-surface soil may be attributed to higher OM content and good aggregation *Neris et al., (2012), Singh and Sidhu (2014), Gautam et al., (2023),* also reported higher BD at lower depths due to formation of traffic pan and lower content of organic matter in soil**.**

Soil chemical properties before and after maize plant harvesting.

The data in (Tables 2 and 5) present the chemical properties of soil samples irrigated by the three irrigation systems at three depths (0–20, 20–40, and 40–60 cm). The soil pH was neutral, ranging from 7.43 to 7.75 for all three irrigation systems. The EC of the soil extract ranged from 1.17 to 1.75 dSm^{-1} across all depths for the three systems. Organic matter content ranged from 0.25% to 0.44%, with higher values observed at the surface, decreasing with depth in all irrigation systems. Calcium carbonate content ranged from 2.80% to 4.35%, also showing an increase at the surface and a decrease with depth across the three irrigation systems. Additionally, the CEC ranged from 22.99 to 29.97 $c.mol.kg^{-1}$, with higher values at the surface and decreasing with depth, likely due to the high clay content. These variations in soil chemical properties can be attributed to soil management practices such as organic manure application and crop rotation. In this respect, they found similar results *Yimer and Abdulkadir (2011)* displayed that exchangeable cations in soil depend greatly on the soil texture and organic matter content.

Table (5): Effect of using modern irrigation systems on some chemical properties of clay soil after maize plant harvesting

Irrigation systems	Depth (cm)	pH (1:2.5)	EC dSm^{-1}	O M %	$CaCO^3$ %	CEC $c.molekg^{-1}$
FI	0 – 20	7.43	1.53	0.44	4.27	29.18
	20 – 40	7.58	1.62	0.34	3.44	27.10
	40 – 60	7.73	1.71	0.28	2.81	24.69
SDI	0 – 20	7.52	1.32	0.44	4.35	29.27
	20 – 40	7.63	1.41	0.33	3.55	26.66
	40 – 60	7.75	1.53	0.27	2.90	22.99
SSDI	0 – 20	7.53	1.55	0.41	4.08	29.97
	20 – 40	7.64	1.64	0.33	3.47	25.91
	40 – 60	7.74	1.72	0.26	2.80	23.68
LSD at 0.05		**0.04**	**0.03**	**0.03**	**0.10**	**0.10**

EC = Electrical Conductivity, OM= Organic Matter. CEC = Cation Exchange Capacity.

The concentration of some available nutrients in soil samples irrigated by the three irrigation systems at three depths (0–20, 20–40, and 40–60 cm) is presented in (Tables 3 and 6). The data show that the nutrient concentrations are within safe and permissible levels according to *Ayers and Westcot (1985)* and the recommended concentrations for iron, copper, zinc, and manganese are 5, 0.2, 2.0, and 0.2 ppm, respectively. The macronutrient levels of available (N), (P), and (K) were within suitable limits. However, available phosphorus (P) was found to be below the critical limit at the 40–60 cm depth, according to the permitted range of 10–250 ppm, as specified by Sullivan *et al.* (2011).

Table (6): Effect of using modern irrigation systems on clay soil of Nile Delta content (mg.kg^{-1}) of available macro-nutrient (N, P, and K) and micro-nutrient (Fe, Mn, Zn, and Cu) after maize plant harvesting.

Irrigation systems	Depth (cm)	N	P	K	Fe	Zn	Mn	Cu
FI	0 – 20	33.53	10.86	330.56	3.07	1.18	2.14	0.45
	20 – 40	30.09	10.20	329.79	2.93	1.10	2.02	0.37
	40 – 60	29.76	9.58	321.65	2.75	1.02	1.90	0.28
SDI	0 – 20	38.41	11.16	330.55	3.75	1.39	2.27	0.54
	20 – 40	35.95	10.11	325.65	3.64	1.31	2.12	0.47
	40 – 60	32.14	9.59	315.96	3.56	1.24	1.95	0.37
SSDI	0 – 20	38.32	11.00	339.34	2.95	1.35	1.79	0.35
	20 – 40	35.63	10.37	325.99	2.84	1.26	1.69	0.27
	40 – 60	27.09	9.32	319.08	2.72	1.18	1.60	0.22
LSD at 0.05		**0.06**	**0.5**	**0.35**	**0.03**	**0.03**	**0.04**	**0.02**

Crop growth parameters

Vegetative growth parameters

The data on maize plant height, presented in (Table 7), show that subsurface drip irrigation resulted in higher plant height compared to surface drip irrigation and flood irrigation. So, the highest plant height was observed under subsurface drip irrigation, while the lowest was recorded under flood irrigation. These findings are consistent with studies by *Simsek et al. 2011; Bouazzama et al (2012) and Demir et al. (2021).* Regarding cob length (cm), the lengths of cobs were (26.33, 24.00, and 21.00) cm using SDI, FI, and SSDI respectively. Where drip irrigation produced the longest cobs, followed by subsurface drip irrigation and flood irrigation, respectively. The drip irrigation produced the longest cobs, followed by subsurface drip irrigation and flood irrigation, respectively. This could be attributed to the positive effect of increased soil moisture, which promotes cell enlargement, turgidity, and ultimately cell size *(El-Tantawy et al., 2007; Kuşçu and Demır, 20*12). The number of rows of cob was (59.67, 52.33, and 45.00) rows using SDI, FI, and SSDI respectively while the number of grains of cob was (820.33, 624.00, and 538.67) grains using SDI, FI, and SSDI respectively. Whereas the number of grains per row was higher under drip irrigation, and the total number of grains per cob was also higher under drip irrigation compared to flood irrigation and subsurface drip irrigation. These results align with findings from *Tas (2020) and Demir et al. (2021).*

Table (7): Effect of modern irrigation systems on some vegetative growth parameters of maize planted on clay soil conditions.

Irrigation systems	Plant height (cm)	Cob length (cm)	No. Grains/row	No. grains/cob
FI	226.03 c	24.00 a	52.33 b	624.00 b
SDI	256.67 b	26.33 a	59.67 a	820.33 a
SSDI	262.37 a	21.00 b	45.00 c	538.67 b
LSD at 0.05	**0.04**	**2.4**	**5.84**	**157.27**

Production (straw, grains, and harvest index)

The results in Table 8 indicate that the grain weight per cob (g) was considerably greater under surface drip irrigation than under flood irrigation and subsurface drip irrigation. Additionally, the crop weight of cobs (kg/fed) was significantly greater under surface drip irrigation than under flood irrigation and subsurface drip irrigation. Grain yield values of maize were also higher with surface drip irrigation compared to both flood irrigation and subsurface drip irrigation *(Kuşçu and Demır, 2012; Khoshvaghti et al., 2013).* surface drip irrigation also significantly increased biological yield compared to flood and subsurface drip irrigation. This improvement may be due to the optimal availability of water, which promotes better maize growth *(Kuşçu and Demır, 2012; Khoshvaghti et al.,* 2013; Tas, 2020). Furthermore, the harvest index (%) was significantly higher under surface drip irrigation compared to both flood irrigation and subsurface drip irrigation, as shown in (Table 8).

Table (8): Effect of modern irrigation systems on maize production (straw and grains) yields under clay soil conditions.

Irrigation systems	Grain in cob (g)	Crop weight of cobs (kg/fed)	1000 grains weight (g)	Biological yield (kg/fed)	Grain yield (kg/fed)	Harvest index (%)
FI	163.33 b	4391.33 b	427.33 b	7536.67 b	3220.00 b	42.73 b
SDI	183.67 a	4815.67 a	472.33 a	7989.67 a	3642.80 a	45.59 a
SSDI	144.67 c	3403.00 c	392.33 c	7224.67 c	2984.80 c	41.31 c
LSD at 0.05	**7.91**	**5.61**	**8.16**	**12.04**	**14.53**	**0.16**

Quality traits of maize

Tables 9, 10, 11, 12, and 13 present the concentrations (%) and uptake (g/fed) of nitrogen (N), phosphorus (P), and potassium (K) in the grains and straw of maize plants, as determined by Jackson (1967), along with the protein content (%) assessed by AOAC (1990), for plants subjected to flood irrigation, surface drip irrigation, and subsurface drip irrigation, respectively. The application of compost had a significant effect on crop vegetative growth, dry matter weight, and grain yield (*Ayers and Westcot, 1985; Adeyeye et al., 2014).* Additionally, the concentrations (mg/kg) and uptake (g/fed) of Fe, Mn, Zn, and Cu in the different irrigation systems were within the permissible safe limits set by *WHO (1999).*

Table (9): Effect of modern irrigation systems on straw maize plant content of macronutrients (%) and micronutrients (mg/kg) during the middle growing season at 45 days under clayey soil conditions.

Irrigation systems	N	P	K	Fe	Zn	Mn	Cu
FI	1.78	0.33	1.74	50.21	12.44	23.64	2.93
SDI	1.86	0.38	1.92	55.64	13.83	28.04	3.45
SSDI	1.74	0.32	1.32	45.20	11.71	21.81	2.81
G Means	**1.79**	**0.34**	**1.66**	**50.35**	**12.66**	**24.50**	**3.06**
LSD at 0.05	**0.06**	**0.04**	**0.04**	**0.06**	**0.07**	**0.09**	**0.08**

Table (10): Effect of modern irrigation systems on the straw of maize plants concentrations (%) and uptake (kg/fed) of N, P, and K at the harvest stage under clay soil conditions.

Irrigation systems	N		P		K	
	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)
FI	1.65	71.08	0.33	14.24	1.85	79.86
SDI	1.76	76.36	0.39	16.81	1.99	86.50
SSDI	1.60	67.84	0.31	13.00	1.81	76.74
G Means	1.67	71.76	0.34	14.69	1.88	81.03
LSD at 0.05	**0.04**	**1.88**	**0.20**	**1.9**	**0.06**	**2.66**

Table (11): Effect of modern irrigation systems on the straw of maize plants concentrations (mg/kg) and uptake (g/fed) of Fe, Mn, Zn, and Cu at harvest stage under clayey soil conditions.

Irrigation systems	Fe		Zn		Mn		Cu	
	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)
FI	38.44	1659.47	11.45	494.26	23.25	1003.48	3.45	149.07
SDI	49.48	2150.69	12.78	555.67	24.68	1072.95	3.98	173.15
SSDI	35.83	1519.28	10.65	451.55	22.61	958.78	3.32	140.76
G Means	41.25	1776.48	11.63	500.49	23.51	1011.74	3.59	154.33
LSD at 0.05	**0.06**	**4.8**	**0.06**	**2.88**	**0.08**	**5.19**	**0.07**	**3.31**

Table (12): Effect of modern irrigation systems on the grains of maize plants concentrations (%) and uptake (g/fed) of N, P, and K and the content of protein (%) under clay soil conditions.

Irrigation systems	N		P		K		Protein (%)
	Conc. %	Uptake (kg/fed)	Conc. %	Uptake (kg/fed)	Conc. %	Uptake (kg/fed)	
FI	1.81	58.28	0.35	11.16	1.53	49.27	10.41
SDI	2.00	72.74	0.41	14.94	1.66	60.47	11.48
SSDI	1.75	52.13	0.31	9.35	1.46	43.68	10.04
G Means	**1.85**	**61.05**	**0.36**	**11.82**	**1.55**	**51.14**	**10.64**
LSD at 0.05	**0.07**	**1.51**	**0.04**	**1.46**	**0.06**	**1.91**	**0.40**

Table (13): Effect of modern irrigation systems on the grains of maize plants concentrations (mg/kg) and uptake (g/fed) of Fe, Mn, Zn, and Cu under clay soil conditions.

Irrigation systems	Fe		Zn		Mn		Cu	
	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)	Conc. (%)	Uptake (kg/fed)
FI	57.24	1843.02	22.93	738.35	29.67	955.37	3.35	107.76
SDI	59.04	2150.83	25.49	928.67	35.47	1291.98	3.92	142.68
SSDI	56.93	1699.25	19.26	574.87	31.45	938.62	2.13	63.58
G Means	**57.74**	**1897.70**	**22.56**	**747.30**	**32.19**	**1061.99**	**3.13**	**104.67**
LSD at 0.05	**0.07**	**9.02**	**0.06**	**4.35**	**0.08**	**5.95**	**0.06**	**2.00**

Water relations

Amount of water applied

The data shown in (Table 14), the amount of irrigation water (AW) applied per unit area for three irrigation systems, Flood Irrigation (FI) with 2774.80 m^3/fed, Surface Drip Irrigation (SDI) with 2180.20 m^3/fed, and Subsurface Drip Irrigation (SSDI) with 2160.38 m^3/fed. Flood irrigation uses the most water due to surface application, leading to higher evaporation and runoff. Surface drip irrigation uses less water by delivering it directly to the root zone, while subsurface drip irrigation is the most water-efficient, minimizing evaporation and runoff by placing drip lines below the soil surface.

Water use efficiency

The Water Use Efficiency (WUE) values for the irrigation systems are as follows, Flood Irrigation (FI) with 1.16 kg/m^3, Surface Drip Irrigation (SDI) with 1.67 kg/m^3, and Subsurface Drip Irrigation (SSDI) with 1.38 kg/m^3. according *(Dağdelen et al., 2010; Gültekin and Ertek, 2022*, and Simsek *et al.*, 2011), while the application of water in flood irrigation was higher than in surface drip irrigation and subsurface irrigation systems, respectively. Drip systems are more water-efficient than flood irrigation.

Water saving

The water savings were 594.6 m^3/fed, representing a 21.43 % reduction for surface drip irrigation, and 614.42 m^3/fed, or a 22.14 % reduction, for subsurface irrigation compared with flood irrigation.

Table (14): Effect of different irrigation systems on water relationships, water consumption, and productivity of maize crop

Irrigation systems	AW (m^3/fed)	Y (Kg/fed)	WUE (kg/m^3)	Water saving (%)	Water saving (m^3/fed)
FI	2774.80	3220.00	1.16	0.00	0.00
SDI	2180.20	3642.80	1.67	21.43	594.60
SSDI	2160.38	2984.80	1.38	22.14	614.42
G Means	**2371.79**	**3282.53**	**1.40**	**21.79**	**604.51**

AW = Applied water (m^3/fed), Y = Yield (Kg/fed), WUE = Water using efficiency (kg/m^3).

CONCLUSIONS

The study concluded that drip irrigation yielded the highest maize grain production and water productivity compared to both flood irrigation and subsurface drip irrigation. Therefore, drip irrigation is highly recommended to enhance yield and water productivity under clay soil conditions. The important results include:

1) The drip irrigation system functioned efficiently according to its plan.
2) Surface drip irrigation saved 21.43 % of water and produced 13.13 % higher yield compared to flood irrigation.
3) Surface drip irrigation achieved a higher water use efficiency of 1.67 kg/m^3, while flood irrigation had a lower efficiency of 1.16 kg/m^3.

Finally, this study demonstrates that drip irrigation outperforms traditional methods in terms of water conservation, yield enhancement, and water use efficiency. Therefore, it is recommended that farmers adopt drip irrigation systems to replace conventional irrigation practices. However, modern irrigation systems may present challenges, including variations in soil water redistribution based on soil type and characteristics, nutrient availability, differential crop responses, as well as concerns related to system installation and maintenance. To overcome these challenges, it is essential to regularly monitor soil properties and plant growth to ensure optimal system performance and sustainability.

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تأثير نظم الري الحديثة على نبات الذرة في التربة الطينية بالمنوفية ـ مصر

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الملخص العربى

بسبب التحديات المتزايدة المتعلقة بموارد المياه، خاصة في مصر، لجأ العديد من المزارعين إلى استخدام أنظمة الري الحديثة لتحسين كفاءة استخدام المياه، لا سيما في التربة الطينية. تهدف هذه الدراسة إلى تقييم الأنظمة المختلفة للري المستخدمة في التربة الطينية بمحافظة المنوفية، مصر. ولتحقيق هذا الهدف، تم اختبار ثلاثة أنظمة ري مختلفة: الري بالغمر، والري بالتنقيط السطحي، والري بالتنقيط تحت السطحي، وذلك لزراعة محصول الذرة الصيفي. أظهرت النتائج أن استهلاك المياه في الري بالغمر كان أعلى بشكل ملحوظ مقارنة بالأنظمة الأخرى (الري بالتنقيط السطحي وتحت السطحي). أسفر الري بالتنقيط تحت السطحي عن ارتفاع أكبر في النباتات مقارنة بالري بالتنقيط السطحي والري بالغمر. ومع ذلك، كان محصول الحبوب من الذرة أعلى في نظام الري بالتنقيط السطحي مقارنةً بنظامي الري بالغمر والري بالتنقيط تحت السطحي. علاوة على ذلك، أدى الري بالتنقيط السطحي إلى زيادة ملحوظة في الغلة البيولوجية للذرة مقارنةً بنظامي الري بالغمر والتنقيط تحت السطحي.فيما يتعلق بتوفير المياه، فقد حقق الري بالتنقيط السطحي توفيرًا قدره ٥٩٤,٦ متر مكعب لكل فدان، وهو ما يمثل انخفاضًا بنسبة ٢١,٤٣ % في استهلاك المياه مقارنةً بالري بالغمر. كما أدى الري بالتنقيط تحت السطحي إلى توفير ٦١٤,٤٢ متر مكعب لكل فدان، محققًا انخفاضًا بنسبة ٢٢,١٤ % مقارنةً بالري بالغمر.

تسلط هذه النتائج الضوء على الإمكانات الكبيرة لأنظمة الري بالتنقيط في توفير المياه، فضلاً عن تأثيرها الإيجابي على نمو الذرة وزيادة إنتاجيتها في التربة الطينية، مما يبرز فعاليتها في مواجهة تحديات ندرة المياه في مصر.وتوصي الدراسة بضرورة المراقبة الدورية لخواص التربة والنباتات النامية في المنطقة قيد الدراسة.

الكلمات المفتاحية: أنظمة الري، الري الغمر، الري بالتنقيط السطحي، الري بالتنقيط تحت السطحي، الذرة، كفاءة استخدام المياه، المحصول.