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Effects of Inadequate Drip Irrigation and Organo-Mineral Fertilizer on Tomato Production, Quality and Water Use Efficiency in Sandy Soils

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DURING the 2018 and 2019 seasons, field trials were conducted at Farmer's Field in EL-Borulls district, Kafr Elsheikh Governorate, Egypt. to investigate and evaluate the impact of three irrigation regimes—irrigating tomato plants at 100% (I_1), 85% (I_2), and 70% (I_3) of ETc—as well as three organo-mineral fertilization treatments—F_1 (100% RNPK + 33% of recommended poultry manure (R.P.M.)), F_2 (75% RNPK + 50% of R.P.M.), and F_3 (50% RNPK + 60% of R.P.M) – on tomato fruit yields, quality, some water relations and economic return. Results revealed that both I_2 and F_2 treatments in both seasons produced the most fruit of tomato and its components. When comparing the two seasons as a whole, irrigation with (I_2) increased fruit output by (4.12%) compared to irrigation with (I_1), while the comparable value with (F_2) increased fruit yield by (10.21%) compared to that with (F1). The combination of (I_3F_3) produced the highest levels of TSS, %, vitamin C, and acidity, % during both seasons. Furthermore, maximum productivity of irrigation water and water savings, % were discovered with (I_3) during both seasons. The combination of (I_2F_2) produced the highest levels of economic efficiency and net return, whereas the combination of (I_3F_2) in the two seasons, achieved the highest net return from a water unit. It is possible to conclude that the most effective method for increasing the economic fruit output and quality of tomatoes while conserving both water and mineral fertilizers is the combination of (I_2F_2) or (I_2F_3).

Keywords: deficit irrigation; fruit yield and quality parameter; economic return; Poultry manure; Productivity of irrigation water.

1. Introduction

One of the most important vegetable crops, the tomato (Lycopersicon esculentum Mill), is grown on the most land of any vegetable. **(Jensen et al., 2010).** In the world, tomatoes rank third in terms of consumption after potatoes and sweet potatoes (**FAO, 2002).** The production of tomatoes worldwide in 2019 was estimated at 1808 million tons (**FAO, 2019**). One of Egypt's most important vegetable harvests is tomato. It is grown all year long. About 171820 hectares of tomato crops were grown in Egypt, yielding 6.78 million tonnes (2018-2019 statistics, **Faied et al., 2022**). On the other side, tomatoes are healthy and a good source of provitamins, B carotene, and vitamin C. Additionally, tomatoes are particularly abundant in lycopene, a potent antioxidant that aids in the prevention of a variety of cancers **(Evgenidis, et al., 2011 and Arach et al., 2015).** Because of this, efforts are being undertaken to increase the quality and quantity of tomato production in both developed and developing nations **(Kuscu et al., 2014; Adekiya, 2019 and Wu et al., 2021).** In dry and semi-arid regions where rainfall is scarce, tomato cultivation requires irrigation throughout the growing season due to the crop's high-water requirements. Deficit irrigation (DI) solutions could therefore significantly help this crop conserve irrigation water (**Du et al., 2017).** According to **Zou et al. (2020), and Hu et al. (2021),** DI might make it possible to maximize water productivity. and improvement of product quality. Additionally, DI management has the potential to greatly increase irrigation water productivity **(Buttaro et al., 2015 and Yassen et al., 2020).** Without reducing production, deficit irrigation can be utilized to grow tomatoes while also improving fruit quality metrics like sugar and antioxidant content **(Londono-Giraldo et al., 2020).** The use of low-cost and ecologically friendly resources has recently been the focus of significant efforts to produce a good-looking and high-quality tomato. Genetic, environmental, and cultural factors, including plant nutrients, interact to govern the production of high-quality fruits

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(**Xiukang and Yingying, 2016 and Hussien et al., 2020).**

Additional research showed that irrigation at a decreased rate (50% ETc) improved fruit quality, primarily according to total soluble solids (TSS) and vitamin C, with intriguing implications for industrial uses **(Al-Harbi et al., 2015, and Wang et al., 2022)**. Numerous studies have been conducted on the impact of partial root-zone irrigation on horticultural crop development, fruit yield and quality, and water use efficiency. It has been found that water deficits can increase productivity and tomato fruit quality (**Hui et al., 2017 and Lu et al., 2019).** In a study published **in 2010**, **Birhanu and Tilahum** examined the effects of drip irrigation on tomato fruit productivity and quality at crop evapotranspiration deficits of 0%, 25%, 50%, and 75%. The degree of water stress was directly correlated with almost all plant characteristics. Tomato yields were higher in both seasons at a high irrigation rate (6 L hr^{-1}) compared to a low irrigation rate (2 L hr^{-1}), according to **AL-Omran et al. (2010). I**n an experiment on tomatoes, **Celebi (2014)** found that under these conditions, the highest commercial fruit production (83.8-73.9 T ha-1) was obtained under (4 L hr–1 emitter discharge rate and KPC=1.2) and (2 Lhr–1 emitter discharge rate and KPC=1.2) applications, respectively. 507.1 mm and 365.1 mm of irrigation water, respectively, were the maximum amounts applied for the aforementioned applications., while the seasonal ET was measured at 657.0 mm and 538.1 mm. When **Aksic et al. (2011)** studied tomatoes, they discovered that 583.9 mm ET produced the maximum yield (64.6 T ha^{-1}). Water productivity (WP) peaked at 11.3 kg m-3, and irrigation water productivity (PIW) peaked at 8.2 kg m-3. The largest seasonal ET (525-619 mm), the highest irrigation water amount (426-587 mm), and the maximum tomato harvest yield (73.4-74.0 T ha^{-1}) in both seasons, respectively, were also recorded by **Ozbahce et al., (2012).** The average PIW values, on the other hand, frequently increased when seasonal irrigation water quantities declined. On the other hand, in an experiment done by **Cetin and Uygan (2008**) on tomatoes, the treatment where both lateral spaces and row spacing were one metre was found to produce the highest yield. With an irrigation water volume of 551 mm, the yields were 121.1 tonnes ha^{-1} and the PIW ranged from 14.3 to 25.8 kg m^{-3}.

Inadequate levels of macro- and micronutrients, especially in sandy soils, plague Egyptian lands. According to **Sarhan, 2021; Abdrabou et al., 2022 and Khalifa (2022)**, applying poultry manure and farmyard manure to sandy soil has positive benefits on the soil and plants. Because tomatoes have a high output, they need enough fertilizer to grow and produce (**Pandy and Chandra, 2013).** Higher soil organic matter and total-N with the use of organic agriculture has been identified by research comparing the soils of developing systems that are chemically managed and those that are managed organically **(Ali et al., 2019).** Additionally, organic agriculture is defined by the FAO as a production system that makes the best use of available resources, protects soil fertility and biological activity, uses the fewest non-renewable resources possible, and limits the use of synthetic chemicals that are harmful to the environment and living beings **(FAO,2020b).**

Poultry manure is one type of organic material that is recognized as a viable organic fertilizer. When treated appropriately, poultry manure is the most useful of all animal manures. It has been documented that tomato yield, growth, and soil fertility can all benefit from using poultry manure **(Abo-Shady et al.,2014; Agbede et al., 2018 and Adekiya 2019).**

Higher soil organic matter and tomato growth and yield were created by the incorporation of poultry manure three weeks prior to tomato transplanting (**Adekiya and Agbede, 2017 and Adekiya , 2018).** Sulfur is crucial for increased plant growth and development as well as for plants' ability to withstand stress, according to **Osman and Rady (2012).**

In light of the foregoing, the purpose of this study is to investigate the impact of irrigation practices and organo-mineral fertilisation on tomato growth, fruit output, and quality, as well as water conservation and financial return.

2. Materials and Methods

Two field studies were carried out in a farmer's field in the EL-Borullus district (north of EL-Sheikh Mubark Village), Kafrelsheikh Governorate, Egypt, over the course of two winter seasons in 2018 and 2019 to examine and assess the impact of applying organo-mineral fertilizers and implementing drip irrigation regimes, as well as their interactions, on tomato fruit yield, quality, and irrigation water productivity. The study area lies between latitudes 31^0 07 N and longitude 30^0 57 E. According to the procedures and methods outlined and described by **Klute (1986) and Page et al., (1982**), the experimental site soil's chemical and physical properties, as well as a chemical analysis of the irrigation water and poultry manure, were carried out. The results are displayed in the tables below (1-3). According to data from Table 1, the soil has a sandy texture, EC of 0.55 ds m^{-1}, pH range of 8.19 to 8.27, SAR of 2.12, and organic matter of 0.25 %.

Tomato seeds (Lycopersicom Esculentum Mill., CV.GS 12) were planted in seedling Trays under a plastic greenhouse on December 10th and 12th, 2017 and 2018, respectively. After 4 weeks of seed germination, uniform-sized seedlings with 5 true leaves were transplanted into rows that were 12 m long and 1.80 m wide. The plants were separated by 60 cm. The experiment was designed in a split-plot design with three replicates; each plot had a surface area of 64.8 m^2 (12 m long 1.8 m width 3 rows).

Prior to installing lines of the drip irrigation above each row, the soil was prepared by adding 7, 10, and 12 m^3 fed^{-1}, or 33 %, 50 %, and 60 %, respectively, of recommended poultry manure per fed. (R.PM). Each previous rate of PM was then combined with 300 kg fed^{-1} of calcium super phosphate (15.5% P_2O_5), 100 kg of ammonium sulphate (20.5 % N), 150 kg of mineral sulphur, and 10 kg of magnesium sulphate, and was then ploughed 40 cm deep. A fertigation programme was initiated based on the tried-and-true irrigation and fertilization methods two weeks after transplanting.

Table 1. Chemical and physical characteristics of the soil at the test site (average over two seasons).

Soil depth cm	Chemical analysis				Particle size distribution, %			Textural class	Bulk density Mg m^{-3}	Soil moisture constants, %***		
	*pH	**EC dSm^{-1}	SAR	O.M, %	Sand	Silt	Clay			FC	PWP	Aw
0-20	8.22	0.65	2.67	0.31	93.31	2.78	3.91	Sandy	1.82	12.4	6.72	5.68
20-40	8.19	0.58	2.22	0.26	94.12	2.19	3.69	Sandy	1.80	11.12	6.10	5.02
40-60	8.27	0.42	1.48	0.17	95.40	1.88	2.74	Sandy	1.80	10.8	5.86	4.98
0-60	-	0.55	2.12	0.25	94.22	2.38	3.40	Sandy	1.81	11.44	6.23	5.23

FC= Field Capacity, PWP= permanent wilting point, A.W= available water, water table (110-120 cm), **it was determined in 1:2.5 soil water suspension, ** it was determined in saturation paste extract , ***it was determined as gravimetric method*

Table 2. Irrigation water chemical analysis.

pH	EC dS m^{-1}	Soluble cations mmolc L^{-1}				Soluble anions mmolc L^{-1}				SAR
		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-2}	
7.52	0.84	3.46	0.52	4.45	0.22	--	1.28	4.96	2.41	3.16

Table 3. Some chemical composition of the used poultry manure (PM) in the study.

pH (1:10)	EC, dS m^{-1} (1:10)	O.M. g kg^{-1}	Total macro elements, g kg^{-1}			Available micro elements, mg L^{-1}			Moisture, %	Density, Mg m^{-3}
			N	P	K	Zn	Mn	Fe		
6.98	0.96	325	21	19.7	16.6	145	492	564	19.60	0.45

With three replicates, a split-plot design was used to set up the experiment. The drip irrigation system was used to apply three distinct irrigation levels, each of which was defined as a percentage of ETc (main plots) as follows:

I1 = Irrigation water applied at 100% ETc (control).

I2 = Irrigation water applied at 85% ETc level

I3= Irrigation water applied at a 70% ETc level

A drip irrigation system made up of laterals (16 mm) coupled to a manifold (63 mm) was used to apply irrigation water. The in-line emitters (GR) of 4 Lh-1 discharge are installed in the laterals that are spaced 3 meters apart.

The experiment's subplots were divided up according to the following fertilization treatments:

F_1= Applying the recommended dose of NPK (100 % RNPK) through drip irrigation net + (33%) of recommended poultry manure per faddan (R.P.M.) (7 m^3 fed^{-1}). as soil addition.

F_2= Applying 75% RNPK through drip irrigation net +(50%) R.P.M. per fed. (10 m^3 fed^{-1}) as soil addition.

F_3= Applying 50% RNPK through drip irrigation net + (60%) R.P.M. per fed. (12m^3 fed^{-1}) as soil addition.

In order to provide the recommended amount of mineral fertilizers to tomato plants, drip irrigation was used to add 100 kg N fed-1 in the form of urea (46% N), 19.7 kg P fed^{-1} in the form of phosphoric acid (85%P), and 52.3 kg K fed^{-1} in the form of potassium sulphate (50%K_2O) during the growing season in each of the two growing seasons.

Applied irrigation water (AIW): Different irrigation water applications were made to tomato plants at intervals of two days. AIW was calculated as an amount of crop evapotranspiration (ETC) that corresponded to one of the three treatments I_1 (100% ETC), I_2 (85% ETC), or I_3 (70% ETC). According to Eq. (1) **(Allen et al., 1998),** the daily ET_0 was calculated using the Penman-Monteith approach as follows:

$$ETo = \frac{0.408\ \Delta\ (Rn-G) + \gamma\ 900/T+273 * U2\ (es - ea)}{\Delta + \gamma\ (1 + 0.34\ U2)}$$

where:

ET_o reference evapotranspiration [mm day^{-1}],R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],G soil heat flux density [MJ m^{-2} day^{-1}],T mean daily air temperature at 2 m height [°C],u_2 wind speed at 2 m height [m s^{-1}],e_s saturation vapour pressure [kPa],e_a actual vapour pressure [kPa],e_s - e_a saturation vapour pressure deficit [kPa],D slope vapour pressure curve [kPa $°C^{-1}$],g psychrometric constant [kPa $°C^{-1}$].

During the study period, the average daily ET_0 in Kafrelshikh region was 1.35, 1.90, 2.83, 4.40 and 5.79 mm day^{-1} for January, February, March, April, and May, respectively.

The crop water requirements (ET_c) were estimated using the crop coefficient according to Eq.(2): $ET_c = ET_0 \times Kc$…………(2)

Where ET_c is the crop water requirement (mm day^{-1}) and Kc is the crop coefficient. The duration of the different crop stages were 15, 35, 60 and 20 days fothe r initial, crop development, mid-season, and late-season stages, respectively and the crop coefficient (Kc) of corresponding to the same growth stages were 0.45, 0.75, 1.10 and 0.60, respectively, according to **Allen et al.(1998).**

With emitters set at a distance of 60 cm apart and a flow rate of 4 L h^{-1}, irrigation water was delivered using polyethylene drip tubes. The system consisted of one emitter and one line per plant. The following equation was used to determine how much irrigation water (AIW) was applied to each treatment during the irrigation regime: $AIW = \frac{A \times ETC \times Li \times Kr}{Ea \times 1000}$

Where AIW denotes the amount of applied irrigation water (m3), A is the treated irrigated area (m2), ETC denotes crop water requirements (mm day-1), Li denotes irrigation intervals (day), Ea denotes application efficiency (%) (Ea=85), and Kr denotes coverage coefficient. , which equals 0.7 for mature plants, and to calculate (kr) **(Allen et al., 1998),** Kr= (0.1+Gc)>1 where Gc is the ground cover.

Ismail (2002) provided the following formula for calculating irrigation time: T=AIW*A/q, where T is the irrigation time (hour), A is the area wet by an emitter (m2), q is the emitter discharge (4 L hr-1), and AIW is irrigation water applied as a depth in (m). According to **(Wang et al.,2011),** productivity of irrigation water (PIW, kg m-3) was calculated using the following equation: PIW= Y/WA, where PIW= is measured in kg m-3, Y= total fruit yield (kg fed^{-1}) and WA= water applied (m^3 fed^{-1}). Before applying each rate of irrigation treatment, soil samples were taken and the minimum optimal moisture, which equals (FC+PWP)/2, was determined in order to keep the soil moisture content from reaching PWP.

Ripe tomatoes were harvested, and the fresh total yield and number of tomato fruits from all of the plants in each plot were calculated. Throughout the crop, fruit yield was measured.

Fruits were harvested twice a week for a period of four weeks, beginning on April 16th and ending on May 13th, 2018 and April 20th and ending on May 16th, 2019, as well as the following characteristics: Fruit number plant-1, mean fruit yield plant-1 (kg), fruit weight (g), fruit yield (kg fed-1), and total revenue were computed using the average market price of 3.5 and 3.6 LE kg^{-1} tomato fruit for the first and second seasons, respectively.

A random fruit sample (about 2 kg) was selected from each experimental unit at the peak of harvest (the third harvest) for laboratory analysis. The following parameters were examined on the homogenised fruit juice: Total soluble solids (Tss oBrix) were determined using a portable refractometer, vitamin C concentration was determined using a 2,6-dichlorophenol-indophenol pigment, and pH was determined using a glass electrode pH metre **(AOAC, 1990).**

Statistical analysis

Each year, an analysis of variance for (fruit yields and quality) was performed separately. The difference in means was tested for significance using a revised least significant difference test at the 0.05 and 0.01 levels, as described by **Sendecor and Cochran (1989).** All statistical analysis was performed using SAS software.

Economic evaluation

conomic evaluation of profitability. The FAO, 2000 equation was used in its calculation.According to the local market pricing in Egypt, cash inflows and outflows for various treatments were computed, along with some economic data like:

- Net return (L.E fed^{-1}) equals seasonal total return (L.E fed^{-1}) minus seasonal total cost (L.E fed-1).
- Net return from water unit (L.E m^{-3}) = net return (L.E fed^{-1})/ applied water (m^3 fed^{-1})
- Economic efficiency = net return (L.E fed^{-1})/ total cost (L.E fed^{-1}).

3. Results

1. Tomato fruit yield and its constituents

The bulk of tomato fruit production and components were considerably affected by both irrigation regimes and organo-mineral fertilization application, as well as their interaction in both seasons, as shown in Tables (4 and 5) and Figures (1 and 2).

Results showed that irrigation level (I_2) produced the highest tomato fruit yields in the 1st and 2nd seasons, respectively (50.792 and 51.085 Mg fed^{-1}), fruit number plant^{-1} (135.01 and 138), mean weight of fruit (114.10 and 111.99g), and fruit weight plant^{-1} (15.63 and 15.45 kg). Conversely, irrigation level (I_3) was responsible for the lowest values of the aforementioned parameters in both seasons.

In comparison to I_1-treatment, irrigation level (I_2) increased mean fruit weight (3.26 and 1.9%), fruit weight plant^{-1} (5.54 and 4.53%), and fruit yield (3.70 and 4.53%) in the first and second seasons, respectively.

regarding the effect of organo-mineral fertilization revealed that the highest fruit number plant^{-1} (134.66 and 137.11), mean weight of fruit (114.28 and 113.33g), fruit weight plant^{-1} (15.32 and 15.38 kg), and fruit yield (50.642 and 51.047 Mg fed^{-1}) were recorded with application fertilizer level of (F_2) in both growing seasons, respectively, while the lowest values of the aforementioned parameters were detected with F_1-treatment, in both seasons. It was clear that there were no appreciable differences between F_2 and F_3 treatments in both seasons, making F_3 the most effective treatment that allowed for a 50% reduction in the use of mineral fertilizers in both seas.

The results from the same Tables (4 and 5) regarding the effect of organo-mineral fertilization revealed that the highest fruit number plant^{-1} (134.66 and

In the 1st and 2nd seasons, respectively, F_2-Treatment increased fruit number plant^{-1} by 2.28 and 4.10 %, fruit weight plant^{-1} by 10.14 and 9.43 %, and fruit yield by 10.10 and 10.31 %. For F_3 compared to F_1 in both seasons, the corresponding values were (2.10 and 4.66%), (7.05 and 7.79 %), and (8.74 and 7.76 %).

Additionally, the findings demonstrate that the interaction between irrigation practices and amounts of organo-mineral fertilization resulted in notable variations in both growing seasons, except for fruit number plant^{-1}, which was not significantly impacted. The combination of I_2- treatment (irrigation with 85% ETc and F_2 – treatment [75% RNPK+ 50%RPM] gave the highest fruit yield and its components of tomato, followed by the combination between I_2 and F_3-treatments in both seasons.

Table 4. Tomato crop quality and fruit yields are affected by irrigation practices and the use of organo-mineral fertilizers in the first season.

Treatments	Fruit No plant^{-1}	Mean weight of fruit (g)	Fruit weight, kg, plant^{-1}	Fruit yield Mg fed^{-1}.	Fruit qualities		
					Vitamin c, mg/100	TSS, %	Acidity, %
Irrigation regime (I)							
I_1	135.20	110..49	14.81^{ab}	48.978^{ab}	21.80^{c}	4.31	0.45
I_2	135.01	114.09	15.63^{a}	50.792^{a}	23.78^{b}	4.62	0.61
I_3	130.53	108.90	13.94^{b}	46.881^{b}	25.76^{a}	4.79	0.87
F-Test	NS	NS	*	*	*	NS	NS
Fertilization(F)							
F_1	131.66	105.92^{b}	13.91^{b}	45.995^{b}	22.52	4.56	0.64
F_2	134.66	114.28^{a}	15.32^{a}	50.642^{a}	23.44	4.57	0.67
F_3	134.43	113.28^{ab}	14.89^{a}	50.013^{a}	25.10	5.49	0.68
F-Test	NS	*	*	*	NS	NS	NS
Interaction(I×F)							
I_1×F_1	136	100.37^{b}	13.65^{bc}	45.128^{bc}	21.80	4.30	0.45
I_1× F_2	136.3	113.99^{ab}	15.43^{ab}	51.049^{ab}	21.78	4.30	0.47
I_1× F_3	133.3	117.10^{a}	15.35^{ab}	50.759^{abc}	21.82	4.33	0.48
I_2× F_1	132.67	109.02^{ab}	14.48^{abc}	47.872^{abc}	21.97	4.60	0.61
I_2× F_2	134.67	119.34^{a}	15.98^{a}	52.830^{a}	22.77	4.62	0.64
I_2× F_3	137.70	113.92^{ab}	15.63^{ab}	51.673^{a}	25.74	4.64	0.66
I_3× F_1	126.3	108.36^{ab}	13.61^{c}	44.985^{c}	23.78	4.78	0.87
I_3×F_2	133.0	109.52^{ab}	14.54^{abc}	48.049^{abc}	25.77	4.80	0.89
I_3×F_3	132.3	108.82^{ab}	13.68^{abc}	47.608^{abc}	27.74	4.80	0.90
F-Test	NS	*	*	*	Ns	Ns	Ns

**, ** insignificant, significant at 0.05 and 0.01 level of probability, respectively*

I_1=100% ETC, I_2=85% ETC and I_3=70%ETC

F_1=100%RNPK+ 33% R.P.M,, F_2= 75% R_{NPK}+50% R.P.M,, F_3=50% RNPK+ 60% R.P.M,

Table 5. Fruit yields and the quality of tomato crops as influenced by irrigation regimes and organo-mineral fertilizers application in the second season.

Treatments	Fruit No plant^{-1}	Mean weight of fruit (g)	Fruit weight, kg plant^{-1}	Fruit yield Mg fed^{-1}.	Fruit qualities		
					Vitamin c, mg/100	TSS, %	Acidity, %
Irrigation regime (I)							
I_1	135.32	109.81	14.78^{ab}	48.867^{ab}	21.87^{c}	4.33	0.5
I_2	138.0	111.99	15.45^{a}	51.085^{a}	23.76^{b}	.65	0.65
I_3	131.12	108.77	14.23^{b}	47.024^{b}	25.61^{a}	4.83	0.90
F-Test	Ns	Ns	*	*	*	Ns	Ns
Fertilization (F)							
F_1	131.0	107.08^{b}	14.0^{b}	46.274^{b}	22.83	4.59	0.66
F_2	136.33	113.33^{a}	15.38^{a}	51.047^{a}	23.67	4.60	0.68
F_3	137.11	110.17^{ab}	15.09^{a}	49.866^{a}	24.74	4.62	0.70
F-Test	Ns	*	*	*	Ns	Ns	Ns
Interaction (I×F)							
$I_1 \times F_1$	135.33	101.93^{b}	13.78^{b}	45.558^{b}	21.85	4.32	0.47
$I_1 \times F_2$	136.30	114.20^{ab}	15.40^{ab}	50.913^{ab}	21.87	4.33	0.50
$I_1 \times F_3$	134.33	113.30^{ab}	15.17^{ab}	50.131^{ab}	21.88	4.35	0.52
$I_2 \times F_1$	133	109.13^{ab}	14.54^{ab}	48.059^{ab}	22.96	4.63	0.63
$I_2 \times F_2$	137.70	117.04^{a}	16.07^{a}	53.128^{a}	23.45	4.65	0.65
$I_2 \times F_3$	143.3	109.81^{ab}	15.75^{a}	52.069^{a}	24.86	4.67	0.67
$I_3 \times F_1$	124.67	110.18^{ab}	13.68^{b}	45.206^{b}	23.67	4.81	0.88
$I_3 \times F_2$	135.0	108.75^{ab}	14.66^{ab}	48.467^{ab}	25.68	4.83	0.90
$I_3 \times F_3$	133.70	107.39^{ab}	14.34^{ab}	47.399^{ab}	27.49	4.85	0.92
F-Test	Ns	*	*	*	Ns	Ns	Ns

**, ** insignificant, significant at 0.05 and 0.01 level of probability, respectively*
I_1=100% ETC, I_2=85% ETC and I_3=70%ETC
F_1=100%RNPK+ 33% R.P.M,, F_2= 75% R_{NPK}+50% R.P.M,, F_3=50% RNPK+ 60% R.P.M,

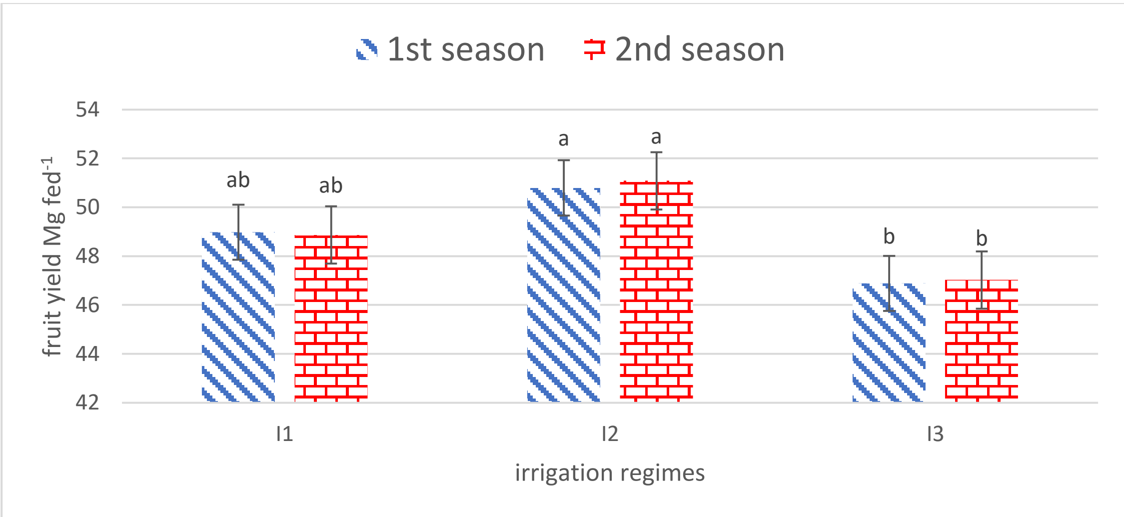

Fig. 1. Effect of irrigation practices on tomato fruit production throughout the course of two growing seasons.

**means with one common letter had no significant differences (P≤0.05)*

I_1=100% ETC, I_2=85% ETC and I_3=70%ETC

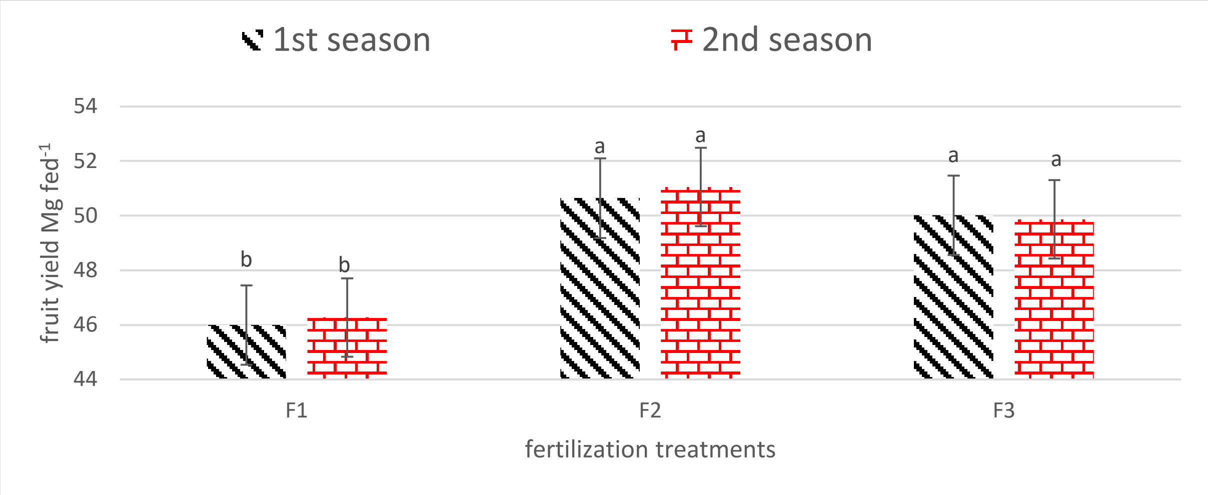

Fig. 2. The impact of fertilization practices on tomato fruit yield over the course of two growing seasons.

**means with one common letter had no significant differences (P≤0.05)*

F_1=100%RNPK+ 33% R.P.M,, , F_2= 75% R_{NPK}+50% R.P.M,, F_3=50% RNPK+ 60% R.P.M,,

2. Fruit quality of tomato

Tomato fruit characteristics (TSS,%, VC, mg/100g, and acidity,%) were not significantly impacted by both irrigation regimes and organo-mineral fertilisation and their interaction, according to data in Tables 4 and 5, with the exception of vitamin C, which was considerably affected in both seasons.

In terms of the effect of irrigation regimes, data showed that the highest values of TSS (4.79 and 4.83%), Vitamin C (25.76 and 25.61 mg/100g), and acidity (0.87 and 90%) were obtained with irrigation levels of (I_3) in both seasons, respectively. While the irrigation level (I_1) produced the lowest values of the aforementioned parameters in both seasons.

Regarding organo-mineral fertilization, the data shown in Tables (4 and 5) demonstrate that the highest values of vitamin C (25.10 and 24.74 mg/100g), TSS (4.59 and 4.62%), and acidity (0.68 and 0.7%) were obtained with F_3 treatment in both seasons, whereas the lowest values of the aforementioned parameters were recorded with F_1 treatment in both seasons.

Furthermore, data showed that the I_3- treatment (irrigation with 70% ETc) and F_3- treatment (50% RNPK+ 60% R.P.M) combinations produced tomatoes with the best fruit quality in both seasons.

3. Applied water and water saving

The irrigation water given to tomato plants over the two growing seasons and under various irrigation techniques is shown in Table (6). According to data from the same table, the average amounts of water applied to tomato plants through drip irrigation were 2044.32 m^3 fed^{-1} (486.74 mm), 1737.67 m^3 fed^{-1} (413.73 mm), and 1431.04 m^3 fed^{-1} (340.72 mm) in the first season and 2049.51 m^3 fed^{-1} (487.98 mm), 1742.08 m^3 fed^{-1} (414.78 mm), and 1434.66 m^3 fed^{-1} (341.59 mm) in the 2nd season, For irrigating Tomato plants at I_1, $I_2$and I_3-Treatments, respectively. Additionally, data in the same table showed that, for I_2 and I_3 treatments, respectively, average water savings over I_1-treatment were (15 and 30%) in both seasons. Therefore, irrigation of water at 85% ETc may be sufficient to provide a high yield of tomatoes with little irrigation water.

4. Productivity of irrigation water (PIW)

The yield of a unit of applied water is shown by the productivity of irrigation water (PIW). Table (6) and Fig. (3) display the PIW values that were established for irrigation treatments over the two growing seasons of the study. In general, PIW values increased with declining seasonal water use and rising tomato fruit yield over both seasons. In both seasons, it was evident that the greatest PIW values (32.78 and 32.77 kg fruit m^{-3}) were obtained with irrigation levels of (I_3), indicating a relatively more effective use of irrigation water. While tomato plants with irrigation levels of (I_1) during both seasons were found to have the lowest PIW values (23.96 and 23.84 kg fruit m^{-3}, respectively). Regarding the fertilization treatments, the data in Table (6) and Fig. (4) demonstrate that F_3-treatment recorded the greatest values of PIW (34.95 and 34.76 kg fruit m^{-3}) followed by F_2-treatment in the first and second seasons, respectively. Conversely, F_1-treatment in both seasons led to the lowest PIW values (22.44 and 22.58 kg fruit m^{-3}).

Table 6. Applied water, water saving and Productivity of irrigation water (PIW) for tomato crop in the two growing seasons.

Irrigation regime Treatments	Applied water, m^3 fed^{-1}		Water saving, %	Fruit yield, kg fed^{-1}		PIW, kg m^{-3}		Fertilization treatments	Fruit yield, kg fed^{-1}		PIW, kg m^{-3}	
	1st season	2nd season	Means of the 2 seasons	1st season	2nd season	1st season	2nd season		1st season	2nd season	1st season	2nd season
I_1=100% ETC	2044.32	2049	-	48978	48867	23.96	23.84	F_1	45995	46274	22.49	22.58
I_2=85% ETC	1737.67	1742	15	50792	51085	29.40	29.32	F_2	50642	51047	29.14	29.30
I_3=70% ETC	1431.02	1434	30	46881	47024	32.78	32.77	F_3	50013	49866	34.95	34.76

I_1=100% ETC, I_2=85% ETC and I_3=70%ETC
F_1=100%RNPK+ 33% R.P.M, F_2= 75% R_{NPK}+50% R.P.M, F_3=50% RNPK+ 60% R.P.M.

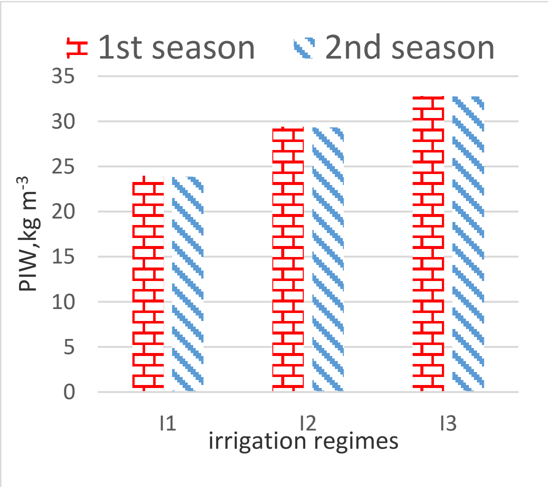

Fig. (3): Irrigation water productivity (PIW) as affected by irrigation regimes in both seasons

I_1=100% ETC, I_2=85% ETC and I_3=70%ETC

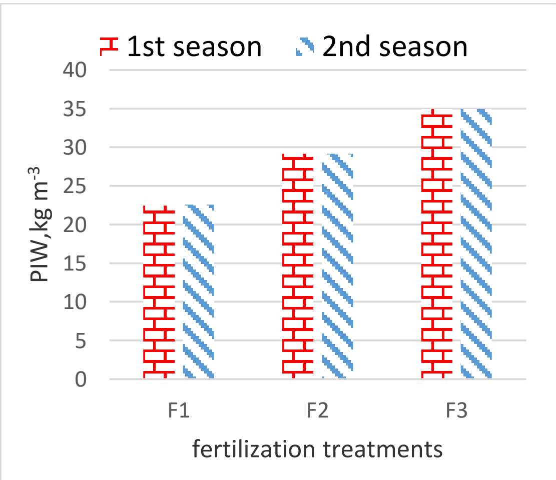

Fig. 4. Irrigation water productivity (PIW) as affected by fertilization treatments in both seasons.

F_1=100%RNPK+ 33% R.P.M, F_2= 75% R_{NPK}+50% R.P.M, F_3=50% RNPK+ 60% R.P.M,.

5. Economic evaluation

Some components are necessary for economic assessment so that the evaluation procedure can be carried out. In the two growing seasons, the production cost components for tomato fruit yield based on the local market price in Egypt (L.E) were estimated (Table 7). Table (8) summarises the total revenue, net return, net income from water unit, and economic efficiency of irrigation and fertilisation treatments for tomato fruit output over both seasons. Obtained data show that the combination of I_2 and F_2 treatments recorded the highest values of seasonal net income (161713.3 and 167567.7 L.E fed^{-1}) and economic efficiency (6.97 &7.01) in the 1st and 2nd seasons, respectively, followed by the combination of I_2 and F_3– treatments, meanwhile, highest values of net income from water unit (101.35 and 105.14 L. E m^{-3}) were detected with the combination of I_3 and F_2. treatments in both seasons, respectively. Additionally, it appears from the results that I_1 and F_1 treatments were combined to produce the lowest values of the aforementioned parameters during both seasons.

Table 7. Values of the production cost components for tomatoes under various conditions (L.E. fed-1) over the course of the two growing seasons.

Cost items	Cost values for various agronomic operations (L.E fed^{-1}								
	I_1			I_2			I_3		
	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3
1-Drip irrigation Net	3200	3200	3200	3200	3200	3200	3200	3200	3200
2- Ca-superphosphate	750	750	750	750	750	750	750	750	750
3- Ammon. Sulphate	300	300	300	300	300	300	300	300	300
4- Mineral sulphur	1500	1500	1500	1500	1500	1500	1500	1500	1500
5- Poultry manure	1750	2500	3000	1750	2500	3000	1750	2500	3000
6- Magnesium sulphate	50	50	50	50	50	50	50	50	50
7-seedlings of tomato	2910	2910	2910	2910	2910	2910	2910	2910	2910
8- land rent	5000	5000	5000	5000	5000	5000	5000	5000	5000
9- N- Urea (46%)	876.8	657.6	438.4	876.8	657.6	438.4	876.8	657.6	438.4
10- P-as phosphoric acid	450	337.5	225	450	337.5	225	450	337.5	225
11- K- as potassium sulphate	1008.8	756.6	504.4	1008.8	756.6	504.4	1008.8	756.6	504.4
12-fertilizer (19:19:19)	180	180	180	180	180	180	180	180	180
13- pesticides and Fungi	900	900	900	900	900	900	900	900	900
	Machinery cost, L. E								
Plowing	250	250	250	250	250	250	250	250	250
Corrugations for added fertilizers	500	500	500	500	500	500	500	500	500
Irrigation	450	450	450	400	400	400	350	350	350
	Wages, L. E								
Transplanting	600	600	600	600	600	600	600	600	600
Fertilizer broadcast	500	500	500	500	500	500	500	500	500
Irrigation	250	250	250	250	250	250	250	250	250
Spraying fungi, pesticide control	650	650	650	650	650	650	650	650	650
Harvesting	600	600	600	600	600	600	600	600	600
Transporting	400	400	400	400	400	400	400	400	400
Total cost (1st season)	**23075.6**	**23241.7**	**23157.8**	**23025.6**	**23191.7**	**23107.8**	**22975.6**	**23141.7**	**23057.8**
Total cost (2nd season)	**23425.6**	**23741.7**	**23757.8**	**23375.6**	**23691.7**	**23707.8**	**23225.6**	**23641.7**	**23657.8**

**items 2,3,4,5 and 6 were mixed and added to the soil depth of 40cm before installation drip irrigation net.*
**items 9,10,11 and 12 were added through drip irrigation net. Price of m^{3}P.M. (250 and 300L.E) in the 1st and 2nd seasons, respectively.*
** I_1=100% ETC, I_2=85% ETC and I_3=70%ETC*
** F_1=100%RNPK+ 33% of R.P.M, F_2= 75% R_{NPK}+50% of R.P.M, F_3=50% RNPK+ 60% of R.P.M*
** increment total cost in the 2nd season, belonged to increasing the priced of mineral-fertilizers and poultry manure.*

Table 8. Economic evaluation for tomato fruits yields in both seasons.

Treatments: Irrigation regime (I)	Treatments: fertilization (F)	Fruit yield kg fed^{-1}	Total income L.E fed^{-1}	Total cost L.E fed^{-1}	Net income L.E fed^{-1}	Water applied m^{3}fed^{-1}	Net income from water unit L.E m^{-3}	Economic efficiency
				1st season				
I_1	F_1	45128.2	157948.7	23075.6	134873.7	2044.32	65.97	5.84
	F_2	51048.5	178670	23241.7	155428.3	2044.32	76.03	6.68
	F_3	50758.6	177655	23157.8	154497.2	2044.32	75.57	6.67
I_2	F_1	47872	167552	23025.6	144526.4	1737.67	83.17	6.28
	F_2	52830	184905	23191.7	161713.3	1737.67	93.06	6.97
	F_3	51673.2	180856.2	23107.8	157748.7	1737.67	90.78	6.83
I_3	F_1	44985.4	157449	22975.6	134473.4	1431.04	93.97	5.85
	F_2	48048.8	168170.8	23141.7	145029	1431.04	101.35	6.27
	F_3	47607.7	166627	23057.8	143569.21	1431.04	100.39	6.23
				2nd season				
I_1	F_1	45558.3	164010	23425.6	140584.4	2049.51	68.59	6.0
	F_2	50913.3	183288	23741.7	159546.3	2049.51	77.85	6.72
	F_3	50130.5	180470	23757.8	156712.2	2049.51	76.46	6.60
I_2	F_1	48059	173012.4	23375.6	149636.8	1742.08	85.90	6.40
	F_2	53127.6	191259.4	23691.7	167567.7	1742.08	96.19	7.1
	F_3	52069.3	187449.5	23707.8	163741.7	1742.08	93.99	6.91
I_3	F_1	45205.6	162740.2	23225.6	139514.6	1434.66	97.24	6.01
	F_2	48467	174481.2	23641.7	150839.5	1434.66	105.14	6.38
	F_3	47398.5	170635	23657.8	146977.2	1434.66	102.44	6.21

Net income from water unit= Net income L.E fed.$^{-1}$/ water applied m^3 fed^{-1},
economic efficiency= net income L.E fed.$^{-1}$/ total coast (L.E fed^{-1})

I_1=100% ETC, I_2=85% ETC and I_3=70%ETC
F_1=100%RNPK+ 33% of R.P.M, F_2= 75% R_{NPK}+50% of R.P.M, F_3=50% RNPK+ 60% of R.P.M

4. Discussions

Tomato fruit yield and its constituents

Irrigation level (I_2) produced the highest tomato fruit yields in the 1^{st} and 2^{nd} seasons, conversely, irrigation level (I_3) was responsible for the lowest values. The results of this study for the highest tomato fruit yields are, somewhat comparable to those of (**Kuscu et al., 2014; Alaoui et al., 2015, AL-Harbi et al., 2015 and Wu et al., 2021)** They found that irrigation of tomato plants with non-saline water at 75% ETC at the fruiting or vegetative growth stage did not significantly affect growth and fruit yield but improved WUE, increased vitamin C and Total Soluble Solids (TSS) content and conserved about 21% of irrigation water. **Zhang et al. (2017)** hypothesized that irrigation with 80% ETc rather than 100% ETc produced the highest fruit output of tomato in a layered soil with a silt loam surface and deep sandy soil. Due to sandy soil's low water-holding capacity, provided water under 100% ETc treatment is lost and cannot be used by crops in a timely manner. The increased tomato fruit yield under the I_2 treatment may be attributable to better soil aeration, which speeds up the breakdown of organic matter and increases nutrient availability, resulting in healthy plants with strong vegetative growth **(Xing et al, 2015 and Khalifa, 2020).**

The same Tables (4 and 5) showed the results for the effect of organo-mineral fertilization, showing that the highest fruit number per plant, mean fruit weight, fruit weight per plant, and fruit yield were recorded with application fertilizer level of (F2) in both growing seasons, respectively, while the lowest ones were detected with F1- treatment. This outcome might be attributable to an improvement in the physical characteristics of the soil and an increase in its water-holding capacity, which led to greater aeration and drainage that promote better growth and nutrient absorption.

In addition, the combination of organic fertiliser (poultry manure) with appropriate rates of mineral fertilisers could help to increase the efficiency of these fertilisers and to reduce the extensive use of mineral fertilisation, due to their ability to use free available solar energy and atmospheric nitrogen and water. This study findings concur with those of (**Yaseen et al., 2014, Celebi (2014), and Bilalis et al., 2018).**

The results of the current study's results for the highest tomato fruit yield are comparable to those of **(Fawzy et al., 2010; Wu et al., 2021),** who discovered that the highest tomato fruit yield and quality were obtained by using 50% poultry manure + 50% mineral fertilizer or 25% poultry manure + 75% mineral fertilizer.

Additionally, **Adekiya and Agbede (2009 and 2017)** reported that adding poultry manure to the soil three weeks prior to transplanting increased soil organic matter and soil, as well as tomato growth and production. Moreover, **Rady (2012)** discovered that the application of humic acids has been documented to promote plant growth and chemical composition under various soil conditions, which favorably reflects improved crop yields and quality.

The combination of I_2- treatment (irrigation with 85% ETc and F_2 – treatment [75% RNPK+ 50%$R_{P.M.}$] gave the highest fruit yield and its components of tomato, followed by the combination between I_2 and F_3- treatments in both seasons. The obtained result is in line with that of **Yaseen et al., 2014.**

Fruit quality of tomato

Tomato fruit characteristics (TSS, VC, and acidity) were not significantly impacted by both irrigation regimes and organo-mineral fertilization and their interaction, according to data in Tables 4 and 5, with the exception of vitamin C, which was considerably affected in both seasons.

Strong agreement existed between these findings and those of **(Wang et al., 2016; Wang et al., 2019; and Khalifa, 2022**), who reported that higher values of TSS, vitamin C, and acidity of tomato fruit juice were recorded under the conditions of deficit irrigation. However, **Wu et al. (2021)** found that tomato fruits irrigated with 100% ETc had the lowest levels of soluble solids, vitamin C, and soluble sugar.

Regarding organo-mineral fertilization, the data shown in Tables (4 and 5) demonstrate that the highest values of vitamin C, TSS and acidity were obtained with F_3 treatment in both seasons, whereas the lowest values of the aforementioned parameters were recorded with F_1 treatment in both seasons. These findings are consistent with those made by **Abd ELmageed and Semida (2015), and Velez-Terreros et al. (2021),** who claimed that tomato plants grown with 50% R.P.M + 50% mineral fertilizer had the highest fruit quality. Furthermore, **Hossain sani et al., (2020)** demonstrated the efficacy of combining organic and synthetic fertilizers, resulting in a sustainable tomato production technique with higher yield and quality.

Furthermore, data showed that the I_3- treatment and F_3-combinations produced tomatoes with the best fruit quality in both seasons this may be due to deficit irrigation leads to the improvement of soil aeration and the availability of nutrients in the soil, which is reflected in the quality characteristics of the tomato crop.

Applied water and water saving

Irrigation of water at 85% ETc may be sufficient to provide a high yield of tomatoes with little irrigation water. The findings of **(AL-Harbi et al., 2015; Alaui et al., 2015; and Wu et al., 2021**) are consistent with the findings of the current study, which show that using deficit irrigation (DI) strategies at 75% ETC to tomato crops may significantly contribute to saving about 21% of irrigation water.

Productivity of irrigation water (PIW)

the greatest PIW values were obtained with irrigation levels of (I_3), indicating a relatively more effective use of irrigation water. While tomato plants with irrigation levels of (I_1) during both seasons were found to have the lowest PIW values this might be due to in general, PIW values increased with declining seasonal water use and rising tomato fruit yield over both seasons. These findings are consistent with those made by **(Lu et al., 2019 and Fayed et al., 2021**), who claimed that DI management has the ability to significantly raise the productivity of irrigation water (PIW) used for tomato crops.

Regarding the fertilization treatments, F_3-treatment recorded the greatest values of PIW followed by F_2-treatment in the first and second seasons, respectively. Conversely, F_1-treatment in both seasons led to the lowest PIW values. The results are consistent with those of (**Abd EL-Mageed and Semida 2015 and EL-Sayed et al., 2022),** who found that mixing organo-mineral fertiliser and deficit irrigation increased agricultural water production.

Economic evaluation

the combination of I_2 and F_2 treatments recorded the highest values of seasonal net income and economic efficiency in the 1st and 2nd seasons, respectively, followed by the combination of I_2 and F_3– treatments, meanwhile, highest values of net income from water unit were detected with the combination of I_3 and F_{2-} treatments in both seasons, respectively. Additionally, it appears from the results that I_1 and F_1 treatments were combined to produce the lowest values of the aforementioned parameters during both seasons, it might be due to I_2 F_2 had the highest fruit yield and net income. The outcomes are consistent with those of **Xiukang and Yingying (2016), and Habashy and Mohamedin (2019).** In addition, **Attia et al. (2021)** revealed that deficit watering is a suggested strategy to maximise the economic return during drought situations

5. Conclusions

According to the findings of the current study, using organic fertilizers (poultry manure) as a partial replacement for NPK-mineral fertilizers is one of the most efficient ways to improve tomato crop production and environmental conditions. As a result, the combination of I_2 (irrigating tomato plants with 85% ETC) and F_2 (applying 75% of recommended NPK through fertigation technique +50% poultry manure as soil addition) outperformed other treatments, achieving the highest tomato yield and yield components while saving water and mineral fertilizers.

Conflicts of interest

that "There are no conflicts to declare".

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