

MAXIMIZING THE PRODUCTIVITY AND WATER USE EFFICIENCY OF TOMATO PLANTS (*LYCOPERSICON ESCULENTUM* MILL.) CULTIVATED IN THE NEW RECLAIMED LANDS USING DIFFERENT IRRIGATION WATER QUANTITIES AND SOME WATER SAVING SUBSTANCES

Kamal, A. M.* and M. M. El-Shazly**

*** Veget. Res. Dept., Hort. Res. Inst., Agric. Res. Center, Giza, Egypt**

****Soil Fertility and Plant Nutrition Dep., Soil, Water and Environment Res. Inst., Agric. Res. Center, Giza, Egypt**

ABSTRACT

Egypt is one of the countries facing great challenges due to its limited water resources, so it has become necessary to study the best ways to rationalize irrigation water use and maximizing the efficient use of water under those circumstances. Two field experiments were conducted at a private farm at Al-Nubaria region, Behira Governorate, Egypt, during the two successive seasons of 2011 and 2012, to investigate the effect of three irrigation water quantities (2400, 1800 and 1200 m³ fed⁻¹) and some water saving substances, *i.e.*, control, zeolite, super absorbent polymer and K-humate as well as their interactions on growth, chemical composition, yield, water use efficiency and fruit quality of tomato plants (Jacal F1 hybrid) cultivated under drip irrigation system in new reclaimed lands during early summer season.

The obtained results indicate that:

- Increasing water quantity applied to tomato plants up to the highest used level (2400 m³ fed⁻¹) significantly increased vegetative growth characters, *i.e.*, stem diameter, foliage fresh weight, leaf area and leaf relative water content as well as total N, P and K uptake by tomato plants. On the other hand, total chlorophyll contents enhanced significantly with decreasing irrigation water supply. Tomato yield characters, *i.e.*, number of fruits per plant, average fruit weight and total yield increased with increasing irrigation water quantity up to 2400 m³ fed⁻¹. The medium irrigation water level (1800 m³ fed⁻¹) recorded the highest values of water use efficiency. Under the low level of irrigation water (1200 m³ fed⁻¹) tomato fruit quality characters, *i.e.*, flesh firmness, lycopene, TSS and total soluble sugars recorded the highest significant values.
- Soil application of K-humate led to the significant increases in all vegetative growth traits, total NPK uptake, total chlorophyll, yield characters and water use efficiency as well as tomato fruit quality characters compared to soil application of zeolite, super absorbent polymer and control.
- Tomato vegetative growth characters were significantly affected by the combination of 2400 m³ fed⁻¹ and K-humate soil application. Applying 2400 or 1800 m³ fed⁻¹ of irrigation water combined with soil application of K-humate resulted in the highest significant NPK uptake as well as all studied tomato yield characters. Soil application of K-humate combined with the low irrigation level (1200 m³ fed⁻¹) showed the highest significant chlorophyll contents in tomato leaves. Water use efficiency showed the highest value using the medium level of irrigation water (1800 m³ fed⁻¹) combined with the soil application of K-humate as compared to the other treatments. Soil application of K-humate combined with the medium irrigation water level (1800 m³ fed⁻¹) or the low level (1200 m³ fed⁻¹) recorded the highest values of tomato fruit quality characters. Using the medium irrigation level (1800 m³ fed⁻¹)

combined with the soil application of K-humate obtained the highest net return and returned the highest benefit-cost ratio (3.48) in comparison with other treatments.

It could be concluded that irrigation tomato plants with 1800 m³ fed⁻¹ combined with soil application of K-humate (2 kg fed⁻¹ in every addition, 4 times during the season) incorporated with drip irrigation system could be recommended to improve yield and quality of tomato plants as well as maximizing the water use efficiency by tomato plants, saving about 25% of the total used irrigation water quantity commonly used in tomato production. Such treatment is found to be economically and more agronomically feasible and can be recommended under drip irrigation system in sandy soil in new reclaimed lands, giving the highest net return and benefit-cost ratio to the farmers.

INTRODUCTION

Egypt is one of the countries facing serious shortage of water resources, so it is advised to evaluate new possible approaches to minimize the plant water consumption and hence to rationalize irrigation water use. Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetables grown in Egypt in terms of planted area and crop value. Tomato plants are sensitive to water stress and their yield showed high correlation with the amount of irrigation water (Berihun, 2011), therefore, the management of water is critical for both economic yield and fruit quality. That is why many investigations tried to optimize the irrigation regime for tomato; however, most of them reported that the higher growth and yield aspects were associated with higher irrigation treatment (Adams, 1990; Fattahallah, 1992; Condido *et al.*, 2000 and Zhai *et al.*, 2010).

Sandy soils are poor with respect to their physico-biochemical properties (El-Hady and El-Dewiny, 2006) that, unfortunately, resulted in a significant loss of irrigation water through drainage. Minimizing such losses can be applied using soil conditioners, which reported to improve the soil physical condition and increase water irrigation efficiency as well as rationalization of irrigation water (El-Hady *et al.*, 2000; Bernardi *et al.*, 2009 and Ezzat *et al.*, 2011). One of the newest soil conditioners used in this respect is zeolite mineral; it is a hydrated Aluminosilicates, characterized by the ease of retaining and releasing water and exchanging cations without structural changes (Polat *et al.*, 2004). Zeolite application is a soil conditioner, reported to increase soil water-holding capacity, reducing water evaporation, encouraging salt leaching and improving water used efficiently as well as enhancing nutrient use efficiency by increasing P availability, improving the use of NH⁴⁺ and NO³⁻, reducing leaching losses of exchangeable cations, especially K⁺, furthermore, acting as slow-release fertilizer (Bernardi *et al.*, 2009). Armandpisheh *et al.* (2009) reported that zeolite can preserve the moisture of the soil for long-term and can modify the effects of drought stress of plant. Zeolite had positive effects on many plants, including tomato (Valente *et al.*, 1986) and lettuce (Gul *et al.*, 2005). Azarpour *et al.* (2011) showed that application of 5 t/ha of zeolite recorded the highest seed yield of cowpea. Additionally, Ashraf (2011) indicate that addition of zeolite in tomato field improved soil bulk density, porosity and increased plant fresh weight, nutrient elements of leaves, number of fruits and total fruits yield.

Considerable attention has been focused in the last few decades to the use of synthesized conditioners to avail suitable environment for cultivation sandy soils. Among these conditioners are the water absorbent polymers or hydrogels. The use of absorbent polymers had many advantages, it improved the chemical and biological properties of sandy soil by enhancing soil structure, increasing water-holding capacity, improving availability of water to plants and increasing soil aeration as well as reducing soil compaction, leading to better root development (El-Hady *et al.*, 2000). Absorbent polymers was reported to improve the establishment and growth of tomato plants in the deficit of water (Johnson and Piper, 1997). Soil addition of 24 kg hydrogels fed^{-1} increased growth, nutrients uptake and yield as well as water and fertilizers use efficiency by tomato plants in sandy soil (El-Hady and El-Dewiny, 2006). Furthermore, Ezzat *et al.* (2011) indicated that applying veterra hydrogel at 37.3 kg fed^{-1} as a soil conditioner under low water irrigation positively affected vegetative growth characters of potato plants; it enhanced macro, micro-nutrients uptake, plant water relations, total chlorophyll and increased nitrogen use efficiency as well as tuber yields and quality.

Application of humate substances in agriculture as a soil conditioner has been extensively discussed by many researches; they demonstrated conclusively that humic acid showed significant impacts on the soil structure and plant growth (Fong *et al.*, 2007). It was reported that when humic acid applied to tomato plants cultivated in sandy soils, it adds essential organic material necessary for water retention and enhancing the sandy soil's ability to retain and not leach out vital plant nutrients, and hence improving plant growth parameters (Adani *et al.*, 1998). Moreover, humic acid reduces soil compaction and increases the soil fertility aggregation, it enhances the soil exchange capacity, the nutrients and water retention and improves fertilizer efficiency due to its chelating property, in addition, humic acid stimulate the absorption of nutrients and encourage the solubility of many nutrients, *i.e.*, P, Zn, Fe, Mn and Cu (Hernandez *et al.*, 2001; Nardi *et al.*, 2002; Mikkelsen, 2005 and Selim *et al.*, 2010).

The present study was planned to evaluate the effect of three irrigation water quantities (2400, 1800 and 1200 $\text{m}^3 \text{fed}^{-1}$) and some water saving substances, *i.e.*, control, zeolite, super absorbent polymer and K-humate as well as their interactions on growth, chemical composition, yield, fruit quality and water use efficiency of tomato plants cultivated under drip irrigation system in new reclaimed lands.

MATERIALS AND METHODS

Two field experiments were conducted at a private farm at Al-Nubaria region, Behira Governorate, Egypt, during the two successive seasons of 2011 and 2012, to study the effect of three irrigation water quantities (2400, 1800 and 1200 $\text{m}^3 \text{fed}^{-1}$) and some water saving substances, *i.e.*, control, zeolite, super absorbent polymer and K-humate as well as their interactions on growth, chemical composition, yield, fruit quality and water use efficiency of tomato plants cultivated under drip irrigation system in new reclaimed

lands during early summer season. Table 1 shows some physical and chemical properties of the experiment soil before planting, according to the methods described by Page (1982).

Table 1: Physical and chemical properties of the experimental soil.

Physical properties	Value		Chemical Properties	Value	
	1 st Season	2 nd Season		1 st season	2 nd season
Sand (%)	86.0	87.2	Wilting point (%)	2.57	1.91
Silt (%)	9.2	7.8	Water holding capacity (%)	25.08	26.4
Clay (%)	4.8	5.0	Field capacity (%)	10.87	9.20
Texture class	Sandy	Sandy	Available nutrients (mg kg ⁻¹)		
CaCO ₃ (%)	5.20	4.74	Nitrogen	24.7	44.3
pH	8.42	8.38	Phosphorus	4.7	8.9
EC dSm ⁻¹	0.57	0.70	Potassium	110	99.8

On February, 1st week of both seasons, 40 day old tomato seedlings (Jacal F1 hybrid, product of ELITE, USA), were transplanted in open field at 50 cm apart on one side of the ridge.

Layout of the experiment and treatments:

The experiment was adopted in a split plot design with three replicates, containing 12 treatments, which were the combination between three water irrigation quantities, *i.e.*, 2400, 1800 and 1200 m³ fed⁻¹ as well as some water saving substances, *i.e.*, control, zeolite, super absorbent polymer and K-humate soil applications. The first irrigation quantity is the traditional irrigation water amount added by the farmers in the area. Water irrigation quantities were distributed in the main plots, whereas the used water saving substances were arranged in the sub plots. The plot unit consisted of four ridges each of 1 m wide and 5 m long with an area of 20 m². A distance of 2 m between plots was left to avoid the infiltration of irrigation water.

During both seasons drip irrigation system was applied using groundwater with EC of 0.63 dSm⁻¹. The drippers used were of a standard 4 L h⁻¹ discharge at 1.5 bar working pressure. The irrigation treatments started after 20 days from transplanting. The amount of irrigation water at different treatments were adjusted using a water counter and were added according to growth stage of tomato plants during growth season.

Agricultural grade zeolite powder, produced by Shijiazhuang Oushun Minerals Co., Ltd., China, was used, contains SiO₂ (66.45%), Al₂O₃ (12.3%), Fe₂O₃ (1.49%), K₂O (1.54%), CaO (3.97%) and MgO (0.92%), was used at 2 ton fed⁻¹. Super absorbent polymer, product of Zhenjiang Agreeen Co., Ltd., china, was applied at 40 Kg fed⁻¹. Zeolite and super absorbent polymer were added before transplanting in ditches (15 cm depth) next to drippers and then the ditches filled with a wet soil. Potassium humate, manufactured by Zhangjiagang Kangyuan Co., Ltd., China in a powder form, contains 80% humic acid and 12% K₂O in dry basis, was incorporated with drip irrigation system at 2 kg fed⁻¹ in every addition. K-humate was applied through four additions, starting 20 days after transplanting and repeated 20 days intervals during the growth seasons.

The other agricultural treatments for growing tomato plants were followed according to the instruction laid down by Horticulture Research Institute, Agricultural Research Center, Egypt.

Data recorded:

Growth measurements:

At 90 days after tomato transplanting, five plants from each plot were randomly taken for determination of stem diameter, foliage fresh weight and leaf area of tomato plants. Leaf area was calculated as a relation between area unit and dry weight of plant leaves as described by Koller (1972). Leaf relative water content (LRWC) was determined in the fully expanded topmost leaf of the main shoot according to the methods of Turner (1981) by recording the fresh weight of the sample leaves and then the leaves were immersed in distilled water. After 2 hours, the leaves were removed, the surface water was blotted-off and the turgid weight recorded. Samples were dried in an oven at 70 °C to constant weight. Leaf relative water content was calculated using the following formula:

$$\text{LRWC (\%)} = [(FW - DW) / (TW - DW)] \times 100$$

Where; FW: Fresh weight; DW: Dry weight; TW: Turgid weight.

Chemical analysis:

Representative samples of tomato plant foliage from each plot at the same time were used to determine N, P and K contents then their uptake was calculated considering their concentration as percentage in dry weight basis. Total nitrogen was determined according to the method described by Bremner and Mulvaney (1982). Phosphorus was estimated colorimetrically according to Olsen and Sommers (1982) and potassium was determined by flame photometrically as described by Jackson (1973). Representative samples from the fourth upper leaves were taken to determine total chlorophyll content (SPAD units) using a portable leaf chlorophyll meter (Minolta Model SPAD 501) according to Murquard and Timpton (1987).

Yield and quality measurements:

All harvested total fruits from each plot at marketable ripe stage along the season were used to determine number of fruits per plant, average fruit weight and total yield as tons per feddan. Water use efficiency (WUE) was calculated according to equation of Begg and Turner (1976) as follows:

$$\text{WUE} = \text{yield (kg fed}^{-1}\text{)} / \text{water quantity (m}^3 \text{ fed}^{-1}\text{)}.$$

A representative sample of 10 tomato fruits from each experimental plot at the marketable ripe stage was taken from the third harvest for determination some fruits quality characteristics. Flesh firmness (Kg/ cm²) was measured by the Magness and Taylor firmness tester, equipped with an 8-mm diameter plunger tip. Two readings were taken from opposite sides of each tomato fruit after the peel was removed. Lycopene was determined as described by Fish *et al.* (2002), total soluble solids (TSS) and total soluble sugars contents according to the methods described by AOAC (1990) on the basis of fresh weight.

Statistical analysis:

The obtained data were subjected to statistical analysis as technique of split plot design according Senedcor and Cochran (1980). The treatment

means were compared using new least significant difference at 5% level of probability as mentioned by Waller and Duncan (1980).

Economic feasibility of tomato production, *i.e.*, gross return, treatment cost, total variable cost, net return and benefit-cost ratio were calculated based on market prices as average of the two seasons. The benefit-cost ratio was determined according to Boardman *et al* (2001) by dividing the gross return (LE fed⁻¹) on total variable cost (LE fed⁻¹).

RESULTS AND DISCUSSION

Vegetative growth characteristics:

Data in Table 2 demonstrate that the different used irrigation quantities significantly influenced tomato plants vegetative growth characteristics. It is obvious clear that increasing water quantity applied to tomato plants up to the highest used level (2400 m³ fed⁻¹) significantly increased stem diameter, foliage fresh weight and leaf area as well as leaf relative water content of tomato plants in both seasons. The results are in agreement with those reported by Zhai *et al.* (2010) who found that increasing water level increased plant growth characters of tomato plants.

The improvement of vegetative growth with increasing irrigation level may be due to the proper balance of moisture in plant, which creates favorable conditions for nutrients uptake, photosynthesis and metabolites translocation, which ultimately accelerated the rate of vegetative growth (Ezzo *et al.*, 2010). Moreover the reducing effect of the lowest level of irrigation water (1200 m³ fed⁻¹) may be related to the negative effects of water defect stress on the activities of many enzymes leading to decrease in plant growth and dry matter accumulation (Hamlyn, 1986).

With respect to the effect of the used water saving substances on vegetative growth characteristics of tomato plants, the results showed that the used water saving substances significantly affected stem diameter, foliage fresh weight, leaf area, and leaf relative water content. The highest values were obtained from the addition of K-humate compared to the other treatments and control in both seasons. Such results are coincided with Osman and Abdel All (2008) they found that application of humic acids through drip irrigation system stimulated tomato plants height, number of leaves, stem diameter, number of branches, leaf area and dry weight.

The positive significant effect of the soil application of K-humate on the vegetative growth characters and leaf relative water content of tomato plants could be due to many interpretations. Humic acid (the main component of K-humate) stimulate plant growth by the assimilation of major and minor elements, enzyme activation and/or inhibition, changes in membrane permeability, protein synthesis and finally the activation of biomass production (Meshref *et al.*, 2010). Furthermore, there are various lines of evidence confirming that humic acid is endowed with auxin-like activity, which influences root architecture and metabolism (Nardi *et al.*, 2002). As auxin is a water stress hormone, it is a very effective in causing stomatal closure and its accumulation in stressed leaves plays an important role in the reduction of water loss by transpiration under water stress conditions (Taiz and Zeiger,

2002). In addition, it is possible that part of the observed bioactivity of humic substances under water stress conditions is the promoting effect on root growth (Nardi *et al.*, 2002). Furthermore, K-humate as a soil application provide a supplemental source of potassium as it contains 12% K₂O in dry basis. Since potassium has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water-relation (turgor regulation and osmotic adjustment) in plants (Marschner, 1995). It was reported that increasing application of K⁺ enhanced photosynthetic rate, plant growth and yield as well as drought resistance under water stress conditions (Egilla *et al.*, 2001). Also, K⁺ deficient negatively affect stomata function and dramatically increase the loss of water from plant (Gething, 1990).

Table 2: Effect of irrigation water quantities and water saving substances as well as their interactions on vegetative growth characteristics of tomato plants during 2011 and 2012 seasons

Treatment	Stem diameter (cm)		Foliage fresh weight (g)		Leaf area (cm ²)		Leaf relative water content (%)		
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	
	Season	Season	Season	Season	Season	Season	Season	Season	
Irrigation quantities (m ³ fed ⁻¹):									
2400	2.47	2.51	1014	936.4	1911	1768	83.99	84.81	
1800	2.20	2.20	937.7	875.9	1780	1524	82.22	83.22	
1200	1.87	1.84	790.5	750.2	1510	1310	80.29	81.72	
New LSD at 5%	0.112	0.124	55.23	47.57	82.11	98.47	1.60	1.51	
Water saving substances:									
Control	2.05	1.97	846.2	781.0	1595	1394	80.90	81.83	
Zeolite	2.12	2.05	887.7	811.3	1667	1446	80.92	82.63	
SAP*	2.18	2.27	910.2	860.1	1732	1557	82.42	83.38	
K-humate	2.37	2.45	1012	964.2	1942	1739	83.64	84.61	
New LSD at 5%	0.091	0.101	51.38	42.31	75.91	83.11	1.20	1.21	
Irrigation quantities X Water saving substances:									
2400	Control	2.41	2.31	952.0	842.4	1754	1622	83.12	83.78
	Zeolite	2.47	2.39	963.3	874.3	1797	1661	83.17	84.28
	SAP	2.42	2.45	1008	939.1	1906	1759	83.66	84.78
	K-humate	2.59	2.89	1133	1090	2187	2032	86.01	86.39
1800	Control	2.05	1.98	850.0	777.3	1602	1387	81.25	81.85
	Zeolite	2.12	2.06	918.0	847.1	1732	1446	80.28	82.79
	SAP	2.20	2.30	952.0	885.8	1797	1544	82.18	83.03
	K-humate	2.42	2.47	1031	993.3	1992	1720	85.15	85.21
1200	Control	1.70	1.62	736.7	723.6	1429	1173	78.33	79.87
	Zeolite	1.77	1.70	782.0	712.6	1472	1231	79.30	80.82
	SAP	1.91	2.05	770.7	755.4	1494	1368	81.43	82.34
	K-humate	2.11	2.02	872.7	809.2	1646	1466	82.11	83.83
New LSD at 5%	0.110	0.157	63.71	54.84	79.23	91.49	2.31	2.06	

SAP* = super absorbent polymer

Regarding to the effect of the interaction between water irrigation quantities and the used water saving substances on vegetative growth characteristics of tomato plants, it is obviously clear that stem diameter, foliage fresh weight and leaf area were significantly affected by the combination of 2400 m³ fed⁻¹ and soil application of K-humate. Whereas, the highest significant leaf relative water content was observed with the combination of 2400 or 1800 m³ fed⁻¹ and K-humate soil application. The

results had the same trend during the two seasons. In this respect, Ezzat *et al.* (2009) reported that decreasing water irrigation to 1600 m³ fed⁻¹ combined with soil application of humic acid had the most significant effect on potato plants height, dry weight and leaf area per plant.

Chemical composition of tomato foliage:

Data of the uptake of N, P and K as well as the total chlorophyll contents of tomato plants are presented in Table 3. The irrigation quantities significantly influenced such characters, *i.e.*, increasing water quantity up to 2400 m³ fed⁻¹ led to the highest significant increases in total uptake of N, P and K. On the other hand, total chlorophyll contents enhanced significantly with decreasing irrigation water supply to the soil. The low level of irrigation water (1200 m³ fed⁻¹) showed the highest values in this respect compared with the other treatments in both seasons of study. Such results are in line with those of Nahar and Gretzmacher (2002) they showed that uptake of nutrients by tomato plants were significantly reduced by water stress.

Concerning the effect of water saving substances on the chemical composition of tomato foliage, the same data clearly reveal that soil application of K-humate showed the highest significant uptake of N, P and K as well as total chlorophyll compared with soil application of zeolite, super absorbent polymer and control treatment, in both seasons (Table 3). Osman and Abdel All (2008) reported similar observations.

The positive effects of the soil application of K-humate on nutrients uptake and chlorophyll contents may be owing to one or more mechanisms. It was reported that the chelating property of humic substances prevents the losses of nutrients from soil through leaching (Hernandez *et al.*, 2001 and Nardi *et al.*, 2002). Humic substances induce the dynamic of N and P in soil, stimulate plant respiration, photosynthesis process and favor the formation of soil aggregates (Hernandez *et al.*, 2001). Soil application of humic acid improves soil chemical, physical, biological properties and soil fertility status as well as enhances the exchange capacity of nutrients and water retention (Selim *et al.*, 2010). Humic substances have been shown to increase root ATPase activity and hence increase ions uptake (Canellas *et al.*, 2009). Humic acid, also, stimulate root growth and proliferation of desirable microorganisms in soil (Mikkelsen, 2005). All these actions improve the absorption of nutrients by plants that, differentially reflected on the macronutrient contents in plant. The proposed mode of action by which humic acid stimulate chlorophyll content is that humic substances enhance the absorption of Fe (Pinton *et al.*, 1999), which helping in the development of chlorophyll leading to enhancements in photosynthetic process (Mikkelsen, 2005). Furthermore, K-humate is a rich source of potassium. Since potassium is directly involved in the nutrients absorption through the process of phloem loading as a counter ion to H⁺ (Komor *et al.*, 1980) and so enhancing the mineral content of tomato plant foliage.

Concerning the effect of interaction between irrigation water quantities and water saving substances on chemical characteristics of tomato plants (Table 3). It is obvious clear that irrigation water at 2400 or 1800 m³ fed⁻¹ combined with soil application of K-humate resulted in the highest

significant N, P and K uptake by tomato plants foliage. However, soil application of K-humate combined with the low irrigation level (1200 m³ fed⁻¹) showed the highest significant chlorophyll contents in tomato leaves, in both seasons of study. These results are in agreement with those reported by Ezzat *et al.* (2009) on potato plants.

Table 3: Effect of irrigation water quantities and water saving substances as well as their interactions on NPK uptake and total chlorophyll contents of tomato plants during 2011 and 2012 seasons

Treatment	N uptake (mg/dry plant foliage)		P uptake (mg/dry plant foliage)		K uptake (mg/dry plant foliage)		Total chlorophyll (SPAD units)		
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	
	Season	Season	Season	Season	Season	Season	Season	Season	
Irrigation quantities (m ³ fed ⁻¹):									
2400	6256	5829	455.0	418.3	4580	4374	45.37	50.18	
1800	5903	5283	415.2	388.0	4245	4029	49.17	52.84	
1200	4687	4369	352.5	326.4	3522	3404	52.70	55.61	
New LSD at 5%	211.3	284.3	21.54	20.48	172.6	195.2	1.94	2.07	
Water saving substances:									
Control	5182	4856	371.3	341.8	3826	3684	47.91	52.22	
Zeolite	5355	4979	390.6	366.7	3945	3796	48.14	52.21	
SAP*	5675	5237	403.6	373.7	4084	3959	48.97	52.55	
K-humate	6250	5567	464.5	428.0	4608	4303	51.30	54.51	
New LSD at 5%	170.3	235.8	19.45	18.54	145.7	155.7	1.59	1.62	
Irrigation quantities X Water saving substances:									
2400	Control	5845	5697	421.4	385.7	4380	4112	44.31	49.23
	Zeolite	5988	5734	429.7	404.4	4357	4199	44.00	48.88
	SAP	6252	5784	454.2	413.0	4564	4495	45.31	50.56
	K-humate	6940	6099	514.5	472.9	5018	4689	47.84	52.04
1800	Control	5238	4852	366.3	333.1	3889	3699	47.86	52.17
	Zeolite	5572	5010	401.4	367.6	4046	3826	48.44	53.02
	SAP	6054	5423	405.0	392.7	4188	4088	48.83	52.03
	K-humate	6748	5846	487.9	451.5	4857	4504	51.53	54.14
1200	Control	4462	4020	326.1	306.7	3208	3242	51.55	55.27
	Zeolite	4505	4194	340.8	328.0	3432	3363	51.97	54.74
	SAP	4720	4505	351.7	318.3	3499	3294	52.76	55.06
	K-humate	5062	4757	391.2	352.7	3949	3716	54.52	57.35
New LSD at 5%	200.4	261.6	28.14	23.28	194.5	210.3	1.64	1.84	

SAP* = super absorbent polymer

Yield characteristics:

Significant differences were detected among the different irrigation quantity treatments regarding yield characteristics and water use efficiency of tomato plants. Data presented in Table 4 show that number of fruits per plant, average fruit weight and total yield (ton fed⁻¹) increased significantly with increasing irrigation water quantity up to 2400 m³ fed⁻¹. Meanwhile, the medium irrigation water level (1800 m³ fed⁻¹) recorded the highest values of water use efficiency. In this respect, Fattahallah (1992) showed that using water irrigation amount at 6.68 liters/m² compared with 1.67, 3.34 and 5.01 Liters/m² increased number of tomato fruits per plant, average fruit weight and total yield. In addition, Condido *et al.* (2000) used three amounts of irrigation water (33, 66 and 100%) based on the economic requirement of tomato, they found that tomato yield increased with increasing rates of irrigation water, the maximum yield was obtained with 100% level. Moreover, Berihun (2011) indicated that average weight of tomato fruits, marketable and

total fruit yield were significantly affected by the amount of water applied. Forasmuch, Zhai *et al.* (2010) and Berihun (2011) all work on tomato demonstrated that irrigation water use efficiency tended to increase with a decline of irrigation amount.

Such results clearly emphasizes the importance of increasing soil moisture content in the sandy soil on yield aspects of tomato plants. This could be related to the high water quantity applied to tomato plants led to keep higher water content in the plant tissues (Table 2) and this, differentially, reflected on yield than those under water stress. This also may be back to the better performance of growth characters of tomato plants (Table 2) and enhancing the nutrients status in tomato plants (Table 3) which, encourage the plants to utilize nutrients more efficiently; rather increase yield attributes.

With respect to the effect of the used water saving substances on yield characteristics of tomato plants, the same data illustrate that number of fruits per plant, average fruit weight and total yield (ton fed⁻¹) as well as water use efficiency were significantly influenced by the soil application of K-humate followed by the application of super absorbent polymer in comparing with zeolite soil application and control treatment. The results were the same during the two years of the study. In this respect, Osman and Abdel All (2008) on tomato reported that incorporated humic acid with drip irrigation system increased average fruit weight and total yield of tomato.

The positive effect of the soil application of K-humate on yield characteristics and water use efficiency of tomato plants could be related to its enhancing effect on vegetative growth and leaf relative water content of tomato plants (Table 2), in addition, promoting the uptake of N, P and K uptake as well as total chlorophyll (Table 3).

Regarding the interaction between irrigation water quantities and water saving substances on yield and water use efficiency of tomato plants, it is clear that using the high water irrigation level (2400 m³ fed⁻¹) or the medium level (1800 m³ fed⁻¹) combined with the soil application of K-humate resulted in the highest significant number of fruits per plant, average fruit weight and total yield. Meanwhile, water use efficiency showed the highest value using the medium level (1800 m³ fed⁻¹) with soil application of K-humate as compared to the other treatments. The results are in the same line during both seasons.

Such benefits of that combination between the medium level of irrigation water (1800 m³ fed⁻¹) and the soil application of K-humate on yield aspects and water use efficiency of tomato plants may be related to that humic acid application (the main component of K-humate) resulted in increasing endogenous cytokinin and auxin levels which possibly leading to improve plant drought resistance (Zhang and Ervin, 2004). Moreover, K-humate provide an additional source of K⁺, which is closely related with increasing yield (Egilla *et al.*, 2001). Furthermore, K⁺ is important for the stomata function and reducing water losses from plant (Gething, 1990). Such gains can explain the enhancement of yield and water use efficiency.

Table 4: Effect of irrigation water quantities and water saving substances as well as their interactions on yield characteristics and water use efficiency of tomato during 2011 and 2012 seasons

Treatment	No. fruits/plant		Average fruit weight (g)		Total yield (Ton fed ⁻¹)		Water use efficiency (kg/m ³)		
	1 st Season	2 nd Season	1 st Season	2 nd Season	1 st Season	2 nd Season	1 st Season	2 nd Season	
Irrigation quantities (m ³ fed ⁻¹):									
2400	38.20	44.18	112.2	110.1	34.30	38.91	14.29	16.21	
1800	36.96	42.20	107.5	105.4	31.83	35.64	17.69	19.80	
1200	31.43	36.53	80.50	78.56	20.27	22.99	16.90	19.16	
New LSD at 5%	1.45	1.54	3.84	4.41	1.81	1.68	0.54	0.61	
Water saving substances									
Control	34.19	39.65	97.45	95.07	27.06	30.51	15.21	17.22	
Zeolite	34.49	40.06	98.02	96.19	27.32	31.20	15.46	17.61	
SAP*	35.79	40.65	100.3	97.45	29.08	32.12	16.41	18.07	
K-humate	37.64	43.50	104.5	103.3	31.75	36.23	18.10	20.66	
New LSD at 5%	1.21	1.34	3.25	3.11	1.03	1.12	0.47	0.41	
Irrigation quantities X Water saving substances:									
2400	Control	37.01	43.40	110.1	107.2	32.59	37.22	13.58	15.51
	Zeolite	37.20	43.31	111.6	109.8	33.21	38.04	13.84	15.85
	SAP	38.92	44.35	112.8	110.0	35.12	39.03	14.63	16.26
	K-humate	39.67	45.66	114.3	113.2	36.27	41.35	15.11	17.23
1800	Control	36.43	40.09	104.4	101.9	30.43	32.68	16.91	18.16
	Zeolite	34.88	41.72	104.2	100.5	29.08	33.54	16.16	18.63
	SAP	36.98	42.19	107.9	104.8	31.92	35.37	17.73	19.65
	K-humate	39.56	44.78	113.4	114.4	35.89	40.98	19.94	22.77
1200	Control	29.14	35.47	77.86	76.11	18.15	21.60	15.13	18.01
	Zeolite	31.40	35.16	78.27	78.28	19.66	22.02	16.38	18.35
	SAP	31.48	35.41	80.17	77.55	20.19	21.97	16.83	18.31
	K-humate	33.68	40.06	85.70	82.28	23.09	26.37	19.24	21.98
New LSD at 5%	1.28	1.25	3.37	3.49	1.05	1.32	0.59	0.30	

SAP* = super absorbent polymer

Fruit quality characteristics:

The present data in Table 5 declare the effect of irrigation water quantities on fruit quality characteristics of tomato, it is clear that under insufficient water quantity (1200 m³ fed⁻¹), tomato fruit quality characteristics, *i.e.*, flesh firmness, lycopene, TSS and total soluble sugars recorded the highest significant values. The lowest values in this respect were obtained using the high irrigation water quantity (2400 m³ fed⁻¹), in both seasons. Such results were confirmed by the work of Adams (1990), who found that restricting water to 80% of water requirement for tomato plants resulted in the best fruit quality in compared with 100 or 120% levels. Moreover, Fattahallah (1992) stated that vitamin C, TSS and fruit firmness decreased with increasing rates of water. In addition, Shinohara *et al.* (1995) work on tomato observed that water stress decreased tomato fruit yield and improved tomato fruit quality, it relatively promotes the photosynthetic translocation into fruit and hence improves the fruit quality. In this respect, Condido *et al.* (2000) mentioned that increasing rates of irrigation water to 100% from the economic requirement of irrigation water reduced the dry matter content, TSS and firmness.

The enhancing effect of restricting water irrigation treatment on tomato fruit quality characteristics can be explained because water stress affects carbohydrate metabolism, protein synthesis and the activities of many enzymes that may reflect a change in the balance between rates of synthesis and degradation (Hamlyn, 1986).

Regarding to the effect of the used water saving substances on tomato fruit quality characteristics, the same data clearly reveal that soil application of K-humate resulted in the highest significant values of flesh firmness, lycopene, TSS and total soluble sugars followed by the soil application of super absorbent polymer compared to the other treatments, in the both seasons. Recently, Osman and Abdel All (2008) concluded that the average weight of fruit, fruit firmness, total soluble solids, vitamin C, titratable acidity and total sugars of tomato fruits significantly increased with incorporation of humic acid with drip irrigation system.

The positive effect of K-humate soil application on tomato fruit quality could be explained on the basis that humic acid has been observed to affect the photosynthetic metabolism by decreasing starch content accompanied by an increasing of soluble sugars (Merlo *et al.*, 1991). In addition, K-humate is considered as significant supplement of K^+ , since potassium plays an important role in water status of plant, promoting the translocation of newly synthesized photosynthetics and mobilization of stored materials as well as promoting the synthesis of sugars and polysaccharides (Mengel and Kirkby, 1982).

As for the effect of the interaction between irrigation water quantities and the used water saving substances on quality characteristics of tomato fruits. It is clear that using 1800 m^3 or $1200\text{ m}^3\text{ fed}^{-1}$ of irrigation water with the soil application of K-humate resulted in the highest significant flesh firmness, lycopene, TSS and total soluble sugars contents in tomato fruits and this was true in both season of study. Obtained results are in the line with those of Ezzat *et al.* (2009) on potato.

Economic feasibility:

Economic feasibility of tomato production as affected by the interaction between irrigation water quantities and the used water saving substances are demonstrated in Table 6. It is clear that the highest net return (26315 LE fed^{-1}) was obtained using the medium irrigation level ($1800\text{ m}^3\text{ fed}^{-1}$) combined with the soil application of K-humate. Such treatment returns the highest benefit-cost ratio (3.48) in comparison with other treatments, thus, this treatment proved to be the most economical strategy for tomato production under the conditions of this study.

Generally, this investigation conclude that irrigation tomato plants with $1800\text{ m}^3\text{ fed}^{-1}$ combined with soil application of K-humate incorporated with drip irrigation system could be recommended to improve yield and quality of tomato plants as well as maximizing the water use efficiency, saving about 25% of the total used irrigation water quantity in tomato production. Such treatment is found to be economically and agronomically feasible and can be recommended under drip irrigation system in sandy soil

in new reclaimed lands, giving the highest net return and benefit-cost ratio to the farmers.

Table 5: Effect of irrigation water quantities and water saving substances as well as their interactions on fruit quality characteristics of tomato

Treatment	Flesh firmness (Kg/cm ²)		Lycopene (mg kg ⁻¹ fresh fruit)		Total soluble solids (%)		Total soluble sugars (%)		
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	
	Season	Season	Season	Season	Season	Season	Season	Season	
Irrigation quantities (m ³ fed ⁻¹):									
2400	1.18	1.28	55.59	52.22	5.56	6.30	2.86	3.05	
1800	1.29	1.42	59.29	54.24	6.35	6.97	3.07	3.21	
1200	1.37	1.50	61.37	56.09	6.53	7.26	3.20	3.33	
New LSD at 5%	0.07	0.05	1.71	1.62	0.17	0.22	0.12	0.11	
Water saving substances:									
Control	1.25	1.33	58.25	52.83	5.99	6.62	3.00	3.08	
Zeolite	1.25	1.37	58.10	52.82	6.08	6.77	3.00	3.12	
SAP*	1.28	1.40	58.38	54.24	6.13	6.84	3.01	3.19	
K-humate	1.35	1.49	60.26	56.83	6.40	7.13	3.17	3.39	
New LSD at 5%	0.05	0.04	1.54	1.46	0.18	0.20	0.09	0.08	
Irrigation quantities X Water saving substances:									
2400	Control	1.15	1.21	55.14	51.74	5.34	6.11	2.81	2.94
	Zeolite	1.14	1.23	54.05	50.38	5.48	6.34	2.83	3.01
	SAP	1.19	1.27	55.87	52.17	5.52	6.22	2.80	3.04
	K-humate	1.25	1.39	57.29	54.57	5.91	6.52	2.99	3.22
1800	Control	1.24	1.35	58.06	51.77	6.28	6.61	3.02	3.10
	Zeolite	1.26	1.40	59.08	52.65	6.25	6.83	2.98	3.13
	SAP	1.29	1.42	58.88	54.72	6.30	7.05	3.06	3.17
	K-humate	1.36	1.51	61.12	57.80	6.58	7.37	3.22	3.44
1200	Control	1.35	1.44	61.55	54.97	6.34	7.13	3.16	3.20
	Zeolite	1.34	1.48	61.17	55.42	6.51	7.15	3.19	3.22
	SAP	1.36	1.51	60.39	55.84	6.56	7.26	3.17	3.37
	K-humate	1.43	1.56	62.36	58.11	6.72	7.51	3.29	3.51
New LSD at 5%	0.06	0.07	1.67	1.54	0.24	0.22	0.10	0.09	

SAP* = super absorbent polymer

Table 6: Economic feasibility of tomato production as affected by the interaction between irrigation water quantities and water saving substances during 2011 and 2012 seasons

Treatment	Total yield (Ton fed ⁻¹) ⁽¹⁾	Gross return (LE fed ⁻¹) ⁽²⁾	Treatment cost (LE fed ⁻¹) ⁽³⁾	Total variable cost (LE fed ⁻¹) ⁽⁴⁾	Net return (LE fed ⁻¹) ⁽⁵⁾	Benefit cost ratio ⁽⁶⁾	Order	
2400	Control	34.91	38401	1650	12220	26181	3.14	3
	Zeolite	35.63	39193	4750	15320	23873	2.56	7
	SAP*	37.08	40788	3750	14320	26468	2.85	5
	K-humate	38.81	42691	1990	12560	30131	3.40	2
1800	Control	31.56	34716	1250	11820	22896	2.94	4
	Zeolite	31.31	34441	4350	14920	19521	2.31	9
	SAP	33.65	37015	3350	13920	23095	2.66	6
	K-humate	38.44	42284	1590	12160	30124	3.48	1
1200	Control	19.88	21868	825	11395	10473	1.92	10
	Zeolite	20.84	22924	3925	14495	8429	1.58	12
	SAP	21.08	23188	2925	13495	9693	1.72	11
	K-humate	24.73	27203	1165	11735	15468	2.32	8

SAP* = super absorbent polymer

(1) Tomato total yield as average of the two seasons. (2) Gross return as total yield (ton fed⁻¹) x 900 LE Ton⁻¹. (3) Treatment cost was calculated according to the following prices: Zeolite = 1500 LE/ton, Super absorbent polymer = 50 LE/Kg, K-humate = 30 LE/Kg. (4) Total variable cost (LE fed⁻¹) include: Treatment cost plus land leasehold, transplants, N, P and K fertilizers, microelements, pesticides, labors, and other cultural practices which equal nearly 10570 LE fed⁻¹. (5) = (2)-(4). (6) = (2)/(4).

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تعظيم الإنتاجية وكفاءة استخدام المياه لنباتات الطماطم المنزرعة في الأراضي المستصلحة الجديدة باستخدام كميات مختلفة من مياه الري وبعض المعاملات الموفرة للمياه

أحمد مصطفى كمال* ومجدي محمد الشاذلي**

* قسم بحوث الخضر -معهد بحوث البساتين-مركز البحوث الزراعية-الجيزة مصر.

**قسم بحوث خصوبة الأراضي وتغذية النبات-معهد بحوث الأراضي والمياه والبيئة -مركز البحوث الزراعية-الجيزة مصر.

نظراً لمحدودية مياه الري في مصر، فقد أصبح من الضروري دراسة أفضل الوسائل لترشيد وتعظيم كفاءة استخدام مياه الري ولذلك فقد أجريت تجربتان حقلتان خلال موسمي ٢٠١١ و ٢٠١٢ في بمزرعة خاصة بناحية النوبارية، محافظة البحيرة، مصر وذلك لدراسة تأثير ثلاث مستويات مختلفة من مياه الري وهي ٢٤٠٠، ١٨٠٠، ١٢٠٠ م^٣/فدان وتمثل الكمية الأولى الكمية التي يستخدمها المزارعين بالمنطقة، بالإضافة إلى استخدام بعض المعاملات الموفرة لمياه الري وهي الإضافة الأرضية لكل من الزيوليت والبوليمر وهيومات البوتاسيوم، وذلك على النمو والتركيب الكيماوي والمحصول وكفاءة استخدام المياه وجودة ثمار الطماطم هجين أول جاكال وذلك تحت نظام الري بالتنقيط في الأراضي المستصلحة الجديدة خلال العروة الصيفية المبكرة.

وكانت أهم النتائج كما يلي:

- أدى استخدام أعلى مستوي من مياه الري (٢٤٠٠ م^٣/فدان) إلى الحصول على أعلى زيادة معنوية لصفات النمو الخضري لنباتات الطماطم متمثلة في سمك الساق والوزن الغض للنبات والمساحة الورقية والمحتوي النسبي للماء بأوراق النبات وكذلك امتصاص النيتروجين والفوسفور والبوتاسيوم في المجموع الخضري. من ناحية أخرى أدى استخدام مستوي الري الأقل (١٢٠٠ م^٣/فدان) إلى التحسن المعنوي في محتوى الأوراق من الكلوروفيل. كما أوضحت النتائج أيضاً أن استخدام المستوي الأعلى من مياه الري (٢٤٠٠ م^٣/فدان) أدى إلى الحصول على أعلى زيادة معنوية في عدد الثمار للنبات ومتوسط وزن الثمرة وكذلك المحصول الكلي للفدان. وكان لاستخدام المستوي المتوسط (١٨٠٠ م^٣/فدان) من مياه الري أفضل تأثير على زيادة كفاءة استخدام المياه بواسطة نباتات الطماطم بالمقارنة مع المعاملات الأخرى. أدى استخدام المستوي الأقل من مياه الري (١٢٠٠ م^٣/فدان) إلى تحقيق أفضل تأثير معنوي على صفات جودة ثمار الطماطم متمثلة في صلابة الثمار والليكوپين ونسبة المواد الصلبة الذائبة الكلية ومحتوي ثمار الطماطم من السكريات الكلية.

- كان للإضافة الأرضية لهيومات البوتاسيوم حقناً مع مياه الري أفضل تأثير معنوي على صفات النمو الخضري وكذلك امتصاص النيتروجين والفسفور والبوتاسيوم في المجموع الخضري ومحتوي الأوراق من الكلوروفيل، بالإضافة إلي تحسين صفات المحصول وجودة الثمار وكذلك كفاءة استخدام المياه بواسطة نباتات الفلفل وذلك بالمقارنة مع بكل من الزيوليت والبوليمر ومعاملة المقارنة.
- أدي استخدام أعلى مستوي من مياه الري (٢٤٠٠ م^٣/فدان) مع الإضافة الأرضية لهيومات البوتاسيوم حقناً مع مياه الري إلى الحصول علي أعلى زيادة معنوية في جميع صفات النمو الخضري تحت الدراسة. كما أدي استخدام كلاً من المستوي الأعلى من مياه الري (٢٤٠٠ م^٣/فدان) أو المتوسط (١٨٠٠ م^٣/فدان) مع الإضافة الأرضية لهيومات البوتاسيوم حقناً مع مياه الري إلى الحصول علي أعلى زيادة معنوية في امتصاص النيتروجين والفسفور والبوتاسيوم في المجموع الخضري للنباتات وكذلك تحقيق أعلى زيادة معنوية في صفات محصول نباتات الطماطم تحت الدراسة. أدت الإضافة الأرضية لهيومات البوتاسيوم مع استخدام مستوي الري الأقل (١٢٠٠ م^٣/فدان) إلي التحسن المعنوي في محتوى الأوراق من الكلوروفيل. كان لاستخدام المستوي المتوسط من مياه الري (١٨٠٠ م^٣/فدان) مع الإضافة الأرضية لهيومات البوتاسيوم أفضل تأثير معنوي علي زيادة كفاءة استخدام المياه بواسطة نباتات الطماطم بالمقارنة مع المعاملات الأخرى. أدي استخدام المستوي المتوسط (١٨٠٠ م^٣/فدان) من مياه الري أو المستوي الأقل (١٢٠٠ م^٣/فدان) مع الإضافة الأرضية لهيومات البوتاسيوم إلى تحسين صفات جودة ثمار الطماطم وذلك بالمقارنة مع المعاملات الأخرى.
- أدي استخدام المستوي المتوسط (١٨٠٠ م^٣/فدان) من مياه الري مع الإضافة الأرضية لهيومات البوتاسيوم إلى الحصول علي أكبر عائد اقتصادي مع تحقيق أكبر قيمة لنسبة المنافع إلى التكاليف (٣.٤٥) بالمقارنة مع المعاملات الأخرى وذلك تحت ظروف الدراسة.
- وبناء عليه توصي هذه الدراسة بري نباتات الطماطم بمستوي ١٨٠٠ م^٣/فدان مع الإضافة الأرضية لهيومات البوتاسيوم (٢ كجم/فدان في الإضافة، أربعة مرات خلال موسم النمو) حقناً مع مياه الري وذلك للحصول على أفضل النتائج بالنسبة للمحصول الكلي وجودة ثمار الطماطم وكذلك تعظيم كفاءة استخدام المياه مع توفير ٢٥% من كمية المياه المستخدمة وتحقيق أفضل عائد اقتصادي تحت ظروف الأراضي المستصلحة الجديدة في العروة الصيفية المبكرة.

قام قام بتحكيم البحث

كلية الزراعة – جامعة المنصورة
مركز البحوث الزراعيه

أ.د / السيد احمد طرطوره
أ.د / عبد الحميد حبشى عامر