Effect of Kaolin and Fulvic Acid Antitranspirants on Tomato Plants Grown under Different Water Regimes

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ABSTRACT

This study was carried out to evaluate effects of kaolin (KA) and fulvic acid (FA) as antitranspirants (ATs) on relative water content (RWC) of leaves, net CO_2 assimilation rate (CO_2 AR), yield, fruit quality and irrigation water use efficiency (IWUE) of tomato plants (*Solanum lycopersicum L.*). The plants were grown under three water regimes based upon crop daily water consumptive use (ETc). These regimes included 100%ETc, 75%ETc and 50%ETc. Field experiments were achieved for two successive seasons 2012 and 2013 under drip irrigation system in sandy soil at El-Bostan, El-Beheira Province, Egypt. The results revealed that both ATs enhanced effectively the physiological activities and yield production of tomato plants, particularly at water regime of 75% ETc, but they did not compensate the negative effects caused by sever water regime of 50% ETc. FA antitranspirant was more effective than KA. Under water regime of 75%ETc, application of 1.5 FA ml L^{-1} at 21-day intervals increased IWUE by 34.82% compared to untreated plants. Foliar spray by FA reduces the values of crop response factor than KA in the two seasons. These led to conserving soil water and thereby reduce the applied water by 25% of irrigation water. In comparison to untreated FA plants, the FA (75%ETc) led to decreases in the yield to 93.4% of that irrigated at 100%ETc. There were no significant differences in the fruit quality (titratable acidity and vitamin C) between both ATs treatments.

Key Words: Water use efficiency, Kaolin, Fulvic acid, irrigation regimes, fruit quality

INTRODUCTION

Because of the lack of water in arid regions, there is a great need to optimize agricultural water consumption. Thus, water conserving is becoming a decisive consideration for agriculture, particularly in arid and semi-arid regions (i.e. Egypt) where water is the main limiting factor for plant growth (Moftah and AL-Humaid 2005). Indeed, plants are prodigal in the water use because approximately 5% of water uptake is used for its growth and development while the remaining 95% is lost for transpiration (Prakash and Ramachandran 2000b). One way to achieve water conservation in the agricultural sector is to reduce the transpiration rate (TR) of a plant. Studying the effects and potential uses of antitranspirants (ATs) on plant growth showed particular possibilities for conserving irrigation water, increasing water use efficiency. However, ATs applications for this purpose would be justified only if water costs are sufficiently high (Glenn *et al*., 2005).

ATs are classified into three types based on their action role: (1) reflecting materials: they reduce the absorption of radiant energy and thereby reduce leaf temperatures and TR, (2) film forming materials: they are certain emulsions of wax, latex or plastics dries on the foliage to form thin transparent films which hinder the escape of water vapor from the leaves, and (3) metabolic materials: chemical compounds can prevent stomata from opening fully (by affecting the guard cells around the stomata pore), thus decreasing the loss of water vapor from the leaf (Glenn *et al*., 2005).

Early studies demonstrated that the foliar spray by reflective Kaolin had improved both plant water status and yield of water-stressed tomato plants, while it did not reduce carbon assimilation (Glenn *et al*., 2003). Many studies have focused on comparing the effects of reflective ATs on vegetables (Prakash and Ramachandran 2000a), fruits (Glenn *et al*., 2003) and field crops (Gupta *et al*., 2001). Kaolin application on trees was found to (i) reduce plant TR (Cantore *et al*., 2009; and Rosati *et al*., 2006) and to improve whole canopy assimilation rate under high leaf-to-air vapor pressure deficit and temperature (Rosati *et al*., 2006), or to have no effect (Wünsche *et al*., 2004) in apple; (ii) reduce the outer canopy assimilation rate and maximum leaf assimilation rate at saturating light in apple (Grange *et al*., 2004); (iii) increase CO_2 AR rate, stomatal conductance and water use efficiency at mid-day in citrus (Jifon and yvertsen, 2003); and (iv) reduce leaf temperature, without affecting TR, stomatal conductance, net CO_2 assimilation and yield in pecan tress (Lombardini and Glenn, 2005). Kaolin caused a reduction in temperature of vegetation and TR in tea (Anandacoomaraswamy *et al*., 2000), a decrease in leaf temperature in tomato (Saavedra *et al*., 2006), and no effect on yield, leaf temperature, TR, net CO_2 assimilation or stomatal conductance in pepper (Russo and Díaz-Pérez, 2005).

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Humic substances (Fulvic acid and Humic acid) have been used to regulate the plant growth under well watered and drought conditions (Li *et al*., 2005). Furthermore, fulvic acid as metabolic ATs is an organic acid and nontoxic and available compared with the other chemicals used. It is also not expensive and did not cause pollution problems as a result of extensive use (Nardi *et al*., 2002). Anjume *et al*., (2011) reported that Fulvic acid increased chlorophyll and water content of leaves, thus drought stress can be mitigated. Fulvic acid also increased photosynthesis, reduced stomatal opening status and TR, thus led to growth stimulation and water loss reduction. Falvic acid foliar spray resulted in an increase of grain yield by 7.2% at the optimal concentration of 1.5 ml L^{-1} (Li *et al*., 2005).

The objective of the present study was to evaluate the effects of Fulvic acid (metabolic AT type) and Kaolin particle film (reflecting AT type) on irrigation water use efficiency (IWUE), physiological performance, tomato plant response to water stress, plant water status, photosynthesis rate, yield and fruit quality of tomato plants grown in sandy soil under different water regimes.

MATERIALS AND METHODS

The experimental work, crop evapotranspiration, measurements, and fruit quality and statistical analysis are presented.

A: Experimental work

A field experiment was conducted in 2012 and 2013 growing seasons at El-Bostan Farm Experiment Station, Faculty of Agriculture, Damanhour University, El-Behera province, Egypt. El-Bostan region is located between 30.20 N & 30.50 E and altitude 7.4 m above sea level. The climate is typically arid, characterized by average annual rainfall of 20-50 mm distributed mainly during winter, with air temperature ranges between 30–38 ^{o}C in summer. The soil of the experimental field represents the newly reclaimed lands at the western area of Nile Delta. The main chemical and physical properties of the soil are: pH of 8.2; organic matter content of 0.2%; total carbonate of 3.3%; electrical conductivity (EC_e) of 0.75 dSm^{-1}, SAR of 0.35, bulk density of 1.7 $Mg.m^{-3}$; wilting point of 0.09 $m^3.m^{-3}$, field capacity of 0.14 $m^3.m^{-3}$ and saturation water content of 0.33 $m^3.m^{-3}$. The soil texture is sandy (96.1, 2.2, and 1.7% for sand, silt and clay, respectively).

The field studied area was divided into 27 plots (experimental unit). Each unit consists of two rows with 7-m length and 2.6-m apart (18.2 m^2). Prior to tomato cultivation, tomato (*Solanum lycopersicum L.* super hybrid cultivar) seeds were sown in polystyrene trays on 10th and 5th of February, 2012 and 2013, respectively. Seedlings and germination stages were conducted in a greenhouse. Seedlings were transplanted at the third true leaf stage on 10th and 8th of March 2012 and 2013, respectively in rows at apace of 0.4-m between plants, giving a plant density of 2 plants m^{-2}. A drip irrigation system was used for tomato irrigation. The system includes lateral sets along the plant rows with in-line emitters' spaced 0.40- m apart and they possess a flow rate of 4.2 L h^{-1}. The laterals were placed 0.10 m away from the plant rows. The irrigation water discharge was measured using a flow meter installed in the water delivery unit, which was designed for independent control of water delivery to each desired evapotranspiration rate. Three water regimes combined with two foliar applications of ATs materials were achieved. A control treatment (untreated ATs) was conducted for each irrigation regime as well. The first foliar spray was applied on 25th of April at the start of fruit set and repeated every 21-day intervals for three applications. The ATs were applied to plants using a backpack power sprayer. Irrigation regimes (main plot) were selected as a percentage of crop daily water consumptive use (ETc). These regimes were 100%ETc, 75%ET_c and 50%ET_c. Under each level of irrigation, two types of ATs materials were applied (sub plot). Antitranspirants treatments were (1) spraying kaolin with concentration of 4% (w/v) as reflective ATs, (2) spraying fulvic acid with concentration of 1.5 ml L^{-1} as metabolic ATs and (3) control (untreated ATs). All treatments were achieved using three replicates.

B: Crop Evapotranspiration (ETc)

The reference evapotranspiration (ET_0) was calculated by FAO Penman-Monteith equation using FAO-CROPWAT (software version 8) (Allen *et al*., 1998). Crop daily water consumptive use (ETc) was obtained by multiplying ET_0 by Kc. The same software was used to calculate both the net irrigation requirements (NIR) and gross irrigation requirements (GIR) and irrigation intervals. FAO-CROPWAT was used to calculate ETm (a maximum evapotranspiration at 100 % ETc) and ETa (an actual evapotranspiration at 75%ETc and 50% ETc) in m^3 ha^{-1}.

C: Measurements

Relative water content (RWC) was calculated according to (De Pascale *et al*., 2003) using:

$$RWC=\frac{(FW-DW)}{(TW-DW)}\times 100 \qquad (1)$$

Where: TW is leaf turgid weight, FW is leaf fresh weight and DW is leaf dry weight in (Kg ha^{-1})

Canopy Temperature (Ct) Was measured between 12:00 and 14:00 h, on top of plants using an IR thermometer (model 112C; Ev erest Interscience, Tustin, CA) , Net CO_2 Assimilation Rate was measured with a portable photosynthetic open-system (Li-6400 USA). Yield Components, marketable and unmarketable yields were measured, where fruit that were green, cracked, with symptoms of blossom-end rot, sunscald, or damaged by tomato fruit worm were considered unmarketable.

Irrigation Water Use Efficiency (IWUE) was calculated using the following equation:

$$IWUE = \frac{Marketable\ \ Yield\,(kg\ ha^{-1})}{Consumptive\ \ Use\ (m^3 ha^{-1})} \qquad (2)$$

Tomato Water Response Factor (Ky) is a factor that is defined as the decrease in yield per unit decrease in ETc (Singh *et al.*, 2010). Seasonal values of Ky was calculated for each experimental year as:

$$1 - \frac{Y_a}{Y_m} = Ky\left(1 - \frac{ET_a}{ET_m}\right) \qquad (3)$$

Where: Y_m and Y_a (kg ha^{-1}) are maximum and actual yield, respectively. ET_m and ET_a (m^3 ha^{-1}) are maximum and actual evapotranspiration, respectively. Ky was calculated for marketable yield produced by the crop.

D: Fruit quality analysis

Titratable acidity (mg /100 ml juice) determined by titrating five ml of tomato juice with 0.1M of NaOH in the presence of phenolphthalein, Total Soluble Salts (TSS) in tomato juice was determined using a refractometer and expressed as Brix at 20^oC. Vitamin C (mg Ascorbic acid/100ml of tomato juice) was measured by titrating the pigment solution with NaOH in the presence of the acid indicator.

E: Statistical Analysis

The resulted data were analyzed statistically as a complete block design using three replicates (Snedecor and Cochran, 1980). Differences among treatments were tested with LSD at a 5% level of significance.

RESULTS AND DISCUSSION

The applied water, relative water content of leaves, canopy temperature, Net CO_2 assimilation rate, yield components, chemical fruit quality parameters, irrigation water use efficiency, tomato water response factor, unmarketable yield, and marketable yield values are presented and discussed in following section.

A: Applied Water

Data of ET_0 indicated that the maximum value of ET_0 during the growing season of tomato plants was 7.0 mm d^{-1} for June. This relatively high value was due to both high temperature and low relative humidity. The highest value of daily ETc (8.25 mm d^{-1}) was recorded for mid-season growth stages (flowering, fruit set, and fruit formation) with Kc value of 1.21. This (mid-season) growth stages were in May and Jun. Data presented in Table (1) showed that the highest values of water consumptive use were (flowering stage) 2621.2 m^3 ha^{-1} through 45 days within 24 irrigations for the first season and 2710.9 m^3 ha^{-1} through 45 days within 22 irrigations for the second season. The lowest values of water consumptive use were (development stage) 565.08 m^3 ha^{-1} and 750.44 m^3 ha^{-1} through 40 days within 16 irrigations for the first and second season, respectively. The latter stage consumed low water because it occurred during March and April where the ET_0 is 5.4 mm d^{-1}. Total amounts of applied water were 4950.05, 3720.83, and 2647.33 m^3 ha^{-1}, for water regimes of 100%ETc, 75%ETc and 50%ETc, respectively, for the first season. The corresponding amounts were 5334.28, 3964.69, and 2772.01 m^3 ha^{-1}, respectively, for the second season. Obviously, there are slight differences in the consumed water between the two seasons.

Table 1. Amounts of applied irrigation water (m^3/ha/stage), number of irrigations and number of days for each growth stage for the two growing seasons

Growth Stage	Gross irrigation requirements (m^3/period)		Growth stage length (days)		Number of irrigations/ stage length	
	First season	Second season	First season	Second season	First season	Second season
Vegetation (developments stage)	565.08	750.44	40	40	16	16
Flowering (mid-season stage)	2621.2	2710.9	45	45	24	22
Yield formation and repining (end stage)	1672.7	1872.9	30	30	13	14
Total	4858.98	5334.24	115	115	53	52

B: Relative water content of leaves (RWC)

RWC values were shown in Figure (1). The RWC had high values at 100% ETc water regime compared to 50% ETc for both growing seasons. The reduction in RWC was relevant to the levels of soil water content. The RWC under the irrigation regimes followed the order: 100%ETc > 75%ETc > 50%ETc. The values of RWC values were lower by 4.8 and 11.5% for the 75%ETc and 50%ETc, respectively as compared to 100%ETc for the first season. This could be attributed to the high evaporative demand of the atmosphere, and also to relatively low root ability to absorb water from the soil. Generally, Applications of ATs were effective in improving RWC under unfavorable soil moisture i.e., 50%ETc as well as 75%ETc. The enhancement of ATs for the RWC was more pronounced under 75% ETc than the 50%ETc in comparison to the control treatments. The improvement in RWC may be attributed to the decrease in water loss and improved water uptake by plant roots using ATs. Effects of KA on RWC could be attributed to its light reflective nature which had reduced the absorption of radiant energy and consequently transpiration reduction (Glenn *et al*., 2003). Effects of FA on RWC can be attributed to water uptake by roots as well as water conductance (Anjum *et al*., 2011). The presented results are in agreement with those reported by Prakash and Ramachandran (2000a); Moftah and AL-humaid (2005); Cantore *et al*., (2009) and Anjum *et al*., (2011).

C: Canopy Temperature (Ct)

Ct values were presented in Table (2). For the first season, the mean Ct values were 26.35, 28.19, and 28.26 ^{o}C for 100, 75, and 50% ETc, respectively, during mid-day period. Afternoon period, the corresponding values were 24.61, 24.81 and 25.67 ^{o}C. Similar Ct trend was reported for the second season. It is obvious that differences in Ct were great in the mid-day period compared to the afternoon period. These differences are attributed to the great amount of solar radiation received by plant canopy during the mid-day period. At the end of the day, all treatments almost had the same Ct. Application of Kaolin reduced significantly Ct compared to the control (untreated plants) for both 75 and 50% ETc, particularly at the mid-day, when incident solar radiation was high. KA spraying reduced tomato Ct of the 50% ETc treated plants by about 2.9 and 2.3 ^{o}C for the mid-day, and afternoon respectively, compared to its control treatment. Increased reflection of incident radiation from the white colored kaolin-sprayed leaves was probably responsible for the Ct reduction.

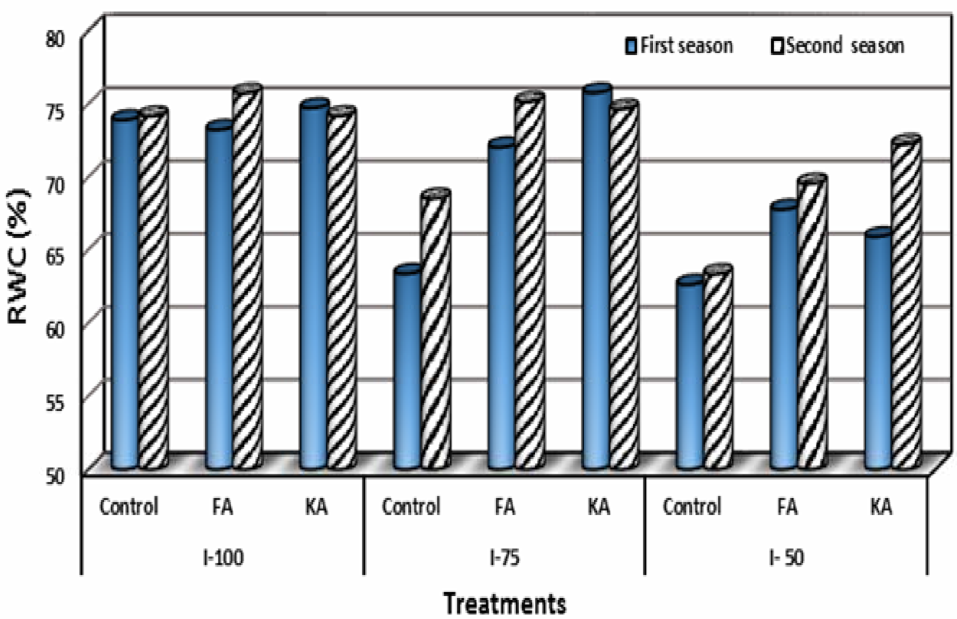

Fig. 1. The relative water content (RWC) of leaves as influenced by water regimes and antitranspirants foliar applications

Table 2. Effect of water regimes and antitranspirants treatments on the canopy temperature

Experimental Treatments		Canopy temperature °C			
		First season		Second season	
Irrigation	ATs	Mid-day 1-2 pm	late afternoon 5-6 pm	Mid-day 1-2 pm	Later Afternoon 5-6 pm
100%	Control	26.82	24.87	26.01	21.15
	FA	26.21	24.57	27.85	22.96
	KA	26.02	24.38	22.72	20.84
	mean	26.35	24.61	25.53	21.65
75%	Control	28.36	24.49	28.78	24.14
	FA	30.02	24.78	29.22	23.10
	KA	26.21	25.16	25.86	21.80
	mean	28.19	24.81	27.95	23.01
50%	Control	30.11	26.24	31.80	25.83
	FA	27.95	25.78	31.88	23.99
	KA	26.72	24.99	28.12	22.28
	mean	28.26	25.67	30.60	24.03
$LSD_{0.05}$		0.43	0.38	1.01	0.85

Kaolin effects on Ct of tomato agree with those obtained for many tree species including apple, pomegranate, pecan, walnut, almond, grapefruit, pear and citrus. For all of them kaolin reduced leaf Ct by 1–6 °C (Jifon and Syvertsen, 2003; Wünsche *et al*., 2004; Lombardini and Glenn, 2005 and Rosati *et al*., 2006). While ATs of the reflecting type cause a reduction in Ct, the stomata-closing types tend to increase leaf temperature by curtailing (TR) and thus reducing evaporative cooling. In contrarily, the FA effects on Ct were not numinous. Some FA treatments possessed higher Ct than its control. These increases might be due to film applications that minimize transpiration cooling; but the increase in temperature is minimal as transpiration only removes part of the energy budget of the leaf and rarely is the leaf completely coated. By the end of the day, all treatments had almost the same Ct implying that longwave emittance was unaffected by ATs sprays.

D: Net CO_2 Assimilation Rate

Data of net CO_2 AR (Figure 2) showed that the values of net photosynthesis rates were higher at 100% ETc water regime as compared to either 75 or 50 % ETc water regimes. Net CO_2 AR means were 14.29, 12.59 and 11.26 µmol CO_2 /m^2.s for 100, 75, and 50%ETc, respectively, in the first season. The corresponding rates were 13.52, 12.61 and 9.80 µmol CO_2 /m^2.s for the second season. These results are in agreement with those found by Rosati *et al*., (2006) and Moftah and AL-humaid, (2005).

This reduction in photosynthesis rate under water stress conditions could be ascribed to the high evaporative demand of the atmosphere and relatively low root ability to absorb water from the soil. It is obvious that roots are the first plant organ response to water stress and send chemical signals through the stem to leaves, where stomatal conductance is reduced (Taiz and Zeiger, 2002). The 'non-stomatal' mechanisms include changes in chlorophyll synthesis, functional and structural changes in chloroplasts and disturbances in processes of accumulation, transport and distribution of assimilates (Farooq *et al*., 2009a, b). Also, drought stress disrupts the photosynthetic pigments, causing irreversible damage to the photosynthetic apparatus, reducing gas exchange, leading to reduction in plant growth and productivity (Anjum *et al*., 2011). Reduction of photosynthesis rate is correlated to low RWC under water deficit conditions as reported previously. Under all water regimes, the photosynthesis rates under both ATs treatments differed insignificantly. For instance under 75% ETc, the rate decreased non-significantly by 4.36% and 16.27% for FA and KA, respectively. This reduction was not significant because of the water deficit is low all over the growing season. The data of the second season are in agreement with those found in the first season. However, these considerations of leaf measurements cannot be scaled up from the leaf to the whole canopy because, in the latter, most leaves are exposed (and adjusted) to less than saturating photosynthesis active radiation (Wünsche *et al*., 2004). Also, the reduction of the photosynthesis rate was relevant to the reduction in applied water more than the effect of the type of ATs. Similar results were found by Rositi *et al*. (2006). Some hypotheses have been formulated to explain the variances in the obtained different results. Particle films have been shown to reduce the light available to the leaf by increasing light reflection (Wünsche *et al*., 2004). This can reduce leaf net photosynthesis of leaves under optimal conditions for photosynthesis. However, at high temperature, net photosynthesis of leaves may be more limited by the heat stress than by low light so that the reduction in leaf temperature, induced by the kaolin film, could be more than compensate for the negative effect of reduced light (Glenn *et al*., 2003). The results of Kaolin coated leaves in the present study are in agreement with those obtained for apple (Grange *et al*., 2004; and Srinivasa, 2010). Also, Moftah and Al-Humaid (2005) observed that the gas exchange of Kaolin sprayed-plants under water stress conditions (plants irrigated with 60% of water added to control well-irrigated treatments) did not reach the values obtained in control plants.

E: Yield Components

Figure (3) showed that marketable yield was reduced by 48.32% and 20.07% for 50%ETc and 75%ETc treated plants, respectively with reference to the 100% ETc in the first season. Low reduction rate was recorded for the second season compared to the first season. The yield reduction could be attributed to the decrease of photosynthesis rate as presented earlier. On contrast, unmarketable yield (Figure 3) increased as water stress increased. Unmarketable yield was increased by 53.17% and 9.52% for 50%ETc and 75%ETc treatments respectively for the first season. The corresponding reductions were 70.00% and 44.72% for the second season.

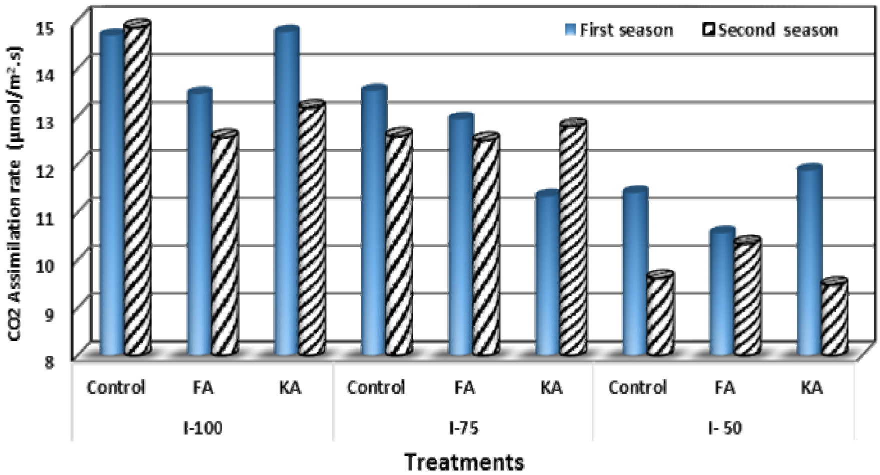

Fig. 2. Effect of water regimes and antitranspirants foliar application on CO_2 assimilation rate (µmol/m^2.s)

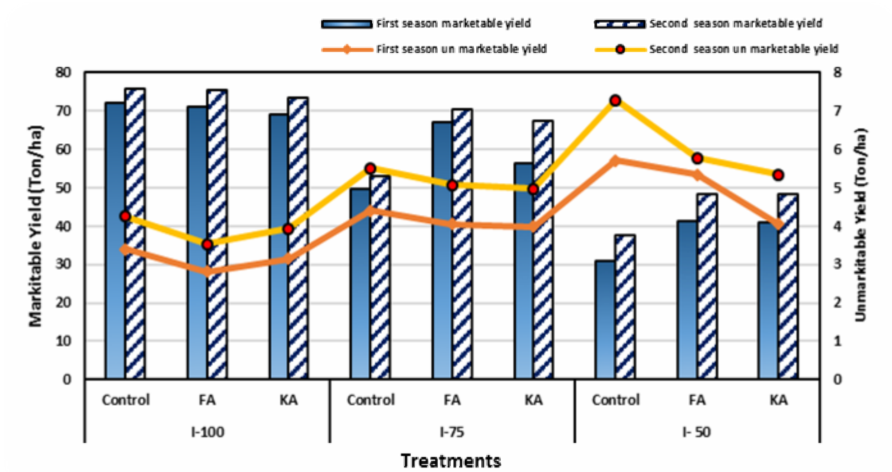

Fig. 3. Effect of water regimes and antitranspirants foliar application on marketable and unmarketable yield (Kg ha^{-1})

This is possibly related to the increase in sunburned fruit, damaged by insects, and those affected by the blossom end rot. These obtained results are in agreement with those found by Rosati *et al*. (2006), Cantore *et at*. (2009) and Savic *et al*. (2011).

The ATs foliar spray enhanced the marketable yield under both 50%ETc and 75%ETc treatments compared to their control treatments. For 50% ETc treatment, the values of marketable yield increased by 24.97% and 24.51%; and 28.43% and 27.88% for FA and KA, in the first and second season, respectively, compared to their control treatments. For 75%ETc treatments, marketable yield increased insignificantly as compared to the control for KA and increased significantly with the metabolic inhibitor FA for the first season. Both ATs significantly increased marketable yield in the second season. Marketable yield increased by about 25.8% and 11.73%; and 23.68% and 21.20% for FA and KA, in the first and second season, respectively comparison to their control treatments. Such yield improvements could be attributed to the reduction of TR as a result of the ATs foliar application. This reduction of TR led to soil water conservation, thus the yield increased compared to control. It is worth noting that under deficit irrigation; reducing water loss would conserve soil moisture for a longer time and could result in yield improvement in arid and semi-arid regions for tomato. Under well irrigation conditions, values of marketable yield reduced slightly, the reduction was not significant for the two ATs. These results are in accordance with those found by Glenn *et al*. (2002), Jifon and Syvertsen (2003) and Contore *et al*. (2009). The potential of both ATs to increase marketable yield was more pronounced under 50%ETc than 75%ETc. For example, the marketable yield of FA-treated plants increased by 4.97, 25.8, and -1.25% for 50%ETc, 75%ETc and 100%ETc, respectively comparison to their controls. Similarly, the marketable yield of KA-treated plants increased by 24.51, 11.73 and -4.18% for 50%ETc, 75%ETc and 100%ETc, respectively. These results agree with those found by Saavedra *et al*. (2006) and Pace *et al*. (2007). Taking the 100%ETc treatment as a reference, there were no significant difference between marketable yield for plants sprayed with FA at 75%ETc and the control at 100%ETc. This indicates that FA application is effective in reducing TR at 75%ETc more than Kaolin. Thus, FA application would reduce the applied water by 25% per irrigation with a maximum reduction in yield was nearly 6.7%. This gives an impression that the use of FA would be an effective tool to alleviate heat stress and to reduce water stress for tomato production grown under arid and semi-arid conditions.

F: Chemical Fruit Quality Parameters

The fruit quality parameters include TSS, titratable acidity and Vit. C. Their values were shown in Table (3). They did not differ significantly among the studied treatments. Similar results were reported by Birhanu *et al*. (2010) and Savic *et al*. (2011). For both titratable acidity and Vitamin (C) values, there were no significant differences between plants treated with any ATs. Kaolin application under 50%ETc increased fruit TSS by 18.63% compared to the control treatment.

Table 3. Effect of water regimes and antitranspirants treatments on chemical fruit quality

Experimental Treatments		Chemical Fruit Quality					
		First season			Second season		
Irrigation	ATs	Vit. C mg/100ml	Titrable Acidity mg/100ml	TSS (Brix)	Vit. C mg/100ml	Titrable Acidity mg/100ml	TSS (Brix)
100%	Control	25.6	0.17	7.33	23.1	0.2	6.03
	FA	25.8	0.19	7.08	21.6	0.2	6.13
	KA	28.2	0.18	7.23	21.2	0.19	6.20
	mean	26.53	0.18	7.21	21.97	0.19	6.12
75%	Control	27.4	0.16	6.67	22.0	0.21	5.90
	FA	24.9	0.17	7.28	22.2	0.18	5.60
	KA	28.6	0.18	7.54	20.2	0.20	5.73
	mean	26.97	0.17	7.16	21.47	0.19	5.74
50%	Control	26.1	0.18	6.87	21.0	0.20	5.94
	FA	28.4	0.16	6.72	23.1	0.20	6.50
	KA	26.3	0.18	8.15	21.0	0.21	6.03
	mean	26.93	0.17	7.25	21.70	0.20	6.16
$LSD_{0.05}$		4.66	0.03	0.87	3.78	0.02	0.61

The results of Kaolin agreed with those reported by Prakash and amachandran (2000a) and Saavedra *et al*. (2006).

G: Irrigation Water Use Efficiency (IWUE)

Data of IWUE were illustrated in Figure (4). Under 75%ETc treatment, IWUE increased by 1.25 Kg m^{-3} and 1.93 Kg m^{-3} amounting to 8.76% and 13.72% compared to its values under 100%ETc irrigation treatment for the first and second seasons, respectively. Under 50%ETc treatments, the value of IWUE was changed slightly and was corresponding to 0.10% lower than those under 100% ETc treatments for the first season. The corresponding value was higher by 4.75% for the second season. This could be attributed to the high drop in the marketable yield, as tomato is a sensitive crop to water stress. Such increase in IWUE is relevant to deficit irrigation studies for tomato cultivars (Costa *et al*., 2007 and Patanèa *et al*., 2011). The IWUE increased by 33.24% and 32.47% for FA and KA, respectively, in comparison to their control treatments for the first season (%50 ETc). The corresponding values were 31.76% and 31.52% for FA and KA, respectively for the second season. Such improvements could be attributed to the reduction of TR since reducing rate of water loss would conserve soil moisture for a longer time and could result in yield improvement. Regarding 75%ETc, IWUE increased as compared to the control by 34.82% and 13.30%, and 30.99% and 26.88% for FA and KA, in the first and second season, respectively. Under optimal irrigation treatments, the values of IWUE decreased slightly. However, the reduction was not significant for the two ATs treatments. These results contradict to those found by Contore *et al*. (2009) but agree with results reported by Glenn *et al*. (2001) and Jifon and Syvertsen (2003) for apple and grapefruit. The superiority of Fulvic acid (FA) over kaolin (KA) may be due to the reduction of TR which is caused by stomata regulators which prevented stomata from opening fully thus decreasing the loss of water vapor from the leaf.

H: Tomato Water Response Factor (Ky)

Values of Ky were shown in Figure (5). They decreased under irrigation of 50% ETc. The reduction was much greater under irrigation regime of 75%ETc than under 50% ETc. However, the reduction in water response factor for each water unit under 75% ETc treatments is lower than that under the 50% ETc treatment.

It is clear from Figure (5) that the values of Ky factor were 1.06, 0.89, and 1.02 for 50%ETc, 75% ETc, and 100% ETc treatments for the first season, and were 0.99, 0.81 and 1.01, for the second season, respectively. This indicates that plants irrigated with 100%ETc were more sensitive to water stress, whereas the presence of Ky with the lowest value under 75%ETc showed that under this treatment, tomato is more capable to tolerate water stress in comparison with the other irrigation treatments. Under severe water stress treatments (50% ETc), the two ATs foliar spray treatments reduced Ky values significantly by 24.6% and 24.6%; 25.9% and 25.9% for FA and KA, in the first and second seasons, respectively as compared to the control treatment.

These improvements could be attributed to the reduction of TR and thus to soil water conservation, which make tomato plants less sensitive to water stress. Under 75% ETc water regime, the data of the first and second seasons revealed that Ky was reduced as compared with the control treatment by 78.2% and 29.8% and by 72.6% and 63.2% for FA and KA, respectively. Under 75% ETc water regime, there was no significant variation between the two investigated ATs treatments. This may be due to the reduction in the TR and the photosynthesis rate.

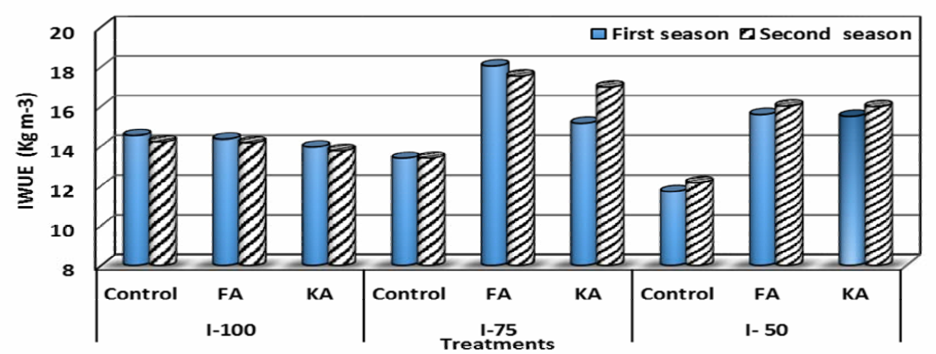

Fig. 4. Irrigation water use efficiency (IWUE) (Kg m^{-3}) as influenced by water regimes and ATs foliar application

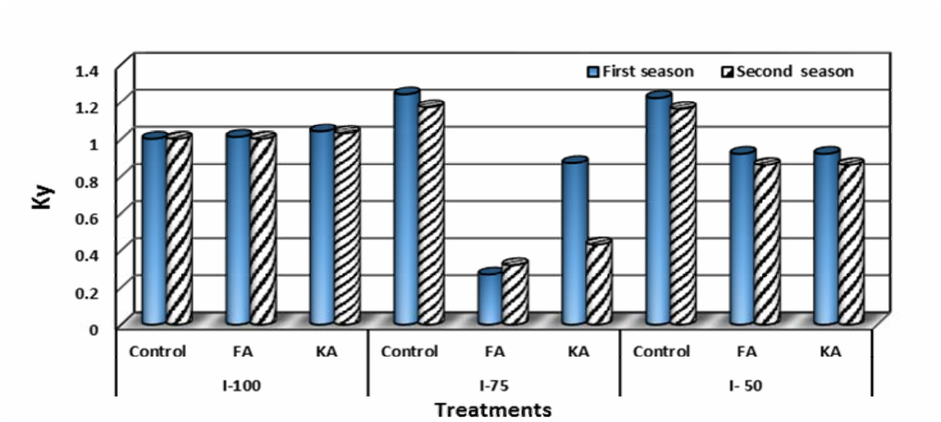

Fig. 5. Crop water response factor (Ky) as influenced by water regimes and ATs foliar application

CONCLUSION

While low water regime (50%ETc) significantly reduces relative water content (RWC) of tomato leaves, photosynthesis rate and marketable yield, the application of both ATs' types (KA and FA) under deficit water irrigation enhanced effectively the physiological activities and yield production of tomato plants, particularly under moderate water stress (75%ETc). It is clear that tomato plant did not compensate the negative effects caused by the 50%ETc irrigation regime. However, Fulvic acid was more effective than Kaolin. Under 75%ETc, foliar spray with 1.5 ml FA L^{-1} at fruit set stage (21-day intervals) produced the minimum reduction of net CO_2 AR and yield. As a result, IWUE increased by 34.82% with respect to well irrigated (100%ETc) - ATs untreated plants. Furthermore, FA application led to conserving soil water and thereby reducing the quantity of the applied water by 25% per irrigation without serious yield reduction, at the same time, fruit quality parameters were sustained.

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الملخص العربي

تأثير الكاولين وحمض الفالفيك كمضادات للنتح على نباتات الطماطم النامية تحت مستويات مياه مختلفة

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أجريت هذه الدراسة لتقييم تأثير الكاولين وحمض الفالفيك كمضادات للنتح على المحتوى الرطوبى النسبى (RWC) للأوراق وصافى معدل امتصاص غاز ثانى أكسيد الكربون(net CO_2 Assimilation Rate) والمحصول وجودة الثمار وكفاءة استخدام مياه الرى لنباتات الطماطم النامية تحت ثلاث معاملات من مياه الرى المعتمدة على الاستهلاك المائى اليومى للمحصول وهى(أ) الرى الأمثل ١٠٠% من البخرنتح للمحصول(100% ETc) (ب) نقص مائى متوسط (75% ETc) (ج)نقص مائى شديد(50% ETc). نفذت تجربة حقلية لموسمين متتاليين ٢٠١٢- ٢٠١٣ تحت نظام الرى بالتنقيط لنباتات الطماطم النامية في ارض رملية بمنطقة البستان بمحافظة البحيرة.

أوضحت النتائج ان كلا النوعين من مضادات النتح شجعت بفاعلية الأنشطة الحيوية وانتاجية المحصول للطماطم وخاصة تحت النقص المائى المتوسط(75% ETc) ولكنها لم تعوض التأثيرات السلبية الناتجة عن النقص المائى القاسى (50% ETc)، كما أن حمض الفالفيك كمضاد للنتح له تأثير أكثر فاعلية من الكاولين. تحت معاملة النقص المائى المتوسط أضافة حمض الفالفيك بمعدل ١,٥مل/لتر على فترات ٢١ يوم يزيد من كفاءة استخدام مياه الرى (IWUE) بمعدل ٣٤,٨٢% بالمقارنة بالنباتات الغير معاملة. الرش الورقى بحمض الفالفيك يقلل قيمة معامل النقص للمحصول Ky أكثر من الكاولين خلال موسمي الزراعة. وهذا يؤدى الى الحفاظ على الماء الأرضى مما يؤدى إلى تخفيض الماء المضاف للرى بمعدل ٢٥%. بالمقارنة بالنباتات الغير معاملة بحمض الفالفيك، معاملة حمض الفالفيك تحت نقص مائى متوسط(75% ETc) أدت للحصول على ٩٣,٤% من انتاج النباتات الغير معرضة للإجهاد المائى(100%ETc). أثبتت التجربة أيضاً أنه لايوجد فروق معنوية في جودة الثمار(الحموضة وفيتامين سى) بين معاملتى الرش بمضادات النتح.