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Reduction of plant water consumption through anti-transpirants foliar application in tomato plants (*Solanum lycopersicum L*)

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ABSTRACT

Optimizing water use efficiency (WUE) is a crucial goal worldwide. However, water savings must not be made at the expense of yield and/or fruit quality to secure economical sustainability for producers. A field study was undertaken to investigate the impact of different anti-transpirants (ATS) on WUE, water requirements (WR), net carbon assimilation rate (P-net), yield and fruit quality of tomato plants *(Solanum lycopersicum* L.). The aim of this study was to select the most suitable anti-transpirant (AT) that produces a satisfactory yield with less water under field conditions. Three types of ATS were sprayed at first fruit set stage: kaolin (KA) 3% and 5% as a reflective AT, Emulsion of Linus seed Oil tri-ethanolamine (ELO) 1% and 2% as a film forming AT and Fulvic acid (FA) 0.15% and 0.2% as a metabolic AT. The results showed that ATS application increased the relative water content (RWC) especially in the case of FA. However, CO_2 assimilation rate was reduced with the minimum reduction observed under FA application. KA application reduced the canopy temperature (Ct) meanwhile, FA and ELO had no effect. ATS significantly reduced tomato WR where irrigation water reduction ranged between 21% up to 28% of that applied to control plants, with or without significant yield reduction or effects on fruit quality parameters depending on the ATs type and concentration. The results indicated that FA at 0.2% gave the maximum reduction in plant WR (28%) and the minimum reduction of P-net (11.13%) and marketable yield (2.3%), consequently WUE was increased by about 33.45% as compared to the untreated plants. Thus, ATS materials can be used to maintain crop yield and increase WUE in the locations where water resources are limited.

1. Introduction

The global climate is changing with a notable increase in average air temperature (Tomasi et al., 2011). The rainfall pattern has become more variable in recent years as a result of climate changes, with severe and unpredictable drought and flooding (Yang et al., 2011). Under those conditions; a strong negative effect is expected on the agricultural production. Furthermore, water is a critical worldwide resource (World Water Assessment Programme, 2012) and agriculture is the largest user of fresh water (70% globally and 85% in Egypt) (FAO, 2015). Thus, optimizing plant WUE without affecting crop yield and/or fruit quality is vital to the limiting use of water for irrigation and to sustainability (Bodner et al., 2015; Medrano et al., 2015a). Sustainable methods to increase crop WUE are gaining importance in arid and semi-arid regions (Debaeke and Aboudrare, 2004). Traditionally, agricultural research has focused primarily on maximizing total production. In recent years, focus has been shifted to maximizing WUE rather than yield (Savic et al., 2011).

Because of nearly 95–99% of absorbed water from the soil by plant roots is transpired (Taiz and Zeiger, 2002), there is a high potentiality of water saving through reducing transpiration) Boari et al., 2014; Del Amor and Rubio et al., 2009). ATS have been defined as chemical materials capable of reducing the transpiration rate (TR) when applied to the plant canopy (Glenn et al., 2003). The most obvious use of ATS is conserving soil water by reducing plant consumption, thus, reducing irrigation frequency (Abdallah, 2017; Del Amor et al., 2010; Jifon and Syvertsen, 2003). Indeed, ATS applications for this purpose might be justified when water costs are high and if possibly saved water quantities are larger than the application cost (Rosati et al., 2006).

Building on that both transpiration and photosynthesis involve

Abbreviations: ATS, Anti-transpirants; AT, Anti-transpirant; WUE, water use efficiency; WR, water requirements; P-net, net carbon assimilation rate; ELO, Linus Seed Oil tri-ethanolamine; FA, Fulvic acid; KA, kaolin; Ct, canopy temperature; TR, transpiration rate; KY, crop water response factor; PPFD, photosynthetic photon flux density

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gaseous diffusion across the leaf-air interphase, an increase in the resistance across this zone would significantly affect both processes (Glenn et al., 2001). As a result, crop growth may be negatively affected, thus, it is important to investigate the effects of ATS compounds on net photosynthesis (P-net) and plant growth (Pace et al., 2007). There is a going debate about ATS effects on gas exchange (GS), TR and P-net. However, the modes of action are not completely understood (Brillante et al., 2016). Some researches indicated that there is no significant negative nor positive effect on P-net and stomatal conductance (Steiman et al., 2007), while other researches detected a significant P-net reduction (Brillante et al., 2016; Tubajika et al., 2007).

Anti-transpirants can be classified into three different functional categories according to the mode of action; i) Film-forming materials; agrochemicals (emulsions of wax, latex or plastics, polymers) that when applied to the crop canopy, dry on the foliage to form transparent films. The films physically block the stomata and hinder water vapor escape from the leaves to the atmosphere, resulting in canopy transpiration decreases (Faralli et al., 2016). The magnitude of reduction in transpiration due to film forming ATS depends on uniformity, thickness and coverage (Palliotti et al., 2013). ii) Metabolic inhibitors (stomata regulating); compounds that can prevent stomata from opening fully by affecting the guard cells around the stomatal pore, thus, decreasing the loss of water vapor from the leaf (Al-Absi and Archbold, 2016). The degree of stomatal opening often depends on the CO_2 concentration in the guard cells, which reflects carbohydrate metabolism as well as the carbon dioxide in the air within the leaf (Taiz and Zeiger, 2002; Iriti et al., 2009). Metabolic ATS have been found to reduce WR, but most have proven toxic to a variety of herbaceous and woody plants (Anjum et al., 2011). Recent studies indicate that naturally occurring ATS compounds such as abscisic acid, aspirin (acetyl salicylic acid) and FA may be promising commercial metabolic ATS (Du et al. 2013; Ma et al., 2008; Wang et al., 2003; Waterland et al., 2010).

iii) Reflective materials; those are effective in reducing water loss in an indirect way. They reflect solar radiation back from plant surfaces, reducing the energy input to the plant, thereby reducing leaf temperatures resulting in reduced TR (Brillante et al., 2016; Glenn and Puterka, 2005). Most of these compounds such as kaolinite or lime are white materials sprayed on plant surfaces that form a coating with a high reflectivity upon drying. The application of reflective material can be either alone or mixed with other ATS (Glenn et al., 2003).

While ATS of the reflecting type cause a reduction in leaf temperature, the film-forming and stomata-closing types tend to increase leaf temperature by curtailing TR, thus, reducing evaporative cooling (Glenn et al., 2010; Shellie and King, 2013a, 2013b(. KA-based particle film maybe used to mitigate the negative effect of heat stress on plant physiology and productivity (Boari et al., 2014; Brillante et al., 2016). KA employs a multifunctional material that provides effective insect control, mitigates heat stress and contributes to production of high-quality fruit and vegetables. KA films not only reflect photosynthetically active and ultraviolet radiations, but also infrared, thus, lowering temperatures of sprayed organs. This property has been effectively used in horticulture to prevent sunburns of fruits (Cantore et al., 2009). KA is a non-abrasive, non-toxic aluminosilicate ($Al_4Si_4O_{10}$ $(OH)_8$), clay mineral that has been formulated as a wettable powder for application with conventional commercial spray equipment (Glenn et al., 2003).

Although application of ATS was largely studied to improve WUE, their utilization in the field was limited. This could be attributed to costs and efficiency of the practice (Brillante et al., 2016). However, to our knowledge, a comparison among the three main classes of ATS effects on yield, WUE, physiological growth and fruit quality in tomato under field conditions has not been described in a single, comprehensive study. Thus, the main objective of this study was to determine and compare the effects of different locally available, environmental friendly and cheap ATS on WUE, WR, physiological performance and yield and fruit quality of tomato plants grown in sandy soil. Consequently, this study would help to select the most suitable ATS for conserving irrigation water in arid regions. Sub-objectives were to determine which of the locally available ATS offer the maximum reduction in TR with a minimum reduction in photosynthesis, as well as pinpointing the optimum ATS concentrations.

Table 1
The main chemical and physical properties of the soil.

Parameter		Parameter	
ECe[a]	0.75 dS m^{-1}	Particle size distribution	
PH	8.20	Sand	96.12%
Organic matter	0.20 %	Silt	2.22 %
Total CO_3^{-2}	3.30 %	Clay	1.66%
SAR[b]	0.35	**Soil texture**	**sandy**
Bulk density	1.70 g cm^{-3}		
Total porosity	33.12%		
P.W.P	0.09 cm^3 cm^{-3}		
FC	0.14 cm^3 cm^{-3}		
TAW	50.00 mm/m		

[a] Electrical conductivity of saturate soil paste extract.
[b] SAR, sodium adsorption ratio, P.W.P, soil moisture at permanent wilting point; FC, soil moisture at field capacity and saturation; TAW, total available water.

2. Materials and methods

2.1. Experimental site and climate

The experiment was conducted in the 2014 growing season at El-Bostan Farm Experiment Station, Faculty of Agriculture, Damanhour University, El-Beheira Governorate, Egypt. El-Bostan region is located at 30.2° N & 30.5° E at an altitude 7.4 m. The climate is typically arid, characterized by average annual rainfall of 20–50 mm distributed mainly during winter, with air temperature lying between 30 – 38 °C in the summer. The soil of the experimental field represents newly reclaimed lands. The main chemical and physical properties of the soil are presented in (Table 1)

2.2. Plant materials

The study area was divided into 21 plots; each experimental unit consists of two oriented rows with a length of 7 m, 1.3 m apart (18.2 m^2) and with 0.4 m between plants in the row, giving a plant density of 1.925 plants m^{-2}. Tomato (*Solanum lycopersicum L.* the cultivar used was super hybrid), seeds were planted and germinated in polystyrene trays on the 5th of February and seedlings were grown in the greenhouse. Seedlings were transplanted by hand at the third true leaf stage on the 5th of March. Irrigation was provided by a drip system consisting of one lateral line per row, placed 10 cm away from plants with in-line emitters located 0.30 m apart. Each emitter provided a flow rate of 4.2 L h^{-1}. The irrigation water applied was measured with a flow meter installed in the water delivery unit of the irrigation system, which was designed for independent control of water delivery to each irrigation treatment.

2.3. Experimental design

To evaluate the effect of different ATS on above-ground dry biomass, yield, yield components, fruit quality, WR and WUE; a completely randomized experimental design with three replicates was established. Under optimal irrigation conditions (plants received 100% of their water requirements), three types of ATS were foliar with two concentration for each type as follow and as presented in (Table 2).

Spraying with Kaolin (KA), "aluminum silicate" ($Al_4Si_4O_{10}$ $(OH)_8$), as a reflecting material at two concentrations [3% and 5% (W/V)].