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EFFECT OF INTERACTION BETWEEN WATER STRESS AND FOLIAR APPLICATION BY ASCORBIC ACID OR MICRONUTRIENTS ON MAIZE PRODUCTIVITY AND IRRIGATION WATER USE EFFICIENCY

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ABSTRACT: Two field experiments were conducted in a new soil in extension field in El Qantra-West, Ismailia Governorate, Egypt during 2017 and 2018 summer seasons. The study aimed to evaluate the effect of six exogenous application levels of ascorbic acid (AsA) and micronutrients mixture on yellow corn hybrid 352 (three way cross) under three amounts of irrigation water (3750, 3000 and 2250 m³/fad., of the estimated crop evapotranspiration) using surface irrigation system. A randomized complete block split plot design with three replicates was used in each season. The irrigation treatments and the levels of AsA and micronutrients mixture were randomly allocated in the main and sub-plots, respectively. The most important findings could be summarized as follows. Decreasing the amount of irrigation water from 3750 to 2250 m³/fad., significantly diminished ear leaf blade area, relative water content and total chlorophyll at 85 days from sowing. Also, at harvest, ear length, 100-grain weight and grain yield/fad., were decreased, but irrigation water use efficiency (IWUE) was significantly ameliorated. Generally, foliar application by AsA or micronutrients mixture significantly increased these traits with increasing irrigation water use efficiency (IWUE) compared with their untreated analogues. The interaction between both studied factors showed that 350 ppm AsA treatment protected about 500 kg/fad., grains from collapse under moderate and severe water stress. Application of AsA saved approximately 750 m³/fad of irrigation water without yield reduction under stress conditions.

Key words: Maize, AsA, IWUE, micronutrients, water stress, evapotranspiration.

INTRODUCTION

Maize is one of the most important cereal crops and is the third crop after wheat and rice. It plays a critical role in animals and human feeding not only in Egypt but also in almost countries. It is used for feeding animals in the form of grain and green fodder and enters in the manufacture of a very large number of products (FAO STAT, 2020). Drought stress is one of the main abiotic stresses and the major causes of osmotic stress to plants under natural marginal lands (Xiong and Zhu 2002). Water deficit-associated with high temperature or salinity or other stresses are often considered to be a limiting factors in corn plants (*Zea mays* L.) grown under arid and semiarid regions. About, one-third of the world's arable land is suffering from chronically inadequate supplies of water for cultivation

(Massacci *et al.* 2008). Water stress induced oxidative stress in two maize lines, the antioxidants of enzymatic and non-enzymatic significantly increased in these both maize lines (Moharramnejad *et al.*, 2019). In addition, drought stress also induces oxidative stress which can cause plant death and decrease productivity at the whole-plant level. Also, exposure to drought stress can affect all the major plant processes, including photosynthesis, protein synthesis, energy and lipid metabolism (Apel and Hirt 2004).

Under drip irrigation, irrigation SC 10 maize hybrid by 1575 m³/fad instead of 2625 m³/fad., of the estimated crop evapotranspiration significantly reduced ear leaf blade area, total chlorophyll, relative water content, grain yield and irrigation water use efficiency (Kotb *et al.*, 2009). Lawlor

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and Cornic (2002) confirmed that the photosynthetic rates are known to be decrease as the relative water content decrease under water stress conditions. The obtaining of optimum leaf area index is very important for improving photosynthesis and dry matter productions in plants (Farooq *et al.*, 2009). Drought imposed at initiation of silking was more lethal in terms of reduction in different yield and yield components including 1000-grain weight, grain and biological yields (Qasim *et al.*, 2019). A complex antioxidative defense system, composed of both non-enzymatic and enzymatic constituents, is present in all plant cells (Foyer, 1993). Low-molecular weight, non-enzymatic and nutrient-derived antioxidants are presented by carotenoids, tocopherols, glutathione and ascorbic acid (AsA). Apart their obvious role as enzyme substrates, they can react chemically with almost all forms of ROS. AsA is a small, water-soluble antioxidant molecule that acts as a primary substrate in the cyclical pathway for detoxification and neutralization of superoxide radicals and singlet oxygen (Foyer, 1993).

Under normal and water stress conditions, the effects of foliar application of vitamin C (AsA) on many plants were indicated. Dolatabadian *et al.* (2010) found that foliar application of 150 mg l⁻¹ ascorbic acid during growing phases on corn increased grain weight. Also, foliar spray of 200ppm AsA improved leaf area, photosynthetic pigments (chl. a, chl. b and total chl.), 100-grains weight and grain yield and irrigation water use efficiency (Abo-Marzoka *et al.*, 2016; Qasim *et al.*, 2019). Grain yield of wheat was increased by about 0.5 t/ha in AsA-treated plants under normal irrigation. Also, AsA treatments protected about 0.8-0.9 t/ha grains from collapse under water stress. Application of AsA saved approximately 852 m³/h of irrigation water without yield reduction (Kotb and Elhamahmy, 2013). Grzebisz *et al.* (2008) reported that the application of micronutrients is simple and easy method for improvement of plant nutritional condition for wheat and maize plants. So, the growth and yield of maize plants are adversely affected by nutrients stress conductions. The effects of micronutrient application such as B, Zn, Cu, Mn and Fe on 100-grain weight of BARI Hybrid Maize 5 were statistically significant (Rahman

et al. 2017). Under rainfed conditions, results of Wasaya *et al.* (2017) showed that leaf area index was significantly improved by combined application of Zn and B on foliage compared to untreated maize plants. On the other hand, using citrine fertilizers which contains (15% citric acid, 2% Fe, 2% Mn and 2% Zn) as foliar application significantly improved growth and yield of maize plants (Tohidi Moghadam *et al.*, 2013; El-Yazal, 2019). Also, Sajedi *et al.* (2011) found that with increasing the drought stress level, addition of micronutrients of Fe (2.6), Zn (4.1), Cu (1.5), Mn (2.6), B (1.5), Mo (0.5) and Mg (4.1%) can alleviate the unfavorable effects of drought stress on corn plants by affecting plant metabolism. In the same direction, Yarnia *et al.* (2013) noticed that a mixture of all combinations of N, Mg, Zn, Mn, B, at all stages had the highest grain yield of corn compared to untreated plants. Waraich *et al.* (2011) found that the micronutrients like Fe, B, Mn and Mo can enhance and improve the IWUE by alleviating the adverse effects of water stress indirectly by activating several metabolisms in crop plants like physiological, biochemical and metabolic processes.

The objective of this study is evaluate the effect of water stress and foliar application by ascorbic acid and micronutrients mixture in improving growth, yield and irrigation water use efficiency of maize under new soil conditions.

MATERIALS AND METHODS

Two field experiments were conducted in a new soil in the extension field in El Qantra-West, Ismailia Governorate, Egypt (30° 58' N, 32° 23' E, and 10m above mean sea level) during 2017 and 2018 summer seasons. The study aimed to find out the effect of six exogenous application levels of AsA and micronutrients mixture (Fe: 6%, Zn: 5%, Mn: 2%, Co: 0.30%, B: 1.50%, Mo: 0.50%) on yellow corn hybrid 352 (three way cross) under three amounts of irrigation water (1.00, 0.80 and 0.60 of the estimated crop evapotranspiration) using surface irrigation system. A randomized complete block split plot design with three replicates was used in each season. The irrigation treatments and the levels of AsA and micronutrients mixtures were randomly allocated in the main and sub-plots, respectively.

Three amounts of irrigation water were calculated as 1.0 (IR1), 0.8 (IR2) and 0.6 (IR3) of the estimated crop evapotranspiration (ETc). Maize plants were given 9 irrigations at 10 days intervals starting after 25 days from sowing. In the two growing seasons, the amount of water needed for each irrigation was calculated according to the crop coefficient (Kc) and the daily reference potential evapotranspiration (ETo). The latter was determined according to the Penman-Monteith equation (Allen *et al.*, 1998) depending on the predicted climatic factors at each irrigation time and the growth stage of maize plant. As recommended by Allen *et al.* (1996) and Neale *et al.* (1996), the FAO Kc of maize plant were 0.40 for initial stage (20 day), 0.80 for crop development stage (35 day), 1.15 for mid-season stage (40 day) and 0.70 for last-season stage (30 day). At the end of the last irrigation, the quantity of water applied for each of the three irrigation treatments was calculated according to the total amount of water added in the 9 irrigations for the two seasons. The average amounts of water during the two growing seasons were 3750, 3000 and 2250 m³/fad., for the irrigation treatments, respectively.

Six exogenous application levels of ascorbic acid and micronutrients mixture levels (S0: spray with tap water, S1:250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: 100% recommended dose of micronutrients mixture and 150% micronutrients mixture) were foliar applied in 100 liter /fad after 30, 50 and 70 days from sowing. Before beginning of the experiment, soil samples were obtained with an auger from soil depths of 0-60 cm to determine the physical and chemical properties of the experimental field (Table 1). The soil texture at this site was predominantly loamy throughout its profile (49.3% sand, 37.2% silt and 13.5% clay). The Soil physical and chemical properties of the experimental field over the two seasons were determined following the method of Cassel and Nielsen (1986) and Grossmann and Reinsch (2002). The climate in this region is almost arid. The temperature averages approximately 28.0°C in summer; and the relative humidity averages approximately 58.0%. The predicted monthly climatic data at Ismailia region during the growing seasons of maize are presented in Table 2.

The sowing date was 15 May in both seasons in hills 20 cm apart. The sub-plot area was 12 m² included 5 ridges of 4 m long and 60 cm apart. The preceding crop was Egyptian clover in the two growing seasons. To ensure full germination and complete establishment of seedlings, the normal irrigation was applied to the all field area at planting up to starting the irrigation water treatments. Twenty days after sowing, maize plants were thinned to one plant/hill. The agronomic practices were done as recommended in this region.

At 85 days from sowing, five plants were randomly taken from the 2nd ridge for estimating the vegetative growth characters as follows:

- 1- Ear leaf blade area (cm²).
- 2- Relative water content (%), was determined according to Schonfeld *et al.* (1988).

$$RWC = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Turgid weight} - \text{dry weight}} \times 100$$

- 3- Total chlorophyll (SPAD value), was determined using the Minolta SPAD-502 chlorophyllmeter according to Markwell *et al.* (1995).

At maturity, yield measurements were estimated from plants of the two middle ridges (the 3rd and 4th ridges) in each sub plot.

- 1- Hundred grain weight (g)
- 2- Grain yield (kg/fad), it was adjusted to 15.5% moisture content.
- 3- Irrigation water use efficiency (IWUE) in kg m⁻³.

It was calculated as IWUE= GY /IR x 100, where GY is grain yield (kg/fad) and IR is the amount of applied irrigation water (m³/fad) for each irrigation treatment.

Statistical Analysis

All data were analyzed using the COSTAT software, version 6.311 (CoHort software, Berkeley, CA 94701). The analysis of variance of a randomized complete block split plot design was used. The least significant difference (LSD at P ≥0.05) was used to compare the differences among interactions means, according to Steel *et al.* (1997). Graphical presentation of data was carried out using Microsoft Excel program (Microsoft Corporation, Los Angeles, CA, USA).

Table 1. Soil physical and chemical properties of the experimental field soil over the two seasons

Soil depth (cm)	EC (dS m ⁻¹)	pH	Sand (%)	Silt (%)	Clay (%)	Texture		
0-60cm	3.96	7.77	49.3	37.2	13.5	Loamy		
Soil depth (cm)	Cations (meq/l)				Anions (meq/l)			
	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
0-60cm	3.5	4.0	23.1	8.6	-	4.4	27.0	7.8

Table 2. The predicted monthly climatic data at Ismailia Governorate during the growing periods of corn as average from 2015 to 2019 seasons

Months	Average temperature °C			Average Relative humidity (RH %)	Average Wind speed (Km/h)
	Minimum	Maximum	Average		
May	14	36	25.0	47.5	15.5
June	17	39	28.0	53.0	13.5
July	19	39	29.0	60.5	14.0
August	21	38	29.5	63.5	12.5
September	19	36	27.5	64.5	11.5

Data collected from Egyptian Meteorological Authority.

RESULTS AND DISCUSSION

The results and discussion were focus on the interaction effect of irrigation treatments and spraying treatments with AsA or micronutrients mixture on measured traits as following:

Plant Growth

Ear leaf blade area (cm²)

The results in Figs. 1 and 2 indicated that the interaction effects between the two studied factors were significant on ear leaf blade area in both seasons at 85 days from sowing. It is clear from these results that foliar application of AsA and micronutrients mixture alleviated the adverse effect of water stress on ear leaf blade area in both seasons at 85 days from sowing. The obtaining of optimum leaf area index is very important for improving photosynthesis and dry matter productions in plants (Farooq *et al.*, 2009). The maximum values of ear leaf blade area were significantly obtained from the interactions between normal condition with 350 or 450 ppm AsA or recommended dose of micronutrients or from the interaction between moderate stresses with 350 ppm AsA without significant differences among them in first season. Meanwhile, in the second season, the

highest values of this trait were significantly obtained from the interaction between normal conditions with 350 ppm AsA at 85 days from sowing. Kotb (2014) studied the effect of foliar application of non-enzymatic antioxidants (ascorbic acid; AsA) on peanut yield and its quality for sprinkler-irrigated peanut. Drought caused significant reduction in leaf area index. Meanwhile, exogenous application of AsA by a suitable level (100 ppm) significantly increased leaf area index. On the same direction, Kotb and Elhamahmy (2013) studied the effect of AsA (0.0, 100 and 200 ppm) on the response of wheat to three surface irrigation rates which represented 4260, 3408 and 2556 m³/ha, respectively. The results stated that, water stress caused a decreasing in leaf area index. Meanwhile, spraying with AsA significantly improved this trait. Under rainfed conditions, results of Wasaya *et al.* (2017) showed that leaf area index was significantly improved by combined application of Zn and B on foliage compared to untreated maize plants. It has been established that under severe drought stress may result in the cessation of photosynthesis, metabolism disturbance consequence finally plant organs death (Smirnov, 1993; Jaleel *et al.*, 2008).

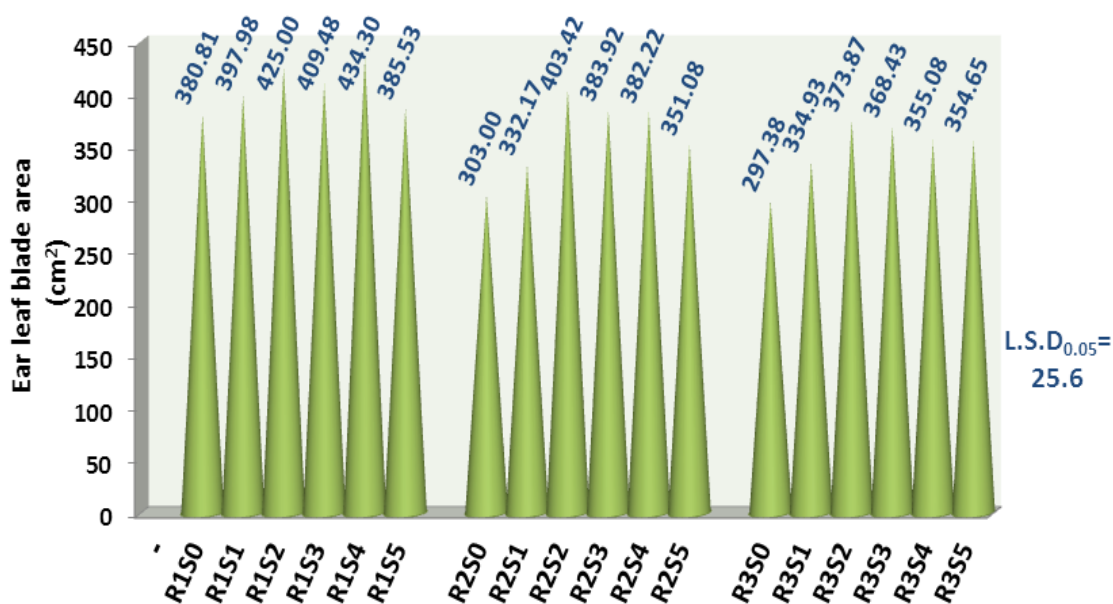


Figure 1. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Ear leaf blade area (cm²) of maize at 85 days from planting in 2017 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

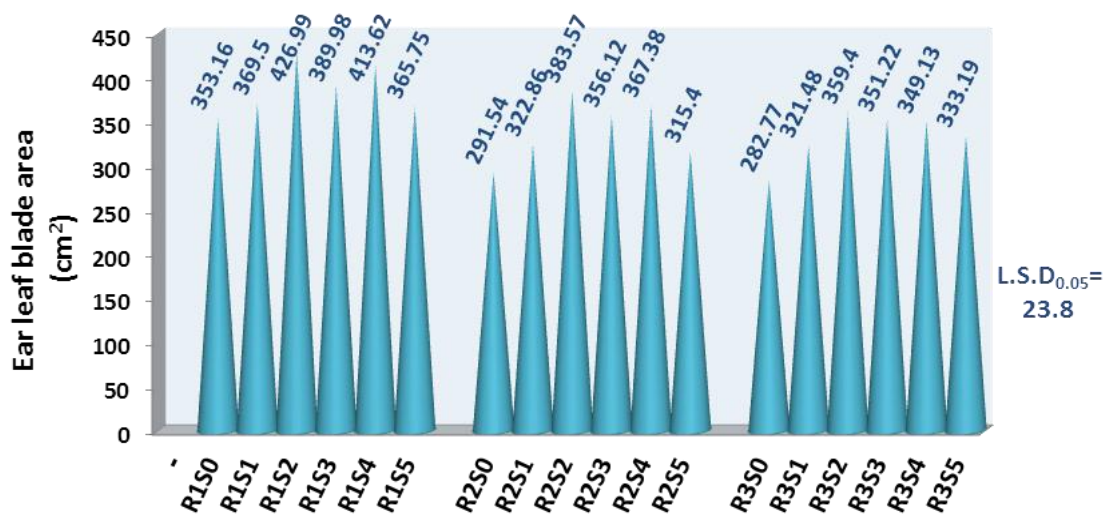


Figure 2. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Ear leaf blade area (cm²) of maize at 85 days from planting in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

Relative water content (%)

Relative water content (RWC) was determined to give an indicator of the plant water status. Relative water content (RWC) was significantly affected by irrigation rate and by spraying with AsA and micronutrients mixture. Our results in the same Figs. 3 and 4 indicated that the interactions between the two studied factors significantly affected on the averages of leaves RWC at 85 days from planting in both seasons. In comparison with all other treatments under any conditions (1.0, 0.8 and 0.6 Etc) of the study, the highest values of RWC were significantly ameliorated by the interaction between 350 ppm AsA and 1.0 Etc (100% of the estimated crop evapotranspiration) and the interaction between 100% recommended dose of micronutrients and 1.0 Etc without significant differences between them in the two seasons (Figs. 3 and 4). In general, it was found that the concentration of 350 ppm led to a significant improvement in the values of relative water content compared to untreated plants under same conditions (0.8 and 0.6 Etc). As average of two seasons and under moderate water stress, the values of this trait were increased by approximately 30%. Meanwhile, under severe water stress; these values were ameliorated by about 24% (Figs. 18 and 19). Water stress causes directly or indirectly reduction in the contents of relative water content of corn plants (Shlemmer *et al.*, 2005; Premachandra *et al.*, 2008; Kotb *et al.*, 2009). Kotb (2014) found that drought caused significant reduction in each of relative water content. Meanwhile, exogenous application of AsA by a suitable level enhanced this trait. Furthermore, El-Yazal (2019) recommend that using citrine fertilizers which contains (15% citric acid, 2% Fe, 2% Mn and 2% Zn) as foliar application for improving growth and chemical constituents of maize plants. Also, Sajedi *et al* (2011) found that with increasing the drought stress level, addition of micronutrients of Fe (2.6), Zn (4.1), Cu (1.5), Mn (2.6), B (1.5), Mo (0.5) and Mg (4.1%) can alleviate the unfavorable effects of drought stress on corn plants by affecting plant metabolism.

Total chlorophyll (SPAD value)

The results obtained from Figs. 5 and 6 revealed that the interactions between the

irrigation rates and foliar spraying with ascorbic acid or micronutrients mixture significantly affected on total chlorophyll at 85 days from planting in both seasons. The highest contents of total CHL were significantly obtained by the interaction between 350 ppm AsA and well watered (1.0 Etc) in comparison with all other treatments under any conditions (1.0, 0.8 and 0.6 Etc) of the study at 85 days from planting in both seasons. Generally, our results indicated that 350 ppm AsA and recommended dose of micronutrients mixture led to a significant increment in the values of total chlorophyll compared to untreated plants under same conditions (0.8 and 0.6 Etc). Under moderate water stress, the values of this trait were ameliorated by about 23 and 14% in first season and by about 19 and 14% in second season, respectively. Meanwhile, under severe water stress; these values were ameliorated by about 22 and 17% in first season and by about 25 and 20% in second season, respectively, (Figs. 5 and 6). Also, Reddy and Rao, 1968 noticed that severe water stress conditions decreased the contents of chlorophyll *a*, *b*, and total chlorophylls and produced changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Anjum *et al.*, 2003; Farooq *et al.*, 2009). These results are in harmony with those reported by Farahat *et al.* (2007), Kotb and Elhamahmy (2013) and Kotb (2014). They found that drought caused significant reduction in this trait; meanwhile, exogenous application of AsA by a suitable level significantly ameliorated this trait. On the other hand, using citrine fertilizers which contains (15% citric acid, 2% Fe, 2% Mn and 2% Zn) as foliar application significantly improved growth and yield of maize plants (Tohidi Moghadam *et al.*, 2013; El-Yazal, 2019).

At Harvest

Hundred grain weight (g)

The significant interactions effects between the studied factors on 100-grain weight (g) are presented in the second season (Fig. 7). These results revealed that using intermediate level of ascorbic acid (350 ppm) with full irrigation significantly gave the highest 100-grain weight (26.41 g) compared with the other interactions under all conditions. Meanwhile, untreated plants or treated with high level of micronutrients under well watered plants gave (19.59 and 19.87 g).

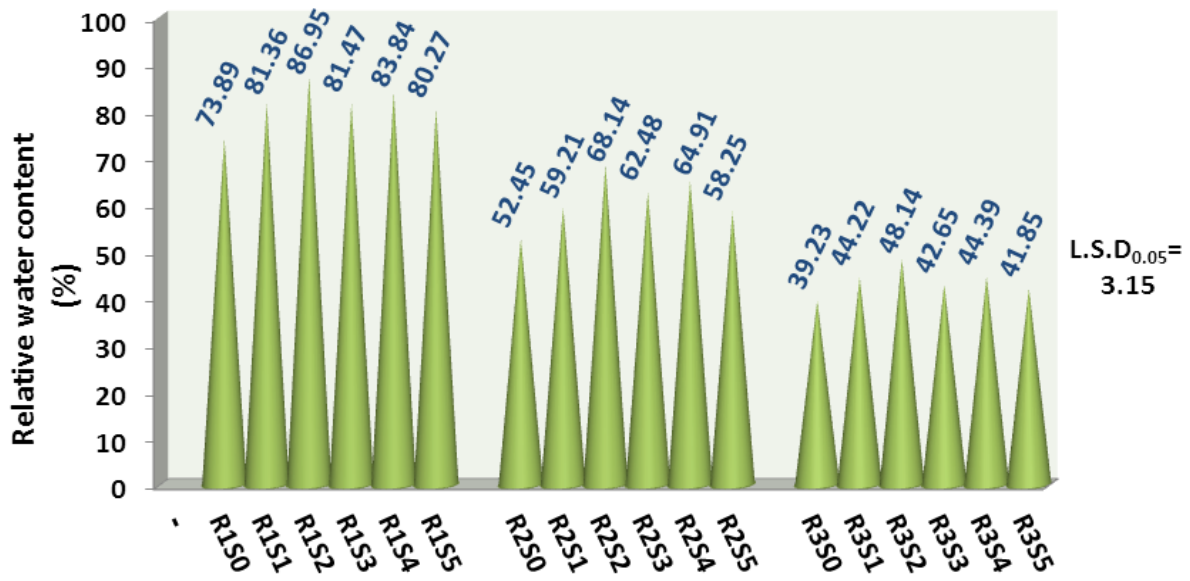


Figure 3. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Relative water content (%) of maize at 85 days from planting in 2017 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

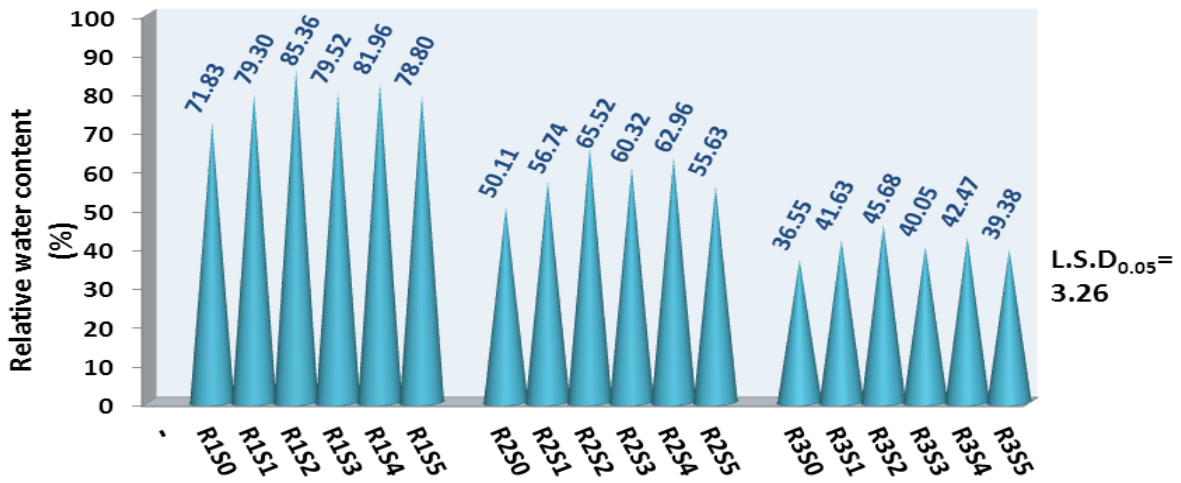


Figure 4. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Relative water content (%) of maize at 85 days from planting in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

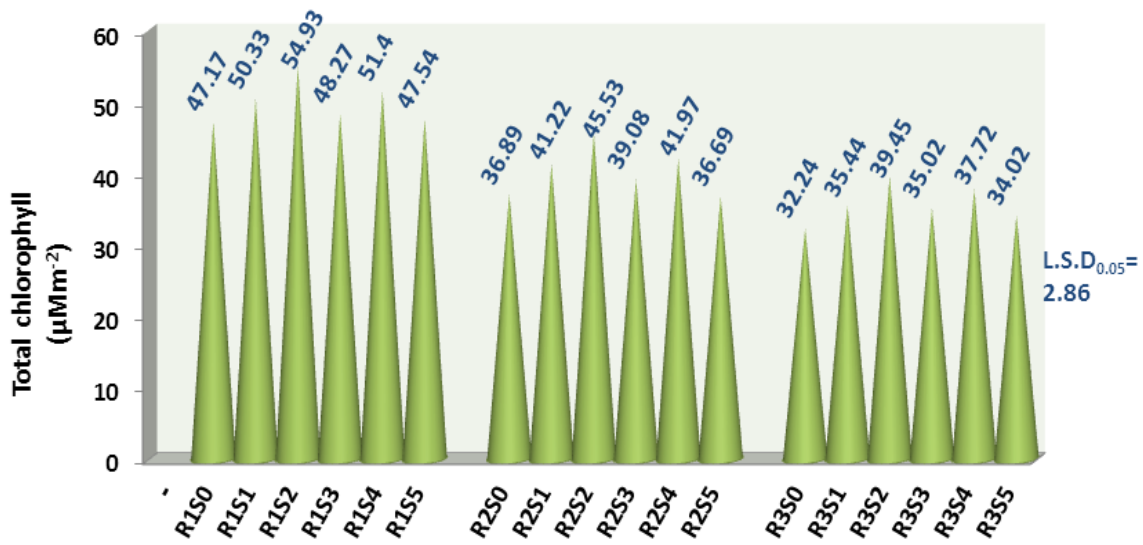


Figure 5. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Total chlorophyll (μMm^{-2}) of maize at 85 days from planting in 2017 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

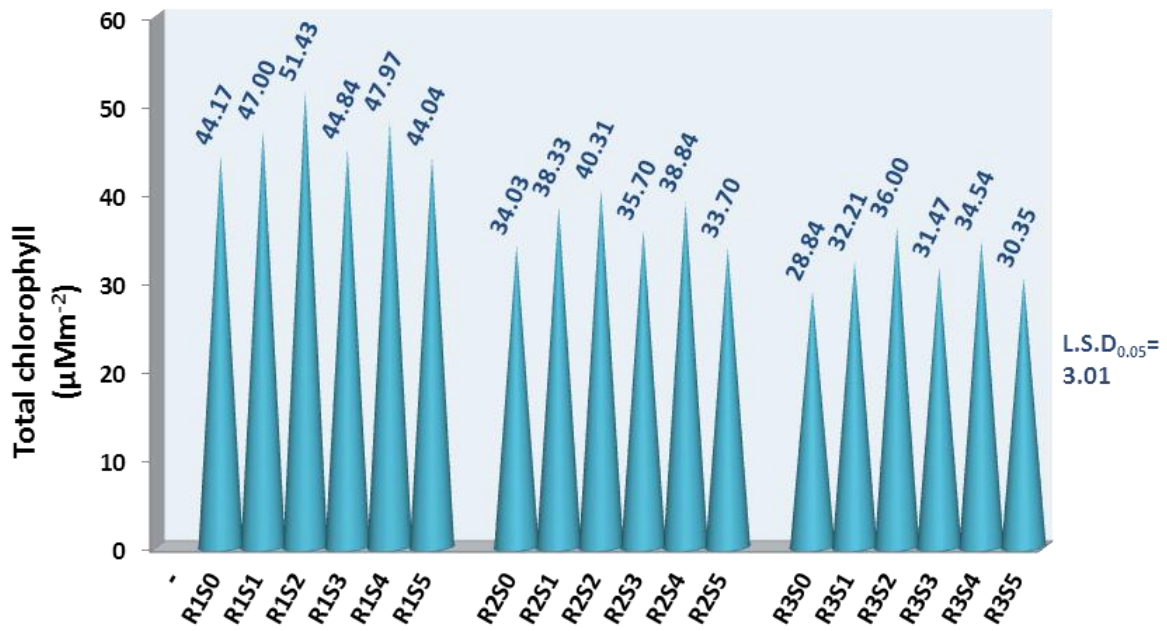


Figure 6. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Total chlorophyll (μMm^{-2}) of maize at 85 days from planting in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m³/fad); R2: 0.8 R1, R3: 0.6 of R1.

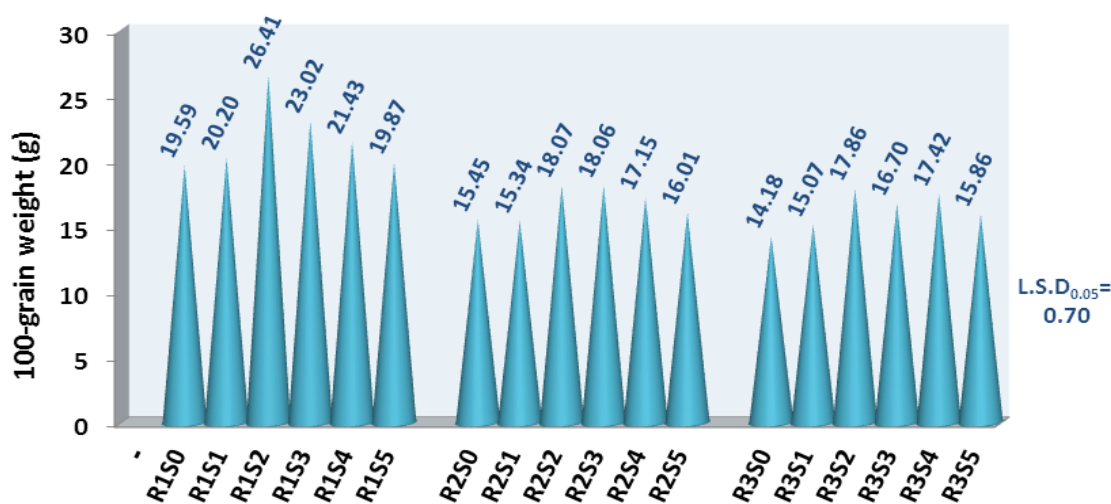


Figure 7. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on 100-grain weight (g) of maize at harvest in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
R1: well-watered (3750 m²/fad); R2: 0.8 R1, R3: 0.6 of R1

In addition, the lowest 100-grain weight (14.18 g) was significantly obtained from the interaction between untreated plants and severe water stress in comparison with 17.86 and 17.42 g which obtained from the intermediate level of ascorbic acid (350 ppm) and recommended dose of micronutrients mixture, respectively (Fig. 7). It has been reported that maize is relatively tolerant to water stress in the vegetative stage, very sensitive during the period of tasseling, silking, and pollination, and moderately sensitive during the grain-filling stage as reported by several searchers such as **Shanahan and Nielsen (1987)**. Also, **Muhammad et al. (2001)** observed that increasing water stress significantly decreased 100-grain weight of maize. Under severe water stress conditions, it could be concluded that both of foliar spray by AsA and micronutrients mixture had the same effects on 100-grain weight and significantly ameliorated 100-grain weight by about 26 and 23% compared to untreated plants (spray with water), respectively. Meanwhile, under moderate water stress conditions (Irrigation by 0.8 ETc), using 350 ppm AsA significantly ameliorated 100-grain weight by about 17% compared to untreated plants in the second season (Fig. 7). It could be concluded that under stressed and unstressed plants both of foliar spray of AsA and micronutrients mixture significantly ameliorated 100-grain weight

compared to untreated plants. These results are in a good relation with those obtained by **Kotb and Elhamahmy, (2013)** **Abo-Marzoka et al., (2016)**, **Ramanjineyulu et al., (2018)**, **Qasim et al., (2019)** and **El-Yazal (2019)**.

Grain yield (kg/fad.)

Relative to the interaction between irrigation treatments and foliar spray treatments, results of both seasons showed that both of them interacted with each other significantly for grain yield/fad., (Figs. 8 and 9). Under full irrigation, the intermediate concentration of AsA and recommended dose of micronutrients significantly gave higher grain yields (4839.95 and 4687.45 Kg/fad.) compared to (4022.18 Kg/fad) which were obtained from untreated plants in 2017 season. The relative increase percentages in grain yield due to using 350 ppm AsA and recommended dose of micronutrients were about 20% and 17% compared with untreated plants, respectively.

Also, under severe water stress (irrigation by 60% Etc); the intermediate concentration of AsA significantly produced 3766.63 Kg grain/fad., compared to 3220.81 Kg/fad., which was obtained from untreated plants in 2017 season. The relative increase percentages in grain yield due to using this level of AsA was about 17% compared with untreated plants. Meanwhile, under

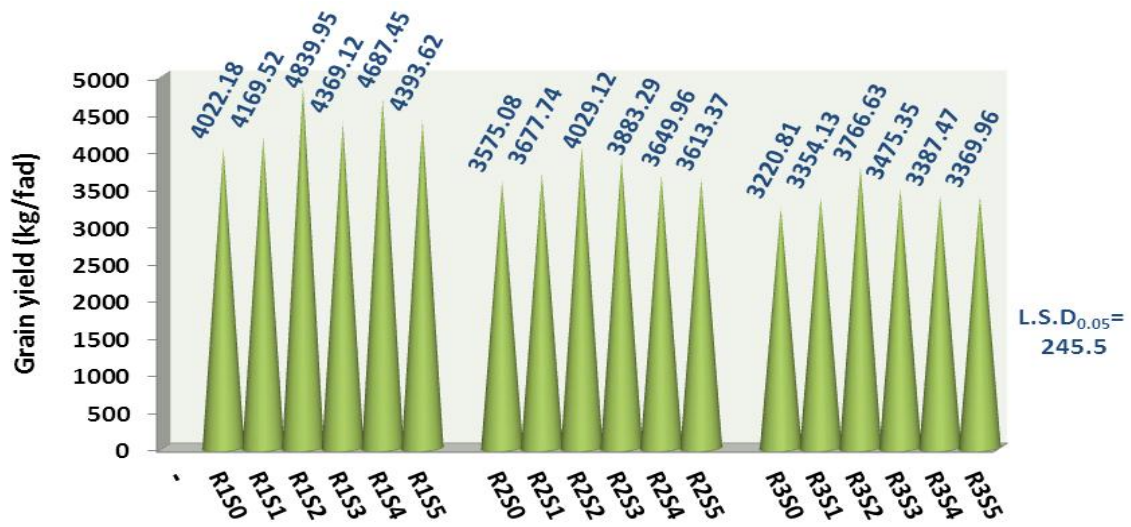


Figure 8. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Grain yield (kg/fad) of maize at harvest in 2017 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m²/fad); R2: 0.8 R1, R3: 0.6 of R1

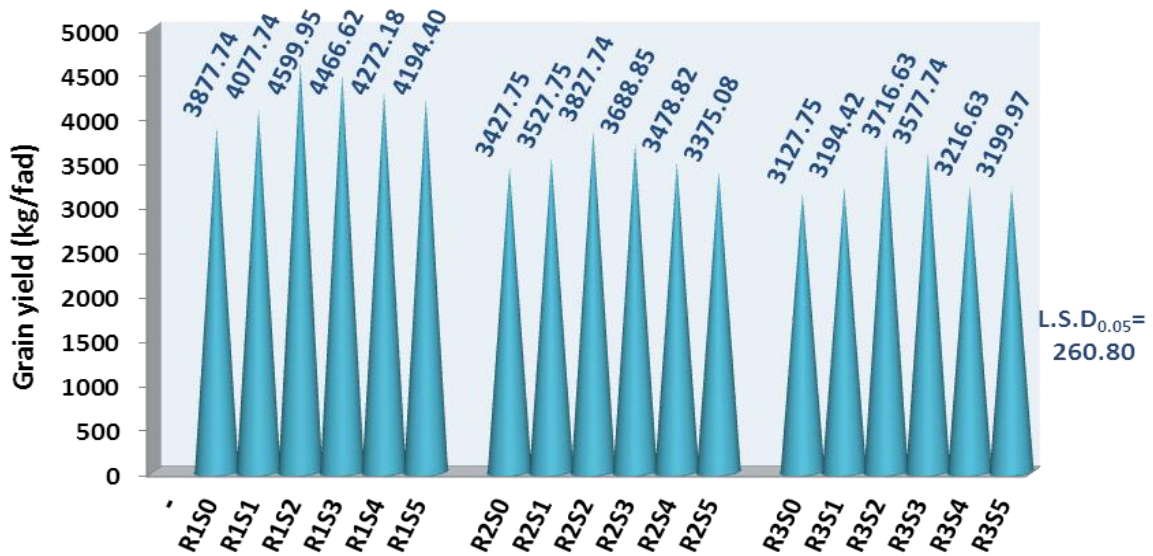


Figure 9. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Grain yield (kg/fad) of maize at harvest in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m²/fad); R2: 0.8 R1, R3: 0.6 of R1

moderate water stress, the intermediate and high concentrations of AsA significantly recorded 4029.12 and 3883.29 Kg grain/fad., in comparison with 3575.08 Kg grain/fad., which was obtained from untreated plants in 2017 season (Fig. 8). The relative increase percentages in grain yields due to using these levels of AsA and micronutrients were about 13% and 9% compared with untreated plants, respectively.

On the other hand, the results of the Fig. 9 explained that, under well-watered plants (3750 m³/fad.), the intermediate and high levels of AsA significantly gave the highest grain yields (4599.95 and 4466.62 Kg/fad.) compared to (3877.74 Kg/fad.) which was obtained from untreated plants in the second year. The relative increase percentages in grain yields due to using these levels of AsA were about 19% and 15% compared with untreated plants, respectively, (Fig. 9). Also, under moderate and severe water stress (irrigation by 80% and 60% Etc., respectively); the two same levels of AsA significantly produced (3827.74 and 3688.85 Kg grain/fad.) and (3716.63 and 3577.74 Kg grain/fad.) compared to 3427.75 and 3127.75 Kg/fad. which was obtained from untreated plants, respectively, in 2018 season. Under moderate and severe water stress conditions, the relative increase percentages in grain yields due to using the levels of 350ppm AsA were about 12% and 19% compared with untreated plants, respectively, (Fig. 9).

It could be concluded that under stressed and unstressed plants both of foliar spray of AsA and micronutrients mixture significantly ameliorated grain yields, however, the effect of foliar spraying with ascorbic acid on corn production was greater than micronutrients mixture. In the same direction, under water deficit conditions, growth, relative water content (RWC) and total chlorophyll as well as grain yield significantly decreased in maize plants compared to those traits under control conditions (Kotb *et al.*, (2009; Qasim *et al.*, 2019; Moharramnejad *et al.*, 2019). The positive effect of AsA and micronutrients on increasing grain yield might be due to their important roles in enhancing enzymes activity and photosynthetic pigment content in turn of enhancing plant metabolism which reflect favorably on yield attributes such as length, diameter and weight of ears as well as 100 grain weight and finally

increased grain yield/fad of corn plants. These results are in a good connection with those obtained by (Abd El-Aziz *et al.*, (2007) and Zhang *et al.*, 2019), they noticed that, foliar application of vitamin C significantly ameliorated the growth and productivity in many plants under normal conditions. In general, the results of Dolatabadian *et al.* (2010) reported that ascorbic acid improved the negative effects of water stress and increased growth and productivity at normal and stressed conditions. Also, under water deficit, foliar application of several concentrations of ascorbic acid on corn plants alleviated the adverse effect of water stress and significantly improved the growth, yield and yield attributes of maize plants (Abo-Marzoka *et al.*, (2016) and (Qasim *et al.*, 2019). It has been reported that foliar application of micronutrients is an easy and simple method for improvement of plant nutritional condition for maize Grzebisz *et al.* (2008). Hussain *et al.* (2011) found that Zn, Fe and Mn significantly enhanced grains/ear and grain weight of corn. In the same direction, Yarnia *et al.* (2013) noticed that a mixture of all combinations of N, Mg, Zn, Mn, B, at all stages had the highest grain yield of corn compared to untreated plants. Also, weight of 100 grain as well as grains (ardab/fad) were positively affected by foliar spraying with the mixture of triple micronutrients of Fe, Mn and Zn compared to untreated plants of maize plant (*Zea mays* L. cv single hybrid 10) (Siam *et al.* 2013).

Irrigation water use efficiency (kg m⁻³)

Concerning to the interaction between irrigation treatments and foliar spray treatments, results of both seasons showed that both of them interacted with each other significantly with irrigation water use efficiency (Figs. 10 and 11). Without a doubt, under moderate and severe water stress conditions, exogenous application of 350 ppm AsA gave significant values from IWUE in both seasons followed by micronutrients mixture with significant differences among them in comparison with untreated plants under the same conditions. Also, the highest significant values from IWUE in both years were obtained from 350 ppm AsA under severe water stress conditions and the opposite; the lowest significant values from IWUE in both years were obtained from untreated plants under well watered (Figs. 10 and 11). On the other hand, under well watered plants, the data recorded in Fig. 10 revealed that

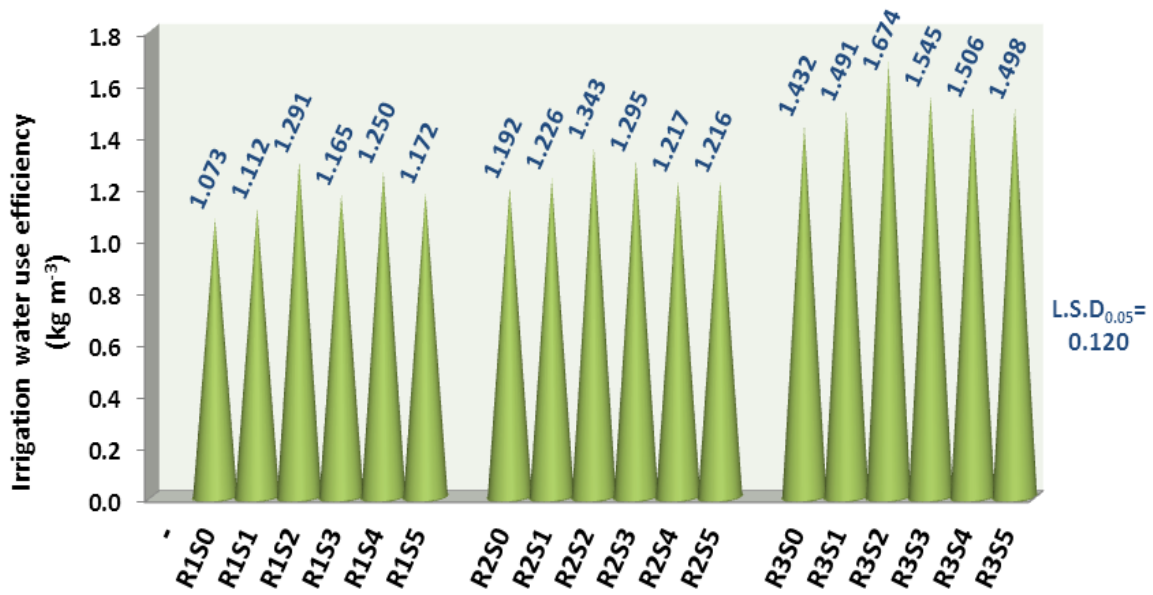


Figure 10. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Irrigation water use efficiency (kg m⁻³) of maize at harvest in 2017 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m²/fad); R2: 0.8 R1, R3: 0.6 of R1

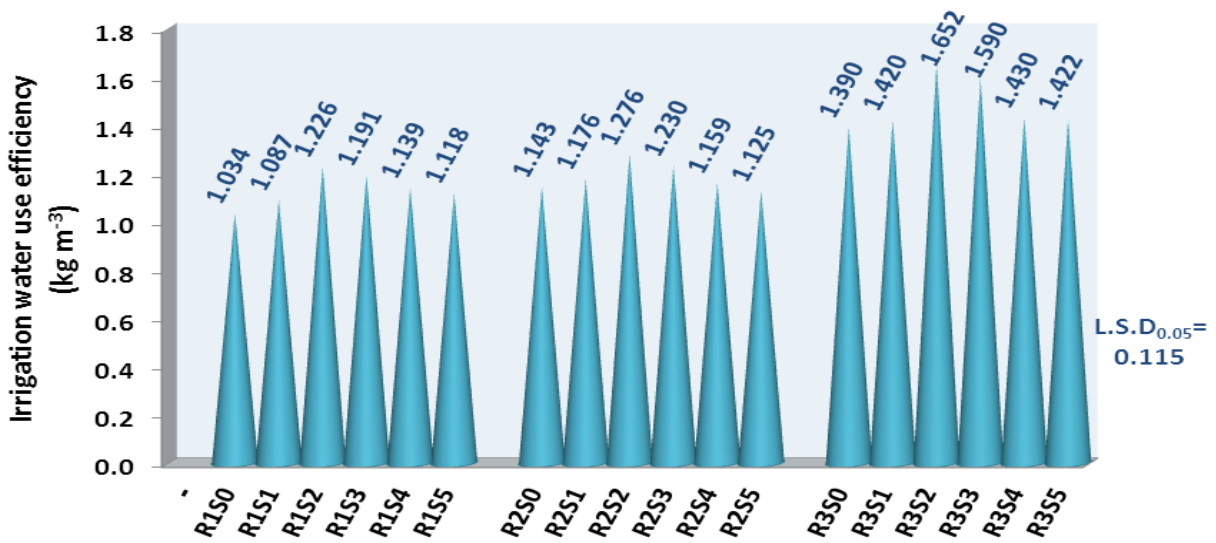


Figure 11. Effect of the interaction between water stress (R) and foliar spray (S) by AsA and micronutrients on Irrigation water use efficiency (kg m⁻³) of maize at harvest in 2018 season.

S0: untreated plants, S1: spray with 250 ppm AsA, S2: 350 ppm AsA, S3: 450 ppm AsA, S4: spray with 100% micronutrient recommended dose and S5: 150% micronutrient.
 R1: well-watered (3750 m²/fad); R2: 0.8 R1, R3: 0.6 of R1

using 350 ppm AsA or recommended dose of micronutrients mixture gave the highest significant values from IWUE without significant differences between them relative to untreated plants. It could be concluded that IWUE responded to AsA and micronutrients under stress condition as well as full irrigation. These results are a good connection with those obtained by **Bakry et al. (2013)**. They reported that under water stress conditions (80% Etc), increasing exogenous application of ascorbic acid up to (300 mg/L) significantly increased grain yield and irrigation water use efficiency. Their results indicated also that the interaction between the water stress of (80% Etc) and (300 mg/L) ascorbic acid significantly produced the maximum values of grain yield and water use efficiency and outyielded the other all interactions. Under newly reclaimed sandy soil, they can save about 20 % of irrigation water by foliar application of ascorbic acid up to (300 mg/L). The positive effects of AsA on plants were in conformity with those recorded by **Kotb and Elhamahmy (2013) and Kotb (2014)**. **Waraich et al. (2011)** found that the micronutrients like Fe, B, Mn and Mo can enhance and improve the IWUE by alleviating the adverse effects of water stress indirectly by activating several metabolisms in crop plants like physiological, biochemical and metabolic processes. Also, they concluded that using some nutrients such as N, K, Mg, B, Zn and Si decrease the toxicity of reactive oxygen species produced under water-stress conditions by enhancing the activities of several antioxidants like superoxide dismutase, peroxidase and catalase in the cells of plant. These antioxidant enzymes have the ability to reduce photo-oxidative stress, scavenge ROS, maintain the integrity of chloroplast membrane and finally, increase the photosynthetic rate in the crop plants which in turn enhances the IWUE and plant production (**Waraich et al., 2011**).

Conclusively, from these results, it could be concluded that the interactions between drought stress and AsA or micronutrients were significant, indicating that these non-enzymatic antioxidants and micronutrients by a proper level have the ability to play important roles for minimizing the adverse effect of water stress and hence improved growth, water use efficiency and grain yield under new soil conditions.

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تأثير تداخل الفعل بين الإجهاد المائي والرش الورقي بحمض الأسكوربيك اوالعناصر الصغرى على إنتاجية الذرة الشامية وكفاءة استخدام مياه الري

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أجريت تجربتان حقليتان تحت ظروف الاراضى الجديدة في منطقة القنطرة غرب، محافظة الإسماعيلية ، مصر خلال فصلى الصيف 2017 و 2018. وتهدف الدراسة إلى دراسة تأثير ستة مستويات من الرش الورقي لحامض الاسكوربيك ومخلوط العناصر الصغرى على الذرة الصفراء هجين ثلاثي 352 تحت ثلاثة مستويات من الاجهاد المائي (3750 و 3000 و 2250م³/فدان من قيمة البخرنتج المقدر لمحصول الذرة الشامية) مستخدما نظام الري السطحي، تم استخدام تصميم القطاعات الكاملة العشوائية للقطع المنشقة مرة واحدة في ثلاث مكررات لكل موسم. تم توزيع معاملات الري ومعاملات الرش بشكل عشوائي في القطع الرئيسية والفرعية ، على التوالي و يمكن تلخيص أهم النتائج على النحو التالي: أدى نقص كمية ماء الري من 3750 إلى 2250 م³/فدان، الى حدوث نقص معنوى فى مساحة نصل ورقة الكوز والكوروفيل الكلي والمحتوى المائي النسبي عند عمر 85 يوم من الزراعة ، بينما عند الحصاد نقص ايضا ووزن 100 حبة، ومحصول الحبوب/فدان مع زيادة كفاءة استخدام مياه الري. بصفة عامة، أدى الرش الورقي بحمض الاسكوربيك او مخلوط العناصر الصغرى الى زيادة معنوية لتلك الصفات مع زيادة كفاءة استخدام مياه الري مقارنة مع نظائرها غير المعاملة. أظهر التفاعل بين كل من عوامل الدراسة أن معاملة 350 جزء في المليون من حمض الاسكوربيك تحت ظروف الاجهاد المائي المعتدل والشديد وفرت حوالي 500 كجم حبوب/فدان من الفقد. وان الرش الورقي بحمض الاسكوربيك قد وفر ما يقرب من 750م³/فدان من مياه الري من الضياع دون نقص فى الانتاج تحت ظروف الجفاف.

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