Growth, Yield, Fruit Quality and Water Use Efficiency of Tomato under Arbuscular Mycorrhizal Inoculation and Irrigation Level Treatments

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Abstract: A greenhouse experiment was performed through 2010/2011 and 2011/2012 seasons to compare the response of tomato plants to arbuscular mycorrhizal fungi (AMF) under different irrigation water levels. Plants was inoculated with a fungus *Glomus deserticola* and subjected to four irrigation levels; IL1 (40%), IL2 (60 %), IL3 (80%) and IL4 (100%, a control treatment) based on crop evapotranspiration (ETc). Plant growth traits, fruit traits, total fruit yield and fruit quality (vitamin C, titratable acidity, total soluble solids and total sugars), as well water use efficiency were evaluated. Plant height, root length, fresh and dry weights of tomato plant parts and leaf area decreased significantly with increasing lower level of irrigation. Plant growth, fruit traits and total fruit yield were superior when water application was in the range of 80-100% ETc. In contrast, fruit quality and water use efficiency tended to increase with a decreased irrigation water level, with the highest values were recorded under water stress (40% ETc). It can be concluded that the +AMF plants with 80% ETc of water requirement were favorable for greenhouse tomato production. This treatment resulted in around 20% saving of water requirements and led to 5.28-6.89% yield increase as compared with the control treatment.

[Wahb-Allah M, Abdel-Razzak H, Alsadon A, Ibrahim A. **Growth, Yield, Fruit Quality and Water Use Efficiency of Tomato under Arbuscular Mycorrhizal Inoculation and Irrigation Level Treatments.** *Life Sci J* 2014;11(2):109-117]. (ISSN:1097-8135). http://www.lifesciencesite.com. 16

Keywords: Tomato; mycorrhizal fungi; water stress; fruit traits; yield reduction

1. Introduction

Tomato (*Solanum lycopersicum* Mill.) is among the highly cultivated vegetable crops with the highest consumption rate and high economic value worldwide. It is valuable from the side of nutritional importance, due to its high content of antioxidants including carotenoids, lycobene, vitamin C and phenolic compounds, which offer a lot of health benefits for the consumers. It also plays a key role in the human diet (Helyes et al. 2006 and Wang et al. 2011).

Irrigationis considered the critical factor that contributes most to the vegetable productivity and quality. Efficient use of irrigation water is becoming more essential in the arid and semi-arid regions because of the limited water resources (Kirnak and Kaya 2004).

Tomato is regarded as a sensitive crop to water stress, revealing the high correlation between evapotranspiration (ET) and crop production, since ET is a direct measure of crop water loss (Nuruddin et al. 2003). The supply of the required water to the tomato plants is crucial for its growth and economic production, especially in the greenhouse (Aziz et al. 2013). High yield of quality tomato fruits can be obtained under the conditions of optimal soil moisture. However, shortage of irrigation water results in decreased fruit yield and quality (Aksic et al. 2011).

Arbuscular mycorrhizal fungi (AMF) are obligatory symbiotic soil fungi that predominate in the soils of agricultural crops, and usually colonize roots of a wide range of plant species (Manila and Nelson 2013). In general, vegetable roots inoculated with AMF are more efficient in nutrient and water attainment, thus causing an improved plant growth, compared with non-inoculated plant roots (Oseni et al. 2010). For the impact of AMF on growth, production and water use efficiency of some vegetable crops, Kaya et al. (2003), Oseni et al. (2010), Guru et al. (2011) and Bolandnazar and Hakiminia (2013) reported that symbiosis of watermelon, tomato and onion plants with AMF promote plants growth, enhance fruits and bulbs yield, respectively as well as improve water use efficiency under well watered and water stress conditions.

This study was carried out to assess the influence of mycorrhizal inoculation treatments in combination with four irrigation water levels on plant growth, fruit traits, yield, fruit quality and water use efficiency of tomato under greenhouse conditions.

2. Materials and methods

Greenhouse soil conditions

Two greenhouse experimental trials were executed during two seasons of 2010/2011 and 2011/2012 at the Agricultural Research and Experimental Station, Faculty of Food and Agriculture

Sciences, King Saud University at Dirab region near Riyadh, Saudi Arabia (24° 39 N, 46° 44 E). As determined by standard analysis methods of page et al. (1982), the soil of experimental plots was sand (90.2 sand, 2.0 silt and 7.8 clay) with pH 7.9, EC 2.18 dS m^{-1}, organic matter content 28.1%, available N 129.8 mg kg, total N 17.5%, available P 165.7 mg kg and available K 345.8 mg kg, as average of the two seasons.

Plant material and mycorrhizal fungus (AMF) source

Seeds of tomato (*Solanum lycopersicum* Mill) cultivar 'Faridah' (Golden Valley Seed Company, USA) were used. Tomato plants were grown from the middle of September until the middle of March in 2010/2011 and 2011/2012 growing seasons, respectively under controlled conditions in a fiberglass greenhouse (day/night temperature 26/18°C and relative humidity of 70%).

Arbuscular mycorrhizal fungus (AMF) species *Glomus deserticola* supplied from the stock mycorrhizal cultures of the Experimental Station of Plant Production Department, Faculty of Food and Agriculture Sciences, College of King Saud was tested. The AMF inoculum was a root-and-soil inoculum consisting of rhizosphere soil holding spores, hyphae and colonized root fragments of Sudan grass plants (*Sorghum halepense* L.), that had been inoculated with the fungus three months earlier. The AM fungal inoculums were placed 5 cm below the soil for seedlings after two weeks from transplanting.

Irrigation level treatments

Tomato seedlings received normal drip irrigation system without considering irrigation treatments for 10 days to encourage root system formation. Following that, irrigation was managed based on evapotraspiration (ETc). Four irrigation level treatments were applied as follows: IL1 (40% ETc), IL2 (60 % ETc), IL3 (80% ETc) and IL4 (100% ETc, as a control treatment, which is a full water requirement). The irrigation scheduling scheme was based on pan evaporation (Harmanto et al. 2005). The total period of the irrigation level treatments was 180 days, and the applied amounts of irrigation water were: 1440 for 40%, 2160 for 60%, 2880 for 80% and 3600 m^3 ha^{-1} for 100% of total water requirements.

Experimental design

The experimental lay out was split-plot system in a randomized complete block design. Mycorrhizal fungi (*G. deserticola*) inoculation treatments (with, +AMF and without, -AMF) were arranged in the main plots and four irrigation levels were distributed in the sub-plots, with four replications. Each sub-plot area occupied 8 m² and included 16 plants. The plants were placed in rows 1.0 m apart, and the plant distance within a row was 50 cm. The plants were fixed by iron wires for supporting.

Agricultural practices

Regular cultural practices were adopted. Harvest-ripe fruits were handpicked and weighed two times per week, started on the middle of December and continued until the middle of March, in both seasons.

Measurement of plant growth, yield and fruit quality traits

At the beginning of harvesting stage, 80 days after transplanting, five plants were collected from each treatment. The plants were washed to be free from the soil particles, and the following growth traits were determined: plant height, root length, fresh and dry weights of shoot, root and whole plant after drying them in a dry oven at 70°C for 48-72 h until constant weight. Total leaf area using a Portable Area Meter (LI-COR model 3000A) was recorded.

Fruit set (%), fruit number $plant^{-1}$, fruit dimension (fruit length and diameter), fruit fresh weight, early fruit yield (the initial five harvests) and the total yield (all collected fruits) were determined. In addition, the qualitative fruit traits in terms of fruit dry weight, vitamin C, titratable acidity, total soluble solids (TSS) and total sugar contents were assessed.

The qualitative traits were determined in a sample of 5 ripe fruits per treatment. Fruit dry weight was estimated in a dry oven at 70°C for 48h. Vitamin C (mg 100 g^{-1} fw, as ascorbic acid) was measured in tomato fruit extract using 2,6dichlorophenol-indophenol dye (Patane et al. 2011). Titratable acidity (g 100 g^{-1} fw, as citric acid) was determined using 10 g of pulp ground in a blender and homogenized with 90 mL of distilled water. The samples titrated to pH 8.1 with 0.1 N NaOH as a standardized titration solution using 15 mL of fruit flesh (Turhan and Seniz 2009). Total soluble solids (TSS) were examined on tomato juice samples via a digital refractometer (PR-101 model, ATAGO, Japan). Total sugars content (%) was detected following AOAC (1995) standard methods.

Determination of fruit yield reduction and water saving

The reduction in the total yield and water saving was computed (Ismail 2010) as follows:

Fruit yield reduction = 100 - (fruit yield of IL1, IL2 or IL3/IL4 x 100)

Water saving = 100 - (water use of IL1, IL2 or IL3/IL4 x 100)

Where: IL4 is a full irrigation water requirement (control treatment).

Water-use efficiency

Water use efficiency (WUE) was calculated by taking the proportion of the total fruit yield (kg ha^{-1}) and the total water applied (m^3 ha^{-1}) for each treatment (Zotarelli et al. 2009).

Statistical analysis

The data were analyzed using analysis of variance (ANOVA) via SAS version 8.1 (SAS Inst. 2008). A revised least significant difference (LSD) test was used to compare the differences between treatments at a significant level of 5% according to Steel and Torrie (1980) procedure.

3. Results and discussion

Plant growth traits

In general, AMF inoculation significantly increased growth traits of tomato plants (Table 1). These findings agree with the recent studies of Oseni et al. (2010) and Guruet al. (2011) in tomato as well as Tanwar et al. (2013) and Castillo et al. (2013) in pepper. These authors reported that AM fungi application was more effective in improving plant growth traits. This positive effect might refer to the role of AMF in enhancing uptake of nutrients and successive water relation which led to better growth and larger plant size (Auge 2001).

Plant growth traits response to different irrigation water levels were found to be linearly affected by increasing water levels except for root length and root fresh weight, where no significant differences were detected between 80 and 100% ETc irrigation water level treatments (Table 1). The improvement of vegetative growth traits of tomato plants with increasing water level may be attributed to the appropriate balance of moisture in plant, which creates good conditions for nutrients uptake, photosynthesis and metabolites translocation, which in final led to speed up the rate of vegetative growth (Ezzo et al. 2010).

Fruit yield and its components

Mycorrhizal plants (+AMF) revealed significant increases in the tomato fruit set, fruit number, early and total fruit yield compared with -AMF plants (Table 2). The superior fruit yield advantage and higher fruit number exhibited in +AMF plants might result from enhanced uptake of mineral nutrients from soil, chiefly immobile ions like P, Cu and Zn, and improve nutrient translocation system, result in increased root and shoot biomass, in addition to enhanced yield (Bryla and Koide 1998 and Guru et al. 2011). Utkhede (2006) indicated also that tomato plants inoculated by AMF produced significantly higher fruit number and fruit yield compared to the non-inoculated plants.

The lowest values of fruit set, fruit number, fruit dimension (fruit length and diameter), early and total fruit yield (Table 2) were recorded with plants supplied with the lowest irrigation level (40% ETc). At this level, the leaf area decreased to about one-third compared with the highest water level (100% ETc) as shown in Table (1). The reduction in the leaf area may primarily be due to decreased turgidity of the cells and tissues. This structure of tomato plants would have caused reduction in photosynthetic area and the rates of photosynthesis per unit leaf area. Accordingly, low carbohydrate production was available for formation of fruits (Vijitha and Mahendran 2010). The highest values of fruit set, fruit number, fruit dimension (length and diameter), early and total fruit yield were obtained when tomato plants were irrigated with 100% ETc. This water level promoted the vegetative growth of tomato plants (Table 1); which in turn reflected its effect on fruit set, fruit number, fruit dimension, early and total fruit yield. Data also displayed that there were insignificant differences between the two irrigation water levels; 80 and 100% ETc, on the former traits (Table 2).

Greater root growth (longer root and heavier root fresh weight), in tomato plants irrigated by 80 or 100% ETc (Table 1), may have resulted in superior fruit number, larger fruit dimension and greater fruit yield in comparison to 60 or 40% ETc water levels. On the other hand, fruit fresh weight was increased with each increase in the water level applied (Figure 1). This finding is in covenant with Birhanu and Tilahun (2010) who reported that total fruit weight was reduced as irrigation amount reduced. This result can be attributed to the role of water as a vital component for growth and development of tomato fruits, since the water forms 94-95% of the total fruit fresh weight (Turhan and Seniz 2009). In general, under water stress conditions tomato plants cannot get enough water for physiological process leading to the production of fruits (Nahar and Gretzmacher 2002).

Fruit qualitative attributes

Inoculation +AMF plants resulted in significant increment in vitamin C, titratable acidity, TSS and total sugars contents compared to their respective -AMF plants (Table 3). These results agreed with the findings of Sirichaiwetchakul et al. (2011) who indicated that AMF species *G. mosseae* improved fruit quality of cherry tomato grown under glasshouse conditions by increasing ascorbic acid and TSS. Generally, AM fungi colonized host roots uses the extra radical mycelium to explore a larger volume of soil, and transfer nutrients from soil to the plants more efficiently, which lead to the improvement of plant growth and enrichment of fruit nutrition (Tanwar et al. 2013).

Water stress treatment (40% ETc) significantly improved all fruit quality attributes in terms of fruit dry weight, vitamin C, titratable acidity, TSS and total sugars contents (Table 3). The positive effect regarding water stress on tomato fruit quality traits can be explained by a reduction in water accumulation in fruit without any significant change in the amount of the accumulated TSS and sugars (Guichard et al. 1999). Increased TSS content in tomato fruits with increasing water stress was also detected in other studies (Favati et al. 2009 and Birhanu and Tilahun 2010). These authors indicated that the highest TSS under water stressed treatments is imperative for the tomato processing industry. This trait is highly valued where water quantity is limited, or expensive for tomato production. On the other hand, Favati et al. (2009) pointed to that vitamin C is positively affected by water deficiency in processing tomato, although the scope of this effect may depend on the cultivar (Dumas et al. 2003). These authors also reported that the larger the fruit, the lower vitamin C content.

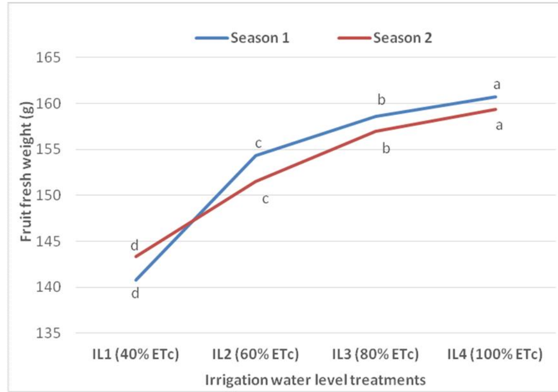

Figure 1. Influence of irrigation water level treatments on fruit fresh weight of tomato plants through 2010/2011 and 2011/2012 seasons

Table 1. Growth variables of tomato plants 'Faridah' cv. as influenced by AMF inoculation and irrigation water level treatments in 2010/2011 and 2011/2012 growing seasons

Response variables	Plant height (cm)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)	Plant fresh weight (g)	Plant dry weight (g)	Leaf area (cm^2)
First season (2010/2011)									
AMF inoculation									
M0 (- AMF)	192.8 b	61.1 b	67.8 b	16.9 b	1376.7 b	176.2 b	1444.5 b	193.1 b	7863.4 b
M1 (+ AMF)	206.6 a	68.6 a	76.6 a	17.6 a	1470.6 a	195.6 a	1547.2 a	213.2 a	8435.8 a
Irrigation levels									
IL1 (40% ETc)	186.6 d	48.0 c	57.4 c	15.6 d	1317.3 d	150.5 d	1374.7 d	166.1 d	6354.9 d
IL2 (60% ETc)	196.9 c	63.8 b	65.9 b	16.9 c	1400.6 c	174.6 c	1466.5 c	211.5 c	8124.5 c
IL3 (80% ETc)	205.4 b	68.5 a	82.0 a	18.8 b	1483.1 b	198.3b	1565.1 b	217.1 b	8874.6 b
IL4 (100% ETc)	209.8 a	69.1 a	83.6 a	19.5 a	1493.6 a	206.5 a	1577.2 a	226.0 a	9458.3 a
Second season (2011/2012)									
AMF inoculation									
M0 (- AMF)	184.4 b	59.0 b	64.3 b	16.8 b	1333.2 b	169.3 b	1397.5 b	186.1 b	7476.8 b
M1 (+ AMF)	194.2 a	63.4 a	69.6 a	17.0 a	1398.9 a	179.1 a	1468.5 a	196.1 a	7633.9 a
Irrigation levels									
IL1 (40% ETc)	177.3 d	45.1 c	52.5 c	15.4 d	1270.6 d	142.3 d	1323.1 d	157.7 d	5876.6 d
IL2 (60% ETc)	189.1 c	61.4 b	63.0 b	16.5 c	1355.8 c	166.6 c	1418.8 c	183.1 c	7159.4 c
IL3 (80% ETc)	195.3 b	63.9 a	76.0 a	17.5 b	1409.4 b	183.9 b	1485.4 b	201.4 b	8347.5 b
IL4 (100% ETc)	199.6 a	64.8 a	76.1 a	18.3 a	1428.5 a	200.8 a	1504.6 a	219.1 a	8837.8 a

Means in each column for each treatment in each season followed by different letters are significantly different using revised LSD at 0.05 level.

Table 2. Fruit set, fruit number, fruit dimension, early and total fruit yield of tomato plants 'Faridah' cv. as influenced by AMF inoculation and irrigation water level treatments during 2010/2011 and 2011/2012 growing seasons

Treatments	Fruit set (%)	Fruit number	Fruit length (cm)	Fruit diameter (cm)	Early fruit yield (ton ha^{-1})	Total fruit yield (ton ha^{-1})
First season 2010/2011						
AMF inoculation						
M0 (- AMF)	86.3 b	46.8 b	5.6 a	5.5 a	29.638 b	143.156 b
M1 (+ AMF)	90.8 a	48.6 a	5.9 a	5.8 a	34.341 a	154.687 a
Irrigation levels						
IL1 (40% ETc)	80.6 c	43.1 c	5.2 c	5.2 c	28.506 c	128.687 c
IL2 (60% ETc)	87.3 b	48.5 b	5.7 b	5.8 b	31.478 b	149.688 b
IL3 (80% ETc)	92.9 a	49.7 a	6.0 a	6.1 a	33.936 a	158.000 a
IL4 (100% ETc)	93.4 a	50.1 a	6.1 a	6.2 a	34.037 a	159.312 a
Second season 2011/2012						
AMF inoculation						
M0 (- AMF)	76.8 c	41.7 c	5.1 c	5.0 c	26.676 c	123.500 c
M1 (+ AMF)	82.6 b	47.4 b	5.9 b	5.6 b	28.582 b	146.625 b
Irrigation levels						
IL1 (40% ETc)	76.8 c	41.7 c	5.1 c	5.0 c	26.676 c	123.500 c
IL2 (60% ETc)	82.6 b	47.4 b	5.9 b	5.6 b	28.582 b	146.625 b
IL3 (80% ETc)	92.0 a	48.7 a	6.0 a	5.8 a	31.542 a	152.750 a
IL4 (100% ETc)	92.4 a	49.1 a	6.0 a	5.9 a	32.023 a	153.250 a

Means in each column for each treatment in each season followed by different letters are significantly different using revised LSD at 0.05 level

Table 3. Influence of AMF inoculation and irrigation level treatments on fruit quality attributes of tomato plants 'Faridah' cv.in 2010/2011 and 2011/2012 growing seasons

Treatments	Fruit dry weight (g)		Vitamin C (mg 100 g^{-1} fw)		Titratable acidity (%)		TSS (%)		Total sugars (%)	
	2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012	2010/2011	2011/2012
AMF inoculation										
M0 (- AMF)	8.9 a	9.0 a	24.2 b	23.9 b	0.5556 b	0.5376 b	5.8 b	5.6 b	3.6 b	3.4 b
M1 (+ AMF)	9.4 a	9.5 a	25.8 a	24.8 a	0.5725 a	0.5742 a	5.9 a	5.8 a	3.7 a	3.6 a
Irrigation levels										
IL1 (40% ETc)	7.3 c	8.1 c	27.9 a	26.9 a	0.6215 a	0.6253 a	6.5 a	6.6 a	3.9 a	3.9 a
IL2 (60% ETc)	8.2 b	8.5 b	26.5 b	26.0 b	0.5635 b	0.5547 b	6.2 b	6.1 b	3.7 b	3.8 b
IL3 (80% ETc)	9.7 a	9.9 a	24.0 c	22.5 c	0.5487 c	0.5399 c	5.6 c	5.5 c	3.6 c	3.5 c
IL4 (100% ETc)	9.8 a	10.2 a	21.4 d	20.6 d	0.5266 d	0.5247 d	5.3 d	5.1 d	3.5 d	3.3 d

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level

Impact of AMF inoculation and irrigation level combinations

The combinations between mycorrhizal inoculation (+AMF) and water levels were significant for the fresh root, shoot and fruit weights, fruit number, total fruit yield and vitam in C content. Results indicated that tomato plants inoculated with AMF and irrigated with the highest irrigation level (100% ETc) gave the heaviest root, shoot and fruit fresh weights, the highest number of fruits and the largest total yield followed by +AMF plants irrigated with 80% of ETc as compared with the other treatments (Table 4). The superiority of these treatments may give more vegetative growth for the plants because the soil remains wetter, thus allowing for more water uptake, which is reflected in a higher fruit yield (Zotarelli et al. 2009). In general, inoculation of tomato plants with AMF under higher irrigation level treatments positively affected productivity. The result was due both to the increase in number of fruits and fruits weight as irrigation level increased (Table 4). +AMF tomato plants under the highest water level (100% ETc) displayed a 35.5% increase in the total fruit yield compared to -AMF plants with the lowest water level (40% ETc), in the first season, and a 26.4% increase for the second season. Thus, the results of the impact of AMF inoculated tomato plants signified that AMF enhanced vigorous root system, mainly under available water level, which in turn improves plant growth and increases yield.

The highest value of vitamin C (27.3-28.3 mg 100 g^{-1} fw) was detected with +AMF plants under the lowest irrigation water level (40% ETc) in comparison with the other treatments (Table 4). Increased vitamin C content in tomato fruit with increase in water stress has also been reported in other researches such as Favati et al. (2009) in processing tomato and Abdel-Razzak et al. (2013) in cherry tomato. The extensive canopy growth that occurs in +AMF tomato plants receiving 100% ETc of water requirement, may generate appropriate shading and fruit cover as compared to tomato plants exposed to the water stress (40% ETc). The expansion of canopy growth reduces light intensity and decreases accumulation of vitamin C in the shaded fruits (Lee and Kader 2000).

Fruit yield reduction and water saving

Based on the interaction results, there were obvious combinations between AMF inoculation and irrigation levels, resulting in improvement of fruit yield and water saving (Table 5). All treatments led to reduction in yield, except +AMF x IL3 (80% ETc) and +AMF x IL4 (100% ETc). The minimum fruit yield reduction (0.89-1.64%) was recorded under -AMF x IL3 (80% ETc) in the first and second seasons, respectively. On the contrary, the yield was increased by (8.21 and 7.87%) under +AMF x IL4 (100% ETc) followed by (5.28 and 6.89%) under +AMF x IL3 (80% ETc) in both seasons, respectively (Table 5). These results indicated that +AMF x IL4 (100% ETc) treatment caused only about 3% and 1% increment in the total fruit yield for the two seasons as compared with +AMF x IL3 (80% ETc). Therefore, it is possible to save water and improve WUE in tomato if water is applied to the crop throughout the growing season, even at irrigation level (80% ETc), to get adequate yield and maintain high fruit quality. This result was in parallel with the new findings of Shahein et al. (2012) in tomato and Abdel-Razzak et al. (2013) in cherry tomato.

Tomato water use efficiency

Water use efficiency was calculated throughout the proportion of the total yield (kg ha^{-1}) and the total water applied under each treatment (m^3 ha^{-1}) as showed by (Zotarelli et al. 2009). The effect of AMF on WUE of tomato plants indicated that +AMF plants exhibited higher value of WUE than -AMF plants (Figure 2). The positive effect of +AMF inoculation on WUE may be due to the fact that AMF can certainly enhance water absorbing capacity of the roots. Moreover, it helps in the maintenance of optimum moisture around root zone (Kaya et al. 2003 and Guru et al. 2011).

Table 4. Interaction influences between AMF inoculation and irrigation water level treatments on root, shoot and fruit fresh weights, fruit number, total yield and vitamin C content traits of tomato plants 'Faridah' cv.during 2010/2011 and 2011/2012 growing seasons

AMF inoculation	Irrigation level	Root fresh weight (g)		Shoot fresh weight (g)		Fruit fresh weight (g)		Fruit number		Total fruit yield (ton ha^{-1})		Vitamin C content (mg 100 g^{-1} fw)	
		2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12
M0 (- AMF)	IL1 (40% ETc)	52.5 g	51.5 e	1280.5 e	1240.8 e	145.6 e	143.5 f	41.7 e	40.7 f	122.750 f	122.250 e	27.0 b	25.0 b
	IL2 (60% ETc)	63.4 f	63.8 d	1365.6 d	1328.5 d	150.1 d	148.3 e	42.6 de	43.1 e	130.688 e	135.200 d	26.1 b	24.5 b
	IL3 (80% ETc)	77.8 d	69.0 c	1422.2 c	1373.0 c	155.8 c	156.0 c	47.1 c	45.2 d	152.375 c	150.000 b	23.2 c	21.5 d
	IL4 (100% ETc)	82.6 b	71.3 c	1438.5 b	1390.5 b	158.5 b	158.0 b	48.8 bc	48.1 bc	153.750 c	152.000 b	20.0 d	20.3 d
M1 (+ AMF)	IL1 (40% ETc)	62.2 f	53.5 e	1354.2 d	1300.5 d	146.9 e	153.0 d	44.4 d	42.6 e	134.625 e	134.750 d	28.3 a	27.3 a
	IL2 (60% ETc)	68.5 e	65.8 d	1435.6 bc	1383.0 c	158.4 b	154.8 d	48.5 bc	46.7 cd	145.625 d	147.750 c	27.2 ab	26.5 a
	IL3 (80% ETc)	86.5 b	78.0 b	1544.1 a	1445.8 a	161.5 a	158.0 b	50.1 b	48.6 b	161.875 b	163.000 a	26.0 b	23.5 c
	IL4 (100% ETc)	89.4 a	81.0 a	1548.6 a	1466.5 a	162.8 a	160.8 a	52.3 a	51.1 a	166.375 a	164.500 a	22.9 c	21.0 d

Means in each column for each treatment followed by different letters are significantly different using revised LSD at 0.05 level

Table 5. Tomato fruit yield reduction (%) and water saving (%) owing to the interaction between AMF inoculation and irrigation water level treatments during growing seasons of 2010/2011 and 2011/2012

Treatments	First season 2010/2011				Second season 2011/2012			
	Total fruit yield (t ha^{-1})	Yield ratio to the control treatment (%)	Fruit yield reduction (%)	Water saving (%)	Total fruit yield (t ha^{-1})	Yield ratio to the control treatment (%)	Fruit yield reduction (%)	Water saving (%)
-AMF x IL1	122.750	68.53	20.16	50	122.250	69.80	19.84	50
-AMF x IL2	130.688	96.15	15.00	33.33	145.500	95.97	11.35	33.33
-AMF x IL3	152.375	111.89	0.89	16.67	150.000	110.74	1.64	16.67
-AMF x IL4	153.750	116.08	00.00	0	152.000	114.76	00.00	0
+AMF x IL1	134.625	58.74	12.44	50	124.750	60.07	11.64	50
+AMF x IL2	145.625	91.26	5.28	33.33	147.750	90.95	3.11	33.33
+AMF x IL3	151.875	99.30	5.28 (-)*	16.67	153.500	98.66	6.89 (-)*	16.67
+AMF x IL4	166.375	100	8.21(-)*	0	154.500	100	7.87 (-)*	0

*(-) Total fruit yield increased as compared with the control treatment

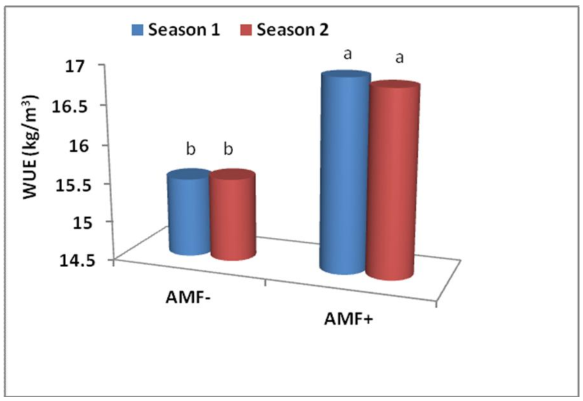

Figure 2. Influence of AMF inoculation treatments on WUE of tomato plants through 2010/2011 and 2011/2012 seasons

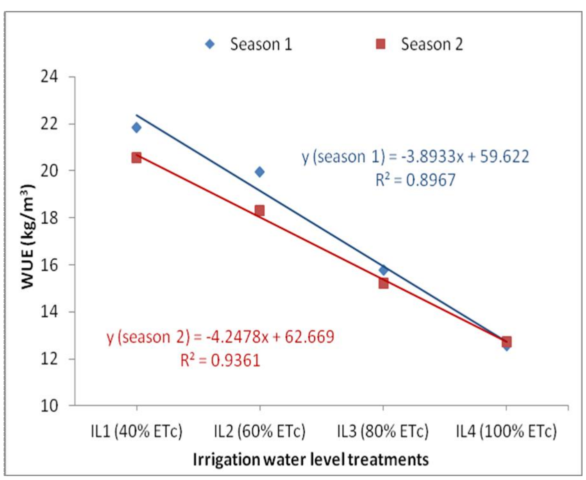

Figure 3. Influence of irrigation water level treatments on WUE of tomato plants through 2010/2011 and 2011/2012 seasons

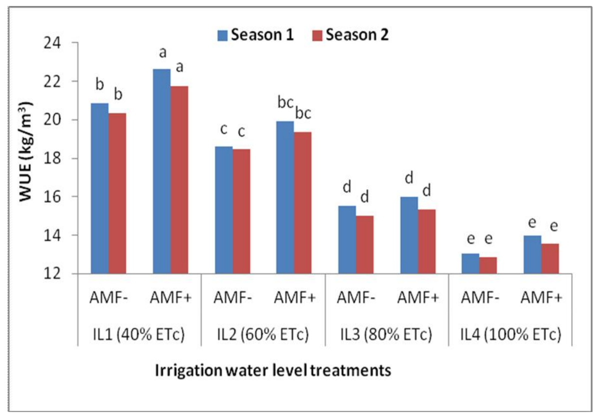

Figure 4. Influence of combination between AMF inoculation and irrigation water level treatments on WUE of tomato plants through 2010/2011 and 2011/2012 seasons

It is evident that WUE decreased with increasing irrigation level (Figure 3). The lowest water level applied (40% ETc) recorded the highest WUE value (21.853-20.554 kg ha^{-1}). However, higher or medium irrigation level applied (100 or 80% ETc) resulted in the lowest WUE values (12.547-12.731 and 15.764-15.225 kg ha^{-1}), in that order. Similar tendency was observed by Aziz et al. (2013) who found that 50% of available water treatment gave higher WUE as opposed to 100 or 75% of available water treatments. On the other hand, the regression analysis showed a good correlation (R^2 = 0.90-0.94) between the tomato fruit yield and the WUE (Figure 3). Such results were in harmony with other studies like Kirnak and Kaya (2004) in tomato and Abdel-Razzak et al. (2013) in cherry tomato.

There was clear combination between AMF inoculation and irrigation level treatments on WUE value (Figure 4). Where, the highest WUE value (21.75-22.64 kg m^{-3}) was reported in +AMF plants under lower water level; IL1 (40% ETc). However, the lowest WUE value (12.85-13.06 kg m^{-3}) was recorded in -AMF plants under IL4 (100% ETc) in the first and second seasons, correspondingly. In general, WUE of the different irrigation levels tended to increase in +AMF tomato plants, especially under the lowest water level (Figure 4). Thus, the results of this study can support the conclusion of Ruiz-Lozano et al. (1995) that AMF species *Glomus deserticola* was the most effective mycorrhizal species for increasing drought tolerance of the host plant both in terms of maintaining growth under stress condition and in allowing more efficient use of irrigation water.

Conclusion

Inoculated tomato plants with AMF, chiefly under a moderate irrigation level (80% ETc) may contribute to good compromise between fruit yield and fruit quality in tomato and allow to save about (20%) of irrigation water. This aspect is vital under arid environment conditions, where water lack is an increasing concern and costs of water are always rising. Hence, application of AMF in greenhouse tomato production is an effective method for improving growth and yield, particularly under available water in the soil and thus expected to be of greater benefits in sustainable vegetable production.

Acknowledgments

Authors are grateful to the Deanship of Scientific Research, King Saud University and Agricultural Research Centre, College of Food and Agriculture Sciences for the financial support.

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1/15/2014