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Full Length Research Paper

Responses of soilless grown tomato plants to arbuscular mycorrhizal fungal (*Glomus fasciculatum*) colonization in re-cycling and open systems

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Mycorrhizal fungi species *Glomus fasciculatum* was used to determine its effects on tomato growth, yield, fruit properties, nutrient uptake and substrate ion accumulation of plants grown hydroponically under open and re-cycling (closed) perlite substrate. AM inoculation in both open and closed soilless systems did not increasingly influence the vegetative plant growing and nutrient uptake of tomato cultivar M19. However, fruit yield absolutely increased with inoculation. AM inoculated tomato plants could effectively use photo assimilates for fruit production instead of vegetative growing. In the closed system with AM, ion accumulation and EC increases (salinity effects) were well controlled. Results indicated that mycorrhizal inoculation improved yield and fruit size, which can help alleviate deleterious effects of re-cycling soilless systems for tomato crop.

Key words: *Lycopersicon esculentum* Mill, hydroponics, AM fungi, vegetative growth, yield, fruit, ion uptake, re-cycling, EC.

INTRODUCTION

The greenhouse vegetable production in Turkey is an important agricultural sector with more than 30 000 ha greenhouse area. This sector aims at supplying out of season vegetables to the markets within the country and also for export. However, production of greenhouse vegetables is mainly performed in soil, and hydroponics or soilless production becomes more and more important. Soil-born pathogens are the main reasons for increasing preference of soilless systems. As hydroponics has proven to be an excellent alternative to soil sterilization, use of chemical soil sterilants is or may be soon be forbidden due to the high toxicity problem (Savvas and Passam, 2002). Moreover, some growers prefer the soilless production on purpose due to high yield and good quality of crops. Soilless cultivation serves to improve better control of the growing medium and to avoid any likely problems for watering and maintaining proper nutrient concentrations. Good control of the plant growth and development in soilless cultivation of vegetables give proportionally higher yield and better quality crops compared to traditional greenhouse production in soil. This technique is mainly practiced with substrate medium. This is due to superior physical and chemical properties of the substrates and their initial low infestation rate with pathogenic pest and due to their ease of disinfestation. Frequent irrigation and continued fertilization should satisfy nutritional plant demands under most practical situations (Raviv et al., 2002). In the substrate culture, there are two main systems for growing plants; the first is the “open” system with the surplus nutrient solution discharged as waste. This is a waste of water and nutrients and results in pollution of groundwater and soil. The second is the “closed” system with re-cycling and re-using of nutrient solution. The term ‘nutrient solution recycling’ in hydroponics includes both continued recirculation and reuse of the excess nutrient solution that drains off after each irrigation cycle (Savvas, 2002). Although the recycling of the nutrient solution brings more sophisticated controlling of plant nutrition than in open

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soilless culture systems, it gives indispensable benefits in saving of both water and nutrients (40-50% of the total supply) in addition to its environmental friendly characteristics (Dasgan and Ekici, 2005). The application of recycling enables restriction or even complete prevention of nutrient leaching into the groundwater (Savvas, 2002).

Arbuscular mycorrhizal (AM) fungi occur in all soils, and commonly colonize roots of many plant species. These fungi can increase plant growth and reproduction by enhancing uptake of nutrients, especially those immobile in soil like phosphorus. AM fungi can also benefit plants by stimulating growth regulating substances, increasing photosynthesis, improving osmotic adjustment under drought and salinity stresses and increasing resistance to pest (Al-Karaki, 2006). The primary effect of AM on their host plant is an increase in plant growth and nutrient uptake (Ortas et al., 2001). Also mycorrhizal inoculation reduces the quantity of fertilizer application, making it less than normally required for non-inoculated plant conditions (Charron et al., 2001). The AM fungi are absent in soilless substrates. Uses of AM fungi on soilless grown pepper (Ikiz, 2003; Ikiz et al., 2008) and melon (Rehber, 2004) plants in open substrate systems have been previously reported. The results suggested that mycorrhiza could promote plant growth and increase fruit yield. Moreover, in recycling soilless systems, mycorrhizal response was not investigated. In hydroponic production all necessary nutrients are required in root medium with optimal ranges and beneficial forms by the plants. However, in closed systems, nutrient composition of the re-circulating solution is different with time from that of the solution initially supplied to the crop. This results in most nutrients tending to accumulate in the drainage, thus increasing its EC to values beyond those of the target EC of the irrigation solution (Savvas, 2002). Therefore, EC increase, pH fluctuation, and nutrient imbalance are possible problems in substrate around the root. Sometimes ion accumulation in the substrate due to inappropriate recycling management can cause serious artificial salinity problems.

The aim of this study is to ascertain whether the presence of mycorrhizal fungus alleviates disadvantages of closed soilless systems. Considering the water, nutrients, and environmental concern with open system, an alternative approach of closed system with better root condition control via mycorrhiza was investigated in this paper.

MATERIALS AND METHODS

Plant material and experimental conditions

The long growing season (from October to June, 9 months) green house experiment was conducted over 253 days of growth period in a research greenhouse at Cukurova University, Faculty of Agriculture (36°59'N, 35°18'E, 20 m above sea level), Adana, Turkey, with autumn planted tomato (*Lycopersicon esculentum* Mill., cv. F_1 M19) in the year 2004-2005. A randomized complete block experimental design with 4 replicates, 18 plants in each replicate, consisting of four treatments, was used. Seedlings were transplanted to perlite on 30 September, 2004, and the experiment was completed on 7 June, 2005. The glass covered greenhouse oriented in north-south direction was 12 x 42 m in size. During the winter, for the period of November 15 - March 15, heating system was used to maintain a minimum temperature of 10°C at nights. Seedlings were planted in density of 3.18 plants m^{-2} in perlite-filled containers made of white PVC, in dimensions of 78 x 38 x 22 cm. Each container had 3 plants with 12 liters of perlite per plant. In order to produce mycorrhizal inoculated plants, sowing medium (mixture of peat: perlite in 2:1 ratio), and transplanting substrate (perlite) were inoculated two times with ratio of 400 and 600 spores of the mycorrhizal fungus per plant *Glomus fasciculatum* (obtained from Department of Soil Science, Cukurova University), respectively.

Four treatments were used in the experiment: (1) Closed (M-); closed system without mychorriza, (2) Closed (M+); closed system with mychorriza, (3) Open (M-); open system without mychorriza and (4) Open (M+); open system with mychorriza. The amount of nutrient solution applied in the treatments was determined based on a daily measured drainage fraction from the base of the growth containers (Schröder and Lieth, 2002). The range of drainage fraction measured was from 20 to 40% during the experimental period. Drainage ratio and EC values during the experimental period were controlled and regulated depending on plant age, fruit load, greenhouse temperature, and light intensities. The pH of nutrient solution was always maintained between 5.5 and 6.5 by applying nitric or phosphoric acids.

Nutrient solution

During the experiment, the open system plants were supplied with the following nutrient solution modified from Dasgan and Ekici (2005) (in ppm): NO_3-N (135 - 225), NH_4-N (15-25), P (40 - 50), K (200 - 400), Ca (150 - 180), Mg (50 - 75), Fe (2.8 - 5.0), Mn (0.8 - 1.0), Cu (0.3 - 0.4), Zn (0.3 - 0.4), B (0.3 - 0.4) and Mo (0.05 - 0.1). Phosphorus concentration of the nutrient solution has been kept between 40 to 50 ppm during the experiment. In re-cycling systems, drainage solution was not directly re-supplied to the plants and was replenished with nutrients and water prior to recycling. The daily EC and pH values of supply and drain nutrient solutions were recorded. When the EC values of the re-circulating nutrient solution were higher than 4.5 dSm^{-1}, the nutrient solution was renewed with fresh solution.

Plant growth and crop measurements

Tomato plants grown under different treatments were compared on 31 and 210 days after transplanting (DAT) for the plant growth parameters such as plant height, leaf number and stem diameter between 3rd and 4th nods (Table 1). At the end of the experiment, total shoot fresh weight including stem and leaves and plant leaf area were determined (Table 2). Early (period from January 3 to March 31) and total (period from January 3 to June 7) yields and some fruit quality parameters such as weight, height, diameter, volume, juice total soluble contents and juice pH, were also investigated (Tables 2 and 3).

Tissue elemental analysis

In order to compare nutritional status of the tomato plants grown under different treatments, periodical plant leaf analysis for N, P, K, Ca, Mg, Fe, Mn, Zn, and Cu was conducted monthly, and data were presented bimonthly (Tables 4). Samples of 3 leaves from each replication of all trails were collected. The leaf position on plant which was taken as sample includes the 9 or 10 leaf from the top. Tomato leaves were dried at 65°C for 48 h. After drying, samples

Table 1. Effects of the treatments on the tomato plant growth at 31 and 210 days after transplanting (DAT).

Treatment	Plant height (cm)		Leaf number per plant		Stem diameter* (mm)	
	31 DAT	210 DAT	31 DAT	210 DAT	31 DAT	210 DAT
Closed (M-)	155.89	474.23 a	18.84	77.92	6.69 b	9.61
Closed (M+)	160.00	446.95 b	19.87	76.33	7.29 a	10.61
Open (M-)	154.48	477.65 a	19.26	80.10	6.72 b	10.27
Open (M+)	156.85	459.93 ab	19.21	77.83	6.94 b	10.25
P	0.1036	0.0118	0.265	0.256	0.006	0.570
LSD 0.05	19.823	17.534	1.088	3.927	0.413	1.580

Closed (M-), closed system without mychorriza; Closed (M+), closed system with mychorriza; Open (M-), open system without mychorriza; Open (M+), open system with mychorriza.
*Between 3rd and 4th nods.

Table 2. Effects of the treatments on total green fresh mass (TGFM), leaf area, tomato fruit yield and number of tomato fruit harvested.

Treatment	TGFM*	Leaf area	Early yield		Total yield	
	(g per plant)	(cm^2 per plant)	(kg per m^2)	(no fruit per m^2)	(kg per m^2)	(no fruit per m^2)
Closed (M-)	1291	22587	5.8	62.1	16.8 b	167.5 b
Closed (M+)	1300	21373	6.6	62.8	18.0 ab	170.9 b
Open (M-)	1456	24472	6.5	66.4	18.5 ab	184.0 b
Open (M+)	1316	22518	6.7	61.5	19.5 a	205.2 a
P	0.541	0.325	0.182	0.613	0.047	0.011
LSD 0.05	284	3560	0.979	8.978	1.758	20.825

Closed (M-), closed system without mychorriza; Closed (M+), closed system with mychorriza; Open (M-), open system without mychorriza; Open (M+), open system with mychorriza.
*TGFM, Total Green Fresh Mass (including shoots and leaves, excluding fruit).

Table 3. Effects of the treatments on some tomato fruit properties (the sampling time is April).

Treatments	Mean fruit weight (g)	Mean fruit height (mm)	Mean fruit diameter (mm)	Mean fruit volume (ml)	Juice TSC* (%)	Juice pH
Closed (M-)	100.74 ab	47.81	59.24 ab	102.29	5.10	4.05
Closed (M+)	105.43 a	48.67	60.28 a	102.92	5.05	4.04
Open (M-)	100.69 ab	48.60	59.09 ab	100.19	5.30	4.02
Open (M+)	94.77 b	48.21	57.28 b	96.63	5.05	4.00
P	0.024	0.925	0.043	0.356	0.290	0.950
LSD 0.05	6.133	1.881	1.959	8.203	0.315	0.182

Closed (M-), closed system without mychorriza; Closed (M+), closed system with mychorriza; Open (M-), open system without mychorriza; Open (M+), open system with mychorriza.
*TSC, Total Soluble Contents.

were ground using a mill with a 20 mesh sieve. Leaf powder was turned to ash at 550°C for about 8 h and the ash dissolved in 3.3% HCl. The concentrations of K, Ca, Mg, Fe, Mn, Zn, Cu, Na in leaves were determined by atomic absorption spectrometry. Nitrogen and phosphorus in plants were determined by Kjeldahl and Barton methods, respectively.

Substrate ion analysis

Perlite analysis were also carried out for SO_4, $H2PO_4$-P, NO_3, NH_4, Cl, Na, K, Ca and Mg, in order to investigate ion accumulation in the growing substrate at the beginning and end of the growing period (Table 5). In order to determine EC, pH and nutrient concentrations of the substrate, water extraction method was used with a ratio of 1:2 (v/v) perlite : water (Gabriëls and Verdonck, 1991). NO_3-N concentration was determined by the distillation of the substrate extract with MgO and Devarda alloy, SO_4 and H_2PO_4-P concentrations were determined by the colorimetric methods according to Tan (1996).The levels of other nutrients in the extraction, K, Ca, Mg, Fe, Mn, Zn, Cu and Na, were determined by the atomic absorption spectrometry. In order to determine chloride concentration of the substrate, the extraction was titrated with $AgNO_3$, a

Table 4. Effects of the treatments on nutrient concentrations of tomato leaves (9 - 10 leaf from the top) during different periods of growth.

	Nov.	Jan.	March	May		Nov.	Jan.	March	May
Nitrogen (N) %						**Iron (Fe) ppm**			
C (M-)	4.18	4.02	3.76	5.10		273	280 a	169 b	116
C (M+)	4.27	4.20	4.05	5.01		269	220 ab	170 b	113
O (M-)	4.15	3.92	3.76	4.88		264	265 a	179 a	109
O (M+)	4.33	4.13	3.72	5.05		250	195 b	174 ab	121
P	0.325	0.446	0.423	0.806		0.794	0.013	0.048	0.623
LSD0.05	0.233	0.395	0.469	0.520		55.654	49.161	7.119	21.338
Phosphorus (P) %						**Manganese (Mn) ppm**			
C (M-)	0.49 b	0.64	0.56	0.67		258	303 a	244 bc	266
C (M+)	0.59 a	0.67	0.57	0.63		234	235 b	225 c	281
O (M-)	0.58 a	0.67	0.54	0.68		265	298 a	319 a	289
O (M+)	0.60 a	0.63	0.55	0.68		243	245 b	283 ab	280
P	0.004	0.707	0.705	0.545		0.322	0.011	0.003	0.704
LSD0.05	0.055	0.081	0.062	0.093		39.80	43.358	41.547	42.938
Potassium (K) %						**Zinc (Zn) ppm**			
C (M-)	2.96	2.84	2.51 b	2.54		49.25	49.54	45.50 b	30.00 ab
C (M+)	3.29	3.16	2.98 a	2.13		72.17	60.36	47.00 b	25.75 b
O (M-)	3.39	3.05	2.50 b	2.57		48.00	54.13	56.50 a	30.25 ab
O (M+)	3.13	2.90	3.22 a	2.35		76.17	63.20	60.50 a	33.00 a
P	0.426	0.308	0.004	0.634		0.173	0.084	0.007	0.016
LSD0.05	0.592	0.399	0.368	0.840		32.926	11.238	8.367	3.918
Calcium (Ca) %						**Cupper (Cu) ppm**			
C (M-)	2.23	1.98	1.27	1.63		29.34	25.54	19.50 b	10.75
C (M+)	2.01	1.78	1.38	1.67		31.25	21.67	25.50 b	10.00
O (M-)	2.09	1.88	1.60	1.55		31.67	25.71	32.75 a	10.50
O (M+)	1.98	1.85	1.45	1.89		29.33	19.86	40.75 a	10.25
P	0.076	0.132	0.066	0.069		0.498	0.104	0.001	0.980
LSD0.05	0.197	0.175	0.236	0.254		4.292	5.586	9.690	4.257
Magnesium (Mg) %						**Sodium (Na) %**			
C (M-)	1.53	1.47	1.53 a	0.83		0.56	0.59	0.57	0.54
C (M+)	1.64	1.43	1.43ab	0.77		0.65	0.58	0.54	0.59
O (M-)	1.48	1.39	1.40ab	0.85		0.65	0.60	0.66	0.70
O (M+)	1.62	1.38	1.31 b	0.79		0.65	0.56	0.51	0.62
P	0.293	0.365	0.029	0.117		0.048	0.312	0.425	0.229
LSD0.05	0.203	0.127	0.1132	0.073		0.073	0.054	0.210	0.162

C (M-), closed system without mychorriza; C (M+), closed system with mychorriza; O (M-), open system without mychorriza; O (M+), open system with mychorriza.

method modified from Johnson and Ulrich (1959).

Mycorrhizal colonization

At the middle period of the experiment (March) plant roots were collected from the growth medium and roots were washed carefully in preparation for the assessment of mycorrhizal colonization. The root clearing and staining procedure was performed according to the method described by Koske and Gemma (1989). The percentage of AM colonization was calculated as a number of 10 mm-long root segments out of 100 identified as colonized under a stereo microscope at a magnification of x 20 (Giovannetti and Mosse, 1980).

Data analysis

Treatment effects in the experiment were analyzed with analysis of variance (ANOVA) and treatments means were compared using LSD procedure.

RESULTS

The root samples from all inoculated with AM fungi showed presence of AM colonization, average 28%, and no AM fungi colonization was observed in the roots of

non-AM plants.

Plant vegetative growth

The adverse effects of re-circulating nutrient solution on plant growth were not evident under closed system practices. The Closed (M+) plants in the first development stage, 31 days after transplanting, showed higher values for the growth parameters, although not significant ($P>0.05$) in comparison to the other treatments (Table 1). Reason for this may be at the beginning of the cultivation, re-circulation procedure in the Closed (M+) trial could spread the fungus to the growing medium faster than the free drainage Open (M+) systems. In later stage of plant development on 210 DAT, the number of leaves and the stem diameter measurements were nearly similar in all the trials and there was no any significant difference among the treatments (Table 1). However, the shorter plants were observed in the Closed (M+) and Open (M+) trials, respectively, than that of the non AM inoculated Closed (-M) and the Open (-M) trials. In soilless production of tomato M19 cultivar (in both closed and open systems), at the later stage of cultivation period, it seems that the mychorrizal colonization may cause shorter plant height due to possible giving advantages to generative growing.

At the end of the growing period (210 DAT), total green fresh mass (including shoots and leaves, excluding fruit) of tomato plants under the treatments were not significantly different. However, the Open (M-) plants produced higher green fresh mass than that of the other treatments (Table 2). The leaf area per plant was not also significantly different among the treatments. However, the interesting indication with leaf area is that AM plants in both closed and open systems showed lower leaf areas than that of non AM plants. This is similar response to plant height. Fotoasimilate compartmentation between fruit development and leaf growing may be the reason of lower leaf area production in AM plants in both closed and open systems. The plants with mychorriza colonization could spend their energy preferably to fruits not vegetative growth. Because the total yield values in AM plants were higher than that of the non AM plants (Table 2).

Early and total yields

Early tomato production was increased under mychorrizal practices. The highest early yield was obtained from the Open (M+) treatment with 6.7 kg m^{-2} (Table 2). The Closed (M+) treatment gave 6.6 kg m^{-2}, and the lowest early tomato yield was from Closed (M-) plants with yield of 5.8 kg m^{-2} (Table 2).

Total tomato yield covering the whole cultivation period was significantly different based on treatments (Table 2). The total highest yield with 19.5 kg m^{-2} was produced with the treatment under Open (M+) system. The lowest yield was from the Closed (M-) treatment as 16.8 kg m^{-2}. The mychorrizal colonization in the open or closed systems increasingly affected the tomato yield. Higher fruit production was found for the mycorrhizal versus the non-mycorrhizal plants in both closed and open systems. Closed (M+) plants and Open (M+) plants produced 6.7 and 5.0% higher yields, respectively, than those of the Closed (M-) and Open (M-) plants. In any case, whether it is a closed or open system, the mychorriza use in soilless cultivation increases the tomato fruit yield.

Fruit properties

Mean fruit weight and mean fruit diameter were significantly different ($P<0.05$) among the tested treatments (Table 3). The heaviest fruits were from Closed (M+) trial as 105.43 g per fruit. Both non AM plants, Open (M-) and Closed (M-), had similar fruit weights with100.69 and 100.74 g, respectively. The lowest fruit weight was from the Open (M+) plants with 94.77 g. Although the differences were important among the trials for fruit diameter, it ranged between 57.28 and 60.28 mm (Table 3). The other fruit properties like mean fruit height and volume, juice total soluble contents, and pH were similar for the different trials.

Leaf nutrient content

The bimonthly leaf analysis for N, P, K, Ca, Mg, Fe, Mn, Zn and Cu showed that the tomato plants were adequately fed throughout the growth period (Tables 4). The ranges of nutrient concentrations recorded were within the order of sufficient levels except K, which was lower than required ranges in March and May (Bergmann, 1992; Plant Analysis Handbook, 2007).

Ion concentration in root medium in perlite

Ion concentrations in root medium in perlite at the beginning (November) and toward the end of growing period (June) can be seen in Table 5. In perlite substrate, all investigated ions were increased toward the end of season. At the end of the season K, Ca, Mg, P, NO_3, Cl and Na concentrations were the lowest, although not significant ($P>0.05$), under the Closed (M+) treatment.

pH and EC of the supply and drain solution

Mean pH and EC values of the drain solution and supply solution in the closed and open systems with and without AM colonization are shown in Table 6. pH values in drain solutions were lower than that of supply solutions, which may happen in soilless cultivation. However, there was

Table 5. Ion concentrations in root medium perlite at the beginning (November) and end (June) of the experiment (ppm).

Treatment	K		Ca		Mg	
	November	June	November	June	November	June
Closed (M-)	356	790 b	213	289 ab	89	83 a
Closed (M+)	427	560 c	240	226 b	77	37 b
Open (M-)	397	728 b	229	341 a	88	90 a
Open (M+)	437	945 a	252	320 a	74	49 b
P	0.299	0.0006	0.452	0.013	0.430	0.0008
LSD0.05	97.168	126.630	54.226	63.013	23.122	21.713
	H_2PO_4-P		NO_3		NH_4	
	November	June	November	June	November	June
Closed (M-)	54 b	107	1065 b	2248	289	346
Closed (M+)	49 b	84	1775 a	1661	347	380
Open (M-)	80 a	107	1220 b	2300	295	342
Open (M+)	62 b	125	1712 a	1935	298	376
P	0.0013	0.392	0.0001	0.134	0.211	0.928
LSD0.05	12.229	49.847	230.522	612.794	62.913	163.256
	SO_4		Cl		Na	
	November	June	November	June	November	June
Closed (M-)	485	817	160	309 a	234	245
Closed (M+)	575	895	167	216 b	223	201
Open (M-)	416	757	125	314 a	228	257
Open (M+)	560	997	175	340 a	245	222
P	0.584	0.790	0.421	0.002	0.915	0.157
LSD0.05	284.996	560.801	68.518	50.078	72.546	53.228

Closed (M-), closed system without mychorriza; Closed (M+), closed system with mychorriza; Open (M-), open system without mychorriza; Open (M+), open system with mychorriza.

no effect of AM on the pH of the drain solution. As expected, EC values in the re-circulating nutrient solutions in closed systems were higher than that of free drainage open systems. Supply solution EC values in closed systems with or without AM colonization were not different (M+ = 3.66 and M- = 3.71 dSm^{-1}, respectively). However, 0.27 dSm^{-1} EC difference in drain solution of the re-circulating systems with or without AM would be important; Closed (M+) 4.33 and Closed (M-) 4.60 dSm^{-1}, respectively. The reason of EC decrease in drain solution of Closed (M+) should be mychorrizal fungal colonization.

Table 6. Means of daily measured pH and EC values of the nutrient solution in the root environment (drain solution) and in supply solution in closed or open systems with and without myhorrizal inoculation.

Treatment	Supply solution		Drain solution	
	pH	EC	pH	EC
Closed (M-)	6.35	3.71	5.95	4.60
Closed (M+)	6.39	3.66	6.00	4.33
Open (M-)	6.57	2.85	6.04	3.47
Open (M+)	6.67	2.86	6.19	3.43

DISCUSSION

Some previous studies in soil and open soilless systems with different plant species (Cigsar et al., 2000; Sari et al., 2001; Charron et al., 2001; Sari et al., 2002; Karagiannidis et al., 2002; Ortas, 2003; Ikiz, 2003; Rehber, 2004; Ikiz et al., 2008) have shown that the AM fungi colonization is essentially accompanied with plant growth increases.

Contrary to these studies, the vegetative plant growth was not significantly increased for tomato in our study (Tables 1 and 2). Although the Closed (M+) plants in the first development stage, 31 days after transplanting, showed higher values for the growth parameters in comparison to the other treatments, it was not significantly important and this effect was not observed in later developmental stage (210 DAT). Bryla and Koide (1998) reported that changes in responsiveness to mycorrhizal colonization occurred with plant development stages in tomato. And one tomato genotype was unres-ponsive to mycorrhizal colonization in early stages of growth, but in later stages, mychorrizal fungi positively affected repro-

ductive characteristics such as fruit and seed development. In our work, the tomato genotype M19 was not significantly responsive to AM colonization for plant vegetative growth. However, fruit yield was higher in inoculated plants than that of non inoculated plants for both open and closed systems. On the other hand, the responsiveness to mychorriza could be related to "genetic control" of the genotype. Therefore, the responsiveness of a given genotype M19 may be differed in the same species.

Several studies in vegetables (Bryla and Koide, 1998; Sari et al., 2001; Rehber, 2004; Ikiz, 2003) have shown that mycorrhizal and phosphorus responsiveness is related. In the present study, phosphorus level (40-50 ppm) in nutrient solution was not so poor, which should be characteristic of hydroponics production of tomato plant. And also the phosphorus form (H_2PO_4-P) in nutrient solution makes for easier uptake of this nutrient for soilless cultivation versus to soil cultivation. Therefore, phosphorus level and its form in nutrient solution could be responsible for relatively low inoculation (28%) and less responsiveness on the vegetative growth. Ryan and Graham (2002) reported that highly available P often limits AM colonization and causes the C-costs to the host to outweigh any benefits from colonization.

AM inoculated plants in both closed and open systems produced less amount of leaf area in comparison to the non AM plants (Table 2). However, the plants with the less leaf area resulted in higher total fruit yields than that of non AM plants (Table 2). Open (M+) plants in comparison to Open (M-) plants produced 8% less leaf area, however, it produced 5% more fruit yield. Similarly, Closed (M+) plants produced 5% less leaf area than that of Closed (M-) plants; however, it produced 5% more fruit yield. This may be explained with effective photo assimilates use of AM plants for fruit production instead of vegetative growth. In AM conditions, since the root is colonized with mycorrhiza, there should be some benefits by adequate supply of water and nutrients to the fruits. The fruits in AM plants may act as stronger sink organs for photo assimilates and could compete with other plant parts. Inoculation with *G. fasciculatum* increased fruit yield and fruit number of tomato plants grown hydroponically in open and closed systems (Table 2). Similar positive effects were reported for pepper (Ikiz, 2003), melon (Rehber, 2004) and tomato (Utkhede, 2006) grown in open soilless systems. The higher EC in root medium of the closed systems could limit the fruit set. For this reason, the fruit number per m^2 in the closed systems was less than that of open systems (Table 2). However, the biggest fruit size was obtained by Closed (M+) plants. Open (M+) plants had the highest fruit yield but the fruit size was the smallest (Table 3). Therefore, higher fruit load under the Open (M+) treatment might have led to the observed decrease in fruit weight. The reverse was also true: the smaller the fruit size was, the higher the fruit load was. These results show that by the Closed (M+) plants the fruit set was well controlled and the fruit quality in terms of "size" was not reduced.

Many studies have indicated that AM fungi contribute to plant growth via enhancement of mineral nutrient uptake, especially immobile soil nutrients. Here in this study, the only slight N increases can be seen in AM fungi inoculated plants during the whole growing period in both open and close systems. During the first two analyses, Zn and, in some cases, K also were higher in AM plants (Table 4). In this soilless study, inoculated tomato plants did not have higher nutrient contents than non-inoculated plants in both open and closed systems. The reason could be perfect supply of nutrients in optimal ranges with pH regulated nutrient solution, in soilless systems. Root nutrient acquisition was increasingly influenced by acidifying the nutrient solution in optimal pH ranges in soilless systems versus in soil. No difference in the P concentration of mycorrhizal and non-mycorrhizal plants was observed, possibly owing to the lack of diffusion limits for P in hydroponic solution (Hawkins and George, 1997).

In re-circulating hydroponic systems, EC increase with time in root medium is a common disadvantage. And this may result in salinity problems. In this study, although AM fungi mitigate against growth and fruit yield reductions in Closed (M+) plants caused by EC increases in root medium, the mechanism involved remains unresolved (Al-Karaki, 2006). The aim of this study was whether AM inoculation of tomato plants grown in closed soilless systems alleviates EC increases in root medium and obtains better control of ion accumulation in the substrate. At the end of the growing period in June, ion concentrations in Closed (M+) substrate was lower for NO_3, Cl, Na, Mg, Ca and K, except SO_4 and NH_4, than that of substrate in the Closed (M-) (Table 5). Also EC of Closed (M+) was lower than Closed (M-) (Table 6). This can be explained by AM fungus excretion of some enzymes which allow dissolving of those ions for plant use purposes. Possibly, mycorrhizal inoculated plants depleted nutrients in the re-circulating solution. In the present experiment, in inoculated substrate SO_4 and NH_4 concentrations were higher than that of substrate in the non inoculated medium. This may be related to anion and cation balance by the mycorrhiza. It seems, under several conditions, mycorrhizal infected plant utilized NO_3^--N better than NH_4^+-N. On the other hand, plant species are different in terms of N form perforation. Ruan et al. (2000) has shown that tea plant's leaf dry matter production was significantly greater in the treatments with NH_4 than NO_3. Also, it has been shown that some forest tree plants are able to utilize ammonium preferentially over nitrate and ammonium net uptake rate several times higher than nitrate uptake (Malagoli et al., 2000).

Better root medium in Closed (M+) plants resulted in higher tomato yield than that of Closed (M-), 16.8 and 18.0 kg tomato per m^{-2}, respectively. Results indicate that inoculation with AM fungus improved yield and fruit size and may help alleviate deleterious effects of re-cycling closed soilless systems for tomato crop.

Conclusion

AM inoculation in soilless systems did not increasingly influence the plant vegetative growth and nutrient uptake of tomato cultivar M19. However, fruit yield absolutely increased with inoculation. AM inoculated tomato plants could effectively use photo assimilates for fruit production instead of vegetative growing and sink source regulation is better controlled. In the closed system with AM, ion accumulation and EC increases (salinity effects) were well controlled. In the future, because of water saving and environmental protection, use of closed soilless systems with re-circulating nutrient solution may be indispensable. In this case, arbuscular mycorrhizal (AM) fungi use in re-cycling soilless systems can have some advantages for better root medium.

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