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Growth and yield promoting effect of artificial mycorrhization on field tomato at different irrigation regimes

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ABSTRACT

Plant inoculation with formulations of vesicular–arbuscular mycorrhiza (VAM) can be a sustainable technique for the improvement of tomato yield and plant resistance to biotic and abiotic stresses. Combination of artificial plant mycorrhization with water deficit irrigation could be an effective agronomical technique for the optimization of water use efficiency of tomato in the areas with a limited water availability. A 2-year research on field tomato was undertaken in Southern Italy (40°24′N; 16°48′E; 10 m a.s.l.) to evaluate the effects on crop growth, yield, and fruit quality of the combination of seedling inoculation with two VAM formulations, alone or integrated with plant growth promoting rhizobacteria (PGPR), with different irrigation regimes (restoration of 0%, 50%, and 100% of maximum crop evapotranspiration). A split-plot experimental design with three reps was followed, with irrigation regimes in the main plots and mycorrhizal treatments in the subplots. Both VAM treatments, either with or without PGPR, demonstrated to be highly and rapidly effective on plant growth, as significantly increasing growth of tomato seedlings and plant biomass at mid and end of both crops compared to the non-inoculated control. Positive effects of mycorrhizal inoculation were extended also to marketable yield, mainly as a result of an increased number and weight of fruits. Both VAM inocula did not significantly affect fruit quality parameters, though increased water use efficiency of marketable yield. Both irrigation regimes positively affected tomato growth and marketable yield, whereas the fruit quality was better in less- and non-watered plants. Adversely to expectations, no synergism was found between artificial mycorrhization and irrigation regimes.

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) is classified as a crop with a high water demand and sensitive or moderately tolerant to water stress (Zheng et al., 2013; Karlberg et al., 2007). Tomato tolerance to water deficit was generally reported as depending on the cultivar, the phenological stage of deficit occurrence and the severity of the stress (Patanè et al., 2011; Candido et al., 2000; Perniola et al., 1994).

Under conditions of water scarcity, the large water demand of tomato can be a limit to crop productivity and, therefore, all agronomical practices enhancing drought resistance, plant water-use efficiency (WUE), and plant growth can be highly beneficial (Hardeman et al., 1999; Egilla et al., 2001; Kirnak et al., 2001; Sangakkara et al., 2000). Deficit irrigation is an agronomical practice aimed to maximize WUE and to stabilize yields by limiting water applications to the drought-sensitive growth stages of the crop (Fereres and Soriano, 2007). Deficit irrigation has been widely investigated on many crops, among which also tomato, and generally reported as a valuable and sustainable production strategy for dry regions (Geerts and Raes, 2009; Kirda et al., 2004). Under an average reference crop evapotranspiration (ETc), ranging from 3.3 to 7 mm d^{-1} during initial growing stage and full crop growth, respectively. Zairi et al. (2003) reported the application of 65% of ETc as economically acceptable to tomato crop. Moreover, Baselga Yrisarry et al. (1993) documented an enhancement of fruit quality as consequent to a moderate water stress, mainly due to the increase of soluble solids content. Adversely, Topcu et al. (2007)

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reported a significant reduction of tomato yield after the application of 50% of ETc.

Vesicular–arbuscular mycorrhiza (VAM) are mainly known to supply plants with additional nutrients, mainly nitrogen and phosphorus (Hodge et al., 2001; Harrison and van Buuren, 1995). An improvement of plant photosynthetic activity, absorption of microelements, and resistance to root pathogens, as well as of soil properties, were also reported as further effects of VAM symbiosis (Turk et al., 2006; van der Heijden et al., 2006). Moreover, the endotrophic symbiotic association of VAM with plant roots can also induce a better plant WUE and resistance to drought stress-saline (Augè, 2001; Lee et al., 2012).

Plant-growth-promoting rhizobacteria (PGPR), such as nitrogen fixers, fluorescent *Pseudomonas* and sporulating *Bacillus* can also play a relevant role in plant growth and soil pathogen suppression, mainly due to their synergistic interaction with VAM (Elshafie et al., 2013; Compant et al., 2005).

The positive effects of mycorrhizal symbiosis on plant health and growth are raising the interest in the use of these fungi as bio-fertilizers, bio-regulators, and bio-protectors, thus reducing the input of synthetic fertilizers and pesticides (Akhtar and Siddiqui, 2008; Gera Hol and Cook, 2005; Tilman et al., 2002). Seedling pre-inoculation with commercial preparations of VAM in nursery containers is the most promising method for the implementation of mycorrhization in horticultural crops (Candido et al., 2013; Douds et al., 2007; Larsen et al., 2007). A reduced seedling mortality, as well as a greater uniformity of crop growth and an increased crop yield were reported as effects of the pre-inoculation of seedlings with VAM, though largely depending on the specificity of the association between the fungus and the species/cultivars of host plant (Sorensen et al., 2008; Sensoy et al., 2007). Commercial inocula consists mostly of a mixture of VAM (*Glomus mosseae*, *G. intraradices*, *G. viscosum*) either pure or in a mixture with PGPR and ectomycorrhizal fungi (Dalpé and Monreal, 2004).

The association of artificial plant mycorrhization with water deficit irrigation can be an interesting technique for the optimization of water use in tomato, due to the better resistance to drought of mycorrhized plants (Davies et al., 2002; Augè, 2001). An increased root length and density or an altered root system morphology, as enhancing soil exploration and water extraction, have been hypothesized as potential mechanisms for the improved drought resistance of mycorrhized plants (Bryla and Duniway, 1997; Davies et al., 1996). Enhancement of plant stomatal control or root water uptake by mycorrhizal hyphae, as well as turgor maintenance by osmotic adjustment, have been also documented (Auge et al., 1986; Allen, 1982). The exploitation of beneficial effects of combining artificial plant mycorrhization with water deficit irrigation can be particularly useful to tomato crop in the areas where the availability of irrigation water is generally limited, such as Southern Italy and, in general, Mediterranean regions. This paper reports the results of a 2-year research on open field tomato aimed to investigate the agronomical effects of the combination of two different VAM inocula (with or without PGPR and saprophytic fungi) with different irrigation regimes (0%, 50%, and 100% restoration of ETc).

2. Materials and methods

The experiment was carried out at the experimental farm "Pantanello" (40°24′N; 16°48′E; 10 m a.s.l.), situated in the Metapontum plain (Basilicata Region, Southern Italy) in the years 2008 and 2009, on a silty-loam soil, with pH 7.68 ± 0.11, a low total nitrogen content (0.80 ± 0.12 g kg^{-1}) and a good level of exchangeable phosphorus (21.2 ± 1.2 mg kg^{-1}) and potassium (215 ± 9 mg kg^{-1}).

Soil was ploughed to a depth of 30 cm and then rotavated and leveled at the time of basal dressing (50 kg ha^{-1} N, 123 kg ha^{-1} P_2O_5, and 245 kg ha^{-1} K_2O).

2.1. Plant material

Tomato hybrid (F_1) cultivar 'Faino' (Syngenta Seeds Co.; Wilmington, DE, USA) was sown on 21 April 2008 and 28 April 2009, respectively, within a 62 × 35 cm box containing a turf-based substrate (COMPO SANA®, COMPO Italia Co., Cesano Maderno, Italy; 60% OM, 6.0–6.5 pH) and reared in a metal-plastic (PE 200 μm) greenhouse provided with lateral openings and anti-insect net. At the full extension of cotyledon leaves, i.e., on 5 May 2008 and 13 May 2009, respectively, the bare root seedlings were singly transferred to 60-cell polystyrene alveolate containers, filled with 63 ml of the same turf-based substrate per each cell. Seedlings at the 4–5 true leaf development stage were transplanted into the field on 26 May 2008 and 28 May 2009, respectively, 30 cm spacing between plants and 150 cm between twin rows (4.44 plants per m^2).

Tomato seedlings were inoculated with VAM formulations at their transfer into the alveolate containers (20 days before transplanting in field), by pipetting 1.15 ml of mycorrhizal formulations into each alveolus, corresponding to 0.1 g $plant^{-1}$ of biologically active ingredient.

2.2. Experimental design

A total of nine experimental treatments were provided, according to a split-plot block design, with three replicates of each treatment. Three irrigation treatments were placed in the main plots, and three mycorrhizal treatments in the 24.3 m^2 (4.5 × 5.4 m) subplots. Each subplot (experimental unit) consisted of three twin rows including 108 tomato plants. The three irrigation regimes were:

(1) *V100*, full restoration (100%) of ETc.
(2) *V50*, 50% restoration of ETc.
(3) *V0*, no restoration of ETc, i.e., a single irrigation at transplanting time.

The mycorrhizal treatments were:

(1) *M0*, control without any inoculation.
(2) *M1*, seedling inoculation with a commercial mycorrhizal formulation (Micosat F®, CCS Aosta S.r.l. Company; Quart, Italy) containing VAM (*G. mosseae* GP 11, *G. intraradices* GB 67, and *G. viscosum* GC 41), rhizosphere bacteria (*Agrobacterium radiobacter* AR 39, *Bacillus subtilis* BA 41, and *Streptomyces* spp. SB 14), and saprophytic fungi (*Beauveria* spp., *Trichoderma harzianum* TH 01, *Pichia pastoris* PP 59). In particular, 100 g of this formulation contained 25 g of ground mycorrhizal roots together with spores and hyphae of *Glomus* (crude inoculum). The percentage of biologically active ingredients was 6.2%.
(3) *M2*, treatment with the single *Glomus* spp. commercial inoculum described above, without bacteria and saprophytic fungi.

A drip irrigation system (water flow 2.5 L h^{-1}/dripper) was used. Hoses, pierced with holes every 30 cm, were placed in the middle of the twin-rows.

Irrigation scheduling of V100 and V50 was based on simplified soil water balance method (Evapotranspirometric Criteria) (Doorenbons and Pruitt, 1977); ETc was calculated according to the evapotranspiration approach of (ETc = ET0 × Kc), where ET0 is the reference evapotranspiration, calculated according to Hargreaves and Samani (1985), and the crop coefficient (Kc) as reported by Tarantino and Onofri (1991) for tomato. Water was applied on a weekly basis.