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Impact of mycorrhizal fungi on P acquisition, yield and water use efficiency of onion under regulated deficit irrigation

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An experiment was conducted during 2009 for evaluation the effect of mycorrhizal colonization and regulated irrigation at different stages of growth on yield and water use efficiency (WUE) of onion. Pre-inoculated of onion (Red Azar Shahr cv.) seedling with two species of Arbuscular Mycorrhizal (AM) fungi (*Glomus versiforme* and *G. etunicatum*) and non-mycorrhizal ones transplanted at density of three plants per pot. Plants were subjected to four irrigation regimes, so at different growth stages including: vegetative growth period, bulb formation and ripening, onions were received different amount of water based on ET, I_1 (100,100 and 80% of ET) I_2 (75, 100 and 80 % of ET), I_3 (75, 75 and 60% ET) and I_4 (75, 60 and 80% of ET) at three growth stages respectively. After bulb maturation, bulb yield and dry weight and P concentration were determined and WUE was calculated. The results indicated that mycorrhizal plants had high P concentration, and produced greater bulb than non-mycorrhizal onions in all irrigation regimes. WUE was improved by mycorrhizal symbiosis regardless of irrigation regime; however *G. versiforme* was more effective in comparison with *G. etunicatum*. Among irrigation regime treatments only sever water stress in bulb formation stage (I_4) led to drastic decrease in WUE. In aspect of interaction of mycorrhizal colonization and irrigation regime result indicated that onions inoculated by *G. versiforme* at I_2 and treatment by *G. etunicatum* at I_2 and I_3 led to highest WUE and control plants under I_4 irrigation regime showed the lowest WUE.

Key Words: Onion, Mycorrhizal fungi, Deficit irrigation, WUE, Phosphorus.

Onion (*Allium cepa* L.) is considered as an important vegetable crop in many parts of the world and mostly grown in irrigated lands. Onion is regarded as fairly large consumer of water, its irrigation requirement in the North West of Iran being in the region of 8000 m^3 ha^{-1} which restricts its production. Restricted water resources are limiting irrigation application in the world especially in arid and semi arid regions. In some location, the available water supply is inadequate to production of suitable yield on irrigated lands. In the other regions, the available water for irrigation is already regulated and requires deficit irrigation (Martin *et al*., 1989).

Deficit irrigation is a suitable way to increasing water use efficiency for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (Kirda, 2000). By controlled deficit irrigation (CDI) it is possible to ration water application on a highly selective basis at particular phonological stages with

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negligible losses in aspects of quantity and quality for final output (English and James, 1990). Kadayifci *et al*. (2005) reported that under water deficit irrigation, onion yield was decreased whereas, in water limited condition deficit irrigation could be used during either the ripening or vegetative growth stages of onion. Martin *et al*. (2004) reported that water shortage during the vegetative growth and bulbification stages led to higher percentage of small size bulb.

Water deficit stress limits crop production in arid and semi arid areas (Kramer and Boyer, 1995). Optimization of irrigation is particularly critical for production and profitability of horticulture crops (Hardeman *et al*., 1999). Kadayifci *et al*. (2005) reported that regulated water deficit irrigation increases onion water use efficiency, so it is possible producing of onion by applying less water at suitable period of onion growth.

Arbuscular mycorrhizal fungi (AMF) can mitigate plant response to water deficit stress (Davies *et al*., 1992). According to Fitter (1985), the influence of AMF on plant water relations may be a secondary consequence of enhanced host P nutrition. Bolandnazar *et al*. (2007) reported that symbiosis of onion with mycorrhizal fungi enhance onion yield and water use efficiency under well watered and water stress condition. The objective of this research is the evaluation the effect of two mycorrhizal fungi specious and deficit irrigation at different stages of onion growth on phosphorus acquisition and its effects on bulb yield and water use efficiency.

Material and Methods

A pot experiment was conducted for the study the effect of mycorrhizal colonization of onion under regulated deficit irrigation during 2009 in the Agricultural Research Station of the University of Tabriz, Iran. A factorial experiment based on complete randomized block design with two factors and three replications was carried out. The factors were arbuscular mycorrhizal fungi (AMF) species, *Glomus versiforme* (Karsten Berch) and *Glomus etunicatum* (Becker & Gerdman) and non-mycorrhizal (NM) plants as control and four irrigation regimes I_1, I_2, I_3 and I_4. For seedling production, onion (*Allium cepa* L. cv. Red Azar-Shahr) seeds were sown in a sandy loam soil that was autoclaved in 121◦C for 2 h. Fifty grams of mycorrhizal fungi inoculums were mixed in to 1 kg of soil. At transplanting time (9 weeks after sowing) root colonization in mycorrhizal seedlings had reached above 60% and root colonization was not seen in control plants. Onion seedlings were then transplanted at the density of three plants per pot; each pot was 22 cm in diameter and 21 cm in deep and contained 5.6 kg soil. Water content in all pots was kept at field capacity (FC = 29.7%, w/w) until 12 days after transplanting for seedling establishment. Irrigation was conducted based on evapotraspiration (ET) at different stages of onion growth, vegetative growth period, bulb formation and bulb maturity. So, four irrigation regime were constructed, I_1, I_2, I_3 and I_4. I_1 (100,100 and 80% of ET) I_2 (75, 100 and 80 % of ET), I_3 (75, 75 and 60% ET) and I_4 (75, 60 and 80% of ET), plants received aforementioned amount of water based on ET at each growth stages. Plants were kept in a greenhouse under a 16 h photoperiod, 24±4 / 18±3°C (day/ night temperatures) and 40-60% relative humidity and all pots were weighted every day. Onion bulbs were harvested at maturity and bulb yield and dry weight was measured. Daily evapotranspiration from the pots was estimated by (Kadayifci et al. (2005):

$$ET_{(o)i} = (W_{i-1} - W_i) / (\rho_w \cdot A);\ i = 1,2,3,\ldots \quad (1)$$

$ET_{(o)i}$ is the i^{th} day evapotranspiration (mm), W_{i-1} and W_i are weights (kg) of the pot at day $i-1$ and i, respectively, ρ_w is water density (g cm^{-3}), and A is surface area (m^2) of the pot. Water use efficiency (WUE) was computed as:

$$WUE = Y / W \quad (2)$$

Y is the onion bulb yield (g pot^{-1}) and W is the irrigation used water for total growth period (kg).

Phosphorus was analyzed by a vanadate-molybdate method using a spectrophotometer (Motic, CL-45240-00, China). Data were statistically analyzed by analysis of variance with the Mstat-C Program (Mich. University, East Lasing, Mich., USA). Significant differences at P=0.01 were tested using Duncan's multiple range tests.

Results and Discussion

Plants inoculated by *G. versiforme* and non-mycorrhizal plants produced the highest and lowest bulb yield respectively. However mycorrhizal onions (both plants inoculated by *G. versiforme* and *G. etunicatum*) produced more dry bulb yield than control ones (Table 1). I_1 irrigation regime led to highest bulb yield and under I_4 irrigation regime bulb yield was decreased severely (Table 2). In aspect of interaction between mycorrhizal colonization and irrigation regime, onions inoculated by *G. versiforme* at I_1 irrigation regime and control plants under I_4 irrigation regime produced the highest and lowest bulb yield respectively (Fig. 1). It must be mention that mycorrhizal colonization mitigate moderate water deficit stress at vegetative growth stage (I_2) and moderate water stress at vegetative growth and bulb formation stages and sever water deficit stress at bulb maturation stage (I_3), but this positive effect of mycorrhizal symbiosis under sever water stress at bulb formation was not significant. Data indicated that inoculation of onion plants by mycorrhizal fungi increased P acquisition significantly; there was no significant difference between of two species of mycorrhizal fungi, *G. versiforme* and *G. etunicatum* (Table 1). This finding is in agreement with our previous results (Bolandnazar *et al*., 2007 and Aliasgharzad *et al*., 2009). Results showed that irrigation regimes affected P concentration and onion bulb dry weight significantly (Table 2). Improvement growth effects of mycorrhizal colonization have been attributed to improved water relations resulting from enhanced P nutrition (Bethlenfalvay *et al.*, 1988; Davies *et al*. 1992) and hyphal uptake of water by mycorrhizl fungi (Faber *et al*., 1991; Ruiz-Lozano *et al.*, 1995). There was significant positive correlation between P concentration and onion bulb dry weight (R= 0.76). Bulb dry matter enhancements attributed to root AMF colonization which decreased under water-stressed conditions. This may have occurred because of reduced AMF-root colonization under water-stressed conditions, with subsequent lower effects of AMF on plant growth (Al-Karaki, 1998).

Table 1 Effect of mycorrhizal fungi on P concentration and bulb dry weight and yield and water use efficiency of onion

Mycorrhizal Fungi	P (mg/g)	Bulb yield (g/pot)	Bulb dry weight (g/pot)	WUE (gFW/kg)
G. versiforme	0.865 a*	278.4a	27.675a	11.91a
G. etunicatum	0.767 a	260.3b	25.419a	11.40b
Non-Mycorrhizal	0.45 b	209.4c	19.911b	9.12c

*-Within each column, means followed by the same letter aren't significantly different (P<0.01) using Duncan's multiple range test.

Table 2 Effect of irrigation regime on onion P concentration and bulb dry weight and yield and water use efficiency

Irrigation Regime	P (mg/g)	Bulb yield (g/pot)	Bulb dry weight (g/pot)	WUE (gFW/kg)
I_1	0.657 b	337.8a	25.611a	12.21a
I_2	0.767 ab	280.7b	25.590a	12.34a
I_3	0.860 a	244.1c	25.806a	12.19a
I_4	0.499 c	134.9d	20.337b	6.60b

*-Within each column, means followed by the same letter aren't significantly different ($P<0.01$) using Duncan's multiple range test.

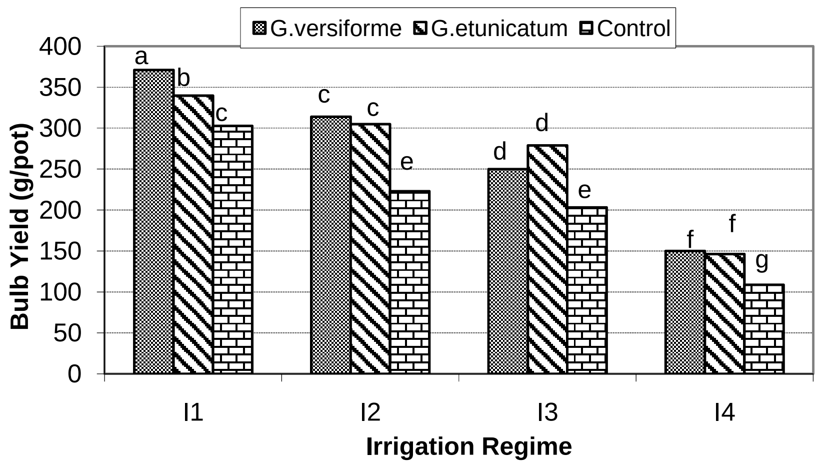

Fig. 1 Effects of AMF species and irrigation regime on bulb yield of onion. Dissimilar letters indicate significant differences (P<0.01).

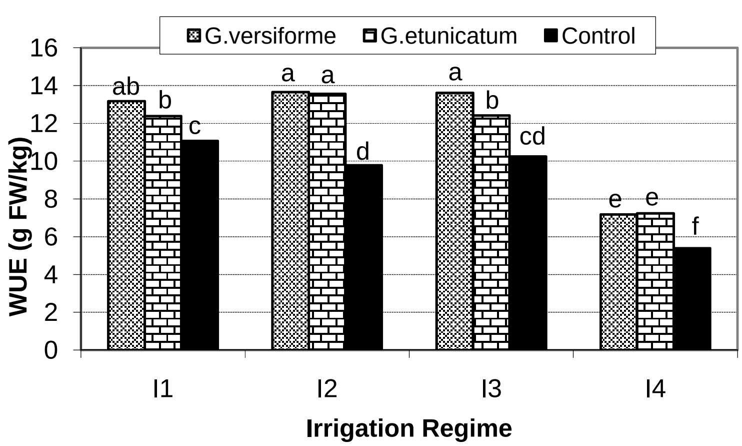

Fig. 2 Effects of AMF species and irrigation regime on water use efficiency of onion. Dissimilar letters indicate significant differences (P<0.01).

Plants under I_3 irrigation regime that received water in amount of 75, 75 and 60% of ET at three growth stages (vegetative growth, bulb formation and bulb maturity) respectively, had the highest P concentration and plants under I_4 treatment had the lowest P. Whereas onion under I_1, I_2 and I_3 irrigation regimes produced greater bulb than I_4 significantly which indicating that only at I_4 irrigation regimes plants suffered from deficit water so bulb yield were decreased at this treatment. It seems that onion is very sensitive to water stress at bulb formation stages and this finding is in agreement with the results of Kadayifci et al. (2004).

Water use efficiency (WUE) was improved by mycorrhizal symbiosis regardless of irrigation regime; however *G. versiforme* was more effective in comparison with *G. etunicatum* (Table 1). Among irrigation regime treatments only sever water stress in bulb formation stage (I_4) led to drastic decrease in WUE (Table 2). In aspect of interaction of mycorrhizal colonization and irrigation regime result indicated that onions inoculated by *G. versiforme* at I_2 and treatment by *G. etunicatum* at I_2 and I_3 led to highest WUE and control plants under I_4 irrigation regime showed the lowest WUE (Fig. 2). It seems that restrictive control on stomatal opening and closure, improvement of root water uptake characters, and probably better nutrition status specially phosphorus (Table 1), all enhanced by AMF symbiosis have led to higher yield and WUE . This conclusion corroborates the finding of Ebel *et al*., (1997), Green *et al*., (1998), Auge (2001) and Auge *et al*., (2004). They reported that mycorrhizal plants under both well watered and deficit conditions had higher stomatal conductance, ET and leaf growth rate compared to non-mycorrhizal ones. They also found that the differences in the effectiveness of fungi species to enhance water uptake was related to their ability to produce external mycelium. Increases in accessibility to greater available soil water reserves, have also been reported by Fitter (1985). Higher WUE in mycorrhizal than non-mycorrhizal plants may indicate that AMF improved the ability of roots to acquisition of soil moisture, thus maintaining opened stomata in leaves and enhancing dry matter production. Enhanced water conductivity has been attributed to increased area for water uptake provided by AMF hyphae in soil (Bethlenfalvay *et al*., 1988; Hardie and Leyton, 1981). Increased water transport by roots of mycorrhizal plants has been reported for different plant species (Ellis *et al*., 1985).

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