



Effect of mycorrhiza application on plant growth and yield in potato production under field conditions

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Abstract

The effect of mycorrhiza fungi was studied on growth and yield of potato (*Solanum tuberosum* L.) in Fereidoonshahr, Esfahan, Iran during 2013 growing season. The experiment treatments were arranged in a factorial design based on a complete randomized block design with three replications. Four phosphorus fertilizer levels of 25%, 50% 75% and 100% P recommended with two levels of Mycorrhiza: with and without Mycorrhiza (control) were assigned in a factorial combination. Results showed that tuber size, number of tuber per plant, tuber yield, and starch yield were significantly higher in inoculated plants than in non-inoculated plants. Tuber size, number of tuber per plant, tuber weight per plant, number of tuber in m², tuber yield, and starch yield increased with increasing P level above 75% P recommended in non-inoculated plants, whereas no significant difference was observed between 75% and 100% P recommended. The positive effect of mycorrhizal inoculation decreased with increasing P levels due to decreased percentage of root colonization at higher P levels. According to the results of this experiment, application of mycorrhiza in the presence of 50% P recommended had a favorable result and could increase tuber yield and starch production to an acceptable level. Therefore, mycorrhiza could be considered as a suitable substitute for chemical phosphorus fertilizer in organic agricultural systems.

Keywords: phosphorus fertilizer; tuber yield; potato; mycorrhiza

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Introduction

Phosphorus is an important plant macronutrient, making up about 0.2% of a plant's dry weight. Phosphorus is one of the most essential elements for plant growth after nitrogen. However, the availability of this nutrient for plants is limited by different chemical reactions especially in arid and semi-arid soils (Mehrvarz et al., 2008). Phosphorus plays a

significant role in several physiological and biochemical plant activities like photosynthesis, transformation of sugar to starch, and transporting of the genetic traits. Sharma (2002) reported that one of the advantages of feeding the plants with phosphorus is to create deeper and more abundant roots. Phosphorus causes early ripening in plants, decreasing soil moisture as well as improving crop quality and is the most sensitive nutrient to soil PH (Malakooti, 2000).

Malakooti and Nafisi (1995) declared that the best PH for phosphorous uptake by plants is

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6.5. Arpana et al. (2002) reported that a great proportion of phosphorus in chemical fertilizer becomes unavailable to the plants after its application in the Soil. They referred this to formation of strong bonds between phosphorous with calcium and magnesium in alkaline PH and the same bonds with iron and aluminum in acidic soil. The mobility of this element is very slow in the soil and cannot respond to its rapid uptake by plants. This causes the creation and development of phosphorus depleted zones near the contact area of roots and soil in rhizosphere. Therefore, the plants need an assisting system which could extend beyond the depletion zones and help to absorb the phosphorus from a wider area by developing an extended network around root system (Salehrastin, 1999). The research on Mycorrhiza fungus and its role in soil and plant has been an interesting scientific subject since 1800. The presence of this fungus in rhizosphere provides with an advantageous and interactive symbiosis relationship between a higher plant root and a nonpathogenic fungus. Through receiving energetic carbon resources from plant, fungus facilitates the uptake of many inorganic nutrients such as phosphorus, zinc, molybdenum, copper and iron for it. Arbuscular mycorrhizal (AM) symbioses are mutualistic associations between soil-borne fungi belonging to the phylum Glomeromycota and the roots of about 80% of land plant species, including the most important agricultural crops (Ceccarelli et al., 2010). AM fungi play a key role in water uptake (Marulanda et al., 2003), increased antioxidant activity (Marulanda et al., 2007), altered aquaporin expression (Uehlein et al., 2007), osmotic adjustment (Wu and Xia, 2006), hormone relations (Estrada-Luna and Davies, 2003), biocontrol of pathogens (Ozgonen et al., 2001), soil fertility, plant nutrition, enhancing the uptake, and translocation of mineral nutrients (mainly P, N, S, K, Ca, Fe, Cu, and Zn) from soil to host plants (Alguacil et al., 2006; Ceccarelli et al., 2010), by means of an extensive below ground hyphal network, which spreads from colonized roots into the soil environment (Ceccarelli et al., 2010). The symbiotic relationship between Mycorrhiza and plants is one of the most abundant symbiotic activities in plant kingdom which exists in most of the ecosystems.

Unfortunately, the neglectful interference of human activities such as over-application of fungicides and frequent chemical phosphorous fertilizers application (mainly in intensive agricultural systems), have seriously threatened this advantageous symbiosis. Efforts to produce inoculants from Mycorrhiza fungi and to use it in proper environmental conditions is a significant environmental friendly way to help plant growth and development through the enhancement of this natural phenomenon (Mehrvarz et al., 2008). The significance of this practice, especially under low fertility conditions, has been very obvious.

Photosynthesis improvement in plants through Mycorrhiza symbiosis is mainly due to the increase in transporting of inorganic elements from soil to plants. One of the most important means to achieve the goals of sustainable agriculture is to extend the application of biological fertilizers. To reach this goal, it is necessary to moderately use chemical fertilizers and pesticides through the time and in the mean time increase the soil organic matter content (Salehrastin, 1999).

Potato is the world's fourth most important food plant after rice, wheat and maize. Potato plant has one of the heaviest demands for fertilizer inputs over other vegetable crops, i.e., its N, P, and K requirements are respectively 100%, 100%, and 33% greater than other vegetable crops (khoshnevisan and et al., 2013). Increased plant growth in the presence of mycorrhizal infection has been attributed mainly to the enhanced uptake of P. The beneficial effects of VAM inoculation on P uptake, growth, and yield responses in field experiment studies have not been carried out on potato. Hence, the effect of VAM on P availability, growth, and yield of potato was investigated at different P levels.

Materials and Methods

Mycorrhizal inoculum

The mycorrhizal inoculum for each endophyte consisted of soil, spores, mycelium, and infected root fragments. *Glomus intraradices* isolates used as inoculum had similar characteristics (an average of 100 spores per g and 80% of roots infected). Symbiotic fungal partner, *Glomus intraradices* (isolate no. OM/95)

was produced in a soil:sand (1/1, v/v) mixture using maize as the host plant. Inoculum of *Glomus intraradices* (30 g), consisting of spores, external mycelium, and AMF colonized roots was laid under the tube. The same amount of sterilized inoculum was laid into the Mycorrhiza plots.

Experimental design

The experiment was conducted in fereidoonshar, esfahan, Iran. The height of the experimental site from the sea level was 2530 m. The mean annual precipitation is 540 mm and the long term minimum and maximum monthly precipitation ranges from 2.5 to 179.6. mm, respectively. The mean annual temperature is 10.1° C while the mean maximum and minimum temperatures are 15 and 4.4° C, respectively. The soil texture of the research site was clay-loam with a pH of 7/7. The soil chemical properties before the start of the experiment are presented in (Table 1). A factorial design was used with two factors: with and without AM inoculum, P fertilizer at four levels, P1 (25% recommended), P2 (50% recommended), P3 (75% recommended), and P4 (100% recommended), on the basis of a randomized complete block design in three replicates. Each plot consisted of 6 rows, 5m long with 75cm spaced between rows and 25cm

distance between plants on the rows. Potato (*Agria cultivar*) was planted at 5/33 plants m² density. Tuber bed preparation was done in early spring. Nitrogen (250 kg ha⁻¹) was applied in the form of urea (one third before planting and the rest as side-dressed at the beginning of flowering stage).

In the flowering stage, root colonization by AM was determined by preparing root samples at 0.5 g and one hundred root segments were examined for each sample. The stained roots were observed under a compound microscope. A root segment was considered as AM positive if it showed any fungal bodies like mycelium, vesicle and arbuscules. Percentage of root colonization was calculated as follows:

Root colonization (%) = Number of AM positive segments/Total number of segments observed × 100

At the harvest stage, the two middle rows were used for sampling and study parameters such as plant height, number of tubers per plant, tuber weight per plant, tuber yield, number of tuber in m², tuber protein, starch percentage, and starch yield were assessed.

Statistical analysis of the data was done by using SAS (Sas Institute Inc, 1988). Means were compared using the Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Table 1
Soli physical and chemical properties of the experimental area

Depth (cm)	Silt (%)	Sand (%)	Clay (%)	Soil texture	PH	E.C (ds/m)	Organic Carbon (%)	Total N (%)	Available P (P. P. M)	Available K (P. P. M)
0 - 30	32	38	30	Clay-loam	7.7	1.8	1.8	0.12	5.5	266

Table 2
Analysis of variance of the measured parameters

S.O.V	d.f	Mycorrhizal Colonization	Plant Height	Tuber Size	Number of Tuber per Plant	Tuber Weight per Plant	Tuber Yield	Number of Tuber in m ²	Tuber Protein	Tuber Starch	Starch Yield
Rep	2	4.041ns	6.680ns	2.110ns	25.305ns	300.616**	1.257ns	0.115ns	7.271ns	2.183ns	0.166ns
M	1	2998.375**	11.269ns	4.616*	669.327*	1.338ns	1.597*	0.446ns	17.361n	13.801ns	0.447*
P	3	291.152**	10.354ns	10.717**	433.758*	116.864**	1.624**	1.950*	3.860ns	11.487ns	0.439**
M*P	3	262.708**	4.961ns	0.293ns	96.849ns	12.794ns	1.072ns	0.016ns	7.419ns	0.069ns	0.113ns
Error	14	23.279	33.162	0.698	39.242	12.167	1.093	0.688	15.877	7.551	0.138
C.V (%)		29.1	2.8	7.7	7.8	2.7	6.9	7.4	11.1	6.2	9.9

*: Significant at 0.05 level, **: Significant at 0.01 level, ns: No significant difference

Results

Root mycorrhizal colonization

Analysis of variance (Table 2) showed significant differences in root Mycorrhizal colonization ($P \leq 0.01$). The maximum Mycorrhizal colonization of 25.7% was obtained in 25% P recommended and the minimum Mycorrhizal colonization of 13.1% was obtained using 100% P recommended which was not significantly different from 75% P recommended level (Table 3). In this study, Mycorrhizal colonization fluctuated from 3.5 in treatment (MOP3) to 46.1 in treatment (M1P1) (Table 4).

Plant height

The analysis of variance (Table 2) showed no significant effect of phosphorus fertilizer, Mycorrhiza treatment, and their interaction effects on plant height

The number of tubers per plant

The number of tubers per plant was significantly affected by mycorrhiza and phosphorous levels, but there no interaction effect was observed (Table 2). Mycorrhizal plants had about 14% more tubers per plant compared with non-mycorrhizal plants (Table 3).

Tuber yield

Mycorrhiza and phosphorus fertilizer had significant effects on tuber yield, but no

interaction of their effects was observed on the tuber yield. Mycorrhiza through symbiosis activity could cause an increase in P nutrient around roots and improve its absorption by roots. At all levels of phosphorous fertilizer, the mycorrhiza plants had higher tuber yield. In fact, at 25% level of P fertilizer, the mycorrhizal plants had 3% higher tuber yield compared to non mycorrhizal plants, while at 50%, 75%, and 100% P recommended, mycorrhizal association resulted in higher tuber yield of 2%, 1%, and 5%, respectively. The tuber yield in M1P2 ($21.624 \text{ t. ha}^{-1}$) had no significant effect with M1P4 ($21.925 \text{ t. ha}^{-1}$) (Table 4). Applying biological fertilizer treatment (inoculation by mycorrhiza) with 50% phosphorous recommended did not make a significant difference compared with the high rate of chemical phosphorous application (MOP4 treatment) (Table 4).

Number of tuber per m^2

Number of tuber per m^2 was significantly affected by phosphorus fertilizer (Table 2) but mycorrhiza had no significant effect on this trait. Maximum number of tuber per m^2 (33.62) was obtained in P4 (100% P recommended) which was not significantly different from P3 and P2 treatment; on the other hand, the minimum number of tuber per m^2 (28.02) was obtained in P1 (25% P recommended) (Table 3).

Tuber protein

Among the treatments, the highest and lowest tuber protein were obtained in (M1P1)

Table 3
Mean comparisons of the main effects

Treatment	Mycorrhizal Colonization (%)	Plant Height (cm)	Tuber Size (cm)	Number of Tuber per Plant	Tuber Weight per Plant (gr)	Tuber Yield (ton. ha^{-1})	Number of Tuber in m^2	Tuber Protein (%)	Tuber Starch (%)	Starch Yield (ton. ha^{-1})
M levels										
M0	4.4b	70.7a	4.4b	6.8b	354.4a	21.287b	22.39b	9.2a	23.5a	4.87b
M1	31.7a	72.1a	5.3a	7.9a	354.1a	21.603a	40.91a	11a	25.1a	5.07a
LSD	5.86	6.99	0.73	5.48	3.05	0.915	0.726	3.48	2.40	0.32
P levels										
P1 (25%)	25.7a	69.8a	3.2c	6.9b	352.1c	21.066c	28.02b	9.9b	22.8a	4.80c
P2 (50%)	18.9b	71.2a	4.4bc	7.1ab	354.5ab	21.300bc	33.50a	8.9bc	23.4a	4.88bc
P3 (75%)	14.7bc	71.7a	5.5ab	7.6a	354.2b	21.634ab	33.38a	10.5a	24.7a	5.07ab
P4 (100%)	13.1c	72.8a	6.4a	8.0a	356.2a	21.780a	33.62a	11a	26a	5.20a
LSD	5.97	7.13	1.03	7.75	5.99	1.29	1.02	4.93	3.4	0.46

Means which have at least one common letter are not significantly different at the 5% level using (DMRT).

with average 11.8 % and (MOP2) with average 7.1 %, respectively (Table 4). Mycorrhizal plants were more successful than non-mycorrhizal plants in transportation of assimilates from source to sink parts and produced high tuber protein; however, the difference was not statistically significant.

Starch yield

Starch yield was significantly affected by mycorrhiza and phosphorous fertilizer levels (Table 2). The maximum starch yield of 5.2 t.ha⁻¹ was obtained in 100% P recommended which was not significantly different from 75% P recommended level and the minimum yield of 4.8 t.ha⁻¹ was obtained using 25% P recommended (Table 3). Also, Mycorrhizal plants had about 4% more starch yield compared to non-mycorrhizal plants (Table 3).

Discussion

There is little information about mycorrhizal colonization of the potato. A variety of studies suggest that phosphorous uptake by plant roots can be enhanced when they are infected by arbuscular mycorrhiza (AM) fungi. Thus, it can be concluded that the high rate of chemical phosphorus fertilizers application, leads to antagonistic interaction with mycorrhiza. At low levels of chemical phosphorus fertilizer, mycorrhiza was able to increase the root colonization significantly. It seems that phosphorus does not play an important role in enhancement of plant height. Mycorrhiza plays an important role in potato generative growth

and therefore makes a significant increase in the number of tubers per plant. Tohidi-Moghaddam et al. (2004) reported that phosphorous solubilizing microorganisms increase the available phosphorous in the soil which could enhance the tuber number per plant. According to the results of this experiment, application of mycorrhiza in the presence of 50% P recommended had an appropriate performance and could increase tuber yield and starch production to an acceptable level. It thus could be considered as a suitable substitute for chemical phosphorus fertilizer in organic agricultural systems. On the basis of this study, it seems that mycorrhiza and phosphorous fertilizer did not have much positive effects on number of tuber per m². It can be also concluded that the initial soil phosphorous content may already be adequate without phosphorous fertilizer application. An advantage of mycorrhiza is its effect on plants' photosynthesis. VAM plants often display higher rate of photosynthesis than NM counterparts do, which is consistent with VAM effects on stomatal conductance. Most of the researchers suggest that VAM symbiosis increases the units of photosynthesis and improves the rate of photosynthetic storage and export at the same time (Auge, 2001). As for the positive effect of mycorrhiza on starch yield, it can be concluded that to increase starch yield in potato, use of biological fertilizers is preferred to the application of chemical ones. This can partially encourage farming with the mere use of biological fertilizers (organic systems).

Table 4
Mean comparison of the interaction effect

Treatment	Mycorrhizal Colonization (%)	Plant Height (cm)	Tuber Size (cm)	Number of Tuber per plant	Tuber Weight per Plant (gr)	Tuber Yield (ton. ha ⁻¹)	Number of Tuber in m ²	Tuber Protein (%)	Tuber Starch (%)	Starch Yield (ton. ha ⁻¹)
MOP1	5.0d	68.9a	2.9c	6.3b	351.4c	20.889c	22.898c	7.7a	21.9a	4.591c
M1P1	46.1a	70.8a	3.4c	7.6ab	352.8bc	21.443bc	33.150b	11.8a	23.8a	4.906abc
MOP2	4.7d	71.1a	3.9bc	6.1b	355.3ab	21.177bc	23.934c	7.1a	22.7a	4.752bc
M1P2	33.0b	71.2a	4.9abc	8a	353.7bc	21.624ab	43.073a	10.5a	24.1a	4.999ab
MOP3	3.5d	70a	4.6abc	7.2a	354abc	21.648ab	23.159c	10.3a	23.9a	4.995ab
M1P3	25.7c	73.4a	6.3ab	7.9a	354.4ab	21.820a	43.599a	10.4a	25.4a	5.142a
MOP4	4.4d	72.9a	6.1ab	7.6ab	356.7a	21.835a	23.427c	11.3a	25.3a	5.146a
M1P4	21.7c	72.8a	6.7a	8.3a	355.6ab	21.925a	43.804a	10.6a	26.7a	5.251a
LSD	8.45	10.08	1.46	10.97	6.1	1.83	1.45	6.97	4.81	0.65

Means which have at least one common letter are not significantly different at the 5% level using (DMRT)

Conclusion

Results from the present study indicated that tuber sizes, tuber number per plant, tuber yield, and starch yield have been affected significantly by inoculation with Mycorrhiza, because this biofertilizer can enhance absorption of phosphorous by the plant.

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