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MYCORRHIZAL INOCULATION AND PHOSPHORUS FERTILIZERS TO IMPROVE ONION PRODUCTIVITY IN SALINE SOIL

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ABSTRACT

This study investigated arbuscular mycorrhizal fungi (AMF) inoculation and phosphorus fertilizer on growth, productivity and quality of onion grown under saline soil conditions. The experiment was conducted in the Experimental Farm of Desert Research Center, Ras Sudr, South Sinai Governorate, Egypt. Egyptian local onion cultivar 'Giza 20' was selected. Treatments were: two arbuscular mycorrhizal fungi (AMF) inoculation treatments [without inoculation (–AMF) and with mycorrhizal inoculation (+AMF)] and four phosphorus supplied treatments (0, 48, 96 and 144 kg P_2O_5 ha^{-1}). Mycorrhizal inoculation and phosphorus addition affected the plant growth, bulb yield and quality. Morphological traits of plant (height, leaf number, fresh and dry weight), neck diameter, bulb characters (diameter and weight), total soluble sugars (TSS), protein, P content increased, while proline content decreased due to the inoculation of AMF and phosphorus application. Onion inoculated by AMF combined with 96 or 144 kg P_2O_5 ha^{-1} gave the highest productivity under saline conditions.

Key words: arbuscular mycorrhizal fungi, P_2O_5, *Allium cepa*, salinity

INTRODUCTION

Salinity is one of the important problems that distinguish the lands belonging to the arid and semi-arid conditions. Such a problem is caused by the decrease in the amount of rainfall and unfavorable practices such as fertilization and irrigation with saline ground water [Villa-Astoria et al. 2003]. Harmful effects of salinity may include physiological drought, nutritional imbalance, toxicity of excessive Na^+ and Cl^- ions towards a cell, and all of these factors altogether [Misra et al. 2006, Evelin et al. 2009]. Therefore, to deal with saline soils and minimize crop loss, scientists have found different methods to alleviate the soil salinity stress. One of these methods are biological methods, such as arbuscular mycorrhizal fungi, which comprise a group of root obligate biotrophs that exchange mutual benefits with about 80% of plants. Thus, they are considered natural biofertilizers [Berruti et al. 2016]. Several studies investigating the role of arbuscular mycorrhizal fungi in protection against salt stress have demonstrated that the symbiosis often results in an increased nutrient uptake [Al-Karaki and Clark 1998], an increase in photosynthetic rate [Sheng et al. 2008], water-use efficiency [Graham and Syversten 1984] and enhancing the activities of antioxidant enzymes [Zhong Qun et al. 2007, Hashem et al. 2016], suggesting that salt-stress alleviation by AMF results from a combination of nutritional, biochemical and physiological effects [Evelin et al. 2009]. Other researchers have noted that mycorrhizal fungi inoculation increased the growth, yield

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and nutrients concentration of onion [Poss et al. 1985, Abdullahi and Sheriff 2013, Mohamed et al. 2014].

Phosphorus (P) is the second essential macronutrient in soils, after nitrogen, that plays an important role in plant growth. It is involved in many physicochemical reactions in plants such as energy transfer, photosynthesis, respiration, nutrient movement within the plant. In addition, P is also a contributory factor in promoting the early root formation and growth, increasing water-use efficiency, and plant maturity, rooting, and flowering, and improves the quality of crops [Johnston and Steen 2000, Rafat and Sharifi 2015]. High salinity suppresses the phosphorus uptake and reduces the available phosphorus by sorption processes [Kalifa 1997]; it affects negatively the plant growth and crop productions [Bargaz et al. 2016], thus the supply of plants with phosphorus is effective in mitigating the salt stress effects to protect plants against oxidative injury caused by salt stress [Daei-Hassani et al. 2016]. Many researchers have studied the effect of phosphorus on onion plant. For example, El-Hamady [2017] and Gulmezoglu and Daghan [2017] indicated that application of phosphorus promote the plant growth, yield and quality. Therefore, the present study was aiming to determine the effect of AMF inoculation and/or P_2O_5 and their interactions on growth, yield and quality of onion under saline condition.

MATERIAL AND METHODS

Site description and experimental design

The study was performed in the Experimental Farm of the Desert Research Center in Ras Sudr, South Sinai Governorate, Egypt (30°34'N, 31°34'E). Egyptian local onion cultivar 'Giza 20' was used. Onion seeds were obtained from Agricultural Research Center, Egypt. Seeds were sown into plastic trays under greenhouse conditions on October 1st in both seasons and 60 days later, the seedlings were transplanted into the experimental field. The experimental unit area was 14 m^2 containing 4 drip irrigation rows each, 5 m length and 70 cm width. Seedlings were transplanted on rows, two lines per row, with 10 cm between lines and 15 cm between plants. Physical properties of the soil in this study were: sand 71.30%, silt 6.70% and clay 8%, and chemical properties were: pH 7.9, EC 8.82 mS·cm^{-1}, $CaCO_3$ 56.99%, Na^+ 1353 mg·100 g^{-1}, Ca^{+2} 767 mg·100 g^{-1}, SO_4^{2-} 2832 mg·100 g^{-1}, HCO^{-3}105 mg·100 g^{-1}, Cl^- 2276 mg·100 g^{-1}, total N^+ 30 mg·100 g^{-1}, K^+ 79 mg·100 g^{-1} and available phosphorus 0.37 mg·100 g^{-1}. All agricultural practices were accomplished according to the recommendations of Egypt Ministry of Agriculture for onion production. Fertilization was 450 kg·ha^{-1} ammonium sulfate (20.5% N), 150 kg·ha^{-1} potassium sulfates (48% K_2O). Onion plants were irrigated with saline water (7.03 mS·cm^{-1}), at 3-day intervals. The meteorological data at the experiment site are given in Table 1 (Central Lab. For Agricultural Climate, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Egypt).

Experiments were set up in two successive years 2014/2015 and 2015/2016, the mycorrhizal inoculation was applied to half of plots, but not to the other half. In mycorrhizal plots, inoculation was carried out after three weeks from transplanting of onion seedling with 10 ml of spore suspension (30 spores ml^{-1}) per one plant deposited near the plant roots, whereas 10 ml of distilled water was used for the non-mycorrhizal inoculation. Mycorrhiza of *Glomus* sp. was obtained from the Department of Soil Fertility and Microbiology, Desert Research Center. The soil was amended with 0, 48, 96 and 144 kg P_2O_5·ha^{-1} during soil preparation. This experiment was designed as a split plot with three replicates. The main plots were allocated to the AMF inoculation, whereas P_2O_5 as the sub-plots.

Data recorded

Morphologic traits (plant height, plant leaf number, shoot fresh and dry weight) of five onion plants were sampled randomly from each treatment after 12 weeks from transplanting to measure them. At harvest, all onion plants in each experimental plot were removed to estimate the bulb yield and its components such as bulb diameter, neck diameter, bulbing ratio (bulb diameter/neck diameter) and bulb weight. Total soluble sugars (TSS) were extracted and estimated according to Irigoyen et al. [1992]. Fresh leaf material (0.5 g) was crushed in a mortar and 5 ml of 80% hot alcohol was added. The mixture was centrifuged at 9000 g for 15 min (6000 rpm). The supernatant obtained was separated into another test tube and 12.5 ml

of 80% alcohol was added. 1 ml of the solution was taken and 1ml of 0.2% anthrone was added. The mixture was heated in a water bath at 100°C for 10 min. The reaction was terminated by incubating the mixture on ice for 5 min. Total soluble sugar content was determined using a spectrophotometer at 620 nm. Calculation of the total soluble sugar content was done by creating a standard curve using the standard glucose. Proline in fresh leaves was determined according to Bates et al. [1973]. Fresh leaf material (0.5 g) was homogenized in 10 ml of 3% aqueous sulfosalicylic acid and then this aqueous solution was filtered through Whatman's No. 2 filter paper and finally 2 ml of the filtrate solution mixed with 2 ml acid-ninhydrin and 2 ml of glacial acetic acid in a test tube. The mixture was placed in a water bath for 1 h at 100°C. The reaction mixture was extracted with 4 ml toluene and the chromophore containing toluene was aspirated, cooled to room temperature, and the absorbance was read at 520 nm using Shimadzu UV 1601 spectrophotometer. Appropriate proline standards were used for the calculation of proline in the sample. Protein was determined using the Micro Kjeldahl method described by the AOAC [1995] as follows: 1 g of plant dried sample taken in a Pyrex digestion tube and 30 ml of concentrated H_2SO_4 carefully added, then 10 g potassium sulfate and 14 g copper sulfate. Mixture was placed on sand on a low flame just to boil the solution, and was further heated till the solution became colorless and clear, allowed to cool, diluted with distilled water and transferred to 800 ml Kjeldahl flask, washing the digestion flask. Three or four pieces of granulated zinc and 100 ml of 40% caustic soda were added and the flask was connected with the splash heads of the distillation apparatus. Next, 25 ml of 0.1 N sulfuric acid was taken in the receiving flask and distilled; it was tested for completion of reaction. The flask was removed and titrated against 0.1 N caustic soda solution using Methyl Red indicator for determination of nitrogen, which in turn gives the protein content. Phosphorus (P) content was determined (colorimetric method) in plant according to Cottenie et al. [1982].

Table 1. Meteorological data at Ras Sudr site during 2014/2015 and 2015/2016 seasons

Year	Month	Temperature (°C)		SRAD ($MJ/m^2/day$)	RH (%)	R.F. (mm)
		Max.	Min.			
2014	October	32	24	25.14	57	0.1
	November	28	20	23.10	53	0.00
	December	24	17	20.13	64	0.00
2015	January	19	17	20.39	30	0.00
	February	25	18	22.15	37	0.00
	March	23	17	23.00	51	0.00
	April	24	19	25.46	55	0.00
	May	31	22	28.11	45	0.00
	October	35	28	24.20	65	0.0
	November	31	23	22.12	63	0.0
	December	22	19	19.92	59	0.1
2016	January	15	14	20.51	58	1.1
	February	20	15	21.25	61	0.00
	March	30	24	23.00	36	0.00
	April	28	20	26.10	43	0.00
	May	35	30	28.14	32	0.00

* SRAD = solar radiation; RH = relative humidity; RF = rainfall

Statistical analysis

Data was statistically assessed by one-way analysis of variance (ANOVA) using COSTAT software package. Mean separations were accomplished using multiple range tests of Duncan [1955]. Differences at $p \leq 0.05$ were considered significant.

RESULTS AND DISCUSSION

Morphological traits of onion plant

After 9 weeks of AMF inoculation, mycorrhizal onion plants significantly increased in morphological traits (height, leaf number, shoot fresh and dry weight) compared to non-mycorrhizal onion plants in the two seasons (Tab. 2). Similar results were achieved by Tanwar et al. [2013], Shinde and Shinde [2016] and Sharma et al. [2017]. The AMF beneficial effect in alleviating the negative effect of salinity and improved growth of plants may be attributed to enhancing the antioxidant activity defense, which degraded more reactive oxygen species (ROS) and thus the cell membrane damages under salt tress [He et al. 2007, Abdel Latef and Chaoxing 2011]. Also other mechanisms have been proposed, for instance mycorrhizal colonization may enhance the nutrient acquisition of plants grown at high salinity [Al-Karaki 2000, Kaya et al. 2009].

Table 2. Effects of mycorrhizal inoculation and phosphorus fertilizers on onion plant height, leaf number, shoot fresh and dry weight in 2014/2015 and 2015/2016 seasons

Arbuscular mycorrhizal fungi (AMF)	Phosphorus fertilizer (P_2O_5) kg·ha^{-1}	Plant height (cm)		Plant leaf number		Shoot fresh weight (g)		Shoot dry weight (g)	
		1st S	2nd S	1st S	2nd S	1st S	2nd S	1st S	2nd S
–AMF	0	45.40	42.03	6.89	7.55	58.85	75.07	13.08	15.97
	48	51.98	54.54	8.44	9.55	74.62	89.25	15.88	18.52
	96	56.23	57.77	8.89	10.00	86.96	101.94	18.12	20.19
	114	52.77	56.90	9.89	10.55	90.18	117.17	18.79	22.71
Mean		51.60	52.81	8.53	9.42	77.65	95.86	16.46	19.35
+AMF	0	49.83	51.83	7.89	9.00	77.70	93.93	16.19	18.67
	48	54.20	58.73	9.77	10.66	100.10	126.15	20.02	24.26
	96	59.27	62.33	11.00	11.66	134.40	140.22	25.85	26.66
	114	61.97	62.13	11.11	11.55	134.40	141.23	25.41	26.80
Mean		56.32	58.76	9.94	10.72	111.65	125.38	21.86	24.10
Mean for P_2O_5	0	47.62	46.93	7.39	8.28	68.28	84.50	14.63	17.32
	48	53.09	56.64	9.11	10.11	87.36	107.70	17.95	21.39
	96	57.75	60.05	9.94	10.83	110.68	121.08	21.98	23.42
	114	57.37	59.52	10.50	11.05	112.29	129.20	22.10	24.75
$LSD_{0.05}$ for	AMF	3.66	5.34	0.63	0.32	5.38	5.17	1.08	1.09
	P_2O_5	1.95	2.88	0.34	0.42	6.59	3.39	1.33	0.68
	Interaction	2.76	NS	0.48	NS	9.32	4.80	1.88	0.96

–AMF = non-mycorrhizal plants, +AMF = mycorrhizal plants. 1st S = (2014/2015), 2nd S = (2015/2016)

Data presented in Table 2 showed significant increase in height, leaf number, shoot fresh and dry weight of plant with increasing level of phosphorus. The highest values were recorded under the addition of 144 kg·P_2O_5 ha^{-1} except from plant height obtained due to 96 kg·P_2O_5 ha^{-1}. This trend was found to be true at the two seasons. The same trend has been reported by Miranda et al. [2013] and El-Hamady [2017]. This increase may be due to different reasons as following: 1 – the vital role of phosphorus in carbohydrate metabolism, 2 – the ion accumulation regulation and compartmentalization in the cell [Gibson 1988], 3 – the increase in plant antioxidant enzymes activities [Daei-Hassani et al. 2016]. As a result, these reasons indicate a build-up of protective mechanisms that reduce oxidative damages induced by salinity stress [Harinasut et al. 2003, Chawla et al. 2013] and thus stimulating the plant growth under salinity conditions. With respect to the interaction between AMF and phosphorus treatments in this experiment, it was found that the highest values of onion morphological traits were obtained from the combination between plants inoculated by AMF and 96 or 144 kg P_2O_5·ha^{-1} and there were no significant differences between them in the two seasons.

The bulb characters, neck diameter and total yield

The AMF inoculation had an influence on diameter of bulb and neck, bulbing ratio, bulb weight and total yield (Tab. 3). In general, AMF inoculated plants showed an increase in all values as compared to non-inoculated plants. There were significant differences between treatments in both seasons except bulbing ratio in the second season. These data are in agreement with Muddathir [2004], Sari et al. [2002], Bolandnazar et al. [2007] and Shinde and Shinde [2016]. The increases of bulb and neck diameter, bulbing ratio, bulb weight and total yield under AMF inoculation treatment may be due to AMF causing protection of plants against salinity by alleviating the salt induced oxidative stress [Abdel

Table 3. Effect of mycorrhizal inoculation and phosphorus fertilizers on onion bulb diameter, neck diameter, bulbing ratio, bulb weight and total yield in 2014/2015 and 2015/2016

Arbuscular mycorrhizal fungi (AMF)	Phosphorus fertilizer (P_2O_5) kg·ha^{-1}	Bulb diameter (cm)		Neck diameter (cm)		Bulbing ratio		Bulb weight (g)		Total yield (mg·ha^{-1})	
		1st S	2nd S	1st S	2nd S	1st S	2nd S	1st S	2nd S	1st S	2nd S
–AMF	0	6.06	6.46	1.37	1.36	4.41	4.74	76.42	80.87	19.76	21.35
	48	6.34	7.07	1.52	1.50	4.18	4.70	88.22	86.68	21.20	22.11
	96	6.88	7.78	1.68	1.53	4.10	5.10	93.33	92.39	22.22	23.45
	114	7.10	7.94	1.83	1.55	3.89	5.12	97.81	95.93	22.52	23.58
Mean		6.59	7.31	1.60	1.49	4.15	4.92	88.95	88.97	22.30	22.62
+AMF	0	6.41	7.18	1.50	1.45	4.27	4.96	82.35	87.74	22,07	22.57
	48	7.07	7.64	1.62	1.58	4.37	4.84	93.77	99.53	24,50	24.44
	96	7.92	8.24	1.74	1.67	4.56	4.94	100.72	103.29	26,21	25.47
	114	8.02	8.23	1.79	1.63	4.49	5.06	101.03	103.17	26,08	24.93
Mean		7.36	7.82	1.66	1.58	4.42	4.95	94.47	98.43	24.71	24.35
Mean for P_2O_5	0	6.24	6.82	1.44	1.41	4.34	4.85	79.38	84.31	20.92	21.96
	48	6.71	7.36	1.57	1.54	4.28	4.77	91.00	93.11	22.85	23.27
	96	7.40	8.01	1.71	1.60	4.33	5.02	97.03	97.84	24.21	24.46
	114	7.56	8.08	1.81	1.59	4.19	5.09	99.42	99.55	24.30	24.25
$LSD_{0.05}$ for	AMF	0.29	0.27	0.04	0.07	0.13	NS	2.97	4.91	1.43	0.19
	P_2O_5	0.24	0.21	0.07	0.05	NS	0.15	3.01	2.52	0.45	0.45
	Interaction	0.33	NS	NS	NS	0.27	NS	NS	NS	0.64	NS

–AMF = non-mycorrhizal plants, +AMF = mycorrhizal plants. 1st S = (2014/2015), 2nd S = (2015/2016)

Latef and Chaoxing 2011], and increase plant growth and uptake of nutrient under saline conditions [He et al. 2007], as well as it caused relatively greater allocation of carbohydrates to the plant tissues, which improved plant growth in the salt-stressed plants [Shokri and Maadi 2009], which was reflected in diameter of bulb and neck, bulbing ratio, bulb weight and total yield.

The effect of phosphorus treatments showed significant positive effect on diameter of bulb and neck, bulb weight and total yield in the two seasons, also bulbing ratio only in the second season. Application of 96 or 144 kg $P_2O_5 \cdot ha^{-1}$ treatment gave the highest diameter of bulb and neck, bulb weight and total yield in both seasons, as well as bulbing ratio only in the second season with no significant difference between treatment of 96 and 144 kg $P_2O_5 \cdot ha^{-1}$ in the two seasons. These results are in accordance with those obtained by El Hamady [2017], who found increased diameter of bulb, neck, bulbing ratio, bulb weight and bulb yield with increasing phosphorus application up to 148 kg $P_2O_5 \cdot ha^{-1}$. The effect of different phosphorus treatments on diameter of bulb, neck and bulbing ratio, bulb weight and bulb yield under high salinity soil conditions may be due to their effect on increasing uptake of nutrients (K, Ca and P), which could help to overcome nutrient deficiencies in plant [Okusanya and Fawole 1985], as well as synthesis of more accumulated metabolic material [Gibson 1988], which reflected in plant growth (Tab. 2), which would result in an increase of neck diameter, bulb characters and bulb yield. No stronger influence of the interaction between AMF and P_2O_5 treatments on the neck diameter and bulb weight was found, but the influence of treatments was significant on bulb diameter, bulbing ratio and total yield in the first season. The highest total yield was found in treatment of AMF inoculation combined with 96 or 144 kg $P_2O_5 \cdot ha^{-1}$ in both seasons.

TSS, free proline, protein and phosphorus contents

As evident from Table 4, content of TSS, protein and P recorded in AMF treated plants was higher than in un-inoculated control plants; significant differences occurred between treatments. AMF has positive effects on TSS that may be due to the lower effect of the fungus demanding sugars from the shoot tissues or to hydrolysis of starch to sugars in inoculated plants with mycorrhiza [Nemec 1981]. Similar results were obtained by Kowalska et al. [2015]. AMF inoculated plants revealed higher protein content, which could be due to higher effect of the osmotic regulation mechanism in plants, which not only prevent protein reduction under salt stress [Kumar et al. 2010], but also induce the synthesis of osmotin like protein structure [Amini and Ehsanpour 2005]. These data are in agreement with Sharma et al. [2017]. The higher content of phosphorus in mycorrhizal treated plants might be due to AMF hyphae spread around the roots and avoid P depletion zones roots, or facilitate phosphorus absorbance in salty stress conditions [Beltrano et al. 2013]. Free proline content was significantly higher in un-inoculated than AMF inoculated plants. Proline accumulation is considered a sign of salinity stress and it plays multiple roles in stress tolerance as a mediator of osmotic adjustment [Yoshiba et al. 1997]. The application of AMF could improve the tolerance of plants to salinity by maintaining the osmotic balance and reducing the free radicals damage induced by osmotic stress [Garg and Manchanda 2009]. Ruiz-Lozano et al. [1996] indicated that mycorrhizal plants were less affected by salinity and therefore accumulated less proline. Based on these data, we concluded that AMF inoculation led to alleviation of salinity stress on onion plants and as a consequence, to reduced amounts of proline at plants. These results are similar to those of Kaya et al. [2009] and Rabie and Almadini [2005], who indicated that proline concentration was significantly lower in mycorrhizal than non-mycorrhizal plants under salinity conditions.

Plants treated with P_2O_5 were significantly higher in the TSS, protein and P content than control plants (Tab. 4), and this trend was found at the two seasons. These results are in accordance with Shaheen et al. [2012]. The increased sugar content may be attributed to the role of phosphorus in sugar structural formation as well as the reliance of pathways in reducing-sugar synthesis [Shahriaripour et al. 2011]. Increase in protein content by phosphorus application under salinity may be the result of enhanced synthesis of specific stress-related proteins [Daei-Hassani et al. 2016]. Addition of phosphorus encouraged the root growth, in particular the development of fibrous rootlets and lateral roots, which are responsible for nutrients uptake from the soil [Barker and Pilbeam 2007]

Table 4. Effect of mycorrhizal inoculation and phosphorus fertilizers on TSS, free proline, protein and phosphorus percent of onion plants in 2014/2015 and 2015/2016 seasons

Arbuscular mycorrhizal fungi (AMF)	Phosphorus fertilizer (P_2O_5) kg·ha^{-1}	TSS (%)		Free proline (mg·g^{-1} FW)		Protein (%)		P (%)	
		1st S	2nd S	1st S	2nd S	1st S	2nd S	1st S	2nd S
–AMF	0	12.31	12.69	0.197	0.183	7.14	7.64	0.238	0.249
	48	12.73	13.10	0.189	0.178	7.44	7.84	0.246	0.266
	96	13.02	13.28	0.177	0.170	7.85	8.02	0.277	0.287
	144	13.16	13.44	0.176	0.160	7.97	8.11	0.281	0.302
Mean		12.81	13.13	0.185	0.173	7.60	7.90	0.260	0.276
+AMF	0	12.90	12.92	0.184	0.157	7.40	7.84	0.245	0.261
	48	13.28	13.43	0.172	0.149	7.82	8.27	0.286	0.302
	96	13.40	14.41	0.149	0.142	8.19	8.58	0.308	0.335
	144	13.50	14.26	0.144	0.143	8.25	8.50	0.322	0.350
Mean		13.27	13.76	0.162	0.148	7.92	8.30	0.290	0.312
Mean for P_2O_5	0	12.61	12.81	0.190	0.170	7.27	7.74	0.242	0.255
	48	13.01	13.27	0.180	0.164	7.63	8.06	0.266	0.284
	96	13.21	13.85	0.163	0.156	8.02	8.30	0.293	0.311
	144	13.33	13.85	0.160	0.152	8.11	8.30	0.302	0.326
$LSD_{0.05}$ for	AMF	0.12	0.15	0.003	0.004	0.13	0.07	0.006	0.014
	P_2O_5	0.17	0.12	0.005	0.002	0.13	0.11	0.007	0.007
	Interaction	NS	0.16	0.007	0.003	NS	0.16	0.009	0.010

–AMF = non-mycorrhizal plants, +AMF = mycorrhizal plants. 1st S = (2014/2015), 2nd S = (2015/2016)

and resulted in an increase in phosphorus content in plant. On the other hand, application of phosphorus resulted in decreased free proline content in plant. The 144 kg P_2O_5·ha^{-1} treatment resulted in the lowest free proline content, while the highest proline content was observed in the control treatment in both seasons. These results are similar to those of Shubhra et al. [2003] and Indu and Sharma [2014]. The AMF inoculated plants combined with addition of 96 or 144 kg P_2O_5·ha^{-1} treatment gave the highest contents of TSS, protein and P, while it gave the lowest content of proline. This trend was found to be true at the two seasons.

CONCLUSIONS

In conclusion, the arbuscular mycorrhizal fungi (AMF) inoculation and/or phosphorus application have positive impact on onion quantity and quality. The AMF inoculation and phosphorus addition showed an enhancement in plant growth, bulb characteristics and total yield, as well as TSS, protein and P content were increased. However, the proline level was decreased. The AMF inoculation combined with at 96 or 144 kg P_2O_5·ha^{-1} treatments alleviated the negative salinity effects on onion plants and gave the highest productivity.

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