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Impact of Different Levels of Phosphorus and Seed Inoculation With Arbuscular Mycorrhiza (AM) On Growth, Yield Traits and Productivity of Wheat

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THE GOAL of the present investigation was to assess the effect of phosphorus levels and arbuscular mycorrhizal inoculation on growth, yield related traits, productivity and phosphorus uptake by wheat. Two field experiments were conducted using a split plot design with 3 replications in 2016/2017 and 2017/2018 winter seasons. Five levels of P-fertilization (0%, 25%, 50%, 75% and 100% of the recommended dose) were randomizly arranged in main plots and the two treatments of mycorrhizal inoculation "without inoculation (M_0) and with inoculation (M_1)" were plotted in the sub plots. The results showed that, the yield related traits (number of grains spike^{-1}, number of spikes m^{-2} and 1000-grain weight) significantly higher with 100% P level in both seasons. Arbuscular mycorrhizal inoculation gave the highest yield related traits in both seasons. Increment levels of phosphorus increased the grain, straw yield and harvest index significantly up to 100% P level of wheat crop. Increasing level of P application (0 to 100% P level) and inoculation with arbuscular mycorrhiza significantly increased P concentration in grains and uptake of P in wheat in both seasons. The combined application of 100% P level with arbuscular mycorrhizal inoculation recorded significantly higher phosphorus uptake in both seasons.

Keywords: Phosphorus uptake, Wheat, Arbuscular mycorrhiza, Grain yield, Chlorophyll content.

Introduction

Wheat is considered one of the most crucial crops among cereals. About 30% of the world population is consuming the wheat as a major food. In Egypt, the cultivated area is about 1.4 million hectares (3 million feddan) (FAO, 2015). Wheat consumption annually is roughly 18.9 million ton; however the productivity is roughly 9.0 million ton (FAO, 2015). Increasing wheat yield through increment the productivity is one of the major pivotal objectives. Sustainable wheat production is still an important issue and has attracted significant attention recently (Hafez et al., 2015).

Phosphorus is one of substantial nutrients required for growth and development of wheat and ranked second after nitrogen element (Afzal & Bano, 2008). Although phosphorus is one of the hardest nutrients to be absorbed by plants, it is necessary for plant growth, nucleus formation and cell division. Phosphorus compounds are involved in the transfer and storage of energy within plants. In the recapitulation, it plays an important function in all plant growth stages like root growth, photosynthesis, flowering and seed set, so its deficiency leads to reduction in plant growth (Abou El Hassan et al., 2014). There is an urgent need to provide cheaper solutions like mycorrhizal inoculation to boost nutrients for crops. It can increase the phosphorus use efficiency with plants that get phosphorus from the soil (Aboukhadrah et al., 2014). Plants have promoted many strategies that increase both, phosphorus absorption and availability of P in soil. One of these common strategies is arbuscular mycorrhiza fungi (AMF) symbiosis (Gharib et al., 2016). Arbuscular mycorrhiza fungi (AMF) symbiosis is especially

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vital for plants growth and development under limited available phosphorus. This active role in enhancing P absorption and micronutrients are well documented. Inoculation with AM is efficient in promoting host-plant absorption of immobile nutrients, especially P (Balakrishnan & Subramanian 2012) and it demands up to 25% of phosynthate for promotion and conservation (Subramanian et al., 2009). AMF are obligate biotrophs and when linked to plant roots, it supplies foraging system to ameliorate procuration of soil water and nutrients, especially phosphorus (Santander et al., 2017). Taking into consideration these previous studies, the main goal of this investigation was to assess the effect of different phosphorus levels on growth, yield related traits, productivity and phosphorus uptake, as well as determine the possibility of enhancing its significance by seed inoculation with (AMF).

Materials and Methods

Two fields experiment were carried out at the experimental farm of Zarzoura, Itay EL-Baroud Agricultural Research Station during the two successive winter seasons of 2016/17 and 2017/18. The effect of different phosphorus levels and seed inoculation with arbuscular mycorrhiza on growth, yield traits and productivity of wheat was the main objective of this investigation. The statistical design of the experiments was a split plot design in RCBD arrangement with 3 replications, the five levels of P-fertilization (0%, 25%, 50%, 75% and 100% of the recommended dose) were randomizly arranged in the main plots, while the two treatments of mycorrhizal inoculation [without inoculation (M_0) and with inoculation (M_1)] were in sub plots. The recommended dose of P fertilization was 230kg ha^{-1} super phosphate calcium (15.5% P_2O_5), the soil was analyzed for some physical and chemical properties as shown in Table 1.

The area of sub-plot was 10.5m^2 (3m wide and 3.5m long), each plot contained 20 rows with 15cm apart. Plots were separated by 1m allays. The preceding crops were soybean in both seasons. Wheat seeds Shanwdeel-1 (Bread Wheat) were obtained from seeds production unit; Agriculture Research Center, Egypt. Seeds c.v. Shanwdeel-1 were sown on 21 and 19 November in 2016 and 2017, respectively. Plants were irrigated to catch the field capacity. Mineral N fertilizer was added according to the recommendation of the Ministry of Agriculture and Soil Reclamation. Nitrogen was added at 163kg ha^{-1} in form of Urea (46%) in three doses before irrigation. Weeds were controlled by Topik 15% WP herbicide. Grain yield calculated by harvesting the whole plot, but yield related traits were calculated from the two outer rows within each plot.

Mycorrhizal inocula consisted of roots, hyphae, spores and growth media from a pot culture of onion plants colonization with *Glomus mosseae* NRC31 and *G. fasciculatum* NRC15 originally (Bader EL-Din et al. 1999). The inoculum's material contained 275 spores g^{-1} oven dry bases in addition to the colonization root pieces (the infectivity 10^4 propagola). Mycorrhizal inoculation was done by planting the seed over a thin layer of the mycorrhizal inoculum material at the time of sowing at rate of 10g/plot.

TABLE 1. Physical and chemical properties in the experimental soil in 2016/17 and 2017/18 seasons.

Soil analysis	2016/2017	2017/2018
Physical properties		
Clay%	54.8	51.68
Silt%	24.2	26
Sand%	21.0	22.32
Texture	Clayey	Clayey
Chemical properties		
OM%	0.56	0.86
pH	7.8	8.1
EC*, dsm^{-1}	1.94	1.48
N (ppm)	52	49
P (ppm)	48	42
K (ppm)	240	226

Characters studied

Growth analysis

Flag Leaf area: Ten flag leaves were used to determine the average of flag leaf area at 125 days after sowing for each sub-plot determined by using Leaf Area Meter.

Chlorophyll content: Hand-held chlorophyll meter (SPAD-502; Minolta Sensing Co., Ltd, Japan) was used to record SPAD readings from the topmost fully expanded leaves on each main stem at heading stage. SPAD values were measured at three different points along the flag leaf blade and then the readings were averaged to have a single value for a plant (Markwell et al., 1995).

Days to heading: Determined as number of days from sowing up to 50% of head emerged from sheath.

Days to maturity: Determined as number of days after sowing up to 50% physiological maturity**.** This character was estimated on the basis of 10 spikes randomly collected from each plot

Yield and related traits measurement

Spike length was measured at harvest from the main stems which were used for estimation of plant height. Total number of spikes m^{-2} from each plot were carefully counted and averaged to determine number of spikes m^{-2}. Total number of spikelet's $spike^{-1}$ and number of grains $spike^{-1}$ from ten randomly selected spikes were counted carefully and averaged to record number of spikelet's and grains per spike. Five random samples each of 1000 grains were taken, weighed and averaged to measure 1000-grain weight. At harvest maturity, each plot was harvested manually, sun dried for three days and tied into bundles. These bundles were then threshed manually and grains were separated and weighed to record grain yield (<14% moisture content). Left over straw was again weighed to record straw yield. Grain and straw yields were converted into kg ha^{-1}. Harvest index (HI) was determined as ratio between grain and biological yield and was expressed in percentage.

Statistical analysis

All the data collected were subjected to analysis of variance according to Gomez & Gomez (1984). All statistical analysis was performed using Michigan State University Computer Statistical Package (MSTATC). Different Means were compared using (Duncan, 1955), when the ANOVA showed significant differences ($P<0.05$).

Results and Discussion

Data in Table 2 presents flag leaf area, chlorophyll content, days to heading and days to maturity. Results revealed that, flag leaf area, chlorophyll content of wheat were significantly increased with increasing the applied phosphorus up to 100% of the recommended dose, in both seasons. While, increasing the applied phosphorus to 100% led to decrease in days to heading and days to maturity in both seasons. The mycorrhizal inoculum significantly increased flag leaf area, chlorophyll content in both seasons compared to the un-inoculated control treatments. However, the mycorrhizal inoculum significantly decreased days to heading and days to maturity in both seasons compared to the un-inoculated control treatment. Analysis of variance showed that the interaction between phosphorus and mycorrhiza were not significant (Table 2) for flag leaf area, chlorophyll content traits, while it was only significant for days to heading trait in both seasons, days to maturity in the second season only and highly significant in the first one. The application of AM fungi gave higher plant growth, development, nutrient and water absorption (Wu et al., 2011). The amelioration in growth and yield traits owing to the pivotal impact of phosphorus on plant process, cell division and root elongation in merismatic tissues (Wissuwa et al., 2009).

Addition of P improved yield traits (spike length, number of spikes m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight) in both seasons. The maximum values of spike length (11.02 and 11.03), number of spikes m^{-2} (443.74 and 438.73), number of grains $spike^{-1}$ (56.73 and 62.05) and 1000-grain weight (46.19 and 46.11) were recorded by application of 100% phosphorus level in 2016/17 and 2017/18, respectively. Seed inoculation with mycorrhizae resulted in a significant increment in yield traits (spike length, number of spikes m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight) in both seasons compared to the un-inoculated control treatment. Analysis of variance showed that the interaction between phosphorus and mycorrhiza were not significant (Table 3) for spike length, number of spikes m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight in both seasons.

TABLE 2. Effect of different phosphorus levels and mycorrhizal inoculation on flag leaf area, chlorophyll content, days to heading and days to maturity, in 2016/17 and 2017/18 growing seasons.

Factors	Flag leaf area		Chlorophyll content		Days to heading		Days to maturity	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
Phosphorus levels: (P)								
0%	31.21b	37.74c	40.40c	44.40c	103.0a	102.7a	149.2a	144.2a
25%	38.78ab	40.78bc	46.07b	49.17b	100.6ab	101.3a	143.3b	143.3ab
50%	47.07a	42.44b	52.07a	55.07a	99.05bc	99.17b	142.5b	141.0bc
75%	50.96a	44.67ab	52.95a	55.70a	97.17c	97.83bc	139.7b	139.7c
100%	49.23a	48.04a	55.57a	57.77a	98.00c	96.67c	139.0b	138.8c
Mycorrhiza levels (M)								
M_0	39.51b	37.78b	45.70b	48.80b	101.74a	100.27a	144.267a	142.27a
M_1	47.40a	47.69a	50.12a	52.04a	97.40b	98.80b	141.20b	140.53b
P	**	**	**	**	*	**	**	**
M	**	**	**	**	**	**	**	**
P ×M	N.S	N.S	N.S	N.S	*	*	**	*

Means designated by the same letter in the same column are not significantly different a according to Duncan's Multiple Range Test.
*, ** and N.S indicate P<0.05, P<0.01 and not significant, respectively.

TABLE 3. Effect of different phosphorus levels and mycorrhizal inoculation on spike length, number of spikes m^{-2}, number of grains spike^{-1} and 1000-grain weight, in 2016/17 and 2017/18 growing seasons.

	Spike length (cm)		No. of spikes m^{-2}		No. of grain spike^{-1}		1000-grain weight (g)	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
Phosphorus levels: (P)								
0%	9.215c	9.053c	326.32d	322.56d	41.55c	44.55d	40.56d	39.08d
25%	9.912b	10.46b	393.51c	368.58c	50.37bc	52.65c	41.55c	40.91c
50%	10.45ab	10.77ab	403.84c	377.01c	52.18b	50.62c	42.98b	41.07c
75%	10.60ab	10.88ab	426.85b	423.22b	55.43a	55.30b	43.32b	42.99b
100%	11.02a	11.03a	443.74a	438.73a	56.73a	62.05a	46.19a	46.11a
Mycorrhiza levels (M)								
M0	9.812b	10.13b	355.20b	329.40b	45.70b	48.26b	39.83b	37.24b
M1	10.66a	10.74a	446.46a	396.53a	56.80a	60.60a	47.20a	42.91a
P	**	**	**	*	*	*	*	*
M	**	**	**	**	**	**	**	**
P ×M	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

Means designated by the same letter in the same column are not significantly different a according to Duncan's Multiple Range Test.
*, ** and N.S indicate P<0.05, P<0.01 and not significant, respectively.

Such increase in spike length, number of spikes m^{-2}, number of grains spike^{-1} and 1000-grain weight could be due to the impact of root volume increment and its elongation through cell division and multiplication. In addition, the increment of root biomass ameliorated the nutrient absorption pattern by investing utmost volume of soil which led to improve physiological traits inner the plant system. As well as, phosphorus as one of the main components of ATP, could have help to a larger photosynthetic and luxuriant vegetative growth. These reports confirm the results of (Whitelaw, 2000). Further, a higher productivity of yield under higher phosphorus application led to higher efficiency of absorption causing increase in dry matter accumulation (Hafez et al., 2018). The favorable effect of P application could be explained as a result to less competition for the available metabolites in the grain due to relatively less numbers of grains ear^{-1} at the highest levels of phosphorus. The results corroborate the findings of (Tanwar et al., 2013). Similar results were also reported by many researchers (Smith & Read, 2018).

The results showed that, seed inoculation with mycorrhiza significantly increased the spike length, number of spikes m^{-2}, number of grains spike^{-1} and 1000-grain weight of wheat. A positive influence of fungus inoculation was observed (Table 3). The higher levels of spike length, number of spikes m^{-2}, number of grains spike^{-1} and 1000-grain weight upon inoculation are fundamentally on account of greater enzyme activities in the rhizosphere and higher nutrient availability as long as the production of the plant growth regulators by PSM. (Smith et al., 2011 and Hafez, 2016) stated that production of organic acids like lactic, glycolic, and succinic acids in the medium of *A. niger* can solubilize unavailable inorganic phosphates (Segual et al., 2016).

The results of grain yield, straw yield and harvest index for wheat plants as impacted by P levels and application of mycorrhiza are presented in Table 4. Addition of P improved grain yield in both seasons. The maximum of grain yield (6.26 and 6.23ton ha^{-1}) has been achieved by 100% phosphorus level in both seasons compared to less levels of phosphorus. The inoculation of mycorrhiza resulted in a significant increase of grain yield (5.74 and 5.79ton ha^{-1}) in both seasons compared to the un-inoculated control treatment (4.95 and 5.09ton ha^{-1}), respectively in both seasons. Analysis of variance showed that, the interaction between phosphorus and mycorrhiza was not significant (Table 4) for grain yield trait in both seasons. Similarly, Hafez & Gharieb (2016) has stated that, the number of spikes increased significantly with application of phosphorus in wheat field experiments. The increment in number of spikes might be regarded to good nutrient owing to applied of P (Sandaña & Pinochet, 2016). Hafez et al. (2014) pointed out that, wheat crop didn't produce better spikes under phosphorus shortage. Saxena et al. (2013) stated that, phosphorus application boosts spikes, which finally increases the number of spiked and grain yield of wheat. A gradual increment in grain yield with increment of applied P levels was noticed by many researchers (Seguel et al., 2015). Sandaña & Pinochet (2016) reported that, a significant ratio of mineral phosphorus can be "biologically fixed" by mycorrhiza when soil phosphorus levels are low, while at high phosphorus levels, plants can uptake its needs from phosphorus without supply from mycorrhiza. Addition of P improved straw yield in both seasons (Table 4). The maximum straw yield (11.53 and 11.52ton ha^{-1}) has been achieved by 100% phosphorus level in both seasons compared to less levels of phosphorus. The inoculation of mycorrhiza resulted in a significant increase in straw yield (11.06 and 10.68ton ha^{-1}) in both seasons compared to the un-inoculated control treatment (9.95 and 9.93ton ha^{-1}), respectively in both seasons. Analysis of variance showed that, the interaction between phosphorus and mycorrhiza was not significant (Table 4) for straw yield trait in both seasons.

TABLE 4. Effect of different phosphorus levels and mycorrhizal inoculation on grain yield, straw yield and harvest index, in 2016/17 and 2017/18 growing seasons.

Factors	Grain yield (ton ha^{-1})		Straw yield (ton ha^{-1})		Harvest index (%)	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
Phosphorus levels: (P)						
0%	4.07e	4.35e	8.90e	8.91e	31.38e	32.79e
25%	5.09d	5.01d	10.21d	9.92d	33.26d	33.55d
50%	5.65c	5.66c	10.92c	10.75c	34.09c	34.49c
75%	5.93b	5.94b	11.11b	11.23b	34.80b	34.59b
100%	6.26a	6.23a	11.53a	11.52a	35.18a	33.09a
Mycorrhiza levels (M)						
M_0	4.95b	5.09b	9.95b	9.93b	33.27b	33.85b
M_1	5.74a	5.79a	11.06a	10.68a	34.16a	35.19a
P	**	*	*	*	*	*
M	**	**	**	*	*	*
P ×M	N.S	N.S	N.S	N.S	N.S	N.S

Means designated by the same letter in the same column are not significantly different a according to Duncan's Multiple Range Test.
*, ** and N.S indicate P<0.05, P<0.01 and not significant, respectively.

Campos et al. (2018) proved that, maximum phosphorus application helps in producing more root volumes that makes the wheat crop capable of exploring more soil for nutrients and moisture. The increment in plant canopy may be attributed to the higher leaf area and more effective tillers measured in this paper as also stated by Covacevich et al. (2007). Hafez & Abou El-Hassan (2015) also demonstrated a significant amelioration in straw of wheat with applied of P.

Panda & Rai (2008) also stated that, the increment in leaf area of wheat crop was stimulated by arabscular mycorrhizal inoculation during the early growth phases. Increment in leaf area might ameliorate solar radiation capture by crop and potentially lead to higher yield.

Addition of phosphorus improved harvest index in both seasons (Table 4). The maximum values of harvest index (35.18 and 33.09%) were achieved by 100% phosphorus level in both seasons compared to less levels of phosphorus (Saxena et al., 2013). The inoculation of mycorrhiza resulted in a significant increase in harvest index trait (34.16 and 35.19%) in both seasons compared to the un-inoculated control treatment (33.27 and 33.85%), respectively in both seasons. Analysis of variance showed that the interaction between phosphorus and mycorrhiza was not significant (Table 4) for harvest index in both seasons (Segual et al., 2015 and Hafez & Geries, 2018).

The high applied rates of phosphorus led to a huge canopy in addition to higher P uptake resulting in a high grain yield. The findings cleared that, seed inoculation with AM significantly raised the straw and grain yield (Tanwar et al., 2013). It was observed that, the inoculation with AM had a pivotal impact on biological yield and harvest index. Higher biological yield was owing to higher enzyme activities in the rhizosphere and good nutrient availability along with the production of the plant growth regulators by PSM (Tanwar et al., 2013).

Phosphorus concentration and uptake

The results presented in Table 5 showed that, application of phosphorus at the rate of 100% brought out significant increase in phosphorus percentage and uptake in grains, in both seasons. The highest values of phosphorus percentage and uptake in grains were recorded by 100% of applied phosphorus level and a gradual decrease was noticed with decreasing the applied phosphorus level ending with the lowest values that recorded by the control level in both seasons. The high root volume ameliorated the P absorption by exploiting higher volume of soil leading to improve physiological activity of the plant system.

TABLE 5. Effect of different phosphorus levels and mycorrhizal inoculation on phosphorus percentage (%) and phosphorus uptake (kg ha^{-1}) in grains, in 2016/17 and 2017/18 growing seasons.

Factors	Phosphorus percentage in grains (%)		Phosphorus uptake in grains (kg ha^{-1})	
	2016/17	2017/18	2016/17	2017/18
Phosphorus levels: (P)				
0%	0.24e	0.23e	9.38e	10.23e
25%	0.28d	0.27d	14.34d	13.34d
50%	0.32c	0.32c	18.45c	18.12c
75%	0.35b	0.34b	20.23	20.23b
100%	0.37a	0.36a	23.78a	22.33a
Mycorrhiza levels (M)				
M_0	0.30b	0.30b	14.67b	15.44b
M_1	0.34a	0.33a	19.22a	19.32a
P	**	**	**	**
M	**	**	**	**
P ×M	**	**	**	**

Means designated by the same letter in the same column are not significantly different a according to Duncan's Multiple Range Test.
*, ** and N.S indicate P<0.05, P<0.01 and not significant, respectively.

Application of phosphorus to the soil led to a higher photosynthetic and luxuriant vegetative growth. These findings proved the results of Wu et al. (2011). This could be due to higher phosphorus content in soil solution with increment phosphorus application. The boost in P absorption may be regarded to higher P concentration so as to grain and straw yields with higher rate of P. The findings are in harmony with the results of Afzal & Bano (2008).

The data presented Table 5 revealed that, the seed inoculation with AM significantly increased the phosphorus percentage and uptake in wheat grains, in both seasons. The total P uptake by wheat crop under treatment of inoculation with AM was (19.22 and 19.32kg ha^{-1}) higher than un-inoculated treatment (14.67 and 15.44kg ha^{-1}) in both seasons, respectively. From the findings demonstrated in Table 5 it is clear that, seed inoculation with AM significantly increased the P absorption of wheat. Such of these results are in accordance with those obtained by Balakrishnan & Subramanian (2012), where they noted that, seed inoculation with AM increased the phosphorus absorption compared to un-inoculated owing to microbial activity. The inoculation with AM contributes to stimulate plant growth and nutrient uptake in wheat. The positive impact of AM symbiosis on plant growth has been largely due to higher uptake of phosphorus.

In this research, plants inoculated with AM recorded higher values of phosphorus (Hafez & Seleiman, 2017). This finding shows that, the impact of AM fungi on phosphorus absorption constitutes one of the main mechanisms for increasing wheat yield (Wissuwa et al., 2009). While, the interaction between applied phosphorus levels and the inoculation with AM led to increase in phosphorus uptake in both seasons (Fig. 1).

Conclusion

Raising level of applied phosphorus gradually to 100% of the recommended dose increased significantly flag leaf area, chlorophyll content, yield traits, grain, straw yields and harvest index of wheat crop. Also, these traits were increased significantly with seed inoculation with arbuscular mycorrhiza, where the combined application of phosphorus at the rate of 100% of the recommended dose with arbuscular mycorrhizal inoculation recorded the highest values of these traits. Moreover, increasing level of applied phosphorus gradually from 0 to 100% of the recommended dose and inoculation with arbuscular mycorrhiza significantly increased phosphorus percentage and uptake in wheat grains, where the combined application of phosphorus at the rate of 100% of the recommended dose with arbuscular mycorrhizal inoculation recorded the highest values of phosphorus percentage and uptake in wheat grains, in both seasons.

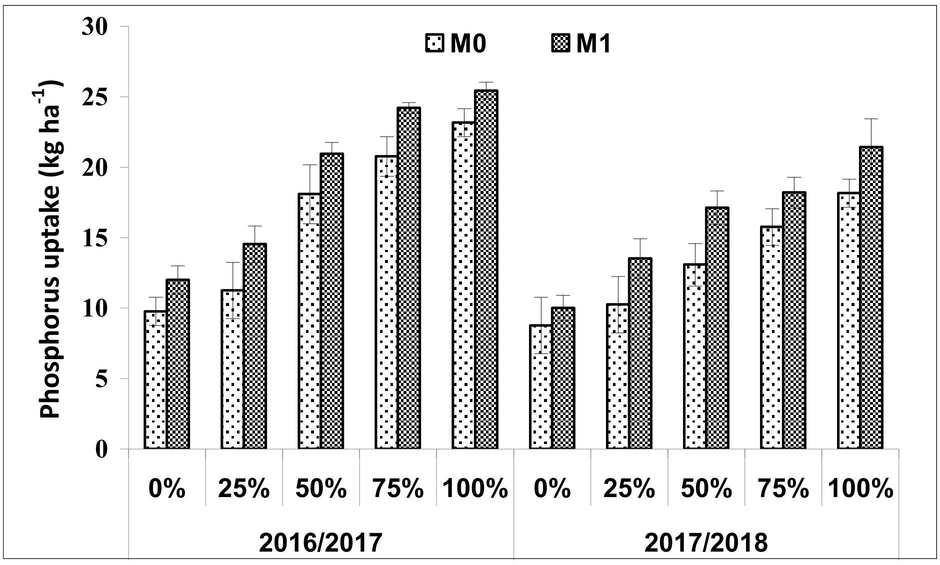

Fig. 1. Effect of different phosphorus levels and mycorrhizal inoculation on phosphorus uptake (kg ha^{-1}) in 2016/17 and 2017/18 growing seasons (Data are the mean±SE of three replicates).

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تأثير مستويات مختلفة من الفوسفور و تلقيح التقاوي بفطر الميكورريزا على صفات النمو والمحصول وأنتاجية القمح

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أقيمت تجربتان حقليتان في محطة بحوث زرزوره أيتاي البارود – محافظة البحيرة خلال موسمي الزراعة الشتويين2016/17 و2017/18 لدراسة تأثير خمس مستويات من الفوسفور المعدني (0%، 25%، 50%، 75% و 100%) من الموصى به، وكذلك تأثير تلقيح البذور بالميكورريزا في معاملتين (معاملة الكونترول أو بدون تلقيح M0 ومعاملة التلقيح M1) وذلك على صفات النمو و المحصول وامتصاص الفوسفور للصنف شندويل 1 من أصناف قمح الخبز. وقد صممت التجربة في تصميم القطع المنشقة مرة واحدة في ثلاث مكررات حيث وزعت مستويات الفوسفور الخمسة عشوائيا في القطع الرئيسية بينما وزعت معاملتي الميكوريزا في القطع الشقية. وقد أظهرت النتائج مايلي:

بالنسبة لصفات النمو أدى زيادة مستوى الفوسفور إلى (100%) من الجرعة الموصى بها إلى تحقيق أعلى القيم لصفات مساحة الورقة العلم ومحتوى الكلوروفيل في حين سجل اقل قيم بالنسبة لصفات عدد الأيام حتى التزهير وعدد الأيام للنضج، من جهة أخرى أدى تلقيح التقاوي بالميكورريزا إلى زيادة معنوية في صفات مساحة الورقة العلم ومحتوى الكلوروفيل ونقص معنوي في صفات عدد الأيام حتى التزهير وعدد الأيام للنضج. كان التفاعل بين مستويات الفوسفور المستخدمة ومعاملتي الميكوريزا معنويا لصفات عدد الأيام حتى التزهير وعدد الأيام للنضج فقط في حين كان غير معنوي لصفات مساحة الورقة العلم ومحتوى الكلوروفيل.

بالنسبة لصفات المحصول كانت هناك زيادة معنوية في كل صفات المحصول المدروسة (طول السنبلة، عدد السنابل/م^2 ،عدد الحبوب/سنبلة و وزن الألف حبة) تحت مستوى الفوسفور (100%) من الجرعة الموصى بها وكذلك كانت هناك زيادة معنوية في كل صفات المحصول جراء تلقيح التقاوي بالميكورريزا. من جهة أخرى لم يصل التفاعل بين مستويات الفوسفور المستخدمة ومعاملتي الميكوريزا إلى المعنوية في أى من هذه الصفات.

أدت زيادة مستوى الفوسفور إلى زيادة تدريجية في محصولي الحبوب والقش ودليل الحصاد وامتصاص الفوسفور والنسبة المئوية للفسفور بالحبوب وتحققت أعلى قيم لهذه الصفات تحت مستوي فسفور 100% من الجرعة الموصى بها، كما أن تلقيح التقاوي بالميكورريزا أدى إلى زيادة معنوية في تلك الصفات، وقد أظهر تحليل التباين عدم وجود معنوية للتفاعل بين مستويات الفوسفور المستخدمة ومعاملتي الميكوريزا لصفات محصولي الحبوب والقش ودليل الحصاد في حين أعطى التفاعل بينهما زيادة معنوية في امتصاص الفوسفور والنسبة المئوية للفسفور بالحبوب.