International Journal of Agricultural and Applied Sciences, December 2024, 5(2): 66-71
https://www.agetds.com/ijaas
ISSN: 2582-8053
https://doi.org/10.52804/ijaas2024.5211

Research Article

OPEN ACCESS

The Impact of Applying Phosphorus and Mycorrhiza on the Morphological Parameters of Cotton Roots and Shoots, as well as Their Phosphorus Uptake and Dry Matter Yield

Mehmet IŞIK* and İbrahim ORTAŞ
Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Çukurova University, Türkiye
**Corresponding author e-mail: isikm@cu.edu.tr*
(Received: 01/09/2024; Revised: 25/10/2024; Accepted: 20/11/2024; Published: 10/12/2024)

ABSTRACT

This study aimed to investigate the effects of P and mycorrhiza application on cotton root and shoot morphological parameters, P uptake and dry matter yield. The hypothesis to be tested is mycorrhiza and P applications increase cotton growth yield and P uptake. The experiment was established under greenhouse conditions in May 2022 and harvested in July 2022, as a pot experiment. In the experiment, two P levels (0 mg P_2O_5 kg^{-1}, and 50 mg P_2O_5 kg^{-1}) three mycorrhizae species (control (without mycorrhiza), indigenous mycorrhiza (IM) and *Rhizophagus Clarus* (*Rh. Clarus))* inoculated with May 505-cotton (*Gossypium hirsutum* L.) variety were used with three replications. Before harvesting, plant height and stem diameter were measured, at harvest; shoot, root, and total dry matter weight (DW) were obtained. The P content of the root and shoot parts of the plant was determined by ICP-OES. Plant root morphological characteristics were determined, and Mycorrhizal Dependency (MD) was calculated by the DW yield of cotton. The JMP8 statistical program was used for ANOVA analysis and LSD test.

Results showed that there was no statistically significant difference in terms of plant height, but P and mycorrhiza treatments made a significant difference in terms of stem diameter. In addition, mycorrhiza application made a significant difference in plant dry weight yield. As a total dry weight yield, the IM application has 45.1 g pot^{-1} and *Rh. Clarus* had 47.38 g pot^{-1} total DW yields. The results showed that mycorrhiza and P applications increased root growth parameters. In addition, P and mycorrhiza treatments improved root morphological characteristics on average. The cotton was found to be an 8.0 to 12.3% MD, and MD was lower in P-treated pots (8.1%) compared to non-P-treated pots (11.3%). Mycorrhiza inoculation and 50 mg P_2O_5 kg^{-1} dual applications seem to be suitable for cotton growth.
Keywords: Phosphorus, Mycorrhizae, Cotton, Dry matter yield and Root morphology

INTRODUCTION

Cotton is an industrial crop used in many industries such as textile, oil, feed, bio-fuel and paper industries. Cotton increased the diversification of industry and trade, increasing the country's dollar income, economic contribution and employment. Over-fertilization and wrong agricultural practices (such as over-cultivation, irrigation and chemical use) reduce the fertility of soils and negatively affect cotton production. Fertilization is extremely important for the plant and soil fertility. P is one of the most consumed elements in terms of quantity for cotton production.

P is involved in many mechanisms such as pollen tube formation, ATP, ADP and phospho-lipids. P, which is not a sustainable resource, is assumed to run out in the next 50-150 years (Schnug and Haneklaus, 2016). Plants take P as water-soluble phosphate ions (especially in the form of H_2PO^{4-}) through their roots (Roberts and Johnston, 2015). Plants cannot benefit from insoluble forms of phosphorus. Inadequate P fertilization decreases yields, while excessive P fertilization causes growth reduction and eutrophication. In soils with high pH, the P element forms compounds such as Ca-P, (Marschner and Rengel, 2007) while in soils with low pH, it forms compounds such as Fe-P (Yli-Halla, 2016). Plants cannot use these compound forms. For this reason, optimum P fertilization and the use of sustainable resources such as mycorrhizal fungi are of great importance.

Arbuscular Mycorrhiza Fungi (AMF) mutualistically with terrestrial plants (80%) provide water and nutrients (especially P) to the plants, while plants provide photosynthesis products to the mycorrhiza (Smith and Read, 2008). Mutualism between them occurs in this way. It is also known that mycorrhizal fungi increase plant resistance against stress factors (salinity, drought, etc.), disease and pests, and increase flowering and yield (Wahab et al., 2023). In addition, mycorrhizal inoculation increases plant root morphologic parameters (Chandrasekaran, 2022).

This study aimed to investigate the impact of P fertilization and mycorrhiza application on cotton root and shoot morphological parameters, P uptake and dry matter yield. The hypothesis to be tested was; that mycorrhiza and P fertilizer applications increase cotton P uptake, growth, and yield.

MATERIALS AND METHODS

The experiment was established in May 2022 and harvested in July 2022, in the University of Cukurova, Department of Soil Science and Plant Nutrition, under greenhouse conditions, as a pot experiment. Table 1 shows some physicochemical properties of the Menzilat (*Typic Xerofluvents*) soil series (Staff, 1999) used in the experiment. In the experiment, two P doses (0 mg P_2O_5 kg^{-1}, and 50 mg P_2O_5 kg^{-1}) as P0 and P50, and three mycorrhiza inoculation (control (without mycorrhiza), indigenous mycorrhiza (IM) and *Rhizophagus Clarus* (*Rh. Clarus))* applied with May 505 cotton (*Gossypium hirsutum* L.) variety were used with three replications. Indigenous Menzilat soil spores were extracted and multiplied via trap culture. Before harvesting, plant height and stem diameter were measured, immediately after harvesting, shoot, root, and total dry matter weight (DW) were obtained. In addition, the P content of the root and shoot parts of the plant was determined by ICP-OES and root morphological characteristics were obtained by WinRhizo software. Mycorrhizal dependency (MD) was calculated by the DW yield of cotton, (Equal 1) according to Ortas and Iqbal (2019).

$$MD = \frac{DW\ Mycorrhizal\ Plant - DW\ Non\ Mycorrhizal\ Plant}{DW\ Mycorrhizal\ Plant} x100$$

Equal 1.

Table 1. Some physical and chemical properties of Menzilat soil series (Işik and Ortaş, 2024).

pH 1:2.5	EC (mmhos cm^{-1})	OM (%)	P_2O_5 (kg da^{-1})	$CaCO_3$ (%)	Texture (%) Sand	Silt	Clay	Texture Classification
7.42	0.13	1.15	7.00	35.21	28.00	33.25	38.75	CL

The experiment was designed as a complete randomized with three replicates for each control, phosphorus and AM treatment. All data was analyzed by using ANOVA and LSD's multiple range test was used to distinguish the main effects of the various treatments at $p \leq 0.05$. Moreover, the JMP8 statistical program.

RESULTS AND DISCUSSIONS

Dry Weight

The effects of P and mycorrhizal inoculation on cotton's different parts (root and shoot) and total dry weight (DW) yield were determined. Table 2 shows that P application and mycorrhizal inoculation made a statistically significant difference in root, shoot and total DW yield. Mycorrhizal inoculation is expected to increase the DW yield of cotton roots and shoots. Previously Ortas and Iqbal (2019) showed that mycorrhizal inoculation increased cotton's root and shoot dry matter yield. This may be because mycorrhizae provide sufficient nutrients (especially P) and water to the plants. Also, under filed conditions, Ortas (2012) reported that cotton plants respond significantly to mycorrhizal inoculation.

P plays an essential role in cotton by enhancing reproductive growth and yield (Iqbal et al., 2020). In our study, P fertilization was expected to increase cotton dry matter yield. There are many studies in the literature that P application increases cotton yield and growth (Ahmad et al., 2009; Iqbal et al., 2020; Saleem et al., 2010).

The fact that mycorrhiza and P co-applications did not make a significant difference in dry matter yield may be because the treatments increased plant dry matter yield. This situation supports our hypothesis.

Table 2. The effects of P and mycorrhizal inoculation on cotton in different parts of DW

P Doses	Mycorrhiza	Root	Shoot	Total
		(g pot^{-1})		
P0	Control	4.1±0.8c	37.6±0.8	41.6±1.4
	IM	5.9±0.2ba	39.4±0.7	45.3±0.6
	Rh. Clarus	5.6±0.0b	41.0±0.5	46.6±0.5
Average	*P0*	5.2A	39.3	44.5
P50	Control	5.7±0.2ba	37.8±3.0	42.2±1.6
	IM	5.8±0.6ba	39.1±0.3	44.8±0.5
	Rh. Clarus	6.5±0.5a	40.8±1.7	48.2±0.3
Average	*P50*	6.0B	39.2	45.1
Average	*Control*	4.9B	37.7B	41.9C
	IM	5.8A	39.3BA	45.1B
	Rh. Clarus	6.0A	40.9A	47.4A
	P	**	NS	NS
	M	**	*	***
	P*M	*	NS	NS

NS (as not significant), *, ** and *** show significant levels at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

Figure 1. Effect of different mycorrhiza application (left side), and phosphorus application (right side) on cotton.

Phosphorus Concentration and Uptake

Phosphorus and mycorrhiza treatments did not make a statistically significant difference in the %P concentration of cotton root parts (Table 3). As shoot parts, there are statistical differences just for P application, while there are no statistically significant differences for mycorrhiza inoculation and P*M interactions. P and mycorrhiza treatments did not make a statistically significant difference as P uptake of cotton shoot and total parts. Moreover, as root parts, there are no statistically significant differences in mycorrhizal inoculation, P application, and M*P interaction. When root P concentration is examined, it is observed that it is very low, especially at the P0 dose. This may be due to the possibility that no matter how much we clean the roots; soil particles may remain on the root surfaces. In the shoot part of cotton, both statistically and on average, P and mycorrhiza treatments increased cotton %P concentration. Also, there is no difference between P50 x IM and P0 x *Rh. Clarus* applications. As seen in Table 4, in terms of plant P uptake (g pot^{-1}) P, M and P*M interactions did not make a significant difference in the shoot and total cotton parts. In the root parts, only the P treatment made a significant difference. P50 dose application provided the highest P uptake. Our study shows that P application increases plant P uptake. And it was expected. For example, Wang et al. (2009) in their study, show that P application rise cotton P uptake. Mycorrhizal fungi association is most beneficial for crops grown by plants through several mechanisms like organic acid production and mycorrhizal hyphae pathway (Elbon and Whalen, 2015). When plant P uptake (nutrition) increases, biomass and yield through photosynthesis will also increase (Veneklaas et al., 2012).

Table 3. The effects of P and mycorrhizal inoculation on cotton different parts P concentration.

P Doses	Mycorrhiza	Root P	Shoot P
		(%)	
P0	Control	0.006±0.002	0.102±0.009
	IM	0.007±0.001	0.108±0.004
	Rh. Clarus	0.009±0.000	0.112±0.014
Average	*P0*	0.007	0.108
P50	Control	0.013±0.003	0.102±0.028
	IM	0.011±0.002	0.112±0.004
	Rh. Clarus	0.016±0.006	0.127±0.010
Average	*P50*	0.013	0.114
Average	*Control*	0.009	0.102
	IM	0.009	0.110
	Rh. Clarus	0.012	0.120
	P	NS	**
	M	NS	NS
	P*M	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

Shoot Morphologic Parameters

Table 5 shows the impact of P and M application on cotton shoot length and steam diameter. P and M treatments did not make a statistically significant ($p>0.05$) difference in shoot length but increased shoot diameter. Since P application increases plant growth and yield, it is expected to increase plant height. For example, Iqbal et al. (2019) reported that increasing doses of P application also increased cotton shoot length. There are so many studies about mycorrhiza increasing cotton plant growth like length and diameter (Price et al., 1989; Rich and Bird, 1974; Wang et al., 2021). Mycorrhizal fungi are known to provide water and nutrients to the plant. This increased cotton growth (like shoot diameter and length). There is no significant difference in shoot length and diameter in terms of P*M interaction. This supports our hypothesis that there is no significant difference between P and M practices.

Table 4. The effects of P and mycorrhizal inoculation on cotton plant's different parts P (g pot^{-1}) uptake.

P Doses	Mycorrhiza	Root		Shoot		Total	
				(g pot^{-1})			
P0	Control	0.0003	±0.000	0.038	±0.003	0.039	±0.003
	IM	0.0004	±0.000	0.043	±0.002	0.043	±0.002
	Rh. Clarus	0.0005	±0.000	0.046	±0.006	0.047	±0.006
	P0	0.0004		0.042		0.043	
P50	Control	0.0007	±0.000	0.039	±0.014	0.040	±0.014
	IM	0.0006	±0.000	0.044	±0.001	0.045	±0.001
	Rh. Clarus	0.0010	±0.000	0.052	±0.004	0.053	±0.003
	P50	0.0008		0.045		0.046	
	Control	0.0005		0.039		0.039	
	IM	0.0005		0.043		0.044	
	Rh. Clarus	0.0008		0.049		0.050	
	P	**		NS		NS	
	M	NS		NS		NS	
	P*M	NS		NS		NS	

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

Table 5. The effects of P and mycorrhizal inoculation on cotton shoot length and diameter.

P Doses	Mycorrhiza	Shoot Length (cm)	Shoot Diameter (mm)
P0	Control	82.0±1.0	5.9±0.6
	IM	84.0±7.9	6.5±0.2
	Rh. Clarus	83.5±4.5	6.3±0.2
Average	*P0*	83.2	6.2B
P50	Control	80.0±4.0	6.5±0.1
	IM	84.0±7.9	6.8±0.2
	Rh. Clarus	90.3±10.7	7.1±0.3
Average	*P50*	84.8	6.8A
	Control	81.0	6.2B
	IM	84.0	6.7A
	Rh. *Clarus*	86.9	6.7A
Average	*P*	NS	**
	M	NS	*
	*P*M*	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

Table 6. Effects of P and mycorrhizal inoculation on cotton root morphological parameters

P Doses	Mycorrhiza	Diameter	Length	Surface Area	Volume
			(g pot^{-1})		
P0	Control	0.328±0.065	10189±1492	1058±295	7.3±2.6
	IM	0.343±0.040	12268±4754	1282±394	10.7±2.3
	Rh. Clarus	0.306±0.011	12122±672	1164±30	9.0±0.1
Average	*P0*	0.326	11526	1168	9.0
P50	Control	0.308±0.018	11122±875	1073±26	8.3±0.4
	IM	0.318±0.036	13056±173	1304±130	10.5±2.2
	Rh. Clarus	0.307±0.013	14632±4141	1400±368	10.7±2.6
Average	*P50*	0.311	12937	1259	9.8
Average	*Control*	0.318	10655.6	1065.6	7.8
	IM	0.331	12662.0	1293.1	10.6
	Rh. Clarus	0.306	13376.9	1282.0	9.9
	P	NS	NS	NS	NS
	M	NS	NS	NS	NS
	P*M	NS	NS	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

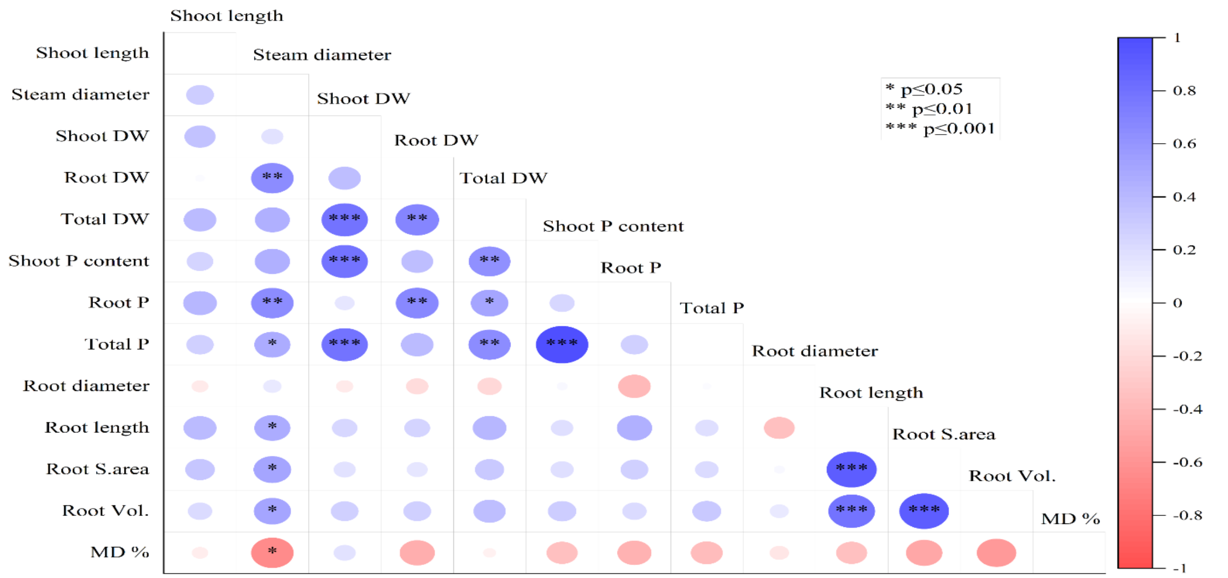

Figure 2. Correlation matrix showing the relationships between the measured plant parameters.

Root Morphologic Parameters

The effect of P and M treatments on cotton root morphological traits is shown in Table 6. There is no significant difference between root morphological characteristics in terms of P, M and P*M interaction. Table 6 shows that P and M application increased cotton root morphological characteristics. In particular, mycorrhiza-treated plots had higher root length, surface area, and volume compared to non-mycorrhiza-treated plots. Mycorrhizal inoculation significantly increased root length between %18.8 and % 25.5. As the root morphological characteristics increase, the soil it comes into contact with and thus its nutrition increases. Therefore, root morphological characteristics are of great importance.

P fertilization affects plant root morphological characteristics. P application is expected to increase plant root morphological characteristics. Öztürk et al. (2019) previously reported that increasing doses of P application increased maize root morphological characteristics, under long-term experiment conditions. This study supports our research findings.

Mycorrhizal fungi affect root morphological characteristics (Liu et al., 2016). Mycorrhiza increases root morphological parameters like length and diameter (Chandrasekaran, 2022; Hetrick, 1991). For example, Soylu et al. (2023) in their study show that M application increases plant root length and surface area. Tian et al. (2024) reported that mycorrhizal inoculation increased root surface area. These studies support our research findings.

From Figure 2 visual representation helps in quickly identifying which plant traits are closely associated with each other. It is observed that total P and root-specific area show a strong positive correlation with other parameters. Conversely, MD% shows a negative correlation with a few other traits. In addition, there is also a positive, correlation between plant tissue P content and shoot length and diameter.

CONCLUSIONS

The cotton plant was found to be between % 8.0 to 12.3% mycorrhizal dependency. In general mycorrhizal dependency is lower in P-treated pots (8.1%) compared to non-P-treated pots (11.3%). Mycorrhiza inoculation and 50 mg P_2O_5 kg^{-1} dual application seem to be a suitable combination. The results showed that mycorrhiza and P applications increased root growth and root parameters. However, MD was found to be low in our study. Phosphorus and mycorrhiza can be inoculated at a dose of P50 for sustainable and environmentally friendly production. Our research findings support our hypothesis.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

ACKNOWLEDGEMENT

The authors wish to express Çukurova University and their contribution and foundation for funding the research.

REFERENCES

Ahmad, M., Hannan, A., Yasin, M., Ranjha, A., and Niaz, A. 2009. Phosphorus application to cotton enhances growth, yield, and quality characteristics on sandy loam soil. *Pak. J. Agri. Sci* **46**, 3.

Chandrasekaran, M. 2022. Arbuscular mycorrhizal fungi mediated enhanced biomass, root morphological traits and nutrient uptake under drought stress: a meta-analysis. *Journal of Fungi* **8**, 660.

Elbon, A., and Whalen, J. K. 2015. Phosphorus supply to vegetable crops from arbuscular mycorrhizal fungi: a review. *Biological Agriculture & Horticulture* **31**, 73-90.

Hetrick, B. 1991. Mycorrhizas and root architecture. *Experientia* **47**, 355-362.

Iqbal, A., Gui, H., Zhang, H., Wang, X., Pang, N., Dong, Q., and Song, M. 2019. Genotypic variation in cotton genotypes for phosphorus-use efficiency. *Agronomy* **9**, 689.

Iqbal, B., Kong, F., Ullah, I., Ali, S., Li, H., Wang, J., Khattak, W. A., and Zhou, Z. 2020. Phosphorus application improves the cotton yield by enhancing reproductive organ biomass and nutrient accumulation in two cotton cultivars with different phosphorus sensitivity. *Agronomy* **10**, 153.

Işik, M., and Ortaş, İ. 2024. Effect of Biochar and Mycorrhiza Inoculation on Maize Growth, Photosynthesis Activity, and Water Use Efficiency Under Deficient Irrigation Conditions. *Communications in Soil Science and Plant Analysis* **55**, 2952-2965.

Liu, J., Guo, C., Chen, Z.-L., He, J.-D., and Zou, Y.-N. 2016. Mycorrhizal inoculation modulates root morphology and root phytohormone responses in trifoliate orange under drought stress. *Emirates Journal of Food and Agriculture* **28**, 251.

Marschner, P., and Rengel, Z. 2007. "Nutrient cycling in terrestrial ecosystems," Springer Science & Business Media.

Ortas, I. 2012. The effect of mycorrhizal fungal inoculation on plant yield, nutrient uptake and inoculation effectiveness under long-term field conditions. *Field Crops Research* **125**, 35-48.

Ortas, I., and Iqbal, M. T. 2019. Mycorrhizal inoculation enhances growth and nutrition of cotton plant. *Journal of Plant Nutrition* **42**, 2043-2056.

Öztürk, F., Akşahin, V., Işık, M., Karadere, Ş., and Ortaş, İ. 2019. Effect of Different Phosphorus Doses on Corn (*Zea Mays* L.) Root Growth and Carbon Content.

Price, N., Roncadori, R., and Hussey, R. 1989. Cotton root growth as influenced by phosphorus nutrition and vesicular–arbuscular mycorrhizas. *New Phytologist* **111**, 61-66.

Rich, J., and Bird, G. 1974. Increased Growth and Development of Cotton. *Phytopathology* **64**, 1421-1425.

Saleem, M., Cheema, M., Rasul, F., Bilal, M., Anjum, S., and Wahid, M. 2010. Effect of phosphorus on growth and yield of cotton. *Crop & Environment* **1**, 39-43.

Schnug, E., and Haneklaus, S. H. 2016. The enigma of fertilizer phosphorus utilization. *In* "Phosphorus in Agriculture: 100% Zero", pp. 7-26. Springer.

Smith, S., and Read, D. 2008. Colonization of roots and anatomy of arbuscular mycorrhiza. *Mycorrhizal Symbiosis. Academic Press: London*, 42-90.

Soylu, E., Işık, M., and Ortaş, İ. 2023. The Effect of Mycorrhiza Inoculation on Pepper Plant Growth and Mycorrhizal Dependency. International Journal of Agricultural and Applied Sciences, **4**(1):127-131. https://doi.org/10.52804/ijaas2023.4121

Staff, S. S. 1999. Soil taxonomy: a basic system of soil classification for making and interpreting soul surveys. 2nd. USDA. *Natural Resources Conservation Service, Washington: Agricultural Handbook, United State of America*.

Tian, K., Lintern, A., Palacios, Y. M., and Winfrey, B. 2024. Drought and mycorrhizal inoculation affect growth and morphology of Australian stormwater biofilter plants. *Ecological Engineering* **206**, 107330.

Veneklaas, E. J., Lambers, H., Bragg, J., Finnegan, P. M., Lovelock, C. E., Plaxton, W. C., Price, C. A., Scheible, W. R., Shane, M. W., and White, P. J. 2012. Opportunities for improving phosphorus-use efficiency in crop plants. *New Phytologist* **195**, 306-320.

Wahab, A., Muhammad, M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., Khizar, C., and Reddy, S. P. P. 2023. Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. *Plants* **12**, 3102.

Wang, L., Wang, X., Maimaitiaili, B., Kafle, A., Khan, K. S., and Feng, G. 2021. Breeding practice improves the mycorrhizal responsiveness of cotton (Gossypium spp. L.). *Frontiers in Plant Science* **12**, 780454.

Wang, X., Tang, C., Guppy, C., and Sale, P. W. G. 2009. The role of hydraulic lift and subsoil P placement in P uptake of cotton (Gossypium hirsutum L.). *Plant and Soil* **325**, 263-275.

Yli-Halla, M. 2016. Fate of fertilizer P in soils: inorganic pathway. *In* "Phosphorus in Agriculture: 100% Zero", pp. 27-40. Springer.

Citation: Mehmet IŞIK* and İbrahim ORTAŞ 2024. The Impact of Applying Phosphorus and Mycorrhiza on the Morphological Parameters of Cotton Roots and Shoots, as well as Their Phosphorus Uptake and Dry Matter Yield. *International Journal of Agricultural and Applied Sciences*, 5(2): 66-71.