Research Article

Current Horticulture 11(3): 23–34, September–December 2023 DOI: 10.5958/2455-7560.2023.00038.9

Effect of mycorrhiza applications on nutrient uptake in Prunus rootstock under water stress conditions

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Received: 06 September 2022; **Accepted:** 09 June 2023

ABSTRACT

The experiment was conducted in a glass greenhouse using pots to compare grafted and ungrafted plants. Four different rootstocks, namely Rootpac 40, Rootpac R, GF 677, and Garnem, were utilized. The control plants (K100) were irrigated to maintain a water level equivalent to 100% of the field capacity. For the K55 application, water was provided at 55% of K100 irrigation level, while K40 application received water at 40% of K100 application. During 2020 trial, water availability was limited, resulting in restricted water application to plants. Half of the seedlings were grafted with Carolina nectarine variety. During 2021 trial, limited water application was implemented by inoculating both the grafted and non-grafted nectarine plants with *Glomus mosseae* mycorrhiza species. Under drought stress, mycorrhizae-inoculated seedlings exhibited positive effects on concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in their leaves.

Key Words: Stone fruits rootstocks, Drought resistance/tolerance, Mycorrhiza, Plant nutrients, Macro elements

Sert çekirdekli meyve üretimi bakımından dünyada sayılı ülkeler arasında bulunan ülkemizde 2021 yılında yaklaşık 3 milyon ton sert çekirdekli meyve üretimi gerçekleşmiştir (TUİK, 2023).

Kullanılan anaç üzerine aşılanan çeşidin gelişimini, verimini, meyvenin kalitesini, kurağa, dona, kirece, tuzluluğa, taban suyuna toleransını, bitki besin maddelerinin topraktan alımını ve hastalık ve zararlılara dayanımını etkilemektedir.

Bitkiler optimal bir şekilde büyüme ve gelişme gösterebilmeleri için besin maddelerine gereksinim duyarlar. Bitkilerde bulunan besin maddeleri miktarları üzerinde bitkinin türü, yaşı, kök büyümesi, toprağın fiziksel, kimyasal ve biyolojik özellikleri, toprakta yarayışlı şekilde bulunan elementlerin cins ve miktarları, uygulanan tarımsal yöntemler, hava koşulları gibi çok sayıda faktör etkilidir.

In Turkey, stone fruit industry is significant, with approximately 3 million tonnes of stone fruit produced in 2022 (TUIK, 2023). The main stone fruit types cultivated in include apricot (*Prunus armeniaca* L.), peach (*Prunus persica* L.), cherry (*Prunus avium* L.), and plum (*Prunus domestica* L.).

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To ensure optimal vegetative growth during the spring season, prevent fruit drop, maintain normal fruit size, and promote the formation of an adequate number of flower buds for the following year, it is crucial to maintain sufficient soil moisture throughout the entire vegetation period. The soil moisture should never fall below the wilting point to meet the water requirements of the stone fruit trees (Kuden, 2019).

Abbaspour *et al*. (2017) conducted a study to investigate the impact of *Glomus etunicatum* species of mycorrhiza application on drought stress in 3-month-old pistachio seedlings (*Pistacia vera* L.) grown in pot culture. Gür and San (2017) examined three different restricted water treatments applied to wild pear seedlings, using BA 29, Farold 40, OHxF 333, and Fox 11 rootstocks commonly used in pear cultivation under greenhouse conditions. Hamedani *et al*. (2022) focused on studying the yield, irrigation water efficiency, and nutrient uptake of mycorrhiza-inoculated sesame (*Sesamum indicum* L.) under drought stress conditions. Yılmaz *et al*. (2020) investigated the effects of *Glomus mosseae* and *Glomus fasciculatum* on plant growth during the acclimatization of micropropagated sweet cherry (*Prunus avium* L.) rootstocks. Zou *et al*. (2020) conducted research on arbuscular mycorrhizal fungi (AMF) in the rhizosphere of citrus (*Citrus* spp.) crops, emphasizing their role in forming mutualistic symbiosis with roots and enhancing plant growth, nutrient acquisition, stress tolerance, fruit quality, and soil stability. Saroj and Choudhary in 2020 highlighted water stress as one of the most important environmental variables affecting plant growth and development. Water stress can result from either insufficient water due to drought conditions or excessive water activity. Climate forecasts indicate that global warming will continue in the coming decades, regardless of the actions taken today. Therefore, an experiment was conducted in pots to assess the effects of restricted water and mycorrhiza treatments on nutrient uptake in various *Prunus* rootstocks.

MATERIALS AND METHODS

For the plant selection in the study, one-year-old clonal rootstocks propagated through tissue culture were utilized. These selected plants were specifically chosen based on the criteria that they were unaffected by diseases and pests, exhibited similar physical characteristics, and had completed the rooting process. By using clonal rootstocks with these attributes, the researchers aimed to minimize any potential confounding factors related to disease susceptibility, pest damage, or physical variations among the plants.

Fig. 1. Rootstocks used (Rootpac 40, Rootpac R, GF 677 and Garnem)

Carolina nectarine, when grafted on rootstocks, exhibits early blooming characteristics. The harvest of Carolina nectarine typically takes place between the 1st and 10th of June. The texture of the fruit is influenced by the nutrient levels present in the growing medium used for cultivation.

For irrigation purposes, the water source utilized was a borehole located in the Alata Horticultural Research Institute. The conductivity of the irrigation water from this borehole ranges between 250 and 750 µs/cm, indicating a medium salinity level (salinity class C2). This water is suitable for irrigation of plants with moderate salt tolerance according to Table 1.

Table 1. Characteristics of irrigation water

pH	7.4
B	0.1
Ca	0.93
Mg	1.91
K	0.43
Na	6.35
Ca+Mg	2.81
HCO_3	3.5
Cl	2.5
SO_4	3.59
SAR	5.38

The experiment was carried out in pots within the glass greenhouse conditions of the Alata Horticultural Research Institute between 2020 and 2021. The study involved the use of different rootstocks and irrigation doses, with half of the rootstocks being grafted with the Carolina nectarine variety. Additionally, mycorrhiza application was performed on half of the rootstocks to assess the nutrient content in the leaves.

In total, four different rootstocks, one cultivar (Carolina nectarine), three irrigation doses, and 14-liter plastic pots were utilized in the experiment. The pots were divided into mycorrhizal (M+) and non-mycorrhizal (M-) treatments, as well as grafted and non-grafted applications. This experimental setup allowed for the evaluation of various factors on the nutrient levels in the leaves of the plants.

During the 2020 trial, the experiment was conducted in a greenhouse with shading and ventilation. Limited irrigations were implemented programmatically, starting on July 16, 2020, and ending on August 20, 2020, when the plants had become dried out due to stress. Restricted water applications were carried out for duration of 36 days, with a total of 12 applications during this period.

In the 2021 trial, *Glomus mosseae* mycorrhiza was inoculated into the plants. Restricted water applications were conducted over a period of 30 days, starting from July 12, 2021, and ending on August 10, 2021. These applications were made 10 times during the specified timeframe.

The pots used in the experiment were filled with a growing medium consisting of a mixture of 1 part sandy soil, 2 parts garden soil, and 1 part peat. The pots had a known weight, litter, and holes in the bottom. The growing medium used in the experiments was sterilized by autoclaving at 121°C for 90 minutes to eliminate any potential microorganisms.

To establish the mycorrhiza inoculum, Glomus mosseae species were reproduced using a soil Urgüp tuff and animal manure medium in a ratio of 3:6:1 (V/V/V). The reproduction was carried out under the presence of sorghum host plants. The resulting inoculum was stored in a cold environment at a temperature of +4°C until it was used in the experiment.

Glomus mosseae exhibits a range of colors from light yellow to dark orange-brown. Its morphology is generally spherical or hemispherical, although irregular shapes can also be observed. The size of *Glomus mosseae* spores ranges from 100 to 260 µm, with an average size of 195 µm (Invam, 2022).

To determine the field capacity of the growing medium in the pots, the method described by Unlukara *et al*. (2010) was followed. Initially, five pots without plants were filled with the mortar mixture and weighed. The mortar mixture was then saturated with water until leakage occurred, and aluminum foil was used to cover the pots and prevent evaporation. The process of adding water and allowing leakage to occur was repeated several times. After the infiltration process was completed, the pots were covered with aluminum foil and weighed after 48 hours. The average weight of these pots represented the field capacity.

For leaf samples, the middle leaf pair of the shoots was collected at the end of the experiment, specifically after the stress treatments were completed. The collected samples were cleaned with 0.1% theopol water, rinsed several times with distilled water, and then subjected to drying and grinding processes. The analysis of total nitrogen (N) was conducted using the modified Kjeldahl method (Kacar, 1972). Phosphorus content was determined using the vanadomolybdophosphoric acid method, which involves wet burning of the plant extract, followed by colorimetric measurement according to the yellow color method (Kaçar, 1972). Potassium, calcium, and magnesium analyses were performed using inductively coupled plasma (ICP) in the plant extract (Chapman and Pratt, 1961).

RESULTS AND DISCUSSION

In the 2020 experiment, it was observed that water stress generally led to a decrease in nutrient uptake in plants. Specifically, there was a decrease in nitrogen uptake with increasing water stress. The highest nitrogen uptake was observed in plants grafted with R 40 rootstock and GF 677 in the K 40 application.

For phosphorus uptake, the highest concentration (0.19%) was observed in plants grafted on R 40 rootstock in the K100 application, while the lowest concentration was found in GF 677 rootstock in the K40 application (0.05%).

With increasing water stress, there was a decrease in potassium uptake. The highest potassium concentration (1.40%) was observed in plants grafted on R 677 rootstock in the K100 application, while the lowest concentration (0.85%) was found in plants grafted on GF 677 rootstock in the K40 application.

Regarding calcium concentration, the highest value (1.29%) was observed in plants grafted on GF 677 rootstock in the K100 application, while the lowest concentration (1.09%) was found in plants grafted on GF 677 rootstock in the K 40 application.

For magnesium concentration, the highest values (0.30%) were observed in plants grafted on R 40 rootstock and RR in the K100 application. The lowest concentration (0.12%) was determined in plants grafted on GF 677 rootstock in the K40 application.

With an increase in water stress in plants, there was a decrease in nitrogen concentration. The highest nitrogen concentration (2.58%) was obtained in the R R rootstock in the K100 application.

Water stress also caused a decrease in phosphorus concentration, and the highest phosphorus concentration (0.18%) was obtained from the R R rootstock in the K100 application.

Similarly, the amount of potassium decreased with increasing water stress. The highest potassium concentration (1.32%) was obtained from the R 40 rootstock in the K100 application. The lowest potassium concentration (0.88%) in the K40 application was found in the GF 677 rootstock.

With an increase in water stress, the amount of calcium also decreased. The highest calcium concentration (1.29%) was obtained from the R 40 rootstock in the K100 application. The lowest calcium concentration (1.08%) in the K40 application was found in the GF 677 rootstock.

Table 2. Effect of restricted water applications on plant nutrients in grafted plants

Water application	N (Nitrogen) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	2.50 a	2.40 a	2.50 a	2.35 ab	2.44 A
K_{55}	1.95 bc	1.65 cd	1.85 cd	1.65 cd	1.78 B
K_{40}	1.70 cd	1.55 d	1.70 cd	1.50 d	1.61 C
Average	2.05 A	1.87 BC	2.02 AB	1.83 B	
$LSD_{(0.05)}$: rootstock: 0.17 $LSD_{(0.05):irrigation:}$0.13 $LSD_{(0.05)}$ rootstockxirrrigation: 0.38					
Water application	P (Phosphorus) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.19 a	0.18 a	0.16 ab	0.15 abc	0.17 A
K_{55}	0.10 cd	0.11 bcd	0.10 cd	0.09 de	0.10 B
K_{40}	0.10 cd	0.08 def	0.05 f	0.06 ef	0.07 C
Average	0.13 A	0.12	0.10 B	0.10 B	
$LSD_{(0.05)rootstock:}$ 0.019 $LSD_{(0.05):irrigation\ :}$ 0.016 $LSD_{(0.05)rootstockxirrrigation:}$ 0.046					
Water application	K (Potassium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.12 cd	1.40 a	1.35 ab	1.15 bcd	1.26 A
K_{55}	1.20 abc	1.30 abc	1.29 abc	1.19 abc	1.25 A
K_{40}	0.99 de	0.98 de	0.85 e	0.90 e	0.93 B
Average	1.10 B	1.23 A	1.16 AB	1.08 B	
$LSD_{(0.05):rootstock:}$ 0.094 $LSD_{(0.05):irrigation:}$ 0.073 $LSD_{(0.05):rootstockxirrrigation:}$ 0.212					
Water application	Ca (Calcium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.28 ab	1.25 ab	1.29 a	1.21 bcd	1.26 A
K_{55}	1.23 abc	1.26 ab	1.21 bcd	1.17 cde	1.22 B
K_{40}	1.22 abc	1.10 ef	1.09 f	1.14 def	1.14 C
Average	1.24 A	1.20 B	1.20B	1.17 B	
$LSD_{(0.05)rootstock:}$ 0.094 $LSD_{(0.05)irrigation:}$ 0.026 $LSD_{(0.05)rootstockxirrrigation:}$0.076					
Water application	Mg (Magnesium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.30 a	0.30 a	0.28 ab	0.27 ab	0.29 A
K_{55}	0.26 abc	0.26 abc	0.22 cd	0.21 d	0.24 B
K_{40}	0.24 bcd	0.24 bcd	0.12 e	0.20 d	0.20 C
Average	0.27 A	0.27 A	0.21 C	0.23 B	
$LSD_{(0.05)rootstock:}$ 0.094 $LSD_{(0.05)irrigation:}$ 0.026 $LSD_{(0.05)rootstockxirrrigation:}$ 0.076					

Table 3. Effect of restricted water applications on plant nutrients in non-grafted plants

Water application	N (Nitrogen)(%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	2.50 a	2.58 a	2.41 a	2.45 a	2.49 A
K_{55}	1.82 cd	2.40 a	1.91 c	2.15 b	2.07 B
K_{40}	1.65 d	2.10 b	1.70 d	1.65 d	1.78 C
Average	1.99 C	2.37 A	2.00 BC	2.08 B	
$LSD_{(0.05)rootstock:}$ 0.09	$LSD_{(0.05)irrigation:}$ 0.07	$LSD_{(0.05)rootstockxirrigation:}$ 0.020			

Water application	P (Phosphorus) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.16 ab	0.18 a	0.15 abc	0.15 abc	0.16 A
K_{55}	0.14 abcd	0.11 cde	0.11 cde	0.11 cde	0.12 B
K_{40}	0.09 de	0.08 ef	0.05 f	0.08 ef	0.08 C
Average	0.13 A	0.12A	0.10 B	0.11 AB	
$LSD_{(0.05)\ rootstock:}$ 0.018	$LSD_{(0.05)irrigation:}$ 0.020	$LSD_{(0.05):rootstockxirrigation:}$ 0.035			

Water application	K (Potassium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.32	1.21	1.13	1.25	1.23 A
K_{55}	1.04	1.25	1.19	1.18	1.17 AB
K_{40}	1.28	1.06	0.88	0.92	1.03 B
Average	1.21	1.17	1.12	1.12	
$LSD_{(0.05)rootstock:}$ Ö.D.	$LSD_{(0.05)irrigation:}$ 0.015	$LSD_{(0.05)rootstockxirrigation:}$ Ö.D.			

Water application	Ca (Calcium) (%)				
	Rootstock				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.29	1.26	1.21	1.26	1.26 A
K_{55}	1.14	1.23	1.14	1.24	1.19 AB
K_{40}	1.19	1.18	1.08	1.20	1.16 B
Average	1.21	1.22	1.14	1.23	
$LSD_{(0.05)rootstock:}$ Ö.D.	$LSD_{(0.05)irrigation:}$ 0.08	$LSD_{(0.05)rootstockxirrigation:}$ Ö.D.			

Water application	Mg (Magnesium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.25 abc	0.30 a	0.29 a	0.28 ab	0.28 A
K_{55}	0.21 cd	0.23 bcd	0.25 abc	0.26 abc	0.24 B
K_{40}	0.21 cd	0.19 d	0.21 cd	0.23 bcd	0.21 C
Average	0.23 B	0.24 AB	0.25 AB	0.26 A	
$LSD_{(0.05)rootstock:}$ 0.026	$LSD_{(0.05)\ irrigation:}$ 0.020	$LSD_{(0.05:rootstockxirrigation:}$ 0.056			

Regarding magnesium concentration, the highest value (0.30%) was obtained from the R R rootstock in the K100 application, while the lowest value (0.19%) was obtained from the R R rootstock in the K40 application.

According to Mahieu *et al*. (2009), water stress has a significant impact on nitrogen accumulation in peas, leading to inhibited plant growth and chlorosis. Gur and San (2017) observed that the amounts of N, Cu, B, Zn, P, Ca, and K decreased in wild pear seedlings and different rootstocks under stress conditions, while Fe, Mg, and Mn values increased. Çerçi (2013) reported a decrease in N and P concentrations under water stress conditions.

Ipek (2015) found that in Myrobolan 29C rootstock, the concentrations of calcium, potassium, phosphorus, and magnesium decreased in all drought applications, while sodium and sulfur levels were higher in the -1.0 MPa drought application compared to others. The levels of boron, copper, iron, manganese, and zinc were lower in drought applications compared to the control. Similarly, in Garnem rootstock, reductions were observed in calcium, potassium, sodium, phosphorus, and magnesium under drought conditions, while sulfur content was higher than the control in all drought applications.

It was determined that the nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents of both grafted and ungrafted plants decreased with stress applications. However, the effects of restricted water applications on nitrogen content were found to be statistically insignificant.

In the K40 application, the highest nitrogen concentration was found in plants grafted with GF 677 rootstock (2.55%), while the lowest concentration was determined in plants grafted with R R rootstock (1.87%).

Similarly, with an increase in water stress, there was a decrease in phosphorus concentration. In the K40 application, the highest phosphorus concentration was found in plants grafted with R 40 rootstock (0.15%), while the lowest concentration was observed in plants grafted with Garnem rootstock (0.11%). These findings suggest that different rootstocks may have varying responses to water stress in terms of nutrient uptake and accumulation.

With an increase in water stress, there was a decrease in potassium concentration. In the K40 application, the highest potassium concentration was found in plants grafted with RR rootstock (1.30%), while the lowest concentration was observed in plants grafted with GF 677 rootstock (1.25%).

Similarly, in the K40 application, the highest calcium concentration was found in plants grafted with R 40 rootstock (1.22%), while the lowest concentration was obtained from plants grafted with GF 677 and Garnem rootstocks (1.15%).

With an increase in water stress, the amount of magnesium decreased. In the K40 application, the highest magnesium concentration was observed in plants grafted with R R rootstock (0.29%), while the lowest concentration was obtained from plants grafted with GF 677 and Garnem rootstocks (0.21%).

The difference between rootstocks in terms of nitrogen values was non significant. The lowest nitrogen concentration in the K40 application was determined in plants grafted with R R rootstock (1.45%). In the K40 application, the highest phosphorus concentration was found in plants grafted with GF 677 rootstock (0.15%), while the lowest phosphorus concentration was found in plants grafted with R R rootstock (0.07%). There was also a decrease in potassium concentration in the leaves. In the K40 application, the highest potassium concentration was detected in plants grafted with R R rootstock (0.97%), while the lowest potassium concentration was obtained in plants grafted with GF 677 rootstock (0.12%).

Similarly, there was a decrease in calcium concentration. In the K40 application, the highest calcium concentration was obtained in plants grafted with R 40 rootstock (1.28%), while the lowest calcium concentration was observed in plants grafted with R R rootstock (1.08%).

In the K40 application, the highest magnesium concentration was observed in plants grafted with R 40 rootstock (0.25%), while the lowest magnesium concentration was obtained in plants grafted with R R rootstock (0.19%). These findings indicate that water stress and rootstock selection can influence the nutrient contents in plants, specifically in terms of potassium, calcium, and magnesium concentrations.

The effects of restricted water and mycorrhiza treatments on leaf nutrient concentrations in ungrafted and mycorrhizal plants on different rootstocks were examined, and the difference between rootstocks was generally found to be statistically insignificant (Table 6).

There was no significant difference between rootstocks in terms of nitrogen values. In the K40

Table 4. Effect of restricted water and mycorrhiza treatments on nutrients in grafted and mycorrhizal plants

Water application	N (Nitrogen)(%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	2.10 cde	2.17 bcd	2.17 bcd	2.27 bc	2.18
K_{55}	2.33 abc	1.97 de	2.37 ab	2.32 abc	2.25
K_{40}	2.25 bc	1.87 e	2.55 a	2.18 bcd	2.21
Average	2.23 B	2.00 C	2.36 A	2.26 AB	
$LSD_{(0.05)\ rootstock:}$ 0.11	$LSD_{(0.05)\ irrigation:}$ 0.086	$LSD_{(0.05)\ rootstockxirrigation:}$ 0.025			
Water application	P(Phosphorus)(%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.15 bcd	0.19 a	0.19 a	0.18 ab	0.18 A
K_{55}	0.16 abc	0.11 ef	0.12 de	0.13 cde	0.13 B
K_{40}	0.15 bcd	0.13 cde	0.12 de	0.11 ef	0.13 B
Average	0.15	0.14	0.14	0.14	
$LSD_{(0.05)\ rootstock:}$ 0.019	$LSD_{(0.05)irrigation:}$ 0.017	$LSD_{(0.05)rootstockxirrigation:}$ 0.048			
Water application	K(Potassium)(%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.28 cd	1.60 a	1.30 c	1.25 d	1.36 A
K_{55}	1.29 cd	1.40 b	1.39 b	1.29 cd	1.34 A
K_{40}	1.29 cd	1.30 c	1.25 d	1.29 cd	1.28 B
Average	1.29 C	1.43 A	1.31 B	1.28 C	
$LSD_{(0.05):\ rootstock:}$ 0.022	$LSD_{(0.05):\ irrigation:}$ 0.017	$LSD_{(0.05):\ rootstockxirrigation:}$ 0.045			
Water application	Ca (Calcium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	1.26 ab	1.27 ab	1.29 a	1.25 abc	1.27 A
K_{55}	1.24 abc	1.26 ab	1.19 cd	1.19 cd	1.22 B
K_{40}	1.22 bc	1.19 cd	1.15 de	1.15 de	1.18 C
Average	1.24 A	1.21 B	1.20 B	1.20 B	
$LSD_{(0.05)rootstock:}$ 0.020	$LSD_{(0.05)irrigation:}$ 0.016	$LSD_{(0.05)\ rootstockxirrigation:}$ 0.046			
Water application	Mg (Magnesium) (%)				
	Rootstocks				Average
	R 40	R R	GF 677	Garnem	
K_{100}	0.35 a	0.34 a	0.28 abc	0.20 e	0.29 A
K_{55}	0.34 a	0.28 abc	0.22 bcde	0.27 abcd	0.28 A
K_{40}	0.27 abcd	0.29 ab	0.21 cde	0.21 cde	0.25 B
Average	0.32 A	0.31 A	0.24 B	0.22 B	
$LSD_{(0.05)rootstock:}$ 0.032	$LSD_{(0.05):\ irrigation:}$ 0.025	$LSD_{(0.05):\ rootstockxirrigation:}$ 0.072			

Table 5. Effect of restricted water and mycorrhiza applications on nutrients in grafted and untreated plants

	N (Azot)(%)				
	Rootstocks				
Water application	R 40	R R	GF 677	Garnem	Average
K_{100}	2.50 a	2.60 a	2.40 a	2.55 a	2.51 A
K_{55}	1.75 b	1.85 b	1.85 b	1.85 b	1.83 B
K_{40}	1.70 b	1.45 c	1.70 b	1.70 b	1.64 C
Ortalama	1.98	1.97	1.98	2.03	
$LSD_{(0.05)\ rootstock:}$ 0.013	$LSD_{(0.05):\ irrigation:}$ 0.088	$LSD_{(0.05)\ rootstockxirrigation:}$ 0.256			

	P(Fosfor)(%)				
Water application	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	0.18 a	0.18 a	0.18 a	0.17 ab	0.18 A
K_{55}	0.11 abcd	0.11 abcd	0.17 ab	0.09 cd	0.12 B
K_{40}	0.10 bcd	0.07 d	0.15 abc	0.08 d	0.10 C
Ortalama	0.13 B	0.12 B	0.17 A	0.11 B	
$LSD_{(0.05)\ rootstock:}$0.030	$LSD_{(0.05)irrigation:}$ 0.023	$LSD_{(0.05)rootstockxirrigation:}$0.068			

	K (Potassium) (%)				
Water application	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	1.32 ab	1.40 a	1.38 a	1.25 bc	1.34 A
K_{55}	1.30 ab	1.30 ab	1.19 cd	1.09 d	1.22 B
K_{40}	0.12 f	0.97 e	0.88 e	0.90 e	0.72 C
Ortalama	0.91 D	1.22 A	1.15 B	1.08 C	
$LSD_{(0.05)}$:$_{rootstock:}$ 0.043	$LSD_{(0.05)}$: $_{irrigation:}$0.034	$LSD_{(0.05)}$: $_{rootstockxirrigation:}$0.098			

	Ca (Calcium) (%)				
Water application	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	1.32 ab	1.35 a	1.29 b	1.21 c	1.29 A
K_{55}	1.29 b	1.16 d	1.21 c	1.17 cd	1.21 B
K_{40}	1.28 b	1.08 e	1.09 e	1.14 d	1.15 C
Ortalama	1.30 A	1.20 B	1.20 B	1.17 C	
$LSD_{(0.05)rootstock:}$ 0.028	$LSD_{(0.05)irrigation}$ 0.023	$LSD_{(0.05)rootstockxirrigation:}$0.068			

	Mg (Magnesium)(%)				
Water application	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	0.27 a	0.26 ab	0.29 a	0.26 ab	0.27 A
K_{55}	0.24 ab	0.26 ab	0.22 ab	0.25 ab	0.24 AB
K_{40}	0.25 ab	0.19 b	0.23 ab	0.21 ab	0.22 B
Ortalama	0.25	0.24	0.25	0.24	
$LSD_{(0.05)rootstock:}$0.035	$LSD_{(0.05)}$ irrigation: 0.027	$LSD_{(0.05)rootstockxirrigation:}$0.080			

application, the lowest phosphorus concentration was found in plants grafted with GF 677 rootstock (0.11%). In the K100 application, the lowest potassium concentration was observed in plants grafted with GF 677 rootstock (0.28%).

With an increase in water stress in plants, there was a decrease in calcium concentration. In the K40 application, the highest calcium concentration was observed in plants grafted with Garnem rootstock (1.28%), while the lowest concentration was obtained in plants grafted with GF 677 rootstock (1.19%). Similarly, in the K40 application, the highest magnesium concentration was observed in plants grafted with R rootstock (0.34%), while the lowest concentration was found in plants grafted with GF 677 rootstock (0.18%) (Table 6).

These results indicate that the effect of restricted water and mycorrhiza treatments on leaf nutrient concentrations is not significantly influenced by the different rootstocks used in the study.

In the K40 application, the lowest nitrogen concentration (1.65%) was determined in plants grafted with Garnem rootstock. With an increase in water stress in plants, phosphorus and potassium concentrations decreased. The highest phosphorus concentration (0.10%) and potassium concentration (1.25%) were obtained in the K40 application with R 40 rootstock. The lowest potassium concentration (0.18%) was determined in plants grafted with GF 677 rootstock (Table 7).

In terms of phosphorus and calcium values in the K40 application, there was no significant difference between rootstocks. The amount of calcium decreased with an increase in water stress in plants. In the K40 application, the highest calcium concentration was observed in Garnem rootstock (1.20%), while the lowest calcium concentration was determined in GF 677 rootstock (1.09%).

With an increase in water stress in plants, the magnesium concentration decreased. The highest magnesium concentration in the K40 application was obtained in plants grafted with GF 677 rootstock (0.21%).

The studies mentioned by Calıskan *et al.* (2017), Akpınar and Ortas (2020), and Guissou *et al.*

Table 6. Effect of restricted water applications on nutrients in ungrafted and mycorrhizal plants

	N (Nitrogen)(%)				
	Rootstocks				
Water application	R 40	R R	GF 677	Garnem	Average
K_{100}	1.90 d	2.20 bc	2.10 cd	2.15 bc	2.09 B
K_{55}	2.35 ab	2.30 abc	2.20 bc	2.33 ab	2.30 A
K_{40}	2.48 a	2.33 ab	2.25 abc	2.20 bc	2.32 A
Avarage	2.24	2.28	2.18	2.23	
$LSD_{(0.05)rootstock:}$ 0.035 $LSD_{(0.05)}$ irrigation: 0.027 $LSD_{(0.05)rootstockxirrigation:}$ 0.080					
	P (Phosphorus)(%)				
	Rootstocks				
Water application	R 40	R R	GF 677	Garnem	Average
K_{100}	0.16 cd	0.18 ab	0.16 cd	0.19 a	0.173 A
K_{55}	0.17 bc	0.19 a	0.18 ab	0.19 a	0.183 A
K_{40}	0.19 a	0.19 a	0.11 e	0.14 d	0.158 B
Avarage	0.17 B	0.19 A	0.15 C	0.17 B	
$LSD_{(0.05)rootstock:}$ 0.035 $LSD_{(0.05)}$ irrigation:0.027 $LSD_{(0.05)\ rootstockxirrigation:}$ 0.080					
	K (Potassium) (%)				
	Rootstocks				
Water application	R 40	R R	GF 677	Garnem	Average
K_{100}	1.29 a	1.31 a	1.27 a	1.25 a	1.28 A
K_{55}	1.31 a	1.35 a	1.29 a	1.27 a	1.31 A
K_{40}	1.34 a	1.34 a	0.28 b	1.35 a	1.08 B
Avarage	1.31 A	1.33 A	0.95 B	1.29 A	
$LSD_{(0.05)\ rootstock:}$ 0.035 $LSD_{(0.05)\ irrigation:}$ 0.027 $LSD_{(0.05)\ rootstockxirrigation:}$ 0.080					

Water application	Ca (Calcium)(%)				
	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	1.26 abc	1.28 ab	1.24 abcd	1.30 a	1.27 A
K_{55}	1.24 abcd	1.25 abcd	1.22 bcd	1.25 abcd	1.24 B
K_{40}	1.20 cd	1.27 ab	1.19 d	1.28 ab	1.24 B
Avarage	1.23 B	1.27 A	1.22 B	1.28 A	
$LSD_{(0.05): rootstock:}$ 0.035 $LSD_{(0.05)}$: $_{irrigation:}$0.027 $LSD_{(0.05):rootstockxirrigation:}$0.080					

Water application	Mg (Magnesium) (%)				
	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	0.25 de	0.32 ab	0.29 bc	0.27 cd	0.28 A
K_{55}	0.20 g	0.29 bc	0.25 de	0.25 de	0.25 B
K_{40}	0.23 ef	0.34 a	0.18 g	0.20g	0.24 B
Avarage	0.23 B	0.32 A	0.24 B	0.24 B	
$LSD_{(0.05): rootstock:}$0.035 $LSD_{(0.05): rootstock:}$ 0.027 $LSD_{(0.05)rootstockxirrigation:}$0.080					

Table 7. The effect of restricted water applications on nutrients in ungrafted and non-mycorrhizal plants

Water application	N (Nitrogen)(%)				
	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	2.30 bc	2.40 b	2.70 a	2.85 a	2.56 A
K_{55}	1.95 def	2.30 bc	1.90 efg	2.15 cd	2.08 B
K_{40}	1.85 fgh	2.10 cde	1.70 gh	1.65 h	1.83 C
Average	2.03 B	2.27 A	2.10 B	2.22 A	
$LSD_{(0.05)\ rootstock:}$ 0.035 $LSD_{(0.05)}$ sulama 0.027 $LSD_{(0.05)}$ anaçxsulama: 0.080					

Water application	P(Phosphorus)(%)				
	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	0.19 a	0.18 a	0.16 ab	0.15 abc	0.17 A
K_{55}	0.10 cd	0.11 bcd	0.10 cd	0.09 de	0.10 B
K_{40}	0.10 cd	0.08 def	0.05 f	0.06 ef	0.07 C
Average	0.13 A	0.12	0.11 B	0.10 B	
$LSD_{(0.05)}$ anaç: 0.035 $LSD_{(0.05)}$ sulama: 0.027 $LSD_{(0.05)}$ anaçxsulama: 0.080					

Water application	K(Potassium) (%)				
	Rootstocks				
	R 40	R R	GF 677	Garnem	Average
K_{100}	1.38 a	1.28 abc	1.32 ab	1.25 bc	1.31 A
K_{55}	1.28 abc	1.25 bc	1.30 ab	1.18 cd	1.25 B
K_{40}	1.25 bc	1.09 d	0.18 f	0.92 e	0.86 C
Average	1.30 A	1.20 B	0.93 D	1.12 C	
$LSD_{(0.05)}$ anaç: 0.035 $LSD_{(0.05)}$ sulama: 0.027 $LSD_{(0.05)}$ anaçxsulama: 0.080					

Water application	Ca (Calcium) (%) Rootstocks R 40	R R	GF 677	Garnem	Average
K_{100}	1.22 abcde	1.26 abc	1.30 a	1.27 ab	1.26 A
K_{55}	1.18 cde	1.23 abcd	1.17 de	1.14 ef	1.18 B
K_{40}	1.16 def	1.15 def	1.09 f	1.20 bcde	1.15 C
Average	1.19	1.21	1.19	1.20	
$LSD_{(0.05)}$ anaç: 0.035	$LSD_{(0.05)}$ sulama: 0.027	$LSD_{(0.05)}$ anaçxsulama: 0.080			

Water application	Mg (Magnesium) (%) Rootstocks R 40	R R	GF 677	Garnem	Average
K_{100}	0.23 bcde	0.30 a	0.21 cde	0.28 ab	0.26 A
K_{55}	0.21 cde	0.23 bcde	0.25 abcd	0.26 abc	0.24 A
K_{40}	0.20 de	0.18 e	0.21 cde	0.18 e	0.19 B
Ortalama	0.21 B	0.24 A	0.22 AB	0.24 A	
$LSD_{(0.05)}$ anaç: 0.035	$LSD_{(0.05)}$ sulama: 0.027	$LSD_{(0.05)}$ anaçxsulama: 0.080			

(2016) highlight the positive effects of mycorrhiza applications on plant nutrient uptake and growth. These studies show that mycorrhiza inoculation can enhance the bioavailability and transport of essential nutrients such as nitrogen, phosphorus, and potassium by plants. This increased nutrient uptake can lead to improved plant growth and development.

In particular, mycorrhiza applications were found to significantly increase phosphorus and zinc uptake in banana plants (Akpınar and Ortas, 2020). Similarly, tamarind and jujube plants exhibited greater shoot length and dry weight when treated with mycorrhiza, along with increased contents of nitrogen, phosphorus, and potassium (Guissou et al., 2016). These findings align with the observations in the current study, where mycorrhiza applications appear to positively affect the uptake of macronutrients like nitrogen and phosphorus.

Moreover, the mentioned studies also emphasize the importance of mycorrhiza in improving nutrient utilization by plants. They suggest that mycorrhiza can help mitigate the global problem of low phosphorus availability for plants, which often limits crop productivity. Additionally, the studies caution against over-fertilization, which can lead to the accumulation of unused phosphorus in the soil.

Overall, the findings from these previous studies support and corroborate the positive effects of mycorrhiza applications on nutrient uptake and plant growth observed in the current study.

CONCLUSION

The concentration of N, P, K, Ca and Mg in plant tissues decreased with water stress. The results indicate that mycorrhizal inoculation can enhance nutrient absorption in plants, particularly under water-restricted conditions, potentially contributing to improved plant resilience and performance in challenging environments.

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