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Effects of salinity and Ca:Mg ratio of irrigation water on pistachio seedlings phosphorus planted under greenhouse conditions

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Abstract

Phosphorus (P) is a key element in many biological processes of plants and animals. We aimed to investigate the effect of different salinity levels and Ca:Mg ratios of irrigation water arid lands on soil available P, soluble P, and P absorbed by the pistachio plant. For this purpose, a greenhouse experiment was conducted by sowing the seeds of pistachio in a factorial randomized block design with four soil salinity levels (S1 (6 $dS.m^{-1}$irrigation water salinity, leaching fraction (LF) = 50), S2, S3, and S4 (9 $dS.m^{-1}$ irrigation water salinity, LF = 50, 30 and 20, respectively)) and three Ca:Mg ratios (M1, M2, and M3 equal to 1, 0.5, and 0.25, respectively). After harvesting the plants, the amount of soil available P (Po), water-soluble P (Pw), and total P (Pt) at soil depths of 0-5, 5-25, 25-50, and 50-75 cm, and P concentration in the leaves of Pistachio seedlings were measured.The results showed that the salinity of soil saturated extract had no significant effect on Po, Pw, and Pt. The reduction in Ca:Mg ratio increased Po and Pw in soil surface but it did not affect Pt. Increasing salinity from S1 to S2 augmented plant P uptake but at higher salinity levels, P uptake was reduced. The decrease in Ca:Mg ratio had no significant effect on plant P contents.

Keywords: Arid lands; Leaching fraction; Plant; Salinity; Soil solution concentration

1. Introduction

Phosphorus (P) is an important component in many biological processes of plants and animals. Plants absorb their required P from the soil-soluble phase which is also a function of surface adsorption and release reactions with soil colloidal particles and dissolution and sedimentation reactions.

Increased surface adsorption or P precipitation reduces its availability for plants; therefore, it is necessary to supply the annual addition of fertilizers to the soil to supply the required P for plants. Since mineral resources for the preparation of P fertilizers are limited and non-renewable, proper management of their use seems to be more important than many other types of nutrients.

The availability of phosphorus in soil and the efficiency of its absorption by plants are affected by a set of factors corresponding to soil properties, such as pH, texture, type and amount of minerals, salinity, and ionic composition of soil soluble phase, as well as physiological characteristics and root morphology of plant.

In order to increase the efficiency of P fertilizer application, the effect of both of the foregoing groups is necessary. The inherent properties of the soil, such as pH and type of solid phase minerals, influenced sorption and release reactions along with phosphorus dissolution and precipitation reactions. When studying soil samples, it is very difficult to separate the effect of each factor on the usability of phosphorus due to the interactions between these factors. Using 0.5 M sodium bicarbonate solution to extract soil samples and estimate the amount of plant available P (Olsen *et al.,* 1954) is one of the solutions that can indicate the combined effects of soil properties on phosphorus status. In this method, the relatively high concentration of bicarbonate ion is used to release the surface adsorbed P part. The other part of the extracted

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phosphorus is caused by the dissolution of certain phosphorus deposits.
Various studies have shown that the amount of phosphorus extracted by this method provides a good estimation of phosphorus availability for plants.

One of the factors affecting the availability of phosphorus in soil is the total amount of solute and the ionic composition of the soluble phase. The study of Khanlari and Jalali (2011) showed that the maximum and minimum P was extracted from soil at SAR = 0.49 with Ca:Mg = 0.33, and SAR= 15 with Ca:Mg = 3, respectively. One of the reasons behind the effects of magnesium on the amount of available P is its lower phosphate affinity with Mg than Ca. In other words, the availability of P depends on the ratio of P to Mg. If the ratio is equal to or less than 2:1, P adsorption on calcite is reduced and its availability in calcareous soils increases (Khanlari and Jalali, 2011).

Ghafour *et al.* (2011) also reported that the ratio of Ca:Mg plays an important role in the availability of phosphorus for the plant. Moreover, Wadu *et al.* (2013) showed that the increase inexchangeable Mg decreased the formation of Ca-P precipitates, positively affecting the P availability in soils with low Ca:Mg saturation.

For instance, it has been shown that the impact of phosphorus fertilizer on wheat increases through combining magnesium sulfate with dicalcium phosphate and octacalcium phosphate, which leads to decrease the ratio of calcium to magnesium.

Increasing the ratio of magnesium to calcium to 1.5 in soil solution and irrigation water increases the availability of phosphorus in soil and its absorption by the plant. If this ratio is raised to more than 1.5, the availability of phosphorus increases due to the formation of high levels of dimagnesium phosphate ($MgHPO_4$) and trimagnesium phosphate ($Mg_3(PO_4)_2$) (Al-Khateeb *et al.*, 1986).

The use of P-containing recycled compounds also shows that the effect of magnesium phosphate is similar to that of monocalcium phosphate, and they are more soluble than other compounds (Johnston *et al.*, 2003).

Organic acids and carbonate and magnesium ions prevent the precipitation of calcium phosphates via the formation of complex on the newly formed surfaces and disrupt the formation of new nuclei.

Separate effects of carbonate and magnesium and their interaction on calcium phosphate sediment have shown that magnesium has a certain inhibitory effect on the growth of crystalline hydroxyl-apatite (HAP), a minor effect on octocalcium phosphate (OCP), and almost no effect on dicalcium phosphate (DCP) growth. The effect of magnesium is attributed to its absorption in active growth sites (competition with calcium). The simultaneous deposition of magnesium and calcium phosphate promotes the formation of ACP relative to HAP. Carbonates negatively affect HAP sedimentation through inhibiting the formation of phosphate nuclei or by producing calcite sediments (Cao, and Harris, 2008). However, the results of another experiment with phosphorus isotope species on different forms of phosphorus showed that the amount of magnesium in the tested range had no observable effect on P exchange and magnesium did not increase the amount of plant available P originating from the utilized fertilizer in calcareous soils (Xiong and Zhou, 1995). Studies on the prevention of the soluble phosphorus entrance into aquatic ecosystems have shown that magnesium-containing depositors such as dolomite have the least effect, and ferric chloride has the most effect (Ann *et al.*, 1999).

Furthermore, Maleki *et al.* (2018) evaluated the effect of three different Ca:Mg ratios (1, 0.5, and 0.25) on phosphorus absorption by halophyte quinoa under saline conditions. Their results showed that different ratios of Ca:Mg had no significant effect on phosphorous absorption by quinoa. Nonetheless, the abovementioned experiment was performed in soilless culture, and the absence of soil interactions might be the reason for this result.

Salinity and ionic composition of soil solution (partly affected by salinity and ionic composition of irrigation water) play major roles in soil P status and its absorption by plant. In this regard, the current study was conducted to investigate the effect of different salinity levels and Ca:Mg ratios of irrigation water on available and soluble P in different depths of a calcareous soil. The effect of the mentioned parameters was further evaluated on P adsorbed by pistachio seedlings. Concerning the extent of saline irrigation water and soil and different ion ratios in the agricultural lands of Iran and the importance of P for optimal plant growth, it is hoped that the results of this study will assist in the better management of P in soil.

2. Materials and Methods

2.1. Water properties

In line with the objective of the study, a completely randomized factorial design experiment was conducted in experimental pots

inside a greenhouse. To irrigate the experimental pots, total salt concentration and ionic composition of a sample of irrigation water (prepared from well water in Yazd) were adjusted using NaCl, $CaCl_2$, and $MgCl_2$ salts. Table 1 shows the general characteristics and ionic composition of the primary and the modified samples of the employed irrigation water. Four soil salinity levels, including S1 (water with 6 $dS.m^{-1}$ salinity level and leaching percentage of 50), S2, S3, and S4 (water with 9$dS.m^{-1}$ salinity level and leaching percentages of 50, 30, and 20) and three Ca:Mg ratios, namely M1, M2, and M3 (equivalent to 1, 0.5, 0.25 Ca:Mg ratios, respectively) were selected as experimental treatments (Table 1).

Table 1. General properties and ionic composition of basic irrigation water sample and water samples adjusted with NaCl, $CaCl_2$, and $MgCl_2$ salts for the application of experimental treatments

treatments	EC	pH	K	Na	Ca	Mg	Ca:Mg	Cl	SO_4^{-2}	SAR
	ds/m	-	meq/L				-	meq/L		-
Basic sample	7.0	7.98	0.17	74.6	15.6	16.3	0.96	90.0	12.9	18.7
S1M1	6.1	8.25	0.17	38.1	14.9	16.5	0.90	54.4	10.5	9.6
S1M2	6.2	8.20	0.35	31.8	12.8	22.3	0.57	58.6	11.2	7.6
S1M3	6.3	8.11	0.50	23.9	9.5	33.8	0.28	61.3	8.5	5.1
S2,3,4M1	9.2	8.00	0.19	65.7	17.2	18.1	0.95	90.1	11.8	15.6
S2,3,4M2	9.1	8.04	0.47	55.3	15.9	32.7	0.48	90.7	12.8	11.2
S2,3,4M3	9.1	8.08	0.84	37.9	12.4	50.8	0.24	91.8	10.6	6.7

2.2. Soil properties

The soil required to fill the experimental pots was sampled from 0 to 50 cm depths in a pistachio garden (Yazd). The soil sample was sieved (8 mm) and became homogeneous. The EC, pH, and concentration of Ca^{+2}, Mg^{+2}, Na^{+}, and Cl^{-}were measured in the soil saturation extract. Moreover, the organic matter content of the soil sample was measured by oxidation method; CCE, CEC, texture, available P, and K were measured by titration, ammonium acetate, hydrometry, Olsen, and, 1N ammonium acetate methods, respectively. Table 2 shows the results of the physicochemical properties of soil samples. According to the data, the soil sample was completely calcareous (CCE = 25%) with an electrical conductivity of 7.3 dSm^{-1} and a pH of 7.8.

Table 2. The results of measuring some physical- chemical properties of soil samples used in experimental pots

EC	pH	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	$SO4^{2-}$	OC
dS m^{-1}				meq L^{-1}			g kg^{-1}
7.3	7.78	26.6	15.7	42.4	45.2	31.3	1.1
SP	CCE	CEC	Clay	Silt	Sand	K.ava	P.ava
%		$cmol_C kg^{-1}$		g kg^{-1}		mg kg^{-1}	
28.6	25.1	6.53	221.0	192.0	587.0	139.0	4.2

Table 3. Mean comparison of the salinity, Ca:Mg ratio effects and their interaction on salinity and main cations of soil solution.

Parameters / treatments	EC	Ca^{2+}	Mg^{2+}	Ca/Mg
	dS. m^{-1}		$cmol_{(c)}$ l^{-1}	
S1	5.80c	15.14c	17.87b	0.97a
S2	8.70b	19.97b	27.83a	0.86a
S3	9.60a	22.53a	27.25a	1.10a
S4	10.40a	24.63a	29.56a	0.99a
M1	8.10a	17.89b	12.58c	1.45a
M2	9.00a	22.80a	24.39b	0.96b
M3	8.90a	21.00ab	39.65a	0.54c

Thirty-six experimental pots (40 cm diameter and 100 cm height) with appropriate floor and drainage were designed to prevent any restrictions on the growth of pistachio roots during the experimental period. The final height of the soil in the pots was 75 cm.

2.3. Planting of pistachio

The Badami-Zarand-cultivar-pistachio seeds were obtained from Pistachio Research Institute (Rafsanjan). After disinfection with fungicide, the seeds were maintained at 25 ° C for 3 days; they were then planted in small pots containing a mixture of pit and sand and irrigated every three days. The used water became gradually salty so that when the seedlings were transferred to the main pot, the salinity of irrigation water was the same as that of the desired treatment. During the growth period of pistachio, the volume of the water required at each irrigation interval was determined based on the weight loss of soil

moisture rather than field capacity as well as desired leaching percentage. Plant specimens were measured 25 weeks after the transfer of seedlings to the main pots (Fig.1).

Fig. 1. Pistachio seedlings during the growth period, and irrigation and leaching of them

In order to supply the seedling demands, a half liter of fertilizer solution containing 200 mg/L P from KH_2PO_4, 400 mg/L K from KNO_3, and 1.7% N from NH_4NO_3 resources was used. After harvesting the seedlings, soil samples were collected from pot depths of 0-5, 5-25, 25-50, and 50-75 cm.

The amount of phosphorus extracted by Olsen method (Po) was used as the reference for plant available P. The water soluble p (Pw) and total P (Pt) were further measured by the following methods:

2.4. Soil total P

The total P was extracted by perchloric acid digestion method. For this purpose, 10 $cm^3$of 60% perchloride acid was added to 1 gr of sieved soil and heated to 200°C for 20 minutes. After separating the liquid phase, the phosphorous amount was measured by spectrophotometery method at 470nm wave length (Olsen et al., 1954).

2.5. Water soluble P

To measure the concentration of water soluble P, 50 ml of distilled water was added to 5g of air-dried soil and shaked for 5 minutes. Following centrifugation, upper smooth solution was passed through the filter paper (Wattman42). P concentration was measured by spectrophotometry at 720 nm (Olsen and Sommers, 1982).

2.6. Plant P

To measure the concentration of P in the leaves of pistachio seedlings, a sample of seedlings was washed and dried at 75° C. After milling and dry digestion, phosphorus concentration was measured by spectrophotometry at 470 nm (Chapman and Pratt, 1982).

3. Results and Discussion

3.1. Soil P

Table 3 shows the results of certain physical and chemical properties of soil samples used in the experimental pots before applying the treatments .The data of this table show that the available phosphorus concentration of the soil was very low (4.2 mg/kg), hence the necessity of P fertilizer for a proper plant growth.

Fig. 2 and Table 4 illustrate the data obtained from measuring the available phosphorus concentrations by Olsen method at pot depths of 0-5, 5-25, 25-50 and 50-75 cm. Comparison of available P mean values at different depths showed that after fertilizer application, the amount of phosphorus in the surface layer was greatly increased from an initial amount of 4.2 mg/kg to 35.69 mg/kg. At the three other depths, the increase in phosphorus concentration was relatively lower (5.77, 4.87, and 4.69 mg/kg). These data indicate that the added P reacted strongly with the soluble phase ions (calcium and magnesium) and the charged surface of colloidal particles; therefore, more than 90% of P remained in the surface layer of the soil.

Given the homogeneity of the soil texture and structure and the lack of preferential water movement in the soil profile, the slight increase in the concentration of P at the deeper layers can be attributed to the gradual transfer of soluble P. In other words, the data confirm that P is immobile in the ionic soil medium, and its deep percolation in the soil profile is very limited. Yu *et al.* (2014) showed that the P forms and distribution heterogeneity in the profiles could be

ascribed to the effects of vegetation cover and hydrologic disturbance.

The effects of salinity treatments and the Ca:Mg ratio of irrigation water on solubility and, consequently, the mobility of phosphorus in the pot soil were compared (Fig. 2). It was shown that although the available concentration of superficial layer (0-5 cm) was much higher than deeper layers, the change in irrigation water salinity (S1, S2, S3 and S4 treatments) had no significant effect on the P concentration of the surface layer and the three other depths.

Table 4. F values in variance analysis of the effect of different salinity treats and ca:mg ratio of irrigation water on total phosphorous, dissolved phosphorous in water and available phosphorous in different depths of pot

	Total P		Dissolved P		Available P			
Depth (cm)	0-5	5-25	0-5	5-25	0-5	5-25	25-50	50-75
Salinity	0.41^{ns}	2.60^{ns}	2.20^{ns}	1.16^{ns}	0.95^{ns}	0.14^{ns}	0.99^{ns}	0.39^{ns}
Ca:Mg ratio	0.51^{ns}	1.01^{ns}	60.93^{**}	10.17^{**}	24.97^{**}	4.52^{ns}	1.96^{ns}	2.96^{*}
interaction	0.76^{ns}	1.33^{ns}	0.96^{ns}	0.39^{ns}	0.59^{ns}	0.34^{ns}	0.36^{ns}	0.50^{ns}
C.V	24.70	19.90	37.80	49.90	18.70	48.50	40.50	57.10

ns: insignificant, * and **: significant in P < 0.05 and 0.01, respectively

Conversely, the changes in irrigation water ion composition, caused by the changes in ratio of irrigation water (M1, M2, and M3 treatments), significantly altered the available phosphorus content of surface layer.

With reducing the Ca:Mg ratio or increasing the concentration of magnesium, the concentration of increased.InM2 and M3 treatments, available P rose by about 24.4 and 70.1%, respectively, compared to M1 treatment. The effect of these three treatments on the lower layers was much lower. This means that although the increase in Mg concentration in irrigation water augmented phosphorus availability in the surface layers, availability of phosphorus did not significantly change in the lower soil layers due to the lack of phosphorus movement in the soil depth.

The experimental data showed similar results concerning the effect of salinity treatments and the Ca:Mg ratio of irrigation water on the concentration of water soluble phosphorus (Table 4 and 5). In this regard, the increase in salinity did not have a significant effect on water-soluble phosphorus; on the other hand, the decrease in the Ca:Mg ratio of irrigation water significantly increased water soluble phosphorus in the surface layers (Table 5).

Table 5. The effect of salinity and Ca/Mg ratio of irrigation water on the extracted phosphorus with different methods and in the different depths of pot soil

	Total phosphorous		Dissolved phosphorous		Available phosphorous			
Depth (cm)	0-5	5-25	0-5	5-25	0-5	5-25	25-50	50-75
S1	108.6^{a}	91.9^{a}	4.6^{a}	0.8^{a}	36.4^{a}	5.7^{a}	4.3^{a}	4.1^{a}
S2	114.0^{a}	89.6^{a}	4.1^{a}	0.7^{a}	36.9^{a}	5.7^{a}	5.4^{a}	5.5^{a}
S3	101.7^{a}	87.9^{a}	4.3^{a}	0.7^{a}	37.0^{a}	6.3^{a}	5.5^{a}	4.6^{a}
S4	113.0^{a}	71.8^{a}	2.9^{a}	0.5^{a}	32.4a	5.4a	4.4a	4.5a
M1	112.7a	84.9a	1.9b	1.1a	27.1c	4.2b	4.2a	5.7a
M2	103.2a	80.6a	2.2b	0.6b	33.8b	7.6a	5.7a	4.7ab
M3	112.9a	90.4a	7.8a	0.4b	46.2a	5.6ab	4.7a	4.2b
S1M1	124.1a	85.4abc	1.9c	1.2ab	30.2def	4.1ab	3.6a	3.0a
S1M2	104.9a	100.9a	3.0bc	0.7abcd	36.2bcde	7.5ab	4.8a	5.7a
S1M3	96.9a	89.3abc	8.8a	0.6abcd	42.7abcd	5.4ab	4.3a	3.7a
S2M1	119.0a	85.4abc	2.1c	1.0abc	27.7ef	4.7ab	4.5a	4.5a
S2M2	96.5a	84.1abc	1.6c	0.6abcd	34.1cde	7.1ab	6.4a	6.9a
S2M3	126.6a	99.1ab	8.4a	0.4cd	48.9a	5.2ab	5.2a	4.9a
S3M1	106.8a	102.4a	2.3c	1.2a	30.1def	4.8ab	5.3a	4.2a
S3M2	89.5a	73.7abc	2.0c	0.5cd	33.9cde	7.1ab	5.6a	4.6a
S3M3	109.0a	87.6abc	8.6a	0.4cd	47.2ab	6.9ab	5.6a	5.1a
S4M1	101.1a	66.5bc	1.3c	0.8abcd	20.6f	3.0b	3.3a	3.3a
S4M2	121.7a	63.5c	1.8c	0.5bcd	30.9def	8.7ab	6.2a	7.5a
S4M3	119.0a	85.4abc	5.5b	0.3d	45.9abc	4.8ab	3.5a	2.8a

Data from total P measurement at different depths showed a significant increase in total phosphorus in the surface layer, which is consistent with available and water soluble P. As predicted, experimental treatments did not have a significant effect on total phosphorus because the treatments maximally altered the shape of phosphorus (Table 5). The pistachio seedlings had no active roots in the surface layer (0-5 cm); thus, the observed changes in available phosphorus concentrations and water soluble P can be totally attributed to the chemical reactions of P with soil.

In all treatments, the average root length of pistachio seedlings was approximately54 cm. The hairy roots in the upper region of the root tip had higher density; therefore, it is obvious that the highest amount of nutrient uptake, including P, occurred in this root zone, which is located at a depth of about 50 cm. To put it otherwise, the increase in available phosphorus concentration and water-soluble pin, the surface layer did not significantly affect the plant P absorption due to the effect of treatments.

Correlation coefficients between the P extracted via different methods (total phosphorus, Olsene, and water soluble) and Ca:Mg ratio of soil saturation extract at different depths showed that Olsen P of surface layer and Ca:Mg ratio and water-soluble P had significant correlations (Table 6).

Table 6. Correlation coefficients between the measured P with Olsen method, dissolved in water and total and Ca:Mg ratio of soil saturation extract in different depths of pot soil

Method	Depth (cm)	Ca:Mg in saturated extract				dissolved P		Total P		Available P			
		0-5	5-25	25-50	50-75	0-5	5-25	0-5	5-25	0-5	5-25	25-50	50-75
Available P	0-5	-0.514**	-0.4**	-0.56**	-0.62**	0.75**	-0.43**	0.2	0.33	1.00	0.25	0.25	0.07
	5-25	-0.13	-0.15	-0.17	-0.03	0.19	-0.19	0.11	-0.02	0.25	1.00	0.79**	0.84**
	25-50	-0.03	-0.2	-0.02	0.13	0.098	-0.23	0.08	-0.06	0.25	0.79**	1.00	0.86**
	50-75	-0.05	-0.13	0.01	0.09	0.05	-0.24	0.18	-0.12	0.07	0.84**	0.86**	1.00
Total P	0-5	0.08	-0.04	0.14	-0.2	0.17	-0.27	1.00	-0.07	0.2	0.11	0.08	0.18
	5-25	0.16	0.1	-0.08	-0.13	0.24	0.23	-0.07	1.00	0.33	-0.02	-0.06	-0.12
Dissolved P	0-5	-0.55**	-0.19	-0.61**	-0.65**	1.00	0.17	0.24	0.25	0.75**	0.19	0.098	0.05
	5-25	0.57**	0.5**	0.27	0.57**	-0.3	-0.27	0.23	0.23	-0.43**	-0.19	-0.23	-0.24

A similar relationship was observed between water-soluble P and Ca:Mg ratio. However, the Olsen P of deeper layers and total P were not significantly correlated with Ca:Mg ratio of soil saturation extract.

The correlation between Olsen P and water-soluble phosphorus can be ascribed to the high contribution of water-soluble Pin the extraction of P by Olsen method. The absence of correlation between available P and total P can be due to the properties of sodium bicarbonate solution in P extraction from soil. This means that the mentioned solution is merely capable of releasing part of the phosphorus adsorbed on the soil minerals. The negative association of available P and water-soluble P with Ca:Mg ratio of soil saturation extract indicates that the increased concentration of magnesium ion positively affected the availability of phosphorus for plants.

3.2. The mechanism of the treatment effects on available P

The results of the experimental treatments showed that the changes in total salt concentrations and salinity did not significantly impact the concentration of available and water soluble P; however, the decrease in the Ca:Mg ratio increased the concentration of available and water soluble P.

Table 1 shows that in M1, M2, and M3 treatments, the concentration of magnesium ion gradually increased; thus, the effect of Ca:Mg ratio on available phosphorus and water soluble phosphorus can be attributed to the gradual increase in the Mg concentration of irrigation water and, consequently, soil solution.

To explain this process, two different mechanisms can be considered. The first one is related to the change in the distribution of P species in the soil solution phase following the change in ionic composition of irrigation water. With raising the concentration of magnesium ions in the soil solution, the concentration of soluble species of Mg-phosphate also increased. Since the K_f of magnesium phosphate (reaction 1) was greater than the K_f of calcium phosphate (reaction 2), the increase in the concentration of magnesium ion augmented the soluble phosphorus in water, in turn increasing the concentration of available P.

Fig. 2a shows the molar ratio of the main species of calcium and magnesium phosphate in the pH range of 6 to 9.

$$Mg^{2+} + H^{+} + PO_4^{3-} \rightleftharpoons MgHPO_4^{o} \qquad \log K = 15.18 \qquad (1)$$

$$Ca^{2+} + H^{+} + PO_4^{3-} \rightleftharpoons CaHPO_4^{o} \qquad \log K = 15.04 \qquad (2)$$

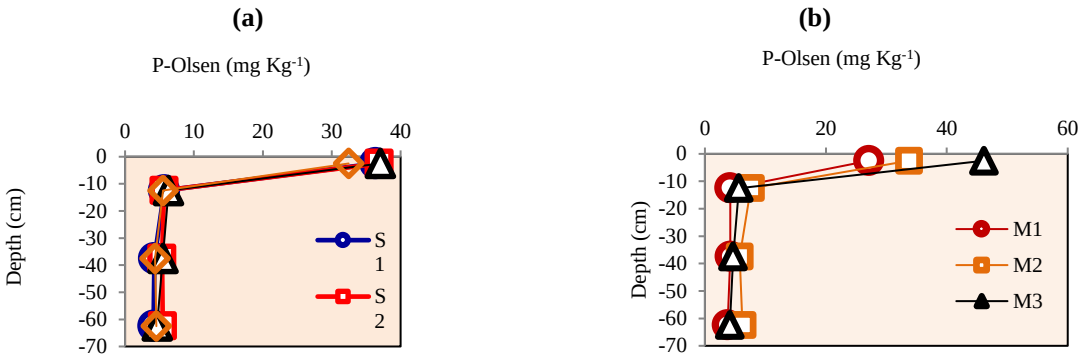

Fig. 2. Available phosphorous changes (extracted by Olsen method) with soil depth as a function to salinity (a) and Ca:Mg ratio (b) of irrigation water

The second possible mechanism is the formation of various calcium and magnesium phosphate deposits. Calculation of the saturation index (SI) for different calcium and magnesium phosphates revealed that in the studied range of soil pH, the saturation index of magnesium phosphates was much smaller than calcium phosphate. This means that the increased magnesium ion concentration and the formation of magnesium phosphate precipitate increased the concentration of phosphate in the solution phase. In other words, it increased the concentration of available phosphorus. Fig. 2b shows the saturation index of the most important types of calcium and magnesium phosphates in the pH range of 6 to 9.

3.3. Plant phosphorus

The effect of salinity treatments on P concentrations of pistachio seedling leaves showed that salinity had a significant impact on the amount of phosphorus in the leaves (Table 7).

Table 7. Effect of salinity and calcium to magnesium ratio of irrigation water on the percent of pistachio seedlings leafs' phosphorus

Treatments	Salinity levels				Ca:Mg ratio		
	S1	S2	S3	S4	M1	M2	M3
Plant P	0.15ab	0.16a	0.15ab	0.12b	0.14a	0.14a	0.16a

*Salinity was significant on plant P (P<0.05).

Augmented plant P concentration caused by the increase in salinity in S2 treatment can be ascribed to the rapid effect of salinity on the reduced skeletal growth of the plant along with the continuation of phosphorus uptake and its transfer to the plant leaf. This process led to a rise in the concentration of phosphorus in the leaves, caused by salinity stress.

At higher salinity levels (S3 treatment), the synchronization of vegetative growth and the decrease in phosphorus absorption reduced the leaf P concentration. The reduction in root growth and availability of phosphorus lowered the phosphorus absorption under saline conditions (Bernstein and Kafkafi, 2002; Grattan and Grieve, 1994).

The experimental data showed that the decrease in the Ca:Mg ratio of irrigation water did not have a significant influence on plant phosphorus concentration (Table 8).

As mentioned before, reducing Ca:Mg ratio resulted in the increased available P of surface layer. However, due to the lack of dynamism and mobility in soil P, available phosphorus content of the underlying layers was not influenced. To put it otherwise, plants absorbed their required P from the lower depths of the pot where its active root was higher (50 to 70 cm depth of soil); meanwhile, in this depth, experimental treatments had no effect on the available P.

Table 8. Correlation coefficients between plant phosphorus (%) and mean dry weight per pot (g) measured phosphorus (mgkg^{-1}) by Olsen, soluble in water, and the total different layers of soil

method		Total P		Dissolved P			Available P (Olsen P)			
Depth (cm)		0-5	5-25	0-5	5-25	mean	0-5	5-25	25-50	50-75
All treatments	Leaf P	-0.09	0.34	0.25	-0.12	0.16	0.36	-0.19	-0.08	-0.28
	Leaf mean weight	0.09	-0.12	-0.02	0.49	-0.29	-0.30	0.00	-0.28	-0.13
S1 and S2 treatments	Leaf P	-0.19	0.37	0.35	-0.22	0.35	0.48	-0.09	0.13	-0.09
	Leaf mean weight	-0.35	-0.52	0.63	0.10	0.63	-0.54	-0.05	-0.41	-0.16

4. Conclusion

The results of this study showed that the salinity of irrigation water had no significant impact on Po, Pw, and Pt. The decrease in Ca:Mg ratio augmented Po and Pw in soil surface but did not significantly affect Pt. With increasing the salinity from S1 to S2, plant P uptake was augmented, and at higher salinity levels, P uptake decreased; however, reducing the Ca:Mg ratio had no significant influence on plant P contents.

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References

Al-Khateeb, I.K., Raihan, M.J.S.R., Asker, 1986. Phase Equilibrium and Kinetics of Orthophosphate in Some Iraqi Soils. Soil Science, 141; 31-37.

Ann, Y., Reddy, K.R.,J.J. Delfino, 1999. Influence of chemical amendments on phosphorus immobilization in soils from a constructed wetland. Ecological Engineering, 14; 157-167.

Bernstein, N., U. Kafkafi, 2002. Root Growth under Salinity Stress. In Plant Roots. pp 787-805. CRC Press.

Cao, X., W. Harris, 2008. Carbonate and magnesium interactive effect on calcium phosphate precipitation. Environmental Science Technology, 15; 436-442.

Chapman, H.D., P.F., Pratt, 1982. Method of Plant Analysis. In Methods of Analysis for Soils, Plants and Water. Ed. H.D. Chapman, P.F. Pratt, A.P. Vanselow. pp 60-193. Chapman Pub, California.

Ghafoor, A.M.R., 2011. The role of magnesium in increasing of phosphorous fertilizer efficiency and wheat yield Mesopotamia. Journal of Agriculture, 39; 33-39.

Grattan, S., C. Grieve, 1994. Mineral nutrient acquisition and response by plants grown in saline environments. In Handbook of Plant and Crop Stress. Ed. M Pessarakli. Marcel Dekker, New York.

Johnston, A.E., I.R., Richards, 2003. The effectiveness of different precipitated phosphates as sources of phosphorus for plants. Soil Use and Management, 19; 45-49.

Khanlari, Z.V., M. Jalali, 2011. Effect of Sodium and Magnesium on Kinetics of Phosphorus Release in Some Calcareous Soils of Western Iran. Soil and Sediment Contamination: An International Journal, 20; 411-431.

Maleki, P., H.A. Bahrami, S. Saadat, F. Sharifi, F., Dehghani, M. Salehi, 2018. Determining salinity threshold value of Quinoa at different growth stages and the role of this plant on soil leaching requirement and ion uptake at different compositions of saline water. Ph.D. thesis. Tarbiat Modares University. Tehran. Iran. (In Persian).

Olsen, S.R. L.E., Sommers, 1982. Phosphorus. In Methods of Soil Analysis: Chemical and microbiological properties. Eds. A Klute and A L Page. pp 403-427. American Society of Agronomy.

Olsen, S.R., Cold, C.V., Watanabe, F.S., L.A., Dean, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Ed. U S D o Agriculture, Washington D.C.

Wadu, M. M., Scott Kroeker, V.K.M., O.O., Akinromi, 2013. Exchangeable Calcium/Magnesium Ratio Affects Phosphorus Behavior in Calcareous Soils. Soil Science Society of America Journal 77; 2004-2012.

Xiong, L.M., Z.G. Zhou, 1995. Magnesium influence on plant uptake of phosphorus in a calcareous soil. Journal of Plant Nutrition, 18; 1251-1261.

Yu, J., F. Qu, H. Wu, B., Xie, 2014. Soil Phosphorus Forms and Profile Distributions in the Tidal River Network Region in the Yellow River Delta Estuary. PubMed, DOI: 10.1155/2014/912083.