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RESEARCH PAPER

Ca^{+2} and Mg^{+2} of pistachio seedling in response to soil compaction under different water levels

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Key words: Soil compaction, Ca^{+2} and Mg^{+2} uptake, translocation factor, pistachio, water stress.

Abstract

In order to study the effects of four levels of soil compaction and six different moisture levels and to determine non limiting water range a nested experiment with three replications was conducted to evaluate changes in Ca^{+2} and Mg^{+2} concentration, uptake content and translocation factor of pistachio seedling (*Pistachio vera L.*). The air dried soil was passed through soil 4.75 mm sieve, and transferred into 36 PVC cylinders, the soils of cylinders were compacted in order to prepare four levels of soil bulk density (1.35, 1.5, 1.65 and 1.8 g cm^{-3}). After transferring the pistachio seedlings into soil cylinders and their establishment, six different volumetric water contents, from saturation to permanent wilting point, for each compacted soils were applied. Ca^{+2} and Mg^{+2} concentration and content in shoot and root and translocation factor of these elements were less under high levels of soil compaction (1.65 and 1.8 g cm^{-3}) than that of low levels of soil compaction (1.35 and 1.5 g cm^{-3}). Concentration and translocation factor of Ca^{+2} significantly enhanced with increasing water deficit, but the amount of Ca^{+2} in shoot and root was reduced. Concentration of Mg^{+2} in root and amount of Mg^{+2} in shoot and root were declined with increasing water stress. Under all soil compaction levels, translocation factor of both elements were declined under water deficit conditions.

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Introduction

Soil compaction is the reduction of soil volume due to external factors and this reduction lowers soil productivity and environmental quality. The threat of soil compaction is greater today than in the past because of the dramatic increase in the size of farm equipment. Compaction is the process of densifying a soil mechanically and influencing thus physical properties of the soil. Physical properties influence all biological and many chemical processes in the soil (Kemper *et al.,* 1971).

Soil compaction influences agricultural sustainability through its effects on soil properties and crop development. Soil layers may become compacted naturally as a consequence of their textural composition, moisture regime, or the manner in which they were formed in place. Soil compaction is bringing an undesirable consequence of mechanization, which must be avoided (Hillel, 1980).

Compaction affects nutrient availability and uptake through a number of mechanisms. Aeration affects availability of nutrients involved in redox reactions, such as nitrogen, manganese and sulphur and the growth and function of roots (Lipiec and Stepniewski, 1995). The transport of nutrients in the soil is affected; compaction normally increases mass flow transport (Kemper *et al.*, 1971) and the diffusion coefficient at a given gravimetric water content (Bhadoria *et al.*, 1991). Compaction also increases root-to-soil contact, which may facilitate nutrient uptake (Veen *et al.*, 1992), but generally reduces root growth through its effect on aeration and mechanical resistance.

Soil compaction reduces root elongation (Taylor and Ratliff, 1969) and can also cause reductions in shoot growth (Schuurman, 1965). The shoot growth responses attributed to messages produced by compact soil include a reduction in mature cell sizes in leaves (Beemster and Masle, 1996) and a reduction in leaf number (Mulholland *et al.*, 1999). The clearest evidence of compact soil reducing shoot growth is obtained when plants are grown in entirely compact soil.

Water stress is considered to be one of the most important environmental factors that limit plant production. Status of soil and water is one of the most important factors that affected on root growth and the genetic analysis of maize roots. Seedling survival in drought prone environments may depend upon the species' ability to compensate for the negative effect of low water potentials in the soil and atmosphere by adjusting root and shoot morphological and physiological patterns (Morgan, 1984).

The concept of an index of optimum soil water content for plant growth, as related to soil physical properties was introduced by Letey (1985) and identified as "non-limiting water range" (NLWR). Later, Silva *et al.* (1994) developed the NLWR concept quantitatively, renaming it as the least limiting water range (LLWR). For a given soil type, the LLWR incorporates the limitations of soil aeration, matric suction and soil penetration resistance

for root growth as a function of a single variable (i.e. soil bulk density).Crop response to soil compaction depends on the interaction among crop, soil type, water content, and compaction degree (Lipiec and Simota, 1994). In this context, soil moisture is the main factor and the Least Limiting Water Range (LLWR) relates soil moisture with aeration porosity (10%) and penetration resistance (2 MPa), which are both dependent upon the degree of soil compaction and represent the upper and lower limit of the LLWR (Silva *et al.*, 1994).

As little information is available on the effect of compaction on the growth of plants and Ca^{+2} and Mg^{+2} concentration, uptake content and translocation factor in root and shoot of pistachio under the least limiting water range (LLWR), thus an investigation was carried out to monitor the effect of different soil compaction and water levels (LLWR) on seedling growth and these treats in pistachio plants.

Materials and methods

Plant material and treatments

In order to study the changes in Ca^{+2} and Mg^{+2} of pistachio seedling (*Pistachio vera L.*) a nested experiment with four levels of soil compaction at six moisture levels with three replications was conducted in university of Tabriz. Requirement soil of this experiment were obtained from Pistachio orchard of East Azarbaijan Research Center for Agriculture and Natural Resources. Some soil physical and chemical properties have been presented in Table 1. The air dried soil was passed through soil 4.75 mm sieve, and transferred into 72 PVC cylinders (diameter 15.24 and height 50 cm), the soils of cylinders were compacted in order to prepare four levels of soil bulk density (1.35, 1.5, 1.65 and 1.8 g cm^{-3}). For proper establishment of seedling, 5 cm of the upper part of cylinders filled by topsoil.

Table 1. Some physical and chemical characteristics of experimental soil.

Texture Class	pH	EC	O.M	CCE	N	P	K	Fe	Mn	Zn	Cu
		dS m^{-1}		%				mg kg^{-1}			
Sandy loam	7.6	1.3	0.97	18	0.05	5	325	2.5	3.94	2.14	**0.6**

Pistachio seed were planted in plastic container and after 25 days, seedling transferred to cylinders with different compaction density. Then, soil moisture in all of cylinders was kept at field capacity up to 7 days. After seedlings establishment, six different volumetric water contents, from saturation to permanent wilting point, for each compaction level were applied. Moisture levels in six ranges determined as Dasilva *et al.,* (1994), which shown in Table 2. For controlling the moisture content in cylinders used from time domain reflectometry (TDR) every each two days.

Table 2. Six ranges of moisture applied in four levels of soil compaction density.

Compaction levels (g cm^{-3})	θ_{fc}	θ_{pwp}	Moisture levels					
			ML1	ML2	ML3	ML4	ML5	ML6
1.35	24.5	10	39-49	24-39	19-24	14-19	10-14	7-10
1.5	24	11	33-43	25-33	19-25	14-19	11-14	7-11
1.65	29	12.2	33-38	28-33	22-28	17-22	12-17	8-12
1.8	31	13.3	27-32	23-27	19-23	15-19	13-15	8-13

The following formulas were used to calculate the amount of water needed.

$V=aD(\theta_{v1} - \theta_{v2})$

V, water volume requirements (cm^3); *a*, cross section of cylinders (cm^2); *D*, soil depth (cm); θ_{v2}, upper limiting range of moisture for each treatment (cm^3/cm^3) and θ_{v1}, volumetric moisture amount reading by TDR (cm^3/cm^3).

Treatments measurement

After 90 days, seedling were cut from the surface of the soil and then the shoot and root of plants dried. The concentration of Ca^{+2} and Mg^{+2} in shoot and root of plants was measured by flame atomic absorption spectrometry (Waling *et al.* 1989). The amount of Ca^{+2} and Mg^{+2} was calculated by concentration × dry mater and transfer factor was also calculated by shoot concentration of Ca^{+2} or Mg^{+2}/root concentration of Ca^{+2} or Mg^{+2} (Waling *et al.,* 1989; Rowell, 1994).

All the data were analyzed on the bases of experimental design, using SPSS software. The means of each trait were compered according to Duncan multiple range test at $p \leq 0.05$.

Results and discussion

Analysis variance of the date showed that the effects of soil compaction and moisture in each compaction on Ca^{+2} concentration of root, Ca^{+2} content of shoot and root and translocation factor were significant. Also, the effects of soil compaction on Ca^{+2} concentration of shoot was significant. Also, soil compaction had significant effect on Mg^{+2} concentration of shoot and root, uptake content of

Mg^{+2} in shoot and root and Mg^{+2} translocation factor. The effects of moisture in each levels of soil compaction was only not significant on Mg^{+2} concentration of pistachio shoot (Table 3).

Table 3. Analysis of variance of the effects of different soil compaction and moisture levels on Ca^{+2} and Mg^{+2} concentration, uptake content and translocation factor of pistachio plants.

		Ca^{+2}					**Mg^{+2}**				
Source	**df**	**Concentration**		**Uptake content**		**Translocation Factor**	**Concentration**		**Uptake content**		**Translocation Factor**
		shoot	**root**	**shoot**	**root**		**shoot**	**root**	**shoot**	**root**	
Compaction	3	7.76^{*}	25.39^{*}	25.9^{*}	16.6^{*}	1.732^{*}	0.05^{*}	0.01^{ns}	2.40^{*}	2.92^{*}	0.143^{*}
Moisture (compaction)	20	1.56^{ns}	4.033^{*}	4.5^{*}	19.1^{*}	0.175^{*}	0.014^{ns}	0.056^{*}	0.44^{*}	0.54^{*}	0.065^{*}
Error	48	0.89	0.51	0.16	3.31	0.042	0.01	0.007	0.02	0.04	0.032

*,** Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Ca^{+2} and Mg^{+2} concentration in shoot

Concentration of Ca^{+2} in shoot of pistachio seedling under high soil compaction (1.65 and 1.8 g cm^{-3}) was lower than that of low soil compaction. There was no significant difference in this treat between 1.35 g $cm^{-3}$and 1.5 g cm^{-3} and also between 1.65 g cm^{-3} and 1.8 g cm^{-3} levels of soil compaction (Fig. 1a). Barraclough and Wier (1988) also indicated that with increasing of soil compaction Ca^{+2} concentration of wheat seedlings declined. Concentration of Mg^{+2} in shoot declined with increasing soil compaction from 1.35 to 1.65 (g cm^{-3}). The least of this treat was showed in severe soil compaction levels (1.8 g cm^{-3}) (Fig. 1b). Barraclough and Wier (1988) reported that with increasing soil compaction, concentration of Mg^{+2} in wheat and barley seedling reduced.

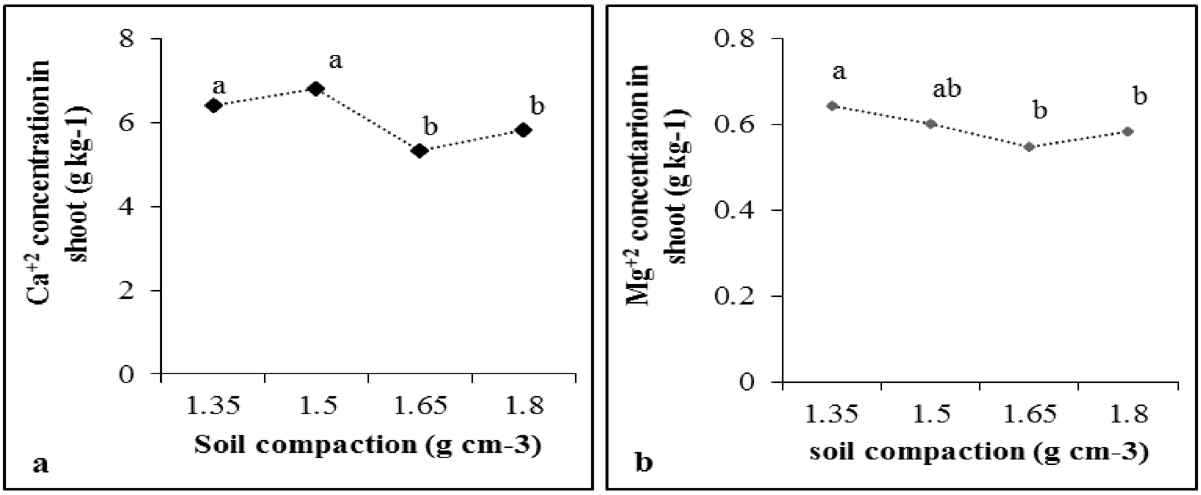


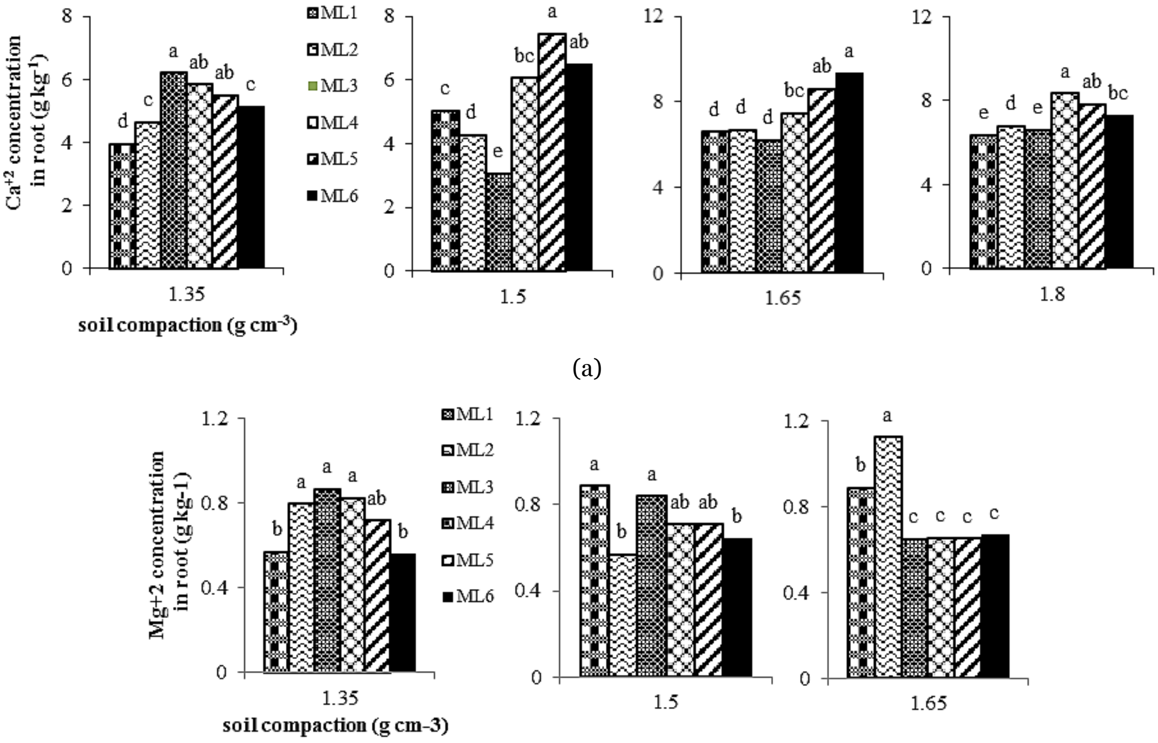
Fig. 1. Ca^{+2} and Mg^{+2} concentration in shoot of pistachio in response to different soil compaction.

Ca^{+2} and Mg^{+2} concentration in root

Under low soil compaction (1.35 g cm^{-3}) the highest Ca^{+2} concentration in root of seedling was showed in moisture levels three (ML3), which difference between ML3, ML4 and ML5 was not statistically significant. Also, there was no significant difference in Ca^{+2} concentration of seedling under ML2 and ML6. The least of this treat was obtained from ML1 (Fig. 2a).

The highest concentration of Ca^{+2} of root in low levels of soil compaction (1.35 and 1.5 g cm^{-3}) was in least limiting water range (LLWR). However, under high levels of soil compaction (1.65 and 1.8 g cm^{-3}) was out of LLWR. Maximum concentration of Mg^{+2} in root under 1.35 (g cm^{-3}) of soil compaction was showed in LLWR, in contrast, under 1.5 (g cm^{-3}) of soil compaction was recorded in ML1 (had no significant difference with LLWR). Under 1.65 (g cm^{-3}) of soil compaction the highest concentration of Mg^{+2} was showed in ML2. Concentration of Mg in shoot was similar in all soil moisture under 1.8 (g cm^{-3}) of soil compaction (Fig. 2b).

This result was confirmed by Trought and Drew (1980) on wheat seedling. Under all soil compaction levels, increasing of water deficit had no significant effect on root Ca^{+2} concentration, as this trait increased under 1.65 g cm^{-3} level of soil compaction. This may be associated with reduction of root dry weight and increasing of Ca^{+2} concentration under water stress. Chahkhoo (2010) also indicated that under water deficit stress, the concentration of Ca^{+2} in roots of pistachio increased.



(a)

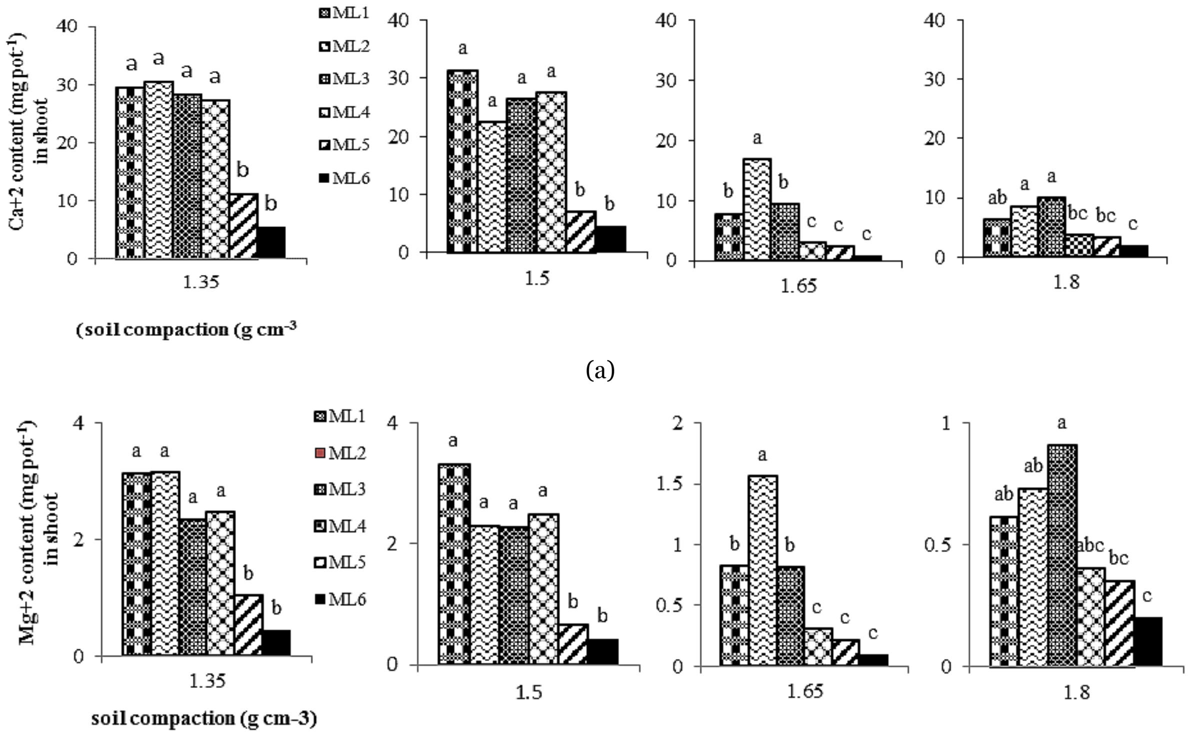
(b)

Fig. 2. Changes of Ca^{+2} and Mg^{+2} concentration (g kg^{-1}) in root of pistachio seedlings under different levels of soil compaction and moisture levels (ML).

Ca^{+2} and Mg^{+2} content in shoot

The amount of Ca^{+2} uptake in shoot of pistachio seedling in 1.35 and 1.65 g cm^{-3} levels of soil compaction under ML1, ML2, ML3 and ML4 was statistically similar and more than that of ML5 and ML6. In soil compaction of 1.65 g cm^{-3} from ML1 up to ML3 the amount of Ca^{+2} uptake was increased. In contrast, under ML4 to ML6 this treat gradually declined. Under severe level of soil compaction (1.8 g cm^{-3}), uptake of Ca^{+2} in shoot of seedlings increased up to ML2 and then significantly reduced (Fig. 3a). Between the highest amount of Ca^{+2} in shoot and LLWR there was no significant difference under 1.35 and 1.5 of soil compaction levels. The highest amount of shoot Ca^{+2}, only under severe compacted soil (1.8 g cm^{-3}) was in LLWR (Fig. 3a). Amount of Mg^{+2} uptake at ML3 and ML4 (in LLWR), ML1 and ML2 under 1.35 and 1.5 g cm^{-3} of soil compaction was not statistically similar. The highest amount of Mg^{+2} in shoot of pistachio under 1.8 (g cm^{-3}) of soil compaction was in LLWR but, under 1.65 (g cm^{-3}) of soil compaction was out of LLWR (Fig. 3b).

Nahar and Germazpeter (2002) on tomato showed similarly result. With reduction soil moisture, the movement of Ca^{+2} form soil to root surface significantly declined and also as the Ca^{+2} uptake by plant is inactive pathway, thus this linked by plant transpiration which declined under water deficit conditions (Yu *et al.,* 2007).



(a)

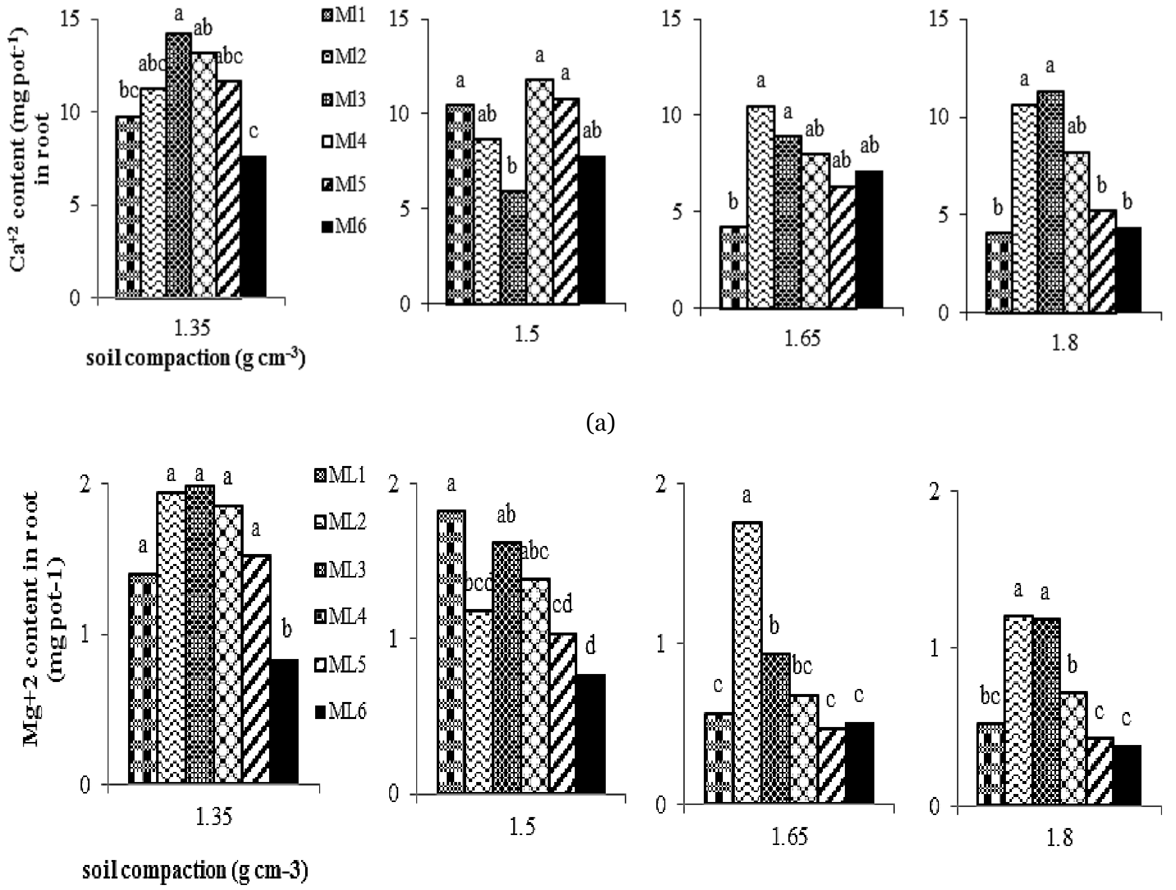
(b)

Fig. 3. Changes of Ca^{+2} and Mg^{+2} content (mg pot^{-1}) in root of pistachio seedlings under different levels of soil compaction and moisture levels (ML).

Ca^{+2} and Mg^{+2} content in root

In lower level of compacted soil (1.35 g cm^{-3}) with decreasing moisture availability from ML1 to ML3 the amount of Ca^{+2} uptake by pistachio seedling significantly enhanced. But, under severe moisture conditions from ML3 to ML6 these treat gradually declined. These changes in Ca^{+2} uptake was mostly similar with plants changes under severe soil compaction condition (1.8 g cm^{-3}). Maximum content of Ca^{+2} uptake in 1.5 g cm^{-3} level of soil compaction was showed in ML4, which had no significantly differences with ML1, ML2, ML5 and ML6. Under 1.65 g cm^{-3} level of soil compaction condition, the least Ca^{+2} uptake obtained from well moisture condition (ML1) and the highest of this trait showed in ML2 and then gradually up to water stress condition (ML6) declined (Fig. 4a). The highest amount of Ca+2 uptake under 1.35, 1.5 and 1.8 g cm^{-3} levels of soil compaction was in LLWR.

The highest amount of Mg^{+2} uptake under low soil compaction (1.35) was in LLWR. Maximum amount of this trait was recorded in ML1 under 1.5 (g cm^{-3}) of soil compaction, and this with ML3 and ML4 (in LLWR) was similar. The highest Mg^{+2} uptake under 1.65 and 1.8 (g cm^{-3}) of soil compaction was obtained from ML2 and this under higher compacted soil (1.8) had no significantly difference with ML3 (Fig. 4b). Najafi *et al.,* (1390) indicated that uptake of Mg^{+2} under logging significantly was declined. This results may be associated to decrease in oxygen and consequently in ATP synthesis by plants under logging and disruption in root growth under this condition. With increasing water limiting (from moisture level 3 to 6), the amount of Mg^{+2} uptake reduced under all soil compaction levels.



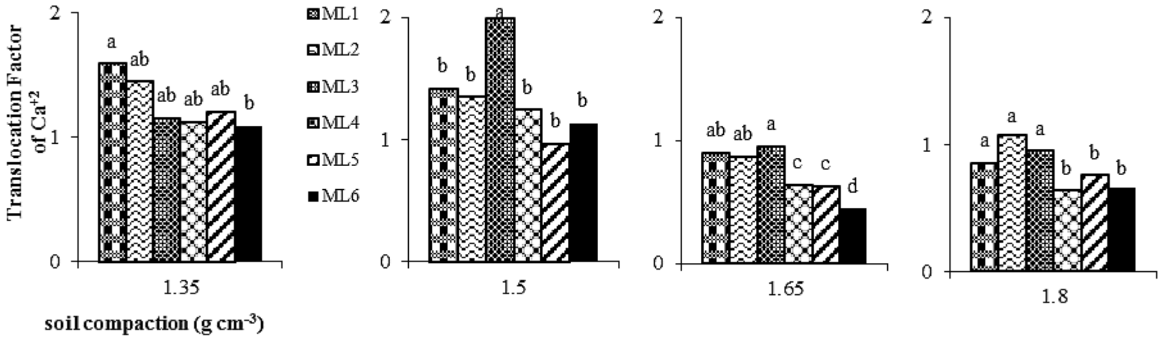
(a)

(b)

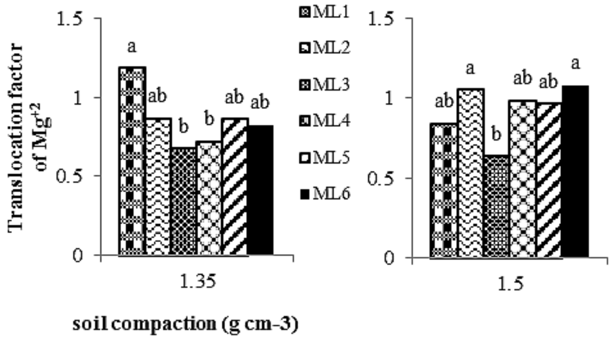
Fig. 4. Changes in Ca^{+2} and Mg^{+2} content in root of pistachio seedling under different levels if soil compaction and moisture levels (ML).

Translocation Factor of Ca^{+2} and Mg^{+2}

Soil compaction levels of 1.35 and 1.5 g cm^{-3} under all moisture conditions had translocation factor more than one. This result clearly indicated that Ca^{+2} translocate from root to shoot of pistachio seedling in these compacted soils. In the lowest soil compaction (1.35 g cm^{-3}) maximum translocation factor was showed in ML1, which had no significantly difference with ML2, ML3, ML4 and ML5. Under 1.5 g cm^{-3} levels of soil compaction, the highest amount of translocation factor was indicated in ML3. There was no significant difference in this trait between ML1, ML2, ML4, ML5 and ML6. In higher levels of soil compaction (1.65 and 1.8 g cm^{-3}) under all moisture levels this trait was lower than one (Fig. 5a). The Ca^{+2} translocation factor of pistachio plants under both two high levels of severe compaction was lower than that of the least levels of soil compaction. In all soil compaction levels under water deficit stress (ML6) in comparison to other levels of moisture this trait declined. Transfer factor of Mg^{+2} only under 1.35 (g cm^{-3}) of soil compaction was higher than one. At ML3 translocation factor of Mg^{+2} from root to shoot adversely declined. The maximum amount of translocation factor under 1.5 (g cm^{-3}) of soil compaction was recorded in ML6 (Fig. 5b). According to Osuagwu *et al.,* (2010) this results is due to the movement of Ca^{+2} from shoot to root, as in these condition Ca^{+2} play a kay roll in tolerance of plants to water stress. Mechanical resistance and poor aeration may restrict root growth, which especially affects the uptake of nutrients (Lipiece and Stepniewski, 1995).



(a)



(b)

Fig. 5. Changes in Ca^{+2} and Mg^{+2} translocation factor of pistachio seedlings under different levels if soil compaction and moisture levels (ML).

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