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Effects of soil compaction on Na and Cu uptake in pistachio seedling under different moisture levels conditions

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Abstract

In order to study Na and Cu uptake of pistachio seedling (*Pistacia vera* L.) in response to four levels of soil compaction at six moisture levels this nested design experiment with three replications was conducted. The air dried sandy loam soil was passed through soil 4.75 mm sieve, and transferred into 72 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. According to the results, concentration of Na in shoot and root under all levels of soil compaction significantly enhanced with increasing water stress. But, Na content of shoot under both low and especially high levels of soil compaction strongly increased. Na content was in LLWR under most of soil compaction levels. Cu concentration in shoot under 1.35, 1.5 and 1.65 g cm^{-3} bulk density increased with increasing water stress but under 1.8 g cm^{-3} bulk density decreased with increasing water stress. But, Cu content of root was more under well moisture levels. Under all levels of soil compaction, maximum Cu content was recorded in ML4 and ML5. Translocation factor of Na in middle level of soil compaction and in Cu under low level of soil level was more than 1 under water stress conditions. Thus, soil compaction and water stress increased accumulation of Na in pistachio seedling. In this hand, soil compaction and water stress decreased Na and Cu uptake in this plant.

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Introduction

Soil compaction occurs when an applied soil stress exceeds the strength of the soil. It means by definition a reduction in porosity, and generally causes an increase in soil strength. Thereby, it changes many properties and processes in the soil, e.g. retention, saturated and unsaturated hydraulic conductivity (Kemper *et al.*, 1971), air content and transport of gases, root growth and function, nutrient uptake and transport, mineralization of organic nitrogen, phosphoric and sulfat (Lipiec and Stepniewski, 1995). Compaction also affects the mineralization of soil organic carbon and nitrogen (Neve and Hofman, 2000) as well as the concentration of carbon dioxide in the soil (Conlin and Driessche, 2000). The liquid and gas contents of a soil are rarely static. In general, as the quantity of liquid decrease the quantity of gas increases (Harris, 1971). Three-phase system of a soil undergoes changes as soon as the external strength exceeds the internal soil strength. Increasing bulk density cause decrease aeration and increase penetration resistance, which results in impeded root development (Horn *et al.*, 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.

Copper is one of the chloroplast protein components and this protein have an important role in photosynthesis, respiration and production of lignin (Homayi and Malakouti, 2004). Heydarinejhad and Abusaeidi (2003) in their study found that copper deficiency causes tiny leaf in pistachio. Pistachio (*Pistacia vera* L.) is one of the most important commercial trees grown in arid and semi-arid regions of Iran. Increased establishment of irrigated pistachio orchards during the last two decades in this region has decreased the availability of underground water resources and prolonged drought periods are the major concern for the pistachio producers (Sheibani, 1994). However, competition for the limited water supply available for irrigation of pistachio orchards is increasing. Although pistachio nut trees are drought tolerant, it does not mean that pistachio trees require less water for optimal performance. Drought stress, in general, reduces nutrient availability in the soil, uptake by roots, transport from roots to shoots and partitioning in plants (Goicoechea *et al.,* 1997) and consequently decreased plant growth and productivity (Ghassemi-Golezani and Lotfi, 2012). In conditions of water deficit, some reports revealed disturbance in nutritional status of pistachio plants (Sepaskhah and Karimi- Goghary, 2005; Tajabadi Pour *et al.,* 2005). Reduces in soil moisture lead to increase in salinity stress. Test on the various types of pistachios indicated that increasing salinity (NaCl) increased root to shoot ratio in all cultivars. Pistachio growth rate decrease with increasing salt concentration in the soil solution (Picchioni *et al.*, 1990). Copper alleviate environmental stress such as water or salt stress in pistachio plants (Eskandari and Mozaffari 2012). Waraich *et al.* (2011) expressed copper optimal nutrition can increase the tolerance of plants to water deficit, thereby improve to nitrogen metabolism and increase in growth. However, when a soil has undergone reduction by waterlogged of the root zone, the breakdown of Fe and Mn oxides can provide an increased surface area with a high adsorptive capacity onto which Cu may be firmly adsorbed (Iu *et al.*, 1982). An investigation was carried out to monitor the effect of compaction and moisture on nutrient uptake and translocation factor of Na and Cu in pistachio seedlings.

Materials and methods

In order to study changes in Na and Cu compaction, uptake and translocation factor of pistachio seedling (*Pistachio vera L.*) in response to four levels of soil compaction at six moisture levels a nested design experiment with three replications was conducted. This experiment was carried out on soil collected from pistachio orchard, Research Center for Agriculture and Natural Resources of East Azerbaijan, Iran.

Soil characteristics

Some soil physical and chemical properties have been presented in Table 1. Soil texture determined by hydrometer method (Gee and Bauder, 1986), organic matter by a modification of the Walkley and Black (1934) procedure, nitrogen by Kjeldahl method (Waling *et al.* 1989), phosphorus by Olsen method (Olsen *et al.*,1954), micronutrients by DTPA whit atomic absorption Shimdzu, AA-6300 model (Waling *et al.* 1989).

Soil compression

The air dried soil was passed through soil 4.75 mm sieve, and transferred into 72 PVC cylinders (diameter 152.4 and height 500 mm), 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 establishment of seedling in cylinders, 50 mm upper part of cylinders filled by none compacted soil.

Pot experiment

Pistachio seeds were planted in plastic container and after 25 days, seedlings transferred to cylinders with different compaction density. Then, soil moisture was hold at field capacity up to 7 days in all cylinders. After establishment of seedlings six ranges, different volumetric moisture according to Table 1 from saturation to permanent wilting point, for each compaction levels of soil were applied. For controlling the moisture content in cylinders used from time domain reflectometry (TDR) every each two days.

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

$V = a\,D\,(\Theta_{v1} - \Theta_{v2})$

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).

Determination of nutrient concentration

After 90 days, seedlings were cut from the surface of the soil and then the shoot and root of plants dried. The concentration of Na and Cu in shoot and root of plants was measured by flame atomic absorption spectrometry (Waling *et al.* 1989). The amount of Na and Cu were calculated and translocation factor was also calculated by shoot concentration of Na or Cu per root concentration of Na or Cu (Waling *et al.*, 1989; Rowell, 1994).

The LLWR is a type of pedotransfer function used to estimate optimum soil water content for plant growth based on quantification of bulk density (Db) for a given soil type under evaluation. However, prior to its computation, it is necessary to parameterize a soil water retention function, θ (ψ), and a soil penetration resistance function, PR (Θ, Db) (Da Silva *et al.*, 1994). The LLWR was determined for each compaction level following the methodology proposed by Da Silva *et al.* (1994).

Statistical analyses

All the data were analyzed on the bases of experimental design, using SPSS-20 software. The means of each trait were compared according to Duncan multiple range test at $p \leq 0.05$.

Results and discussion

The selected chemical and physical characteristics of soil sample are represented in Table 2.

Shoot and Root dry weight

Shoot and root dry weight of pistachio seedlings significantly decreased with increasing soil compaction levels. Under low levels of soil compaction (1.35 and 1.5 g cm^{-3}), maximum shoot and root dry weight were recorded in seedlings under ML1, ML2, ML3 and ML4. Because in these soil compaction levels, in both treatment ML1 and ML2 water added easily drained and soil moisture reached to field capacity (ML3). So aeration was provided for plant roots. While in density level of 1.65 g cm^{-3}, shoot and root dry weight of pistachio seedlings significantly in treatment ML1 compared to ML2 were showed decrease. In this bulk density level, the desired moisture was in treatment ML2 (moisture content of 28 to 33%) and in this range, highest growth and root development was achieved. Pistachio seedlings were encountered with moisture stress in treatments of ML3, ML4, ML5 and ML6 and root development reduction (Figs. 1).

Table 1. Six ranges of moisture applied in four levels of soil compaction in this study.

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

Table 2. Some physical and chemical characteristics of used soil in this study.

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

Na and Cu concentration in Shoot

In soil compaction levels of 1.35 and 1.5 g cm^{-3} maximum concentration of Na was showed under ML6, however there was no significant difference between ML6 with ML4 and ML5 (in LLWR) on this trait. Under 1.65 g cm^{-3} of soil compaction the highest concentration of Na was recorded in ML1 (logging condition), which this may be associate by decrease of shoot dry weight. Najafi *et al.* (2011) on corn plants stated similar results. Strongly decline in Na concentration of seedlings under high soil compaction levels (1.8 g cm^{-3}) in ML3 condition can be due to enhance in shoot dry weight under these conditions (Fig 2a). Bohnert (1999) indicated that concentration of Na increases under water stress. Mahmoodi *et al.* (2014) reported similarly result on alfalfa and they indicated that this effect is due to Na role in osmotic adjustment in plants under stress conditions.

Table 3. Analysis of variance of compaction and moisture effects on shoot and root dry weigh of pistachio seedling.

Source	df	Dry weight	
		SDW	RDW
		MS	
Compaction	3	3.36 *	5.89*
Moisture	5	2.26*	1.41*
Moisture× compaction	15	0.16*	0.19*
Error	48	0.02	0.05

Cu concentration of pistachio seedlings under low level of soil compaction (1.35 g cm^{-3}) in ML6 was more than other moisture levels. The highest concentration of Cu was showed under 1.5 and 1.65 g cm^{-3} levels of soil compaction in ML4 and ML3 (in LLWR), respectively. Minimum amount of this trait was recorded under high level of soil compaction in ML3 and this associated by increasing shoot dry weight (Fig 2b). Sajedi and Rejali (2011) on corn and Mohammadi-Mohamad Abadi *et al.* (2012) on pistachio reported that Cu concentration increased as a result of water stress. In contrast, Chakho (2010) and Maleki Kohbani and Karimi (2013) indicated that Cu concentration of pistachio plants declined under water stress.

Na and Cu content in Shoot

The highest Na content was recorded in seedling under low soil compaction levels (1.35 and 1.5 g cm^{-3}) in LLWR, but under high soil compaction levels (1.65 and 1.8 g cm^{-3}) this obtained from seedling under ML2 and ML3 out of LLWR (Fig 3a). Najafi *et al.*, (2011) indicated that under logging conditions content of Na significantly reduced in corn plants. In general, with increasing soil compaction levels, Na content of shoot significantly decreased. Under all soil compaction levels, reduction in this trait was showed in ML4, ML5 and ML6. Nahar and Gertezmaper (2002) stated with increasing water availability and especially under logging conditions, content of Na in shoot of potato declined.

Table 4. Analysis of variance of compaction and moisture effects on Na^+ and Cu^{2+} concentration, content, translocation factor in shoot and root of pistachio seedlings.

Source	df	Concentration				Nutrient content				Translocation Factor	
		MS				MS				MS	
		shoot (Na^+)	shoot (Cu^{2+})	root (Na^+)	root (Cu^{2+})	shoot (Na^+)	shoot (Cu^{2+})	root (Na^+)	root (Cu^{2+})	Na^+	Cu^{2+}
Compaction	3	*27.4	*117	*47.1	*765	*8.52	*0.003	*180	*0.12	*0.141	*0.678
Moisture	5	*21.9	n.s 28.7	*18.0	n.s 25.3	*10.14	*0.002	*122	*0.15	*0.109	n.s 0.198
Moisture× compaction	15	*6.2	*73.9	*6.3	*203	*1.35	*0.001	*23.3	*0.10	*0.075	*0.65
Error	48	1.8	18.1	1.5	21.1	0.35	0.0	6.35	0.01	0.026	0.122

Maximum content of Cu in shoot of seedlings was under 1.35, 1.65 and 1.8 g cm^{-3} levels of soil compaction in ML2. Under 1.5 level of soil compaction was in LLWR in ML4. Cu content of shoot was significantly decreased with increasing water stress levels from ML4 to ML6. Similar result was reported by Mahmoodi *et al.* (2014) on alfalfa. Maximum and minimum content of Cu were recorded under 1.5 g cm^{-3} level of soil compaction with ML4 and 1.65 g cm^{-3} level of soil compaction with ML6, respectively (Fig 3b).

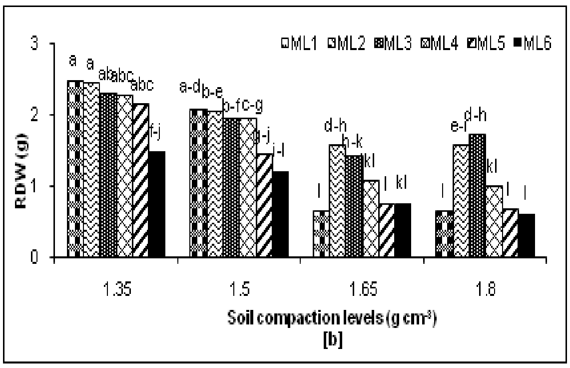

Fig. 1. Changes in shoot (a) and root (b) dry weight of pistachio seedlings in response to different levels of soil compaction and moisture content.

Na and Cu concentration in Root

Under all levels of soil compaction increasing in water stress strongly enhanced Na concentration in root of pistachio seedlings. Low soil compaction levels with ML1 had the lowest Na concentration, which this associated by increasing root dry weight under this condition. Na content under both low and high levels of soil compaction with ML6 had more than that of other ML conditions (Fig 4a).

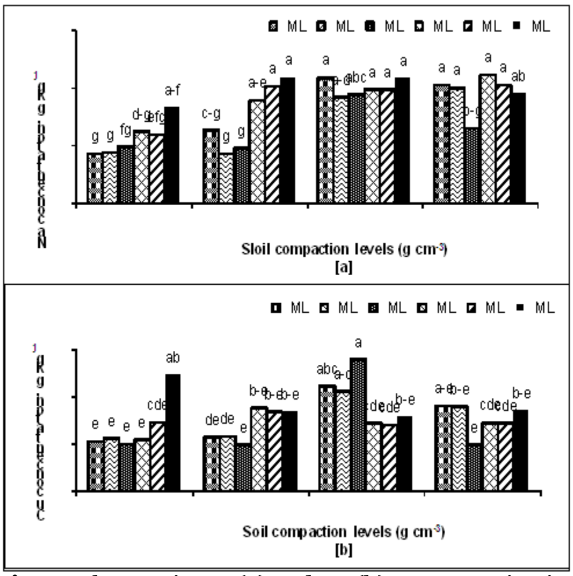

Fig. 2. Changes in Na (a) and Cu (b) concentration in shoot of pistachio seedlings in response to different levels of soil compaction and moisture content.

The highest concentration of Cu was showed in seedlings under low level soil compaction with ML2. However, there was no significant difference between ML2 with ML3, ML4 and ML5 in LLWR. Strongly increase in Cu concentration of root under 1.65 g cm^{-3} level of soil compaction with ML5 can be due to reduction in root dry weight of seedlings in this condition. Under high level of soil compaction, ML3 (in LLWR) had more Cu concentration, compared to other moisture levels (Fig 4b).

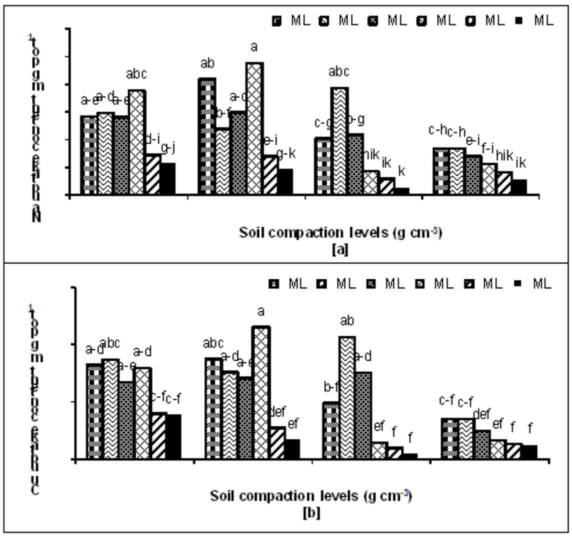

Fig. 3. Changes in Na (a) and Cu (b) uptake content in shoot of pistachio seedlings in response to different levels of soil compaction and moisture content.

Na and Cu content in Root

Maximum content of root under 1.5, 1.65 and 1.8 g cm^{-3} levels of soil compaction was in LLWR but under 1.3 g cm^{-3} level of soil compaction this trait was out of LLWR. Under high levels of soil compactions (1.65 and 1.8 g cm^{-3}) Na content of root was reduced under ML1, compared to ML2. The highest and lowest Na content were recorded in seedlings under low level of soil compaction with ML3 and high level of soil compaction (1.8 g cm^{-3}) with ML1, respectively (Fig 5a). Results that reported by Najafi and Mardomi (2010) on sunflower and Mahmoodi *et al.*, (2014) on alfalfa are in agreement of this research.

Maximum content of Cu uptake content in root under 1.35, 1.5 and 1.65 g cm^{-3} was showed in ML2, ML1 and ML5, respectively, which had no significantly difference with LLWR. Under high level of soil compaction (1.8 g cm^{-3}) the highest content of Cu was recorded in ML3 in LLWR. Content of Cu in root of pistachio seedlings under 1.65 and 1.8 g cm^{-3} levels of soil compaction with ML1 (logging condition) and ML6 (water stress) was lower than other treatments (Fig 5b). Smethurst *et al.* (2005) reported that Cu content of alfalfa under logging condition reduced. In contrast, Mahmoodi *et al.* (2014) indicated reduce of Cu under water stress on alfalfa.

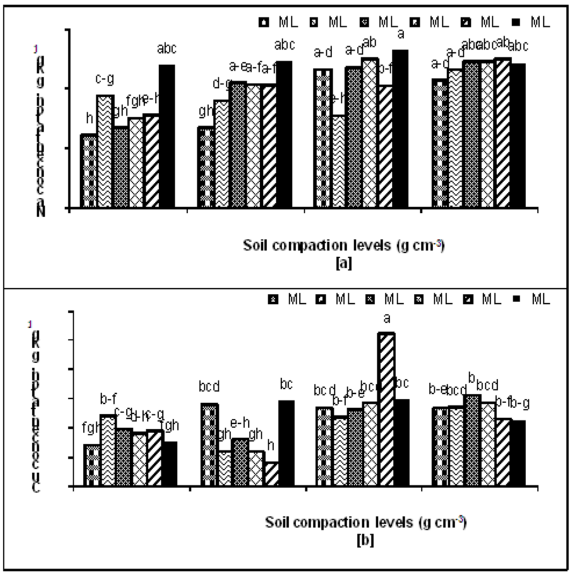

Fig. 4. Changes in Na (a) and Cu (b) concentration in root of pistachio seedlings in response to different levels of soil compaction and moisture content.

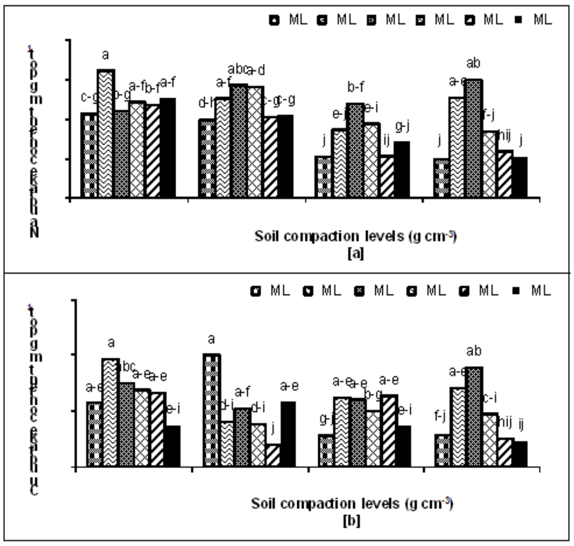

Fig. 5. Changes in Na (a) and Cu (b) uptake content in root of pistachio seedlings in response to different levels of soil compaction and moisture content.

Translocation factor of Na and Cu

Maximum translocation factor of Na under low soil compaction (1.35 and 1.5 g cm^{-3}) in ML2 was in LLWR, but under high soil compaction (1.65 and 1.8 g cm^{-3}) in ML1 was out of LLWR. Under all soil compaction levels, translocation factor of seedlings in ML6 was lower than other treatments (Fig 6a). Saki Nejhad and Bakhshandeh (2009) indicate that maximum concentration of Na in root of corn was under water stress. Under water stress, accumulation of single valance ions increased in root of plants, this decreased osmoses potential in root cells and consequently water uptake from soil improved (Santos and Alejo, 1994).

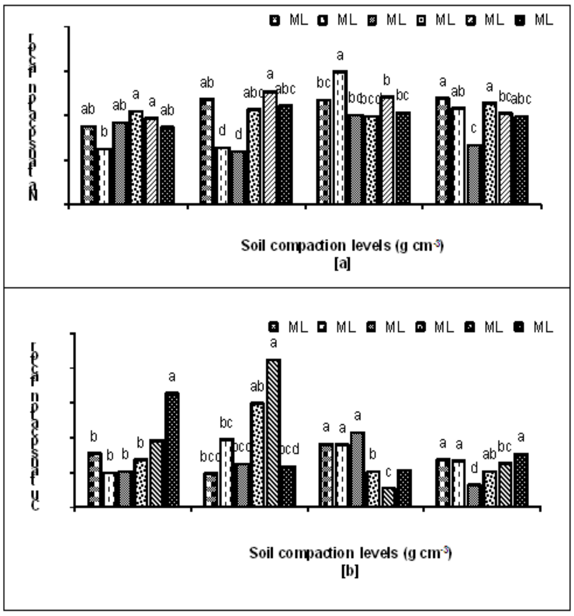

Fig. 6. Changes in Na (a) and Cu (b) translocation factor of pistachio seedlings in response to different levels of soil compaction and moisture content.

Maximum translocation factor of Cu was recorded under 1.5 and 1.65 g cm^{-3} levels of soil compaction in LLWR, but under 1.35 and 1.8 g cm^{-3} levels of soil compaction this trait was in ML6 (water stress). Under 1.35, 1.65 and 1.8 g cm^{-3} levels of soil compaction, the translocation factor from root to shoot in ML6 was more than ML4 and ML5. The highest and the lowest amount of Cu translocation factor was obtained from 1.5 g cm^{-3} level of soil compaction in ML5 and 1.65 level of soil compaction in ML1.65, respectively (Fig 6b).

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