doi: 10.17221/146/2015-SWR

Growth and Development of Pistachio Seedling Root at Different Levels of Soil Moisture and Compaction in Greenhouse Conditions

Davoud ZAREHAGHI[1], Mohammad Reza NEYSHABOURI[1], Manouchehr GORJI[2], Reza HASSANPOUR[1]* and Ali BANDEHAGH[1]

[1]University of Tabriz, Tabriz, Iran; [2]University of Tehran, Tehran, Iran

*Corresponding author: rzh92@yahoo.com

Abstract

Zarehaghi D., Neyshabouri M.R., Gorji M., Hassanpour R., Bandehagh A. (2017): Growth and development of pistachio seedling root at different levels of soil moisture and compaction in greenhouse conditions. Soil & Water Res., 12: 60–66.

Soil moisture and compaction are important factors for growth and development of plant root. This study was conducted as a nested design with two factors and three replications to investigate the behaviour of pistachio seedling roots at different levels of soil compaction and moisture in a sandy loam soil under greenhouse conditions. The first factor was soil compaction at four levels of bulk density (1.35, 1.5, 1.65, and 1.8 g/cm^3). The second factor was soil moisture with six levels ranging 0.07–0.49 cm^3/cm^3. Moisture monitoring at each treatment was carried out by a time domain reflectometer device every two days. At the end of experiment, root and shoot dry weight, shoot to root weight ratio, root length, and rooting depth were measured. Results showed that soil compaction and moisture content effects on all measured characteristics were significant (P < 0.01). At the bulk density of 1.35 and 1.5 g/cm^3 and moisture ranges of 0.14–0.49 cm^3/cm^3 (levels 1–4) the values obtained for all the measured characteristics were the highest. At the bulk density of 1.65 g/cm^3 the optimum moisture range was 0.22–0.33 cm^3/cm^3; at the bulk density of 1.8 g/cm^3 the moisture range optimum for root growth and development was 0.23–0.27 cm^3/cm^3. A drop in soil moisture from 0.49 to 0.07 cm^3/cm^3 and concomitant increase in soil bulk density from 1.35 to 1.80 g/cm^3 led to a severe decline in root dry weight, shoot dry weight, shoot to root dry weight ratio, root length, and rooting depth by as much as 65, 92, 69, 73 and 66%, respectively.

Keywords: aeration stress; bulk density; pistachio; rooting depth; water deficit

The invisibility of roots buried in soil has caused their vital role to be frequently overlooked or even neglected. Root as a vegetative organ is responsible for plant anchorage in the soil and providing water and nutrient for plant growth. Due to the growing demand for food in the world and variable soil moisture regimens related to changing climate patterns, understanding the processes and factors affecting root growth is very important (Glyn Bengough *et al.* 2011).

Soil compaction is one of the physical forms of soil degradation that negatively affects soil productivity. It is estimated that soil degradation induced by soil compaction has affected about 68 million ha of the world's land (Hamza & Anderson 2003). Soil compaction reduces total porosity and increases bulk density (Pagliai *et al.* 2003). In addition to reducing the number and size of large pores, soil compaction alters geometry, morphology, and pore connectivity in soil (Alakukku 2010). This restricts water infiltration and severely reduces saturated (Hakansson & Medvedev 1995) and unsaturated hydraulic conductivity (Richard *et al.* 2001). When roots encounter compacted soil, their growth decreases due to the greater force necessary to move around the soil particles. Compacted soil (with high penetration resistance) limits the availability of water and nutrients to the root system and therefore diminishes the crops yield. Taylor and Gardner (1963) in their laboratory works found that the cotton

doi: 10.17221/146/2015-SWR

roots penetration in fine sandy loam soil columns significantly decreased due to increasing penetration resistance and the penetration was eventually ceased at 3 MPa resistance. In field experiments, Taylor and Burnett (1964) found that cotton roots could not penetrate in Amarillo soil pans with penetration resistance of 2.5 MPa measured by penetrometer at the field capacity moisture. However, considerable rooting occurred in the pans with resistance of 1.9 MPa at the same moisture. According to Barley and Greacen (1967), 59% of the roots of peas and beans were able to penetrate the dense layer, whereas in wheat and barley root penetration was 33 and 36%, respectively. They found that plant species with thicker roots have better penetration into the subsoil that has greater penetration resistance because they are resistant to twist. Lipiec *et al.* (1991) reported that root length of barley at high level of soil compaction (bulk density of 1.55 g/cm^3) compared to the non-compacted soil is reduced by half. Atwell's (1993) studies showed that soil mechanical resistance of approximately 2 MPa or more, reduced root length in different plant species. Andrade *et al.* (1993) found that the high mechanical resistance of soil reduces the initial growth of sunflower stalk. Lipiec and Hatano (2003) reported that increasing soil compaction led to reduction in root size and rooting depth and restricted root growth to the upper part of the soil. This would decrease available water, nutrient uptake, and efficiency of fertilizer application in compacted soils. Usual responses of plant roots system to soil compaction include a reduction in the number and length of roots, restriction of roots penetration into the lower layers, increase in shoot to root dry mass ratio, and reduction in grain yield (Fageria *et al.* 2006). Skinner *et al.* (2009) with five levels of soil bulk density (1.0, 1.1, 1.2, 1.3, and 1.4 g/cm^3) found that increasing the bulk density from 1.0 to 1.4 g/cm^3 reduced the rooting depth of *Eucalyptus albense* and *Volpia* by about 77 and 75%, respectively. Grzesiak *et al.* (2013) with three levels of low (1.1 g/cm^3), medium (1.34 g/cm^3), and high compaction (1.58 g/cm^3) on maize and triticale root growth found that in the medium and high compaction treatments compared to low compaction, root dry weight decreased and the ratio of shoot to root increased.

Despite many studies on these topics, there is still insufficient basic understanding of what soil factors limit root growth, for what periods, and under what weather and associated soil water conditions. Without this information, it is difficult to manage soil to enhance crop production. On the other hand, pistachio is known as one of the Iranian agriculture crops and its production in this country has a long history. In spite of the economic importance of this crop, there is a little information about its moisture needs and root growth response to the stresses such as soil mechanical resistance. The aim of this study was to evaluate the combined effects of soil moisture and compaction on the growth and development of pistachio seedling roots.

MATERIAL AND METHODS

A greenhouse experiment was conducted to investigate the growth behaviour of pistachio seedlings at different levels of soil moisture content and compaction. Soil samples (0–20 cm depth) were collected from a pistachio garden at the Research Center of Agriculture and Natural Resources, East Azerbaijan province in Iran, and passed through a 4.76 mm sieve. Some physical and chemical properties of the studied soil are given in Table 1.

The experiment layout was a nested design with two factors and three replications. The first factor was soil compaction at four levels of soil bulk density (1.35, 1.5, 1.65, and 1.8 g/cm^3). At each soil compaction level, six moisture levels (Table 2) with three replicates were applied. At each compaction level 18 pots (50 cm height and 15.24 cm diameter) and in total 72 pots (4 compaction levels × 6 moisture levels × 3 replications = 72) were prepared and randomly placed on greenhouse bench. Two pistachio (*Pistachio vera* L.) seeds were planted in disposable containers and were irrigated regularly for 25 days to emerge seedlings. Seedlings with their soil were transferred to the prepared pots and regularly irrigated (every two days) for a week until they were

Table 1. Several selected physical and chemical properties of the studied soil

Sand	Silt	Clay	Textural class (USDA)	CCE	OC	pH_e	EC_e (dS/m)
	(%)			(%)			
58	26	16	Sandy loam	18	0.39	7.6	5.5

CCE – calcium carbonate equivalent; OC – organic carbon; pH_e – extraction pH; EC_e – extraction electrical conductivity

doi: 10.17221/146/2015-SWR

Table 2. Six ranges of soil moisture (cm^3/cm^3) maintained at each levels of soil compaction during the experimen.

Compaction levels (g/cm^3)	Moisture ranges					
	1	2	3	4	5	6
1.35	0.39–0.49	0.24–0.39	0.19–0.24	0.14–0.19	0.10–0.14	0.07–0.10
1.50	0.33–0.43	0.25–0.33	0.19–0.25	0.14–0.19	0.11–0.14	0.07–0.11
1.65	0.33–0.38	0.28–0.33	0.22–0.28	0.17–0.22	0.12–0.17	0.08–0.12
1.80	0.27–0.32	0.23–0.27	0.19–0.23	0.15–0.19	0.13–0.15	0.08–0.13

well established. The pots were then thinned to one seedling per pot. At this stage, the desired moisture levels (Table 2) were applied to all pots and maintained till the end of the experiment.

A time domain reflectometer (TDR) (Soil Moisture Equipment Corporation; Santa Barbara, USA) device was used to monitor soil moisture content in pots. The 45 cm TDR wave guide was vertically inserted into pots and its position permanently fixed in the soil during the whole experimental period. Soil moisture was measured once every two days. When the moisture content in the pots decreased to the low limit of the specified range (Table 2), water was added to the pots to raise moisture to the upper limit of the desired range. The volume of water required was calculated from Equation 1.

$$V = aD\,(\theta_{V2} - \theta_{V1}) \quad (1)$$

where:
V – volume of water required (cm^3)
D, a – depth (45 cm) and cross-section area (182.3 cm^2) of the pots
θ_{V2} – upper limit of the selected moisture range (cm^3/cm^3)
θ_{V1} – moisture content (cm^3/cm^3) at the time measured by a time domain reflectometer

After establishing of the moisture levels, the experiment continued until pistachio seedlings rooted out from the bottom of the pots with soil bulk density of 1.36 g/cm^3. This event (rooting out of the pot) occurred after 10 weeks. At this time the pots were placed in buckets of water to easily remove the root system from the pot soil. Roots length was measured by Tennant (1975) method. Separated shoot and roots parts were placed in a paper pocket and oven-dried at 70°C for 48 h. Dry weight of roots and shoots was determined by weighing balance (± 0.001 g). A variance analysis was done using SPSS software (Version 22.0, 2013) and the means were compared by Duncan's test at the 1% probability level. Soil penetration resistance was measured by electronic cone penetrometer (Mobtakeran Corporation, Tabriz, Iran) with cone angle of 30°, bottom diameter of 6 mm, and constant penetration speed of 2 mm/min. Soil texture was measured by hydrometer (Gee & Bauder 1979), soil organic matter content by wet oxidation method (Nelson & Sommers 1996), percentage of equivalent calcium carbonate by acid neutralization and titration method (Jackson 1958). Electrical conductivity (EC) and pH of soil in saturated paste extract was determined by the EC-meter (Testo240; Keison Products, Chelmsford, UK) and pH-meter (Hach EC30, Loveland, USA), respectively (Richards 1969).

RESULTS AND DISCUSSION

The results of the analysis of variance for the five characteristics of pistachio shoot and root growth are given in Table 3. Effects of soil compaction and soil moisture on all the characteristics were highly significant ($P < 0.01$).

Table 3. The analysis of variance for the five shoot and root growth characteristics

Source of variation	df	Mean squares				
		RDW	SDW	S/R	RL	RD
Compaction	3	8.08**	45.81**	2.74**	4 803 504**	2 040.18**
Moisture within compaction	20	0.45**	8.17**	1.62**	378 307**	76.02**
Experimental error	48	0.11	0.29	0.22	75 350	2.23

df – degrees of freedom; **significant at 1% level; RDW – root dry weight; SDW – shoot dry weight; S/R – shoot to root dry weight ratio; RL – root length; RD – rooting depth

doi: 10.17221/146/2015-SWR

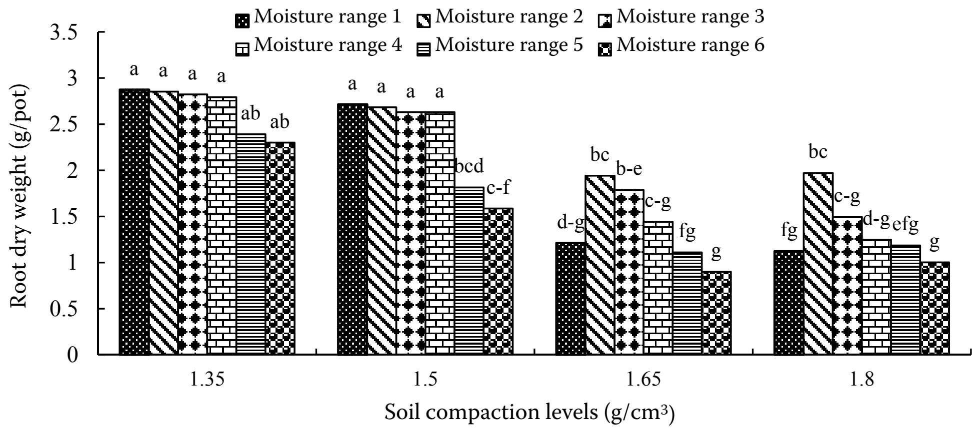

Figure 1. Root dry weight (g/pot) at different levels of soil compaction and moisture content

There was no significant reduction for the measured root characteristics at bulk densities of 1.35 and 1.5 g/cm^3 and in the moisture ranges of 1 to 4 (Figures 1–5). Seemingly at 1.35 and 1.50 g/cm^3 the plants were not encountered either with aeration stress or water deficit. At the mentioned bulk densities, the soil was loose enough and the added water easily drained off and did not lead to aeration limitation. By continuing moisture reduction and reaching to the ranges of level 4 and 5 (below 14% moisture content), the plant faced with severe water deficit stress leading to reduction in root and shoot growth and development. Another factor that may affect the growth is the penetration resistance of soil. The assumed critical value of soil penetration resistance is about 2 MPa (Taylor *et al.* 1966; Atwell 1993; Silva *et al.* 1994); in our experiment at the bulk density levels of 1.35 and 1.5 g/cm^3, the penetration resistance of the soil was much lower than 2 MPa (Figure 6) and therefore the root growth was not reduced.

At the bulk density of 1.65 g/cm^3 and moisture range of level 1, plants were facing aeration stress, and at low moisture content (moisture levels of 4–6) with water deficit stress and soil penetration resistance limitation the growth and root development declined (Figures 1–5). At this bulk density (1.65 g/cm^3) the moisture levels of 2 and 3 (moisture content of 22–33%) were optimum promoting the highest growth and root development.

At the bulk density of 1.8 g/cm^3, the best moisture level was 2 (moisture content of 23–27%). As mentioned earlier, at high moisture range (range 1) the aeration stress, and at low moisture ranges (levels 3–6), water deficit stresses and/or penetration resistance (Figure 6) reduce the measured characteristics.

A decrease in soil moisture level (from 1 to 6) and concomitant increase in soil bulk density level (from 1 to 4) led to a severe decline of as much as 65, 92, 69, 73, and 66% in root dry weight, shoot dry weight, shoot to root dry weight ratio, root length, and rooting depth, respectively.

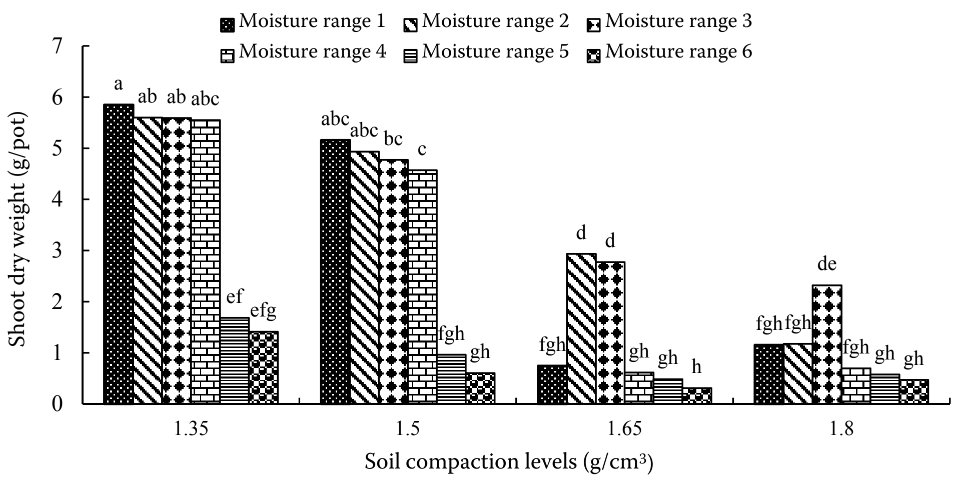

Figure 2. Shoot dry weight at different levels of soil compaction and moisture content

doi: 10.17221/146/2015-SWR

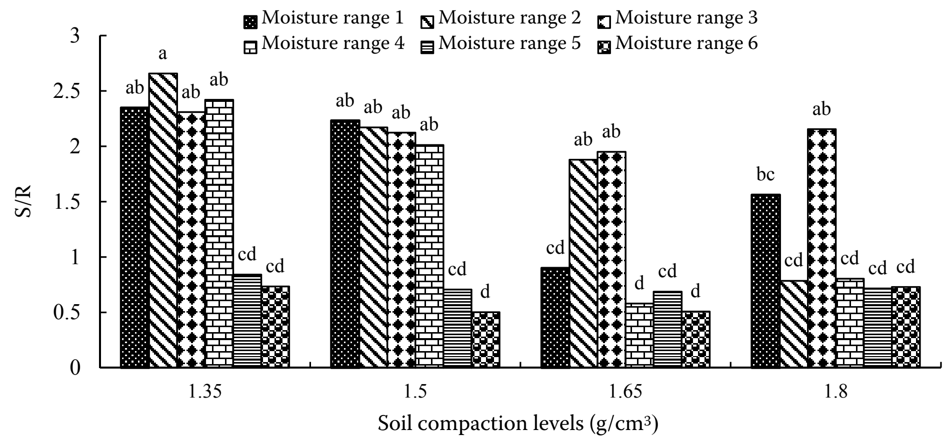

Figure 3. Shoot to root dry weight at different levels of soil compaction and moisture content

Oxygen deficiency under aeration stress increases ethylene biosynthesis in roots and sends abscisic acid to shoots. Plant responses to these hormones are leaf curling, prevention of root and shoot growth, and leaves falling (Drew 1990; He *et al*. 1996).

Reduction in growth and development of corn roots due to soil compaction has been reported by Tubeileh *et al.* (2003) and Grzesiak (2009). In wheat, heavily compacted (bulk density of 1.72 g/cm^3) soil layers significantly decreased dry shoot mass, root mas density, and root length density (Nosalevicz & Lipiec 2014). Soil moisture reduction decreases water potential and soil hydraulic conductivity, leading to sharp decline in water availability particularly in course textured soils. In this condition both root diameter and volume decrease enhances root aging. The later reduces root hydraulic conductivity and eventually root–soil contact surface. Also, under water deficit stress, the number of root hairs decreased significantly and thereby reduced water and nutrients uptake.

As seen in Figure 6, soil mechanical resistance has increased with rise in bulk density and with soil moisture decrease. At high bulk densities soil mechanical strength restricts or even may prevent root growth and development in the soil (Nosalevicz & Lipiec 2014). In this condition, roots encountered a hard and impenetrable soil, and were not capable of a sufficient inflationary pressure to move soil particles around and penetrate through them (Chan & Weil 2010) and consequently soil volume exposed to the root system reduced and efficiently restricted water and nutrients uptake as well as root and shoot growth (Figures 2–4). Further, increase in soil bulk density leads to significant reduction in total porosity, especially of large pores, which may lead to root aeration stress and oxygen problem, and further reduces root growth and development.

Mullins *et al.* (1992) reported reduced root growth at –1.0 MPa matric potential due to soil mechanical strength rather than low soil water energy level.

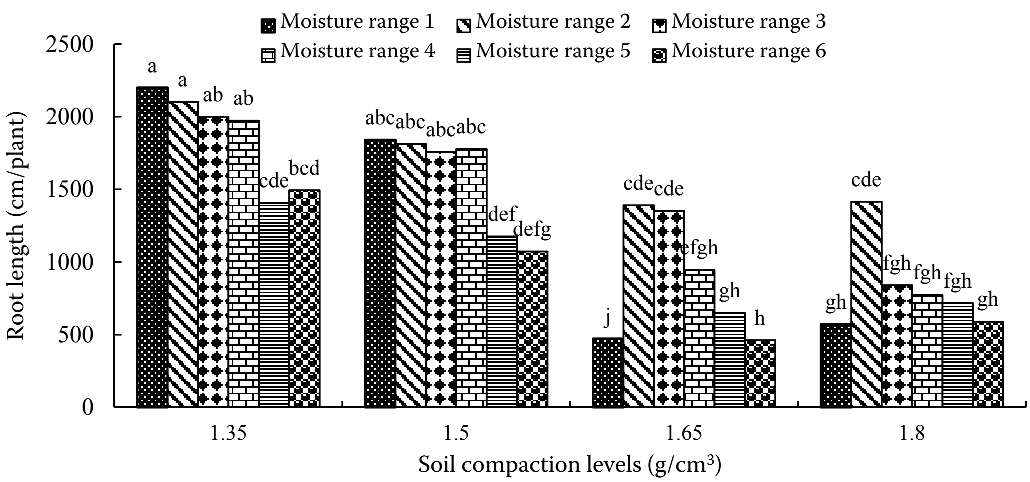

Figure 4. Root length at different levels of soil compaction and moisture content

doi: 10.17221/146/2015-SWR

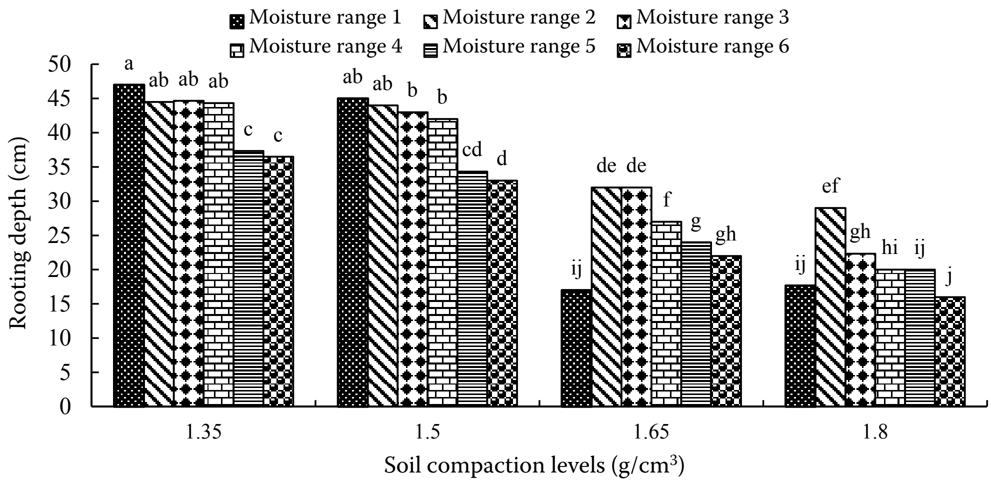

Figure 5. Rooting depth at different levels of soil compaction and moisture content

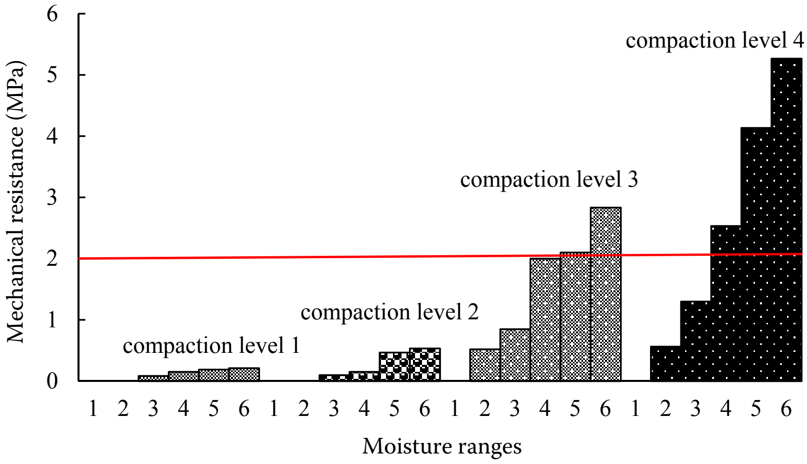

Figure 6. Soil penetration resistance at various moisture and compaction (bulk density) levels. The horizontal line delineates the critical value for root growth (2 MPa)

Thus it is speculated that the suppressive effect of soil moisture on root growth often may be indirect through the soil penetration resistance (Sharp *et al*. 1988). In addition to soil mechanical impedance induced by water deficit, other interacting effects associated with heat, disease, low nutrients status, and even hypoxia should be taken into account (Whitmore & Whalley 2009).

CONCLUSION

Effects of soil compaction and moisture significantly ($P < 0.01$) decreased root and shoot dry weight, shoot to root dry weight ratio, root length, and rooting depth. The highest values for all measured characteristics were obtained at the bulk densities of 1.35 and 1.5 g/cm^3 and moisture range of 0.14–0.49 cm^3/cm^3. At the bulk density of 1.65 g/cm^3, the optimum moisture levels were 0.28–0.33 cm^3/cm^3 and 0.22–0.28 cm^3 per cm^3, and at the bulk density of 1.8 g/cm^3, the moisture level of 0.23–0.27 cm^3/cm^3 was optimum for root and shoot. Meanwhile, the soil moisture range reduction from 0.49 to 0.07 cm^3/cm^{3and} the soil density level increase from 1.35 to 1.80 g/cm^3 led to a decrease of about 65, 92, 69, 73, and 66% in root dry weight, shoot dry weight, shoot to root dry weight ratio, root length, and rooting depth, respectively.

References

Alakukku L. (2010): Soil Compaction. Compacting Soil Degradation. Helsinki, University of Helsinki. Finland, 28: 217–223.

Andrade A., Wolfe D.W., Fereres E. (1993): Leaf expansion, photosynthesis and water relations of sunflower plants on compacted soil. Plant and Soil, 149: 175–184.

Atwell B.J. (1993): Response of roots to mechanical impedance. Environmental and Experimental Botany, 33: 27–40.

Barley K.P., Greacen E.L. (1967): Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Advances in Agronomy, 19: 1–40.

Chan G., Weil R.R. (2010): Penetration of cover crop roots through compacted soil. Plant and Soil, 331: 31–43.

doi: 10.17221/146/2015-SWR

Drew M.C. (1990): Sensing soil oxygen. Plant, Cell and Environment, 13: 681–693.

Fageria N.K., Balingar V.C., Clark R.B. (2006): Physiology of Crop Production. New York, London, Oxford, The Haworth Press Inc.

Gee G.W., Bauder J.W. (1979): Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measured parameters. Soil Science Society of American Journal, 43: 1004–1007.

Glyn Bengough A., McKenzie B.M., Hallett P.D., Valentine T.A. (2011): Root elongation, water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. Journal of Experimental Botany, 62: 59–68.

Grzesiak M.T. (2009): Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. Plant Root, 3: 10–16.

Grzesiak S., Grzesiak M.T., Hura T., Marcinska I., Rzepka A. (2013): Changes in root system structure, leaf water potential and gas exchange of maize and triticale seedling affected by soil compaction. Environmental and Experimental Botany, 88: 2–10.

Hakansson I., Medvedev V.W. (1995): Protection of soils from mechanical overloading by establishing limits for stresses caused by heavy vehicles. Soil & Tillage Research, 35: 85–97.

Hamza M., Anderson W. (2003): Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. Australian Journal of Agricultural Research, 54: 273–282.

He C.F., Drew M.C., Jordan W.R., Morgan P.W. (1996): Ethylene biosynthesis during aerenchyma formation in roots of maize subjected to mechanical impedance and hypoxia. Plant Physiology, 112: 1679–1685.

Jackson M.L. (1958): Soil Chemical Analysis. Englewood Cliff, Prentice Hall.

Lipiec J., Hatano R. (2003): Quantification of compaction effects on soil physical properties and crop growth. Geoderma, 116: 107–136.

Lipiec J., Hakansson I., Tarkiewicz S., Kossowski J. (1991): Soil physical properties and growth of spring barley related to the degree of compactness of two soils. Soil & Tillage Research, 19: 307–317.

Mullins C.E., Blackwell P.S., Tisdall J.M. (1992): Strength development during drying of a cultivated, flood irrigated hard setting soil. I. Comparison with a structurally stable soil. Soil & Tillage Research, 25: 113–128.

Nelson D.W., Sommers L.E. (1996): Total carbon, organic carbon, and organic matter. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis, Part 2, 2nd Ed. Madison, American Society of Agronomy, Inc.: 961–1010.

Nosalewicz A., Lipiec J. (2014): The effect of compacted soil layers on vertical root distribution and water uptake by wheat. Plant Soil, 375: 229–240.

Pagliai M., Marsili A., Servadio P., Vignozzi N., Pellegrini S. (2003): Changes in some physical properties of a clay soil in central Italy following the passage of rubber tracked and wheeled tractors of medium power. Soil & Tillage Research, 73: 119–129.

Richard G., Cousin I., Sillon J.F., Bruand A., Guerif J. (2001): Effect of compaction on soil porosity: consequences on hydraulic properties. European Journal of Soil Science, 52: 49–58.

Richards L.A. (1969): Diagnosis and Improvement of Saline and Alkali Soils. US Salinity Laboratory Staff, Agricultural Handbook No. 60, USDA, USA.

Sharp R.E., Silk W.K., Hsiao T.C. (1988): Growth of the primary maize root at low water potentials. I. Spatial distribution of expansive growth. Plant Physiology, 81: 50–57.

Silva A.P., Kay B.D., Perfect E. (1994): Characterization of the least limiting water range. Soil Science Society of America Journal, 58: 1775–1781.

Skinner A.K., Lunt I.D., Spooner P., McIntyre S. (2009): The effect of soil compaction on germination and early growth of Eucalyptus albens and an exotic annual grass. Austral Ecology, 34: 698–704.

Taylor H.M., Gardner H.R. (1963): Penetration of cotton seedling tap roots as influenced by bulk density, moisture content and strength of soil. Soil Science, 96: 153–156.

Taylor H.M., Burnett E. (1964): Influence of soil strength on root-growth habits of plants. Soil Science, 98: 174–180.

Taylor H.M., Roberson G.M., Parker J.J., Jr. (1966): Soil strength–root penetration relations for medium-to coarse textured soil materials. Soil Science, 102: 18–22.

Tennant D. (1975): A test of a modified line intersect method of estimating root length. Journal of Ecology, 63: 995–1001.

Tubeileh A., Groleau-Renaud V., Plantureux S., Guckert A. (2003): Effect of soil compaction on photosynthesis and carbon partitioning within a maize–soil system. Soil & Tillage Research, 71: 151–161.

Whitmore A.P., Whalley W.R. (2009): Physical effects of soil drying on roots and crop growth. Journal of Experimental Botany, 60: 2845–2857.

Received for publication August 17, 2015
Accepted after corrections July 12, 2016
Published online October 31, 2016