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Water stress and soil compaction impacts on clover growth and nutrient concentration

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Abstract

Soil compaction and insufficient water supply generally decrease crop performance. The effects of varying compaction and water availability levels on the growth of Berseem or Egyptian clover (*Trifolium alexandrimum* L.), water use efficiency and nutrient concentration were investigated under greenhouse conditions. Treatments consisted of three soil compaction levels (bulk density of 1.2, 1.4 and 1.6 Mg m^{-3}), and four water availability treatments (40%, 60%, 80% and 100% of soil field capacity) in a factorial combination. Soil compaction had a significant effect on water use efficiency with the highest (0.32 g l^{-1}) at bulk density of 1.4 Mg m^{-3} and the lowest at the other bulk densities. Soil compaction had no significant effects on leaf area, shoot, root and total dry masses. Water stress resulted in lower leaf area (from 231 to 153 mm^2 pot^{-1}), and the stem lengths were 7.6 cm and 4.3 cm for 80% and 60% of field capacity, respectively. Likewise, the highest (0.47 g pot^{-1}) and lowest (0.33 g pot^{-1}) total dry masses were observed at 80% and 60% field capacities. Water use efficiencies were 0.32 and 0.20 g l^{-1} for 100% and 60% field capacities, respectively. The accumulation of N, P and K per unit length of roots increased with soil compaction. As the water supply increased, the root and shoot dry weight and water use efficiency increased. Treatment of 100% field capacity resulted in the highest accumulation of N, P and K. Results indicated that the treatment of 80% field capacity and bulk density of 1.4 Mg m^{-3} provided the best conditions for clover performance, among the applied treatments. This study suggests that sufficient water supply can moderate the adverse effects of soil compaction on clover performance.

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Introduction

Water scarcity is very pronounced because of meteorological condition, rising population, mismanagement of soil and water resources and the global warming due to climate change. The impact is severe in arid and semi-arid regions where the soil mechanical impedance and water stress are among the most environmental constrain for crop growth.

Soil compaction often alters soil physical properties including water infiltration and distribution, gaseous movement, and nutrient uptake resulting in changes in root elongation and plant-available water. The ability of roots to penetrate strong soil has been studied (Barzegar et al. 2006). The response of roots to soil

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physical constrains was comprehensively reviewed by Bengough et al. (2011). Physical, biological and chemical processes of the root zone have been reviewed (Gregory, 2006; Hinsinger et al., 2009).

Soil degradation due to induced compaction affects about 68 million hectares worldwide (Flowers and Lal, 1998). The severity of soil compaction depends on several factors including soil type (e.g. soil texture and structure), soil water content, machinery properties (e.g. weight, speed, and contact area of tire and soil surface), and farming practices (Chamen et al., 2003). Grzesiak et al. (2013) indicated that soil compaction decreased leaf area, and biomass of shoots and roots.

Taylor (1983) reported that soil water potentials greater than -1 MPa do not have a direct impact on root growth; as soils dries out, resulting in lower soil water potential and causing strength to increases rapidly. Whalley et al. (2005) indicated that higher effective stress between soil particles resulted in lower root growth. Some reports indicated that as the soil water indirectly impacts other soil properties including soil penetration resistance, aeration, composition of soil solution, it would be difficult to isolate soil water impact on root growth. However, some evidence suggested lower root growth at low water potential due to hormonal changes of root (Blum, 2011). The influence of water stress on crop performance may be exacerbated by increased soil compaction associated with heavier farm machinery (Bengough et al., 2006). Bengough et al. (2011) reported that the response of root elongation rate decreases in response to both increasing soil impedance and decreasing matric potential but may vary among different crops.

The impact of water stress on crop growth depends upon the intensity and duration of drought, growth stage, the genotype and physiology of the crop species. Whitmore and Whalley (2009) reviewed the impact of soil drying on root and crop growth and suggested that drought is not a single, simple stress and that agronomic practices need to take into account the multiple facts of both the stress caused by insufficient water along with other interacting stresses such as heat, disease, soil strength and low nutrient status.

This study was conducted to investigate the growth performance of clover under different water stress conditions and various compaction treatments and determine whether water stress increases the negative impact of soil compaction on clover growth and nutrient uptake.

Material and Methods

Soil preparation

A Typic Torrifluvent (USDA), Calcaric Fluvisols (FAO) was used in this experiment. Soil was mixed thoroughly and sieved to remove stones and debris before pouring it into pots, measuring 12 cm height and 10 cm diameter. A subsample of soil was used to measure chemical and physical properties.

Electrical conductivity of a saturated extract (Rhoades, 1982) and pH of a saturated paste were determined. Organic carbon was measured by wet oxidation (Nelson and Sommers, 1982). Particle size distribution was determined by the pipette method (Gee and Bauder, 1986). Water contents at field capacity (-33 kPa suction) and permanent wilting point (-1500 kPa suction) were estimated using a pressure plate apparatus. Soil analysis showed a pH of 7.7, organic matter of 7.7 g kg^{-1}, EC of 1.8 dSm^{-1}. Water contents at field capacity and permanent wilting point were 210 and 90 g kg^{-1}, respectively. The soil had 326 g kg^{-1} clay, 474 g kg^{-1} silt and 200 g kg^{-1} sand. The optimum soil water content was determined using the standard Proctor test (American Society for Testing and Materials, 1992). Soil was moistened at different levels of water contents. Samples were compacted by dropping a 2.5 kg hammer 75 times from a height of 30 cm, and soil bulk density was determined.

Experimental design

A 4×3×3 factorial randomized block experimental design was performed. Treatments included three soil compaction levels, i.e., bulk density of 1.2, 1.4 and 1.6 Mg m^{-3} and four watering treatments, i.e. 40%, 60%, 80% and 100% of field capacity. There were 36 treatment combinations in total replicated 3 times. Preparation of each pot was carried out using the method outlined by Barzegar et al. (2006). After mixing the amount of water required for optimum compaction in a plastic bag the soil sample was transferred to a pot. The soil was poured in four layers of 5 cm increments into a pot mounted on a hydraulic jack and compacted. An increasing load was applied in steps for a short time to obtain the desired bulk density.

Seeds of Berseem or Egyptian clover (*Trifolium alexandrimum* L.) were pre-germinated for 72 h at 25°C on wetted filter paper. Six seedlings were planted in each pot and covered by a 2 cm layer of uncompacted soil. The watering regime of pots consisted of weighing each pot once a day and adding water to the weight corresponding to 70% of the field capacity. Two weeks after transplanting, the number of seedlings in each pot was reduced to three, and the watering treatments were implemented. After 8 weeks, the shoots and roots of each treatment were collected.

Plant measurements

Roots were separated from the soil by washing. Subsamples of roots and shoots were dried for 72 h at 60–65˚C and dry mass determined. Total leaf area was measured with a leaf area meter. Wet and dry weight of both roots and shoot biomass were determined. Water use efficiency was calculated as the ratio of dry weight of above-ground biomass to water used for irrigation. Length of shoot and roots was recorded. Subsamples of shoots and roots of each treatment were digested separately in 20% nitric acid (Mills and Jones, 1996) for determination of P, K and N concentrations.

Analysis of variance of the data was performed using SPSS to determine the significance of water availability regimes and soil compaction levels and their interactions. Means were separated using the Duncan test.

Results and Discussion

Crop growth

Clover did not grow at 40% of F.C for all the compaction treatments; therefore, we presented the results from the other water availability treatments (e.g. 06FC, 0.8FC and FC). The lack of growth at 0.4FC in this study is in contrast with the results reported for tomato by Nahar and Gretzmacher (2002). This inconsistency may be due to differences in crop response to low soil water potential and also can be contributed to difference in the climatic condition (temperature and humidity). There was a significant interaction between clover performance and soil compaction and water availability treatments (Table 1) for all the variables except root dry matter.

Table 1. Mean values of measured clover parameters, water use efficiency (WUE), and nutrient concentration

Treatment	df	Leaf area, mm^2	Stem length, cm	Total dry mass, g pot^{-1}	Shoot dry mass, g pot^{-1}	Root dry matter, g pot^{-1}	WUE, g lit^{-1}	N, %	P, %	K, %
Replication	2	410.2^{ns}	0.32^{ns}	0.005^{ns}	0.001^{ns}	0.0001^{ns}	0.0002^{ns}	0.04^{ns}	0.0003^{ns}	0.006^{ns}
Compaction(C)	2	1950.6*	3.1*	0.041**	0.021**	0.0002^{ns}	0.025**	45.7**	0.049**	0.826**
Water stress (WS)	2	13899.2**	26.1**	0.053**	0.027**	0.001*	0.038**	1.79**	0.014**	2.58**
C×WS	4	8260.3**	8.5**	0.038**	0.011*	0.0002^{ns}	0.011**	9.4**	0.01**	2.62**
Error	18	560.3^{ns}	0.53**	0.006^{ns}	0.003^{ns}	0.0001^{ns}	0.0001^{ns}	0.02^{ns}	0.0001^{ns}	0.007^{ns}

* Significant P≤0.05 ; ** Significant P≤0.01 ; ^{ns}, Not significant

Increasing compaction level reduced clover leaf area, however, the effect was not significantly different among soil compaction treatments. Water stress reduced the leaf area significantly (P≤0.01) with the highest leaf area at FC (231 mm^2) and the lowest at 0.6 FC (153 mm^2). The interactive effects of soil compaction and water stress on the leaf area were significant (P≤0.05) (Figure 1). Hopkins (2004) reported that water stress adversely influences the photosynthesis systems and results in lower leaf area.

Shoot length was significantly affected by both compaction and water stress and their interactions (P≤0.01) (Figure 1). Shoot length of bulk density of 1.2 and 1.6 Mg m^{-3} treatments were 6.5 cm and 5.5 cm, respectively. The highest (7.6 cm) and lowest (4.2 cm) shoot length were obtained at water stress level of 0.8 and 0.6FC, respectively. Comparison of mean indicated that the bulk density of 1.2 and 1.4 Mg m^{-3} had the highest and 1.6 the lowest shoot length respectively, whereas the water stress at 0.8 FC had the highest shoot length. Plaut (2008) suggested that soil physico-chemical degradation by induced compaction in arid and semi-arid regions results in reducing rhizosphere biological activities and lower water and nutrient concentration by crops.

The dry mass of roots, shoots and whole crop was not significantly affected by soil compaction level. However, water stress level significantly (P≤0.01) impacted the dry mass weights with the highest at 0.8FC and the lowest at 0.6FC. The 100 % FC probably reduced oxygen availability, due to excess of water, and in contrast, at 40 % FC the plants do not get enough water for physiological functioning. The 80 % FC gave the highest yield. Similar results were reported for tomatoes where the highest yield was at 70% FC and the 100% and 40% FC resulted in lower yield (Nahar and Gretzmacher, 2002).

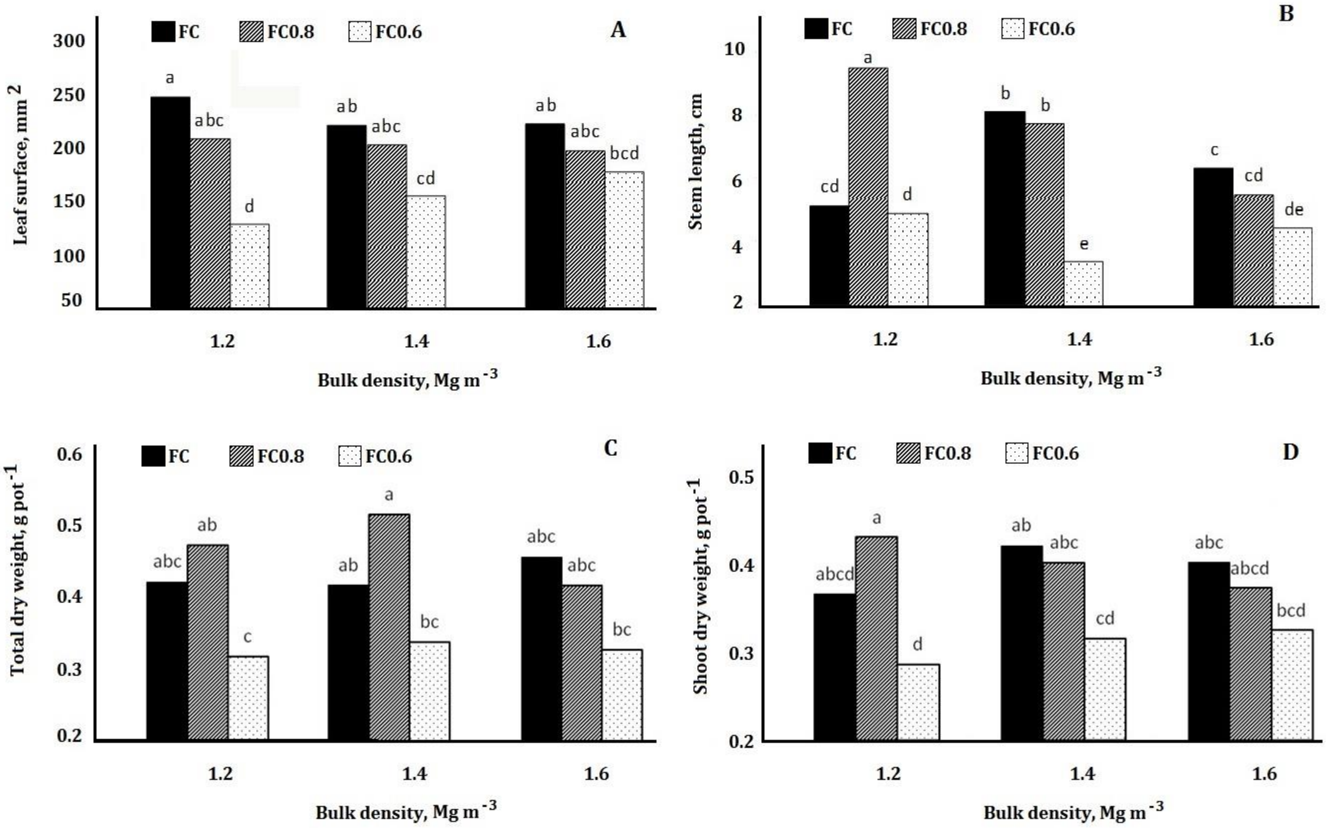

Figure 1. Leaf are (a), Stem length (b), total (c) and shoot (d) dry matter weight of clover as affected by different levels of soil compactions and water sress leve; means with similar letters are not significantly different.

Water use efficiency

The effect of soil compaction levels on water use efficiency (WUE) was significant (P≤0.01). All main effects and their two- way interactions for shoot dry mass and root length were significant. The highest WUE (0.32 g l^{-1}) was found at bulk density of 1.4 Mg m^{-3} and decreased (0.23 g l^{-1}) for bulk density either of 1.2 or 1.6 Mg m^{-3} (Figure 2). The water stress level had significant effects on WUE. The interactive effect of soil compaction levels and water stress revealed the highest WUE (0.38 g l^{-1}) was at bulk density of 1.4 Mg m^{-3} and 100% FC, and the lowest WUE (0.17 g l^{-1}) was obtained with treatment of bulk density of 1.2 Mg m^{-3} and 60% FC. In highly compacted soils oxygen availability is a limiting factor for root growth (Arvidsson, 1999). Lipiec et al. (2003) reviewed the impact of soil compaction on root growth and crop yield in Europe and suggested that an increase in soil compaction results in decreased root size, the higher concentration of roots in the upper soil, lower rooting depth and a greater distance between the nearest roots. Insufficient water supply decreased in compacted soil whereas the efficiency of the use of water by the roots increased.

Nutrients concentration

Soil compaction increased the N uptake by clover. The highest N accumulation (6.9%) was associated with the bulk density of 1.6 Mg m^{-3} and the lowest (2.4%) at 1.2 Mg m^{-3}. Also the highest N concentration was at the 100% F.C. treatments followed by the other water stress treatment (Figure 3). The nitrogen loss in soil is mainly by mass flow of water through the macropores. The higher the bulk density the lower the macropores and lower nitrogen loss due to leaching. The interaction effect of both soil compaction and water stress levels was significant (P≤0.01) and the highest N concentration was at bulk density of 1.6 Mg m^{-3} 100% FC. The results are consistent with those reported by others (e.g. Nahar and Gretzmacher, 2002). Likewise water stress also significantly influenced the concentration of phosphorus and potassium in a similar way to that of N. The mean compare of K and P shows significant difference among treatments. The treatment of bulk density of 1.6 Mg m^{-3} 100% FC indicates the highest P and K concentration of 0.3 and 4.2%, respectively. Logan et al. (1997) reported similar trends for vegetables under water stress condition.

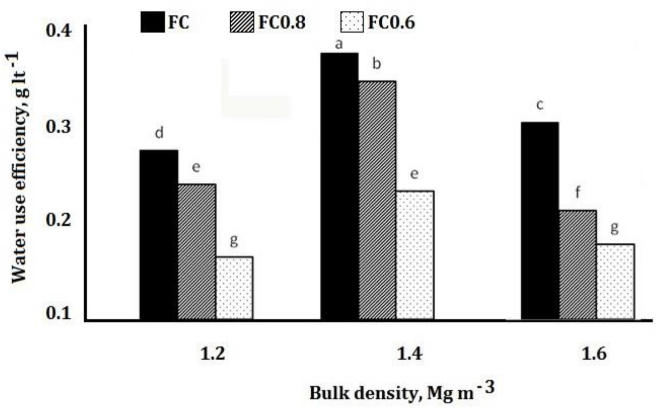

Figure 2. Water use efficiency of clover under diffent levels of water stress and soil compactions; means with similar letters are not significantly different.

Soil compaction results in lower nutrient concentration by plants. Barzegar et al. (2006) indicated the lower P, and Zn by clover as the soil compaction level increases. Similarly, Rahman et al. (2005) showed that Cu, N, P, K, Fe, Mn and Zn concentration by plant decreased as the soil compaction increased. Our results are consistent with those reported by Lipiec et al. (1991; 2003). They indicated that both nutrient concentration and effectiveness of fertilization is reduced by soil compaction. Bharameh and Josh (1993) reported that the concentration of N, P, K, Ca and Mg by sorghum was adversely affected under the irrigation treatments of decreasing soil water potential below field capacity. Our results indicated a tendency to diminish concentrations of N, P and K when increasing water stress (Figure 3).

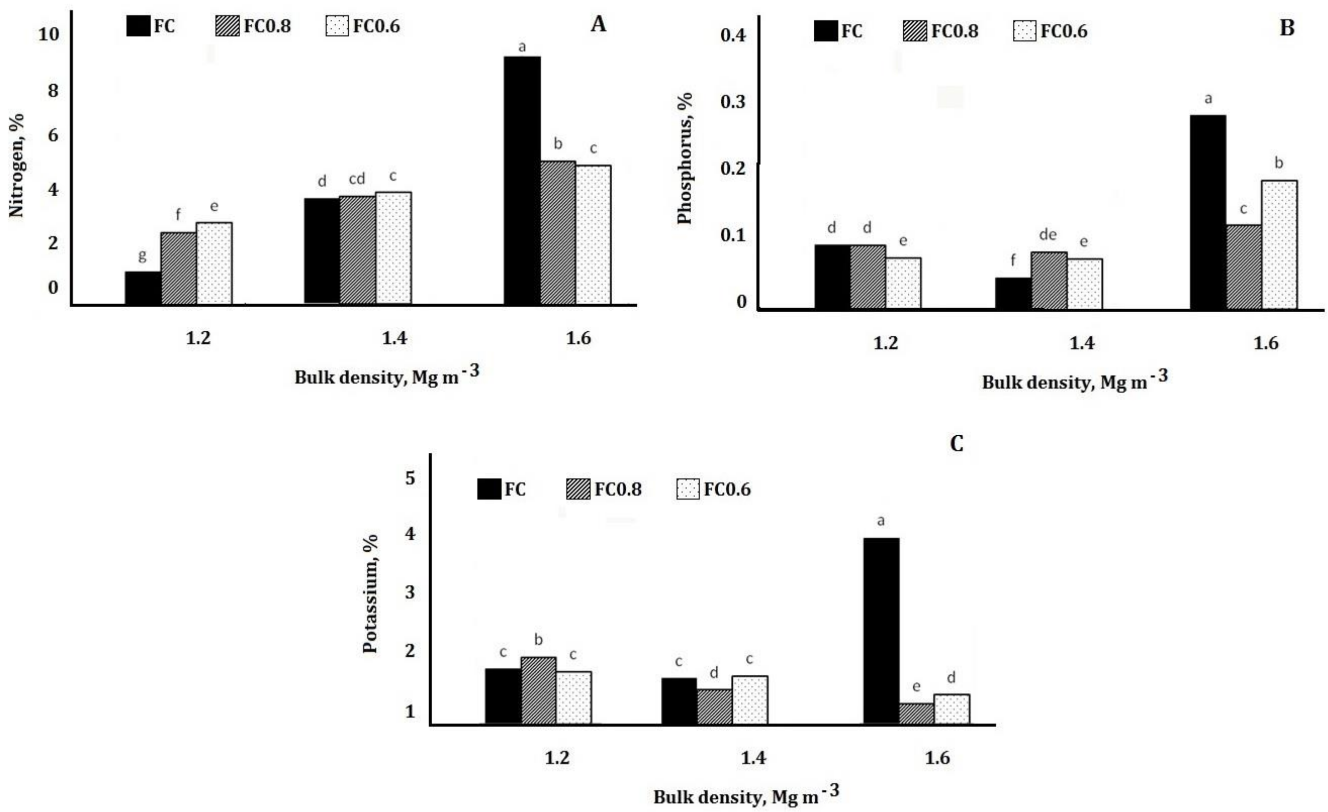

Figure 3. Inflence of diffent levels of water stress and soil compactions on N (a), P (b) and K (c) concentration by clover; means with similar letters are not significantly different.

Conclusion

An increase in soil compaction and insufficient irrigation water reduced shoot and root dry mass, and water use efficiency of clover. Soil water content at or near field capacity resulted in higher water use efficiency and nutrient concentration by clover and higher yield even at higher soil compaction.

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