

An assessment of wheat (*Triticum aestivum* L.) genotypes under saline and waterlogged compacted soil conditions I: Grain yield and yield components

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ABSTRACT: A pot experiment was conducted to study effects of salinity and waterlogging under soil compaction conditions on grain yield and yield components of wheat. Treatments were arranged in a factorial layout assigned to a randomized complete design with three replications. Treatment combinations included: two sets of compaction levels, i.e. non-compacted and compacted soil; four abiotic stresses, i.e. non-saline aerobic (untreated silt loam texture soil having $EC_e = 3 \text{ dS m}^{-1}$); saline \times aerobic (S) ($EC_e 15 \text{ dS m}^{-1}$); saline \times waterlogged (S \times W); and waterlogged alone (W) were applied; and two Iranian wheat genotypes i.e. Kouhdasht and Tajan. Compaction was achieved by dropping a 5 kg weight, 20 times from 70 cm height on a wooden block placed on top of soil-filled pots. In non-waterlogged treatments, soil water was maintained at 70% of available water holding capacity (AWHC). Waterlogging was achieved by maintaining water up to 110% of the soil's AWHC for 25 days during tillering stage. Compaction significantly intensified effect of all other treatments, except waterlogging, on grain yield and yield components of wheat genotypes as compared to control. S \times W caused significantly higher reduction in grain yield and yield components for both genotypes than other treatments.

Keywords: Abiotic stresses, plant tolerance to salinity and waterlogging, soil compaction, semi-arid agriculture

INTRODUCTION

Soil compaction is one of the major causes of soil degradation in modern agriculture and forestry (Saffih-Hdadi et al., 2009). Soil compaction can be influenced by internal and external factors. Internal factors of importance are mineralogical composition, texture, organic matter and water contents during the compaction process; external factors such as natural consolidation, shrinkage, and raindrop impact (Nhantumbo and Cambule, 2006) or induced by vehicle traffic and trampling by livestock (Castellano and Valone, 2007). It thus strongly influences soil physical properties such as movement and distribution of nutrients and water in the profile, porosity, hydraulic conductivity (Rosolem et al., 2002), has the potential to dramatically alter reduce fertilization efficiency, increase waterlogging and runoff (Soane and van Ouwerkerk, 1994). Several plant morphology and physiology are affected when roots are subjected to soil compaction (Bingham, 2001; Passioura, 2002). These characteristics include delayed plant emergence, reduced shoot growth, thin stands, uneven early growth, small grain heads, abnormal rooting patterns, shallow or horizontal root development and reduced nutrient concentrations (Mapfumo et al., 1998; Motavalli et al., 2003) and eventually to reduce grain yield (Motavalli et al., 2003; Sadras et al., 2005). In field conditions, high salinity and waterlogging in root zone often occur together (Asgari et al., 2012b; Hussain et al., 2002), and can cause severe damage to plants due to (1) waterlogging interacts with salinity causes increase Na^+ and Cl^- concentrations in plant shoots; and (2) increased shoot concentrations for Na^+ and Cl^- have adverse effects on plant growth (Barrett-Lennard, 2003). Soil compaction may interfere with salinity and waterlogging thus changing their effects on plant growth (Saqib et al., 2004a). However, consideration of combination effects of soil compaction, soil salinity and waterlogging on plants is lacking, except for Saqib et al. (2004a, b) in Pakistan. They concluded that soil compaction aggravated

negative effect of soil salinity on grain yield and different yield components of both wheat (*Triticum aestivum* L.) genotypes, i.e. Aqaab and MH-97. Average reduction in grain yield was 44% under non-compacted saline soil conditions against 76% under compacted saline conditions. Therefore, aim of the present study was to quantify soil compaction effects on grain yield and some yield components of two Iranian wheat genotypes i.e., Kouhdasht and Tajan under saline × waterlogged soil conditions in semi-arid area of Golestan province.

MATERIALS AND METHODS

A pot study was conducted in 2005-2006 in outdoor conditions in the Aq Qala area of northern Golestan province (37° 07' N, 54° 07' E). Mean annual rainfall and evapotranspiration in the area are 386 and 1445 mm, respectively. Treatments were arranged in a 2×4×2 factorial assigned to a randomized complete design with three replications. Treatment combinations included: (i) two sets of compaction levels, i.e. non-compacted and compacted soil; (ii) four abiotic stresses, i.e. non-saline aerobic (normal soil having $EC_e = 3 \text{ dS m}^{-1}$); saline × aerobic (S) ($EC_e = 15 \text{ dS m}^{-1}$); saline × waterlogged (S×W), and waterlogged alone (W) were applied; and (iii) two wheat genotypes, i.e. Kouhdasht and Tajan. Kouhdasht yield well under salinity whereas Tajan is more sensitive to saline soil conditions (Asgari et al., 2012a). To characterise soil conditions, fifteen sites were randomly selected on an agricultural field. In each site 2-3 sub-samples with approximately 0.5-0.6 kg (wet) weight, were taken manually using a 4 cm diameter Edelman auger. Sampling depths was 0-30 cm, which coincides with the plough layer in the area. The sub-samples were mixed and sieved through a 2 mm sieve before analysis. Soil texture was determined using hydrometer method (Bouyoucos, 1962). Soil organic matter content was determined by the Walkley and Black method (Nelson and Sommers, 1982). Soil bulk density of the 0–30 cm surface layer was progressively determined using the core method (Blake, 1965). Soil pH was determined in a 1:2 (w:v) soil–water extract. Electrical conductivity was measured on a saturated paste. Water content at field capacity and permanent wilting point were determined using pressure chambers. Some physico-chemical properties of the soil at the study site are presented in Table 1. Fifteen seeds were sown in each pot that filling with 8 lit pot⁻¹ soil collected from the study area. After germination, three uniform seedlings were selected whereas the rest was uprooted and discarded. For non-waterlogged treatments, soil water was maintained at 70% of available water holding capacity (AWHC). Waterlogging was imposed by keeping pots (without leaching possibility) in hypoxia conditions at tillering stage by adding water daily (up to 25 days) to 110% of AWHC. To generate soil compaction, a 5 kg weight, that controlled by a tripod stand, dropped for 20 times from a 0.7m height on a wooden block placed inside the pot (as a method described by Saqib et al., 2004a). At grain maturity, all plants from each pot were harvested. On each plant, we counted numbers of spikes and spikelets. All spikes of individual plants were then threshed manually. Wheat leaves dried at 70 °C and then ground in a mortar with a pestle.

Table 1. Some physico-chemical properties of the sampling soil

Soil sampling depth (cm)	Soil texture	Clay 0-2 μm (g kg ⁻¹)	Silt 2-50 μm (g kg ⁻¹)	Sand 50-2000 μm (g kg ⁻¹)	OM (g kg ⁻¹)	Saturated percent (mass%)	Field capacity (mass%)	EC _e (dS m ⁻¹)	pH
0-30	Si-L	14	72	14	1.52	42	24.0	3.0	7.8
30-60	Si-C-L	33	59	8	-	49	28.5	3.9	8.0
60-90	Si-C-L	33	61	6	-	53	28.8	6.2	7.9

OM is organic matter content (not measured for 30-60 and 60-90 cm depths);

EC_e is electrical conductivity on a saturation extract at 25 °C;

Si-L and Si-C-L are silt loam and silty clay loam soils, respectively.

- Not measured

Statistical Analysis

Completely randomized design (Steel and Torrie, 1980) data thus obtained were statistically analyzed using SPSS computer software (version 12.0). Treatment means were compared using Duncan's Multiple Range Test (Duncan, 1955). A p level of 0.05 was considered in all statistical tests, except when otherwise mentioned.

RESULTS

Grain yield

Genotypes responses to treatments were significantly different, and can be ordered as: S×W > S > W. Soil compaction significantly accentuated effects of all treatments on grain yield reduction for both wheat genotypes as compared to control. Soil compaction alone caused significant reduction in grain yield of both genotypes as compared to control. Highest grain yield reduction under compacted soil conditions, was observed with S×W. Kouhdasht showed significantly higher grain yield than Tajan at S and S×W under both non-compacted and compacted soil conditions (Fig. 1a).

Thousand Grain Weight (TGW)

Under non-compacted soil conditions, highest reduction in TGW was observed for S×W. Genotypes trend response to treatments was significantly ordered as: S×W > S > W. Under compacted soil conditions, but except for W, soil compaction significantly aggravated adverse effects of other treatments on TGW of both wheat genotypes. Highest reduction in TGW was caused following S×W. Kouhdasht showed significantly higher TGW than Tajan at S and S×W treatments (Figure 1b).

Straw Weight

Under non-compacted soil conditions, straw weight of both genotypes reduced non-significantly following all abiotic treatments as compared to control treatment (Fig. 1c). Under compacted soil conditions, S and S×W treatments significantly reduced straw weight of both wheat genotypes as compared to control. Similar responses were observed for both wheat genotypes to all treatments for both non-compacted and compacted soil conditions.

Number of Spikes per Plant (NSP)

NSP of both wheat genotypes significantly decreased with S and S×W treatments as compared to control (Fig. 1d). Non-significant NSP reduction was caused by W for both genotypes as compared to control. Lowest NSP value was observed for S×W for both genotypes. Kouhdasht showed significantly higher NSP than Tajan at S treatment. Soil compaction significantly aggravated effect of all treatments on NSP reduction of both wheat genotypes in comparison to control. Soil compaction alone caused significant reduction in NSP for both genotypes as compared to control. Highest reduction in NSP value was caused by S and S×W treatments. Kouhdasht showed significantly higher NSP value than Tajan under compaction alone, but Tajan showed non-significantly higher NSP than Kouhdasht at W treatment.

Number of Spikelets Per Spike (NSS)

Under both non-compacted and compacted soil conditions, but with exception of S×W, treatments did not cause significant change in NSS for either genotype as compared to control (Fig. 1e). Two wheat genotypes showed similar response to all abiotic stresses under both non-compacted and compacted soil conditions.

Harvest Index (HI)

Under non-compacted soil conditions, highest HI reduction was observed for S×W. Genotypes responses to treatments significantly followed S×W > S > W. Soil compaction significantly aggravated adverse effects of all abiotic treatments on HI (of both wheat genotypes) in comparison to control. Soil compaction alone significantly reduced HI of both genotypes. Moreover, highest HI reduction was caused by S×W. Kouhdasht showed significantly higher HI than Tajan by S and S×W under both non-compacted and compacted soil conditions (Figure 1f).

DISCUSSION AND CONCLUSION

Soil compaction significantly reduced grain yield, HI and other yield components, i.e. NSP and TGW of both wheat genotypes tested as compared to control treatment. For example, an average 19, 15.6, 27.6 and 13% reduction, respectively, was observed in grain yield, HI, NSP, and TGW of both wheat genotypes under soil compaction alone in comparison to control. Similarly, Ishaq et al. (2001a) observed a 38% reduction in grain yield of wheat cultivars when soil was compared to a bulk density of 1.93 Mg m⁻³ from an initial bulk density of 1.65 Mg m⁻³. Furthermore, Soil compaction significantly intensified adverse effects of salinity on grain yield, HI, NSP and TGW of both wheat genotypes tested here in comparison to non-compacted soil conditions. For example, an average 53% reduction in grain yield was caused through non-compact × saline treatment against a 66% reduction by compacted × saline soil. Kouhdasht showed significantly higher grain yield, TGW, NSP and HI than Tajan in saline conditions under both non-compacted and compacted soil conditions.

Results of Saqib et al. (2004a) was in agreement with the result of this study. They concluded that average reduction in grain yield of wheat genotypes relative to control was 44% in non-compact × saline against 76% in compacted × saline soil conditions. Moreover, the reduction was about 20% higher for 100 grain weight and shoot length, and 37% higher for number of tillers per plant in compacted × saline in comparison to non-compact × saline treatment.

In a saline environment, plant growth is affected in various ways such as osmotic effects, specific ion effect and nutritional imbalance, probably all occurring simultaneously (Flowers et al., 1991). On the other hand, crop growth largely depends on the ability of roots to grow and exploit soil for water and nutrients. As soil compaction level increases, root elongation rate will decrease. Severe soil compaction therefore, can cause a serious problem in agriculture since it can restrict access of root systems to water and nutrients (Barzegar et

al., 2006; Stenitzer and Murer, 2003). Therefore, the higher reduction in grain yield and different yield components due to interaction effects of salinity and soil compaction stresses may be due to poor permeability resulting from soil compaction and reduced availability of water and nutrients under both salinity and soil compaction stresses (Saqib et al., 2004a). Salinity and salinity × waterlogging treatments caused significantly higher reduction in grain yield and some yield components, i.e. TGW, NSP and HI when compared to waterlogging alone treatment, under both non-compacted and compacted soil conditions. However, non-significant differences were observed in grain yield, TGW, NSP and HI of both genotypes under non-compact × waterlogging and compacted × waterlogging treatment. Occasional irrigation of compacted soil for a few days caused favourable conditions for root growth, under both non-saline and saline soil conditions (Saqib et al., 2004b). Kouhdasht showed better performance than Tajan in saline and saline × waterlogged soil conditions, under both non-compacted and compacted soil conditions. As semi-arid areas of Golestan province often suffer from salt-affected soils and shallow and brackish groundwater, therefore, Kouhdasht would have better survival in this situation in comparison to Tajan.

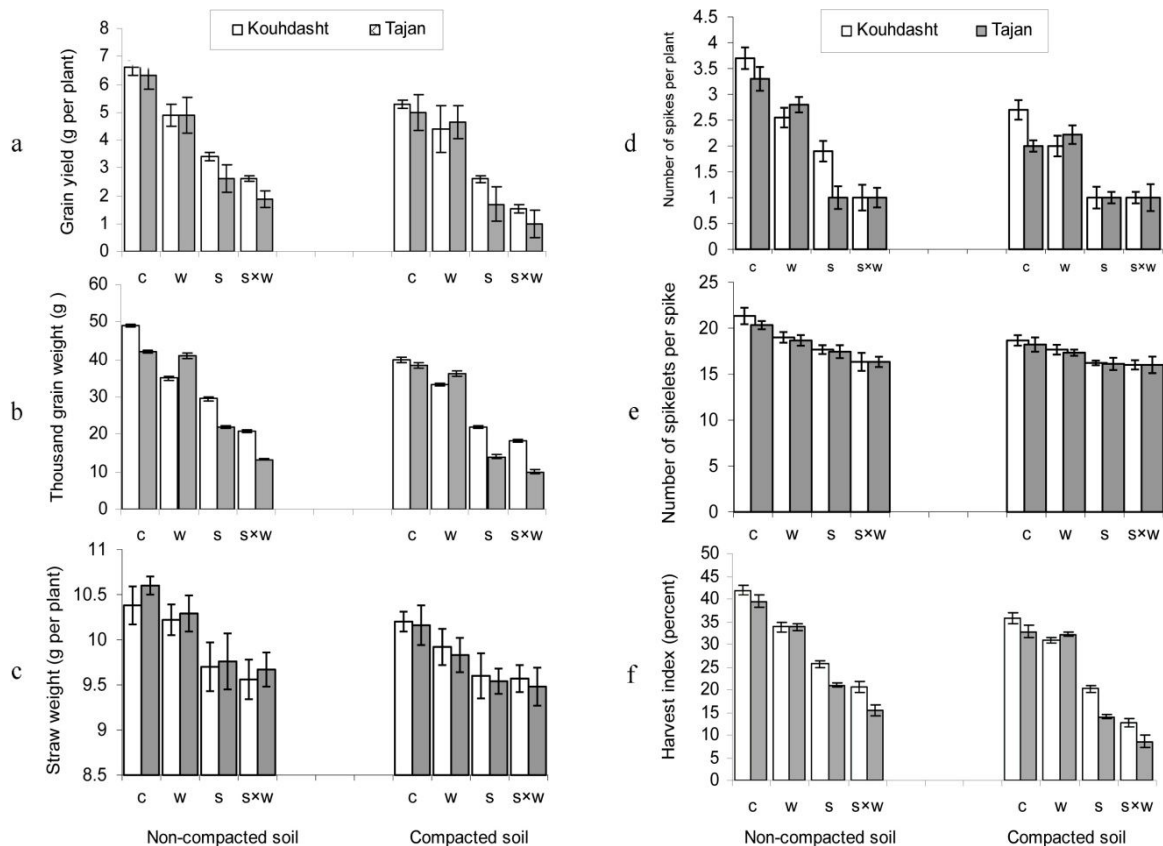


Figure 1. Effect of salinity and waterlogging on a) grain yield; b) thousand grain weight; c) straw weight; d) number of spikes per plant; e) number of spikeletes per spike; and f) harvest index of two Iranian wheat genotypes under non-compacted and compacted soil conditions. C, W, S and S×W denote relatively control, waterlogging, salinity and waterlogging × salinity respectively; error bars indicate standard deviation.

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