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Wheat (*Triticum aestivum* L.) Growth and Yield as Influenced by Flooding and Salinity Stresses in Northern Iran

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Abstract

Salinity and flooding are as two very important factors of soil degradation. They often occur together and can cause severe damage to plants. However, plant response to environmental stresses may vary with growth stage at which exposure occurs. A pot study was conducted in 2005-2006 in northern Aq Qala (northern Iran) to study combine effects of waterlogging and soil salinity at different growth stages on grain yield and some yield components of two Iranian spring wheat genotypes, i.e. Kouhdasht and Tajan. Two salinity treatments were applied, viz. a non-saline (EC_e = 3 dS m^{-1}) and saline soil (EC_e= 10 dS m^{-1}). The six waterlogging treatments within each set consisted of: control (no waterlogging), and waterlogging applied at tillering (T); stem elongation (SE); booting (B); grain filling (GF); and two spells of waterlogging, i.e. at tillering and grain filling stages (T+GF). In this experiment, waterlogging was imposed by keeping pots in hypoxia conditions by adding water daily (during up to two weeks) to 110% of available water holding capacity. Results reveal that highest reduction in grain yield; thousand grain weight (TGW) and harvest index (HI) were observed through waterlogging at T+GF for both wheat genotypes. Non-significant changes in grain yield, TGW and HI were observed via waterlogging at B as compared to control. Kouhdasht showed better performance than Tajan under saline and saline × waterlogged conditions.

Keywords: Abiotic stresses; Plant ecophysiology; Tolerance; Stress physiology; Semi-arid agriculture

1. Introduction

Salinity is one of the major types of chemical deterioration of soils involved in and leading to desertification (FAO, 1994). In addition to naturally salt-affected soils (total area of saline soils is 397 million ha and of sodic soils is 434 million ha at global level) (FAO-AGL, 2000), about 77 million hectares have been salinized by human activities (secondary salinity), with 58% of these concentrated in irrigated area (Ghassemi *et al*., 1995).

Introduction of irrigated agriculture in the arid and semi-arid regions, increase the salinity levels in the soil and groundwater. Over time, if there is inadequate drainage (Houk *et al*., 2006) and improper irrigation water management (Munns, 2002), a shallow saline water table is likely to develop which in turn; crop production may suffer when salts accumulate in the soil profile through capillary rise action and/or directly as a result of waterlogging (Houk *et al*., 2006). These two stresses in root zone often occur simultaneously (Hussain *et al*., 2002; Kahlown and Azam, 2002).

The life cycle of a plant can be divided into a number of distinctive growth stages. Therefore, plant response to different environmental stresses may be variable with the stage of growth at which exposure occurs (Saqib, 2002). For example, wheat is tolerant to salinity at germination but is sensitive during seedling emergence. Moreover, grain-filling stage of wheat is least sensitive to salt stress than anthesis (Ranjbar, 2010). Likewise, spells of waterlogging for few weeks are more common in irrigated lands. These may occur at any growth stage and may cause complete failure especially at most sensitive phase of plant growth cycle (Saqib, 2002). For

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example, wheat is commonly exposed to soil saturation with water due to rainfall during the growing season and at different growth stages (Li *et al*., 2011).

Several studies have been carried out with different wheat cultivars to look for tolerance to salinity and waterlogging interaction in the world and Iran. The results of these experiments showed that a combination of salinity and waterlogging caused a higher reduction in such different growth and yield parameters of wheat genotypes as fresh and dry shoot weight and number of tillers per plant (Akhtar *et al*., 1994; Nawaz, 1993; Qureshi and Barrett-Lennard, 1998), plant height (Hussain *et al*., 2004), root fresh weight, root length and root dry weight (Saqib *et al*., 1999; Ishaq *et al*., 2001b) and grain yield and yield components (Hussqin, 2006; Saqib, 2002; Tashakori *et al*., 2004) as compared to those observed under salinity or flooding alone. However, research to study interaction of salinity and waterlogging stresses on wheat at different growth stages is rare in Iran. Therefore, the aim of the present study was to obtain information on the response of two Iranian spring wheat genotypes, i.e. Kouhdasht and Tajan, to interaction of salinity and waterlogging at different growth stages.

2. Materials and Methods

A pot (greenhouse) study was conducted in 2005-2006 in the Aq Qala area of northern Golestan province (37° 07' N, 54° 07' E) which is located in north of Iran near the Caspian Sea. A semi-arid climate prevails in the area. The experiment was conducted in factorial format based on randomized complete design (RCD). Treatments included two salinity levels, i.e. non-saline soil with EC_e = 3 dS m^{-1} (as control) and saline soil with EC_e= 10 dS m^{-1}. It was further applied six waterlogging treatments: non- waterlogged soil as control; single waterlogging treatments at tillering; stem elongation; booting; and grain filling stage; and two spells of waterlogging, i.e. at tillering and grain filling stages. Two wheat genotypes (i.e. Kouhdasht and Tajan) were tested in this experiment. Kouhdasht responds well to salinity whereas Tajan is more sensitive to saline soil conditions (Asgari *et al*., 2008). To characterize soil conditions, fifteen spots were randomly selected on an agricultural field (with 4 hectares in size). In each spot, 2 to 3 sub-samples of approximately 0.5-0.6 kg (wet) weight were taken from the top 0-30 cm using a 4 cm diameter Edelman auger. Specific spot sub-samples were thoroughly mixed to obtain a composite soil sample for each location. Some physico-chemical properties of the soil at the study site are presented in Table 1. Soil texture was determined using the hydrometer method (Bouyoucos, 1962). After germination, three uniform seedlings were selected and allowed to grow whereas the rest was uprooted and discarded. For non-waterlogged pots, soil water is maintained at 70% of available water holding capacity (AWHC).

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%)	ECe (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.

Waterlogging was imposed by keeping pots (sealed to prevent leaching) in hypoxia conditions by adding water daily (during up to two weeks at each growth stage) to 110% of AWHC. Pots were weighed daily and water lost was replaced by adding water with an EC <1.0 dS m^{-1} to maintain desirable (non-waterlogged or waterlogged soils) conditions. At grain maturity, all plants from each pot were harvested. On each plant, we calculated numbers of spikes, spikelets, leaves, tillers and spike lengths, thousand grain weight, straw weight, grain yield and harvest index.

3. Results

3.1. Grain Yield

Under non-saline soil conditions, waterlogging caused significant reduction in grain yield of both wheat genotypes at all growth stages, except at T (Fig. 1a). Grain yield reduction due to a combination of salinity and waterlogging showed the following classification: T+GF >

GF>B>SE>T. Kouhdasht showed significantly higher grain yield than Tajan at T and B stages.

3.2. Thousand Grain Weight (TGW)

Under non-saline soil conditions, highest reduction in TGW was observed when waterlogging was applied at T+GF (Fig. 1b). Non-significant TGW reduction occurred in both genotypes, when waterlogging was applied at B and T stages. TGW decreased significantly more by waterlogging applied under saline soil conditions than under non-saline soil conditions. Kouhdasht showed significantly higher TGW than Tajan when salinity was imposed alone.

3.3. Straw Weight

Under non-saline soil conditions, a significant decrease in straw weight of both wheat genotypes was observed at T+GF and GF treatments as compared to control (Fig. 1c). Under saline soil conditions, salinity alone significantly decreased straw weight of both genotypes at GF and T+GF stages as compared to control.

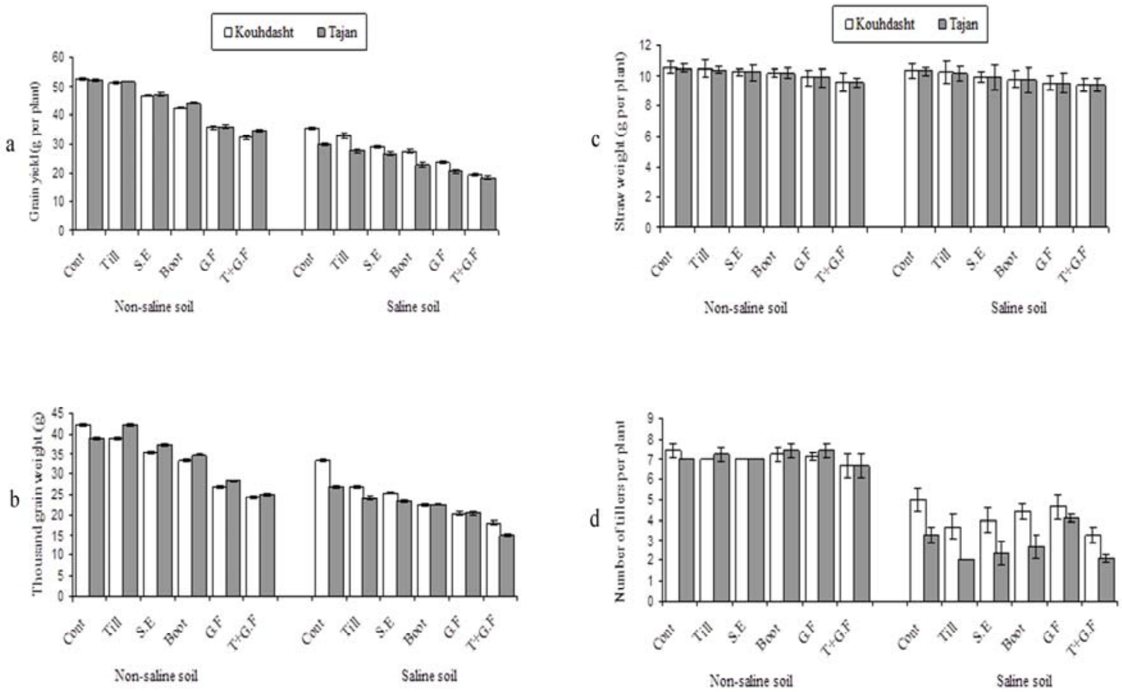

Fig. 1. Effect of waterlogging applied at different growth stages on a) grain yield; b) thousand grain weight; c) straw weight; and d) number of tillers per plant of wheat genotypes under non-saline and saline soil conditions; error bars indicate standard deviation

3.4. Number of Tillers per Plant (NTP)

Under non-saline soil conditions, waterlogging treatments did not cause a significant reduction in NTP of both wheat genotypes as compared to control (Fig. 1d). Lowest NTP was observed through saline-waterlogged treatments at T and T + GF stages for both wheat genotypes. Kouhdasht showed significant higher NTP than Tajan at all waterlogging treatments.

3.5. Number of Spikes per Plant (NSP)

Under non-saline soil conditions, waterlogging applied at B stage caused a significant reduction in NSP of both genotypes as compared to control (Fig. 2a). Under saline soil conditions, all waterlogging treatments caused significant reduction in NSP of Tajan as compared to control. Kouhdasht showed significantly higher NSP than that expressed by Tajan under all waterlogging treatments, except for B and T+GF stages.

3.6. Number of Spikelets per Spike (NSS)

Under both non-saline and saline soil conditions, waterlogging applied at booting, grain filling and tillering + grain filling stages caused a significant decrease in number of spikelets per spike of both genotypes as compared to control (Fig. 2b). Non-significant differences in NSS were observed between the two genotypes at different waterlogging treatments under both non-saline and saline soil conditions.

3.7. Spike Length

Under non-saline soil conditions, spike length of both genotypes decreased through all waterlogging treatments as compared to control (Fig. 2c). However, only waterlogging at T + GF stage caused a significant decrease in spike length. A significant decrease in spike length was observed at salinity alone and also through waterlogging applied at GF and T+GF stage.

3.8. Harvest Index (HI)

Under non-saline soil conditions, waterlogging applied at all growth stages, except T, lead to significant reduction in HI of both wheat genotypes compared to control (Fig. 2d). Under saline soil conditions, all treatments caused a significant reduction in HI of both genotypes compared to control. Significantly higher HI reduction was observed following waterlogging at T+GF in case of Kouhdasht and at GF and T+GF for Tajan as compared to control. Kouhdasht showed a significantly higher HI than Tajan at salinity alone and also when waterlogging was applied at T and B stages.

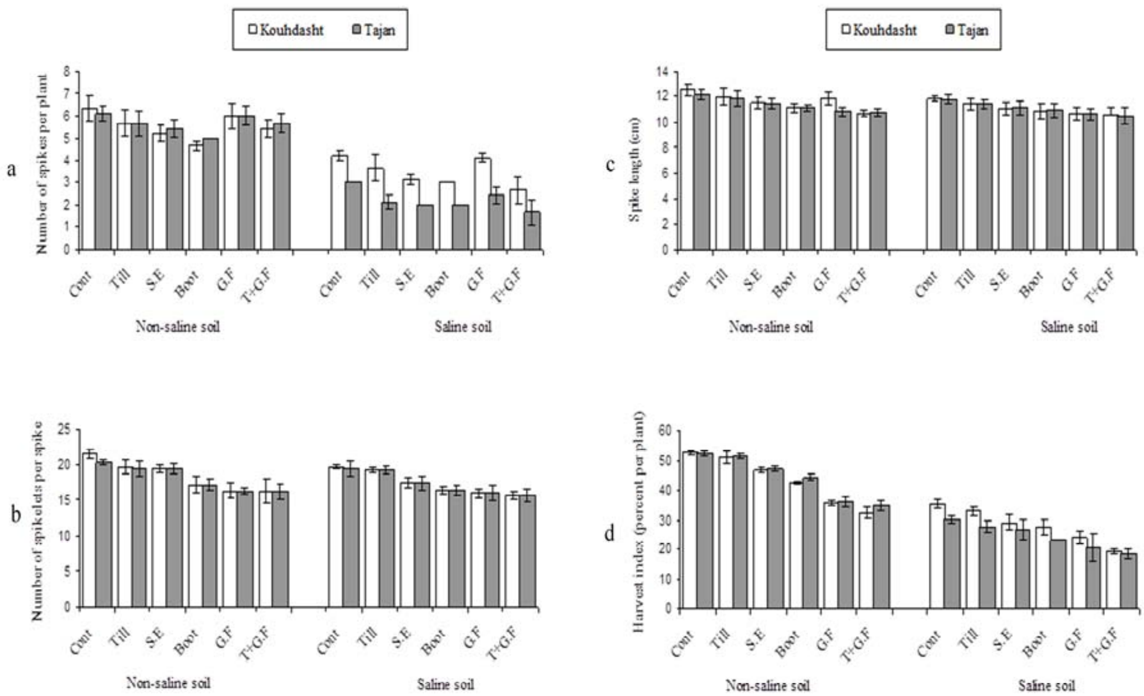

Fig. 2. Effect of waterlogging applied at different growth stages on a) number of spikes per plant; b) number of spikelets per spike; c) spike length; and d) harvest index of wheat genotypes under non-saline and saline soil conditions; error bars indicate standard deviation

4. Discussion and Conclusion

In the present study, wheat genotypes presented a different grain yield response to waterlogging under non-saline and saline soil conditions, but this effect was heavily dependent on stage at which exposure occurred. Waterlogging applied at tillering (horizontal) stage did not cause any significant reduction in grain yield of both wheat genotypes when compared to control. Waterlogging applied at more than one growth stage caused lowest grain yield compared to single waterlogging events. For example, significantly higher reduction in grain yield (52.6% and 49.8% for Kouhdasht and Tajan, respectively) was observed through waterlogging at T+GF when compared to other waterlogging treatments. However, grain yield reduction was similar when waterlogging was applied at both GF and T + GF growth stages. Waterlogging at tillering stage did not cause significant reduction in grain yield nor TGW of both wheat genotypes as compared to control treatment. Similarly, results of Gardner and

Flood (1993) who assessed effect of waterlogging on wheat (*Triticum aestivum* L.) at different growth stages showed that early reproductive stages are more adversely affected by waterlogging than tillering as evidenced by the fact their earlier maturing genotypes yielded much less than the late maturing genotypes they tested on undrained relative to drained field plots. Saqib (2002) also concluded that waterlogging at tillering stage during 25 days did not significantly reduce grain yield of bread wheat genotypes (i.e. Aqaab and MH-97) in Pakistan, while highest reduction in grain yield and 100 grain weight were observed when waterlogging was applied two times (i.e. at stem elongation + grain filling stages).

Under waterlogging the root system is directly exposed to the changes of the soil environment such as a reduction in oxygen level and increase in CO_2 and ethylene concentration. The effect of oxygen deficiency in reducing root respiration is reversible but the accumulation of CO_2 also inhibits root respiration and the effects are not reversible (Paltaa *et al*., 2010). For most plants, the capacity of roots to supply nutrients and water for plant growth and development is inhibited in waterlogged soils, the shoot and root growth of waterlogged plant is also inhibited. The detrimental effects of waterlogging on various crops have been demonstrated in many species, such as wheat and maize (Liu *et al*., 2010). Dickin and Wright (2008) reported that waterlogging restrained growth of winter wheat resulting in reduced shoot dry weight and grain yield. Moreover, Saqib *et al.* (1999) suggested that poor aeration on cereals caused slower rates of leaf elongation, dry matter accumulation and depressed tillering.

In this experiment, waterlogging under non-saline soil conditions also reduced NSP of both genotypes tested here. The higher reduction in number of spike per plant (26%) was observed through waterlogging at booting growth stage. Spike length and number of spikelets per spike of both genotypes also decreased with all waterlogging treatments, but significant difference in spike length was observed when waterlogging was applied at tillering and two spells of waterlogging i.e. tillering and another one at grain filling stages. Also, a significant reduction in number of spikelets per spike of both genotypes occurred when waterlogging was applied at booting, grain filling and tillering + grain filling stages.

Salinity is inimical to plant growth through specific ion toxicities, osmotic effects and induced nutrient deficiencies (FAO, 1994). However, growth inhibition by Na^+ and Cl^- is the most common and for many plants including the graminaceous crops (Saqib *et al*., 1999; Iqbal *et al*., 2001a; Mass and Grrieve, 1990). In this study, saline-aerated soil is also caused grain yield and yield components reduction in both wheat genotypes as compared to control treatment. However, this reduction was significantly higher in Tajan as those were shown by Kouhdasht.

The combination of salinity and waterlogging stresses significantly reduced wheat yield by decreases in grain weight, spike length and the number of spikelets, and showed a more adverse effect than the salinity alone (Zhang *et al*., 2007). In this study, waterlogging under saline soil conditions lead to a significantly higher reduction in grain yield and most yield components (of both wheat genotypes), as compared to control. However, highest reductions in grain yield (75 and 76.5%, for Kouhdasht and Tajan, respectively) were observed after waterlogging at T+GF as compared to others. Kouhdasht consistently showed higher grain yield, TGW and HI than that Tajan. Thus, results of Jiang *et al.* (2002) and Zhang *et al.* (2007) support these findings. They concluded that combined salinity and waterlogging stress significantly reduced wheat yield by decreases in grain weight, spike length and the number of spikelets, and showed a more adverse effect than the single salinity treatment. As a concluding remark it should emphasize that Kouhdasht showed better performance than Tajan under saline and saline × waterlogged soil conditions. Therefore, Kouhdasht seems to be a good genotype for the study area that often suffers from a combination of salinity and waterlogging stresses.

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