Waterlogging effects on wheat yield, redox potantial, manganese and iron in different soils of India

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Abstract
The effect of waterlogging tolerance in wheat genotypes and soil environments in micro plot (Lysimeter) experiment was investigated at the Central Soil Salinity Research Institute (CSSRI), Karnal, India. Redox potentials decreased sharply after waterlogging and were 343, 294,156, and 119 mV at 15 days after waterlogging in alkali soil at pH 7.5 (neutral soil), pH 8.2 (saline soil), pH 9.0 (sodic soil) and pH 9.4 (sodic soil) , respectively. Waterlogging caused a 4 and 9 fold increase in neutral soil (pH 7.5), 4 and 24 fold increase in saline soil (pH 8.2) and 8 and 12 fold increase in sodic soil (pH 9.0 and pH 9.4) in DTPA Fe and Mn, respectively at 15 days after waterlogging in comparison with drained conditions. These increases were higher, than reported critical concentrations for wheat. After 15 days waterlogging, all soils were drained, and the re-aeration resulted in an increase in redox potential and a decrease in DTPA-Fe and DTPA-Mn in soil solutions, but this occurred slowly taking 15- 25 days. Results support the working hypothesis that waterlogging tolerance is a product of tolerance to anoxia and microelement toxicities, and that these are both key factors limiting plant growth during and after waterlogging.

Key Words
Iron, manganese, redox potential, sodic soils, acidic sandy-duplex soil.

Introduction
Waterlogging is a widespread problem for wheat production, especially in the sodic/alkaline soils of India. The former includes 3.77 million ha of sodic soils and 2.96 million ha affected by seepage from irrigation canals (NRSA and Associates 1996). Such problems become more acute when the soils are not leveled or irrigation is followed by excess rain (Gill *et al.* 1992). Transient waterlogging also adversely affects crop production in the usually acidic sandy duplex soils in Australia. In Australia, transient waterlogging occurs primarily in sandy duplex soils, where rainfall rapidly penetrates a sandy topsoil and accumulates above a compacted clay subsoil with low hydraulic conductivity at 5 to >100 cm depth (Tennant *et al.* 1992). More recent estimates of waterlogging areas range from 1 to 2 million ha in Western Australia (Hamilton *et al.* 2000; Short and McConnel 2001), with about 3.8 million ha of crops affected in Victoria, Australia (Fried and Smith 1992).

The adverse effects of waterlogging on plants are often ascribed to decreased availability of O_2 and accumulation of phytotoxins (Armstrong and Armstrong 2001). Oxygen deficiency inhibits aerobic respiration, resulting in severe energy deficiency and eventually death (Greenway and Gibbs 2003). In addition, waterlogging can also reduce the availability of some essential nutrients, e.g. nitrogen, and increase the availability of nutrients, e.g. Fe and Mn (Ponnamperuma 1972). Such increases in micronutrients in soil and subsequently in shoots may affect plants both during waterlogging and also after waterlogging during recovery, as higher micronutrient concentrations in shoots have been reported during recovery period when soils have returned to fully aerated conditions (Setter and Waters 2003). While prolonged waterlogging is detrimental to plants, even short - term transient waterlogging can have long-lasting adverse consequences leading to poor growth and reduced grain yields, especially where temperatures are high and biological activities relating to soil redox processes can occur more rapidly. The objective of this investigation was to monitor changes in redox potential, iron and manganese concentration in different soils India under waterlogged and drained conditions, and evaluate these in relation to yield reductions of wheat in waterlogged soils.

Methods and materials

A micro plot (Lysimeter) experiment for waterlogging (WL) tolerance was conducted at the Central Soil Salinity Research Institute (CSSRI), Karnal, India (N29°42'22.8"E76°57'10.6"), in 2004/05 and 2005/06 in field seasons (November to April). Eight genotypes of wheat (KRL 3-4, NW 1076, Brookton, PBW 343, , KRL 200, KRL 144 and HD 2009) were replicated four times and evaluated under neutral soil (pH 7.5), saline soil (pH 8.2), sodic soil (pH 9.0) and sodic soil (pH 9.4) condition. These micro-plots are highly homogeneous with respect to soil. Micro-plots are small plots of size 2mt x 2mt in which soil is made sodic artificially by adding required amount of sodium bicarbonate to make up the pH of the soil as 9.0 and 9.4 for sodic soil and sodium chloride to make up the pH of the soil as pH 8.2 for saline soil. These micro-plots are highly homogeneous with respect to sodicity as every year the equal amount of soil from each micro plots is taken out and than mixed thoroughly and filled again in each of the micro-plot. Seeds were sown in the third week of November in both the years. The waterlogged treatments were Non –waterlogged (drained), and waterlogged for 15 days. The WL treatment was imposed at 21 days after sowing (DAS). Plants were watered weekly prior to WL treatment. When WL commenced, water was maintained 2-5 cm above the soil surface during waterlogging periods. Samples of each soil were taken during WL and additional samples were taken after surface water was removed by gradual tilting of pots and draining out of water and the soils were allowed to dry.

Redox potential (Eh) were measured in the wet soils on 0, 5, 10, 15, 20 and 25 days after WL and during the recovery periods. Eh was determined in soil using (1) a millivolt meter (Cole-Parmer, Chicago, IL), (2) platinum redox electrodes made from platinum wire (0.75 mm dia; 10 mm long; AGR Matthey, Newburn, WA) manufactured according to Patrick *et al.* (1996). DTPA-Fe and DTPA-Mn were also determined in the wet soils. Fe and Mn were extracted by shaking 10 g of wet soil with 20 ml of diethylenetriaminepentaacetic acid (DTPA) solution for 2 hours (Lindsay and Norvell 1978). After filtering through a 0.42 µm filter, the solution was analyzed for Fe and Mn by atomic absorption spectrophotometry. The grain yield per plant was taken as a mean of five randomly selected plants from each genotype.

Results

Waterlogging treatment reduced grain yield in comparison to drained soils all the genotypes and higher reductions were observed in sodic soils. However, the percent reduction varied differently in different genotypes KRL 3-4 (12 %), NW 1076 (9.8 %), KRL 146 (9.0 %), Brookton (190 %), PBW 343 (162 %), KRL 200 (3.2 %), KRL 1.7 %), and HD 2009 (100 %) in sodic soil (Figure 1). This differential response of genotypes may be due to the operation of different tolerance mechanisms for waterlogging. Redox potential data presented here are corrected to pH 7 to enable comparison between different soils in India. Waterlogging significantly decreased the redox potential relative to initial values in all soil types; this occurred in soils waterlogged for 15d (Figure 2). In drained soil just prior to waterlogging, the Eh values of soil ranged from 450-500 mV; and after 15 d of waterlogging the soil redox potentials in pots had fallen to between 119 and 343 mV. Redox potential were ranged from initial to 15 days WL i.e. 453 to 343, 472 to 274, 485 to 156 and 490 to 119 mv in neutral soil (pH 7.5), saline soil (pH 8.2), sodic soil (pH 9.0) and sodic soil (pH 9.4), respectively. The sodic waterlogged soils (pH 9.0 and pH 9.4) become anoxic, i.e. have redox potentials

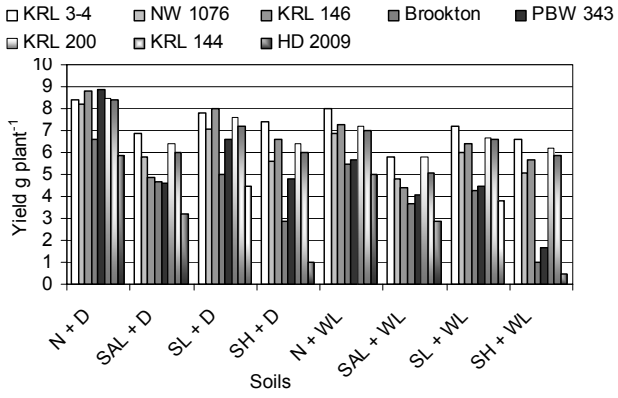

Figure 1. Effects of 15 days waterlogging (WL) on grain yield of different wheat genotypes in neutral soil (N, pH 7.5), saline soil (SAL, pH 8.2), sodic soil (SL, pH 9.0) and sodic soil (SH, pH 9.4) in Lysimeter.

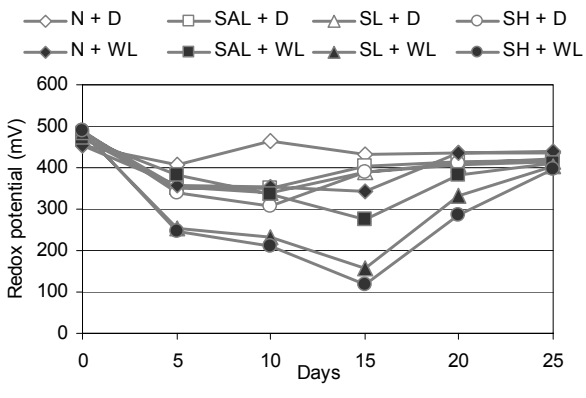

Figure 2. Effects of 15 days waterlogging (WL) on redox potential (mV) in neutral soil (N, pH 7.5), saline soil (SAL, pH 8.2), sodic soil (SL, pH 9.0) and sodic soil (SH, pH 9.4) in Lysimeter.

≤350mV, within 4-5 days after waterlogging while neutral soil (pH 7.5), saline soil (pH 8.2) become anoxic, after 10 days after waterlogging. Furthermore when these soils are allowed to drain after all water is removed from the soil surface at day 15, the natural soils in the field take at least an additional 14 days in sodic soil (pH 9.0 and pH 9.4 and 7 days in neutral soil (pH 7.5), saline soil (pH 8.2) to reach a redox potential similar to the original values in the drained soil as occurring prior to waterlogging . In summary, when waterlogging is visible at the soil surface for 15 days in sodic soils, this results in reduction in the soil for about 28 days, i.e. 14 days during the waterlogging treatment in addition to up to 14 days more after drainage. Rapid initial decrease in soil Eh in the waterlogged Indian soils is apparently due to removal of the oxygen and the release of reducing substances accompanying oxygen depletion before iron and manganese oxide hydrates can mobilize their buffer capacity (Ponnamperuma 1972).

Waterlogging significantly increased DTPA-Fe concentration in soil solutions at 15 days of waterlogging in comparison to drained treatments for all the soils. Waterlogging caused a 4 - fold increase DTPA-Fe in neutral soil (pH 7.5), saline soil (pH 8.2) and 8 - fold increase in sodic soil (pH 9.0) and sodic soil (pH 9.4) due to 15 days after waterlogging in comparison with drained conditions. However, the increase of DTPA-Fe at 15 days after waterlogging was half in neutral soil (pH 7.5), saline soil (pH 8.2) relative to sodic soil (pH 9.0) and sodic soil (pH 9.4). Patrick (1964) found that soluble iron begins to increase when the redox potential decreased to about 150 mV or less, and it continued to increase with further decreases in redox potential. This observation suggests that the transformation of iron is mainly caused by the reduction of ferric compounds to the more soluble ferrous forms.

Waterlogging significantly increased the Mn concentration in both the soils compared with drained conditions. After only 7 days waterlogging, DTPA-Mn had significantly increased about 3-fold in neutral soil (pH 7.5), sodic soil (pH 9.0) and sodic soil (pH 9.4) in relative to 7 - fold in saline soil (pH 8.2). In comparison with drained conditions, waterlogging caused a 24 - fold increase in DTPA-Mn in saline soil (pH 8.2) and 11- fold increase in sodic soil (pH 9.0 and pH 9.4) at 15 days after waterlogging. These increases in concentrations of DTPA-Mn in soil solution during waterlogging are 30 times higher than critical concentrations (DTPA-Mn 2.0 mg kg^{-1}) described by Gupta (2004).

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