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SHORT COMMUNICATION

Individual and combined effects of waterlogging and alkalinity on yield of wheat (*Triticum aestivum* L.) imposed at three critical stages

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Abstract Response of wheat genotype HD 2329 to individual and combined effects of alkalinity and waterlogging (WL) at tillering, panicle emergence and anthesis stage was studied. Both stresses increased Na accumulation and reduced K uptake which leads to higher Na^+/K^+ ratio in the leaves. Yield was decreased under all the stress treatments and highly correlated with Na^+/K^+ ratio at all the three growth stages ($r=-0.83$, -0.82 and -0.73, respectively) with maximum reduction under pH 9.4 + WL. Increase in pH from 7.2 to 9.1 and 9.4 delayed complete panicle emergence (4 and 8 days) and flowering (1 and 2 days) at both, tillering and panicle emergence stages. Dual stress further increased days, required for complete panicle emergence and flowering. These results suggested that high Na^+/K^+ ratio of plant tissue may be the critical factor for growth and development of wheat under WL, alkalinity and dual stress. Due to this delay in flowering and panicle emergence, times required for maturity of grains shorten, resulted in lower grain yield.

Keywords Alkalinity · Flowering · Waterlogging · Wheat

Introduction

Salinity, alkalinity and waterlogging are the major stresses restricting crop stand and yield. In India, 2.5 million ha of alkaline soils of the Indo-Gangetic plains planted with wheat may experience saturated or temporary waterlogging (WL) conditions every year due to excess rains or mismanagement of water drainage from the farmer's fields (Sharma and Swarup 1988). Alkaline soils lose their physical properties having low air spaces and contain excess exchangeable sodium which restrict water and air movement in soils. This problem becomes even more severe when the soils become waterlogged. WL causes a condition of hypoxia in soils, because of the low solubility of oxygen in water (0.28 mol m^{-3} at 20°C), the slow diffusivity in water-filled pores (≈10,000 fold slower than gas-filled soil pores, Grable 1966) and the rapid use of dissolved oxygen by bacteria and roots. Recent progress in molecular genetics and plant electrophysiology suggests that the ability of a plant to maintain a high cytosolic K^+/Na^+ ratio appears to be critical to plant salt tolerance (Ahmad et al. 2005). So far, the major efforts of plant breeders have been aimed at improving this ratio by minimizing Na^+ uptake and transport to shoot (Shabala and Cuin 2007). The present investigation was carried out to investigate the effect of individual and combined effect of alkalinity and WL on grain production of wheat.

Materials and methods

An experiment was conducted in the screen house of the Division of Crop Improvement, Central Soil Salinity Research Institute, Karnal (29° 42′ N & 77° 02′ E), India. Alkaline soil was prepared according to the method of Bains and Fireman (1964) by sprinkling $NaHCO_3$ solution on normal soil (ESP=8, pH 7.2 EC=1.2, CEC=8.85 mEq/100 g, Exchangeable Ca+Mg=7.4 mEq/100 g, $CaCO_3$= 7.5%, Infiltration rate=15 mm 15 day) @ 304 and 484 g for

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Table 1 Individual and combined effect of alkalinity and waterlogging on sodium and potassium accumulation in leaves of wheat at different growth stages

Treatments	Na (mg/g dry wt)			K (mg/g dry wt)		
	Tillering stage	Panicle emergence	Anthesis stage	Tillering stage	Panicle emergence	Anthesis stage
pH 7.2	2.31	2.60	2.73	27.67	29.33	28.00
pH 7.2 + WL	2.03	3.00	3.27	32.78	37.21	38.58
pH 9.1	8.51	10.42	10.42	24.80	25.00	25.00
pH 9.1 + WL	14.19	14.75	13.78	26.33	26.33	36.38
pH 9.4	15.63	22.51	16.47	27.00	27.50	27.00
pH 9.4 + WL	22.78	23.55	20.79	27.00	18.33	15.27
Mean	10.91	12.80	11.24	27.60	27.29	28.37
CD at 5%	0.99	0.41	0.37	1.46	0.84	1.38

100 kg soil for pH 9.1 (ESP=17) and pH 9.4 (ESP=22), respectively and then covered it with polythene sheets for 25–30 days so as to achieve equilibrium conditions. When soil became dry it was mixed thoroughly and used in screen house experiments. Three sets of 18 pots were prepared (6 pots in each set). Out of six pots of a set, two pots used for each pH level; one-well drained till maturity represented pH treatment alone and other pot was subjected to WL, continuous for 8 days (by maintaining 5 cm depth of water at soil surface) at tillering (40–45 DAS), in second set at panicle emergence (70–75 DAS) and at anthesis stage (90–95 DAS) in third set, which represented pH + WL treatment. Well drained pot of pH 7.2 served as control. Ten seeds of wheat genotype-HD 2329 were sown in these sets. Five uniform plants pot were allowed to grow till maturity for yield. Sodium and potassium content were determined from the leaf tissue (in triplicate) with a flame photometer (Analytical Development Co. Ltd. England) using standard KCl for potassium and NaCl for sodium. The values were calculated and expressed as mg per g tissue dry weight. Three plants were sampled after 8 days of WL along with their respective controls for dry weight. Dry weight of plant was taken after drying at 70±1°C for 96 h in oven and expressed as gram per plant. The data collected and statistically analyzed by the method of 'analysis of variance' using factorial completely randomized design (CRD). To compare the treatments, critical difference (CD) at 5% level of significance was used.

Results and discussion

Accumulation of sodium increased by 3.7–4.0 and 6.8–8.7 folds under pH 9.1 and pH 9.4 over control, respectively. Sodium accumulation was not affected by WL at pH 7.2 while at pH 9.1 and 9.4 WL caused further increase in sodium accumulation (5.0–6.1 and 7.6–9.9 times respectively) at all the stages. Maximum increase in sodium was recorded at panicle emergence (4.9 folds) followed by tillering (4.7 folds) and anthesis stage (4.1 folds) (Table 1). WL alone caused an increase in potassium content (18.5–37.8%), whereas at pH 9.1 potassium content decreased by 10.4–14.8% over control while pH 9.4 did not affect potassium accumulation significantly. Interaction of pH 9.1 and 9.4 with WL led to further decreases in potassium content. Ultimately, the ratio of Na^+/K^+ increased in the leaf tissue which was highly correlated with reduction in grain yield at all the three growth stages (r=−0.83, −0.82 and −0.73, respectively) (Fig. 1). A range of evidences is available that suggested that sodium accumulation increased under WL and alkalinity + WL. Moftah and Michel (1987) reported enhanced accumulation of sodium and depletion of potassium by increased ESP of soil in wheat and barley. Varieties tolerant to alkalinity were characterized by lower Na, higher K and lower Na/K ratio in striking contrast to the sensitive genotypes (Sharma 1996; Gupta and Sharma 1990). Increased uptake of sodium and reduced uptake of K appear to be main factors causing higher reduction in plant growth under alkalinity and alkalinity +

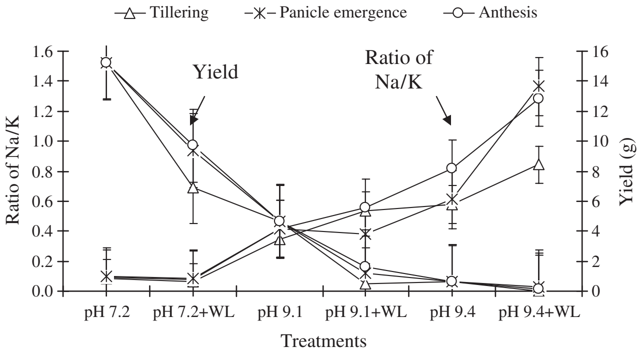

Fig. 1 Effect of different stress treatments on ratio of Na/K and grain yield of wheat variety HD 2329

WL. Disruption of metabolism by WL reduced the uptake of mineral nutrients (Reyer et al. 1977). Key mechanisms identified in *Populas* to mediate salt tolerance are compartmentalization of Cl^- in the vacuoles of the root cortex cells, diminished xylem loading of NaCl, activation of Na^+ extrusion into the soil solution under stress, together with simultaneously avoiding excessive K^+ loss by regulation of depolarisation-activated cation channels. This leads to improved maintenance of the K^+/Na^+ balance, a crucial precondition for survival under salt stress (Chen and Polle 2010). Schachtman and Munns (1992) reported that salt-tolerant *Triticum* species had lower rate of Na^+ accumulation than the salt-sensitive ones. A major physiological effect of WL was reduced uptake and transport of mineral ions by roots (Drew and Sisworo 1979; Slowick et al. 1979; Munns 2007). Similarly, interactive stress of WL and alkalinity caused reduction in ion uptake, especially of N, P, K, Ca, Mg and Zn and led to higher absorption of Na, Fe and Mn (Sharma 2002, 2003; Hauser and Horie 2009). Thus, the injury to wheat plants caused by WL differs in normal and alkali soils; and is marked by higher accumulation of Na, lower K content and reduction in soil redox potential resulting in higher reductions in plant growth in alkali soils.

Increase in pH from 7.2 to 9.1 and 9.4 caused delay in panicle emergence (4 and 8 days over control) and in flowering (1 and 2 days) at tillering and panicle emergence stages. In first set, when WL was imposed at tillering stage (40–45 DAS) in the pH levels—7.2, 9.1 and 9.4, number of days required for complete panicle emergence and flowering at pH 7.2 + WL and 9.1 + WL were increased (3 and 5 days) (4 and 7 days), respectively. While panicle formation did not occur in pH 9.4 + WL in first set. In second set, at panicle emergence stage (70–75 DAS), complete panicle emergence was delayed by 0, 2 and 4 days and flowering by 0, 3 and 4 days due to WL at pH 7.2, 9.1 and 9.4, respectively.

Yield parameters

All the stress treatments reduced grain yield at all the stages. When pH increases from 7.2 to 9.1 and 9.4 grain yield reduced to 69.3 and 95.7%, respectively at all the stages. In first set, WL imposed at tillering stage led to higher reduction in the grain yield under pH 9.1 (96.8%) as compared to 54.7% reduction caused by pH 7.2 + WL, while, at pH 9.4 plants fail to produced panicle. In second set i.e. at panicle emergence stage, WL reduced grain production at pH 7.2 + WL and pH 9.1 + WL to 38.4 and 92.1% as compared to that of control. Maximum reduction of 98% in the grain yield was recorded under pH 9.4+ WL treatments. In third set, hardly any grain was set at pH 9.4 + WL, while, WL reduced grain production to 36.3 and 89.4% production at pH 7.2 + WL and pH 9.1 + WL, respectively. Grain yield was adversely affected at all the stages but maximum sensitivity was recorded at tillering stage (4.7 g) followed by panicle emergence stage (5.2 g) and anthesis (5.3 g) (Fig. 1). It was reported earlier that grain yield was decreased more on flooding in alkali soils than under alkali soil alone, and flooding at flowering than at tillering stage (Gill et al. 1993). Increase in pH from 7.2 to 9.1 and 9.4 caused delay in panicle emergence (4 and 8 days, respectively) and flowering (1 and 2 days, respectively) which results in delayed maturity. Ultimately, this delay in complete panicle emergence, flowering and maturity led to lower grain yield and if WL stress was applied at tillering and panicle emergence stage all above events were further delayed. If WL was applied at anthesis, then early maturity recorded, but this also results in decreased grain yield.

Conclusion

These results manifested that the one reason of WL injury in wheat grown under alkaline soils is higher Na^+/K^+ ratio in leaf tissue and that delayed flowering and panicle emergence which led to late maturity that result to decreased crop yield. Combined effect of alkalinity with WL was cumulative resulting in higher reductions in growth and yield as compared to individual stress. On the basis of these results, it may be suggested that K^+/Na^+ ratio may serve as another criteria for salt tolerance in wheat genotypes. It could be concluded that salt tolerance in wheat is largely determined by their ability to exclude Na^+ from their shoots and their ability to maintain high shoot K^+ concentrations.

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