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GROWTH AND YIELD RESPONSES OF WHEAT TO WATERLOGGING CONDITION UNDER SODIC SOIL: A REVIEW

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Abstract

In this present investigation was carried out in screen house of the rabi season. The experiment was laid out in pots using completely randomized design with four varieties namely NW 1014, HD 2009, PBW 343 and HD 2329 and four waterlogging treatments *viz*., WL_0 (drained control), WL_1 (WL at vegetative stage), WL_2 (WL at boot stage) WL_3 (WL at vegetative + boot stage). 7 kg sodic soil (pH 9.1) was filled in each pot and 10 healthy seeds of each variety were sown in each pot and only 3 plants were maintained after germination. Total number of pots under each variety was divided in four equal groups. The first group was left as drained control. The second group was waterlogged at 30 DAS while the third at 75 DAS. The fourth group was waterlogged at both stages 30 and 75 DAS. The waterlogging treatment was imposed by ponding 5 cm water on the soil surface in pots standard crop management practices were followed to raise the crop. Genotypic variability exists for waterlogging tolerance in wheat varieties evaluated under the present study. NW 1014 gave better performance in survival, plant height, number of tillers, number of leaves, leaf area, biomass, root length, root volume, root dry weight. Poor performance was found in susceptible variety HD2009. Similar response was also recorded in case of yield and yield attributes in both varieties under all the waterlogging treatments. Minerals such as N, P and K content in shoot were also higher in NW 1014 while lowest in HD 2009.

***Keywords*: Wheat, waterlogging and sodic soil.**

Introduction

Wheat (*Triticum aestivum* L.) is one of the oldest and most important cereal crops in India. Wheat plays an important role in total cereal production and global food security. India is the second largest producer of wheat in the world next to China. Wheat is the second most important crop in India after rice and contributes nearly 35% to the national food basket. India will require 109 million tons of wheat to feed the population of 1.25 billion by 2020, which can be achieved by growth rate of 2.2% but the current growth rate is only 1.0%. Wheat cultivation in India occupies 30.42 million-hectare area with the production of 99.87 million tons and productivity of 32.83 q ha^{-1}. Wheat production of India is 99.87 million tons during 2017-18 which is higher by 1.26 million tons than the production of 98.61 million tons achieved during 2016-17. The average wheat productivity of India is 3283 kg ha^{-1}.

Productivity of wheat can only be enhanced by application of scientific tools and techniques in agriculture. About 91% of the Indian wheat is produced in six states- Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan and Bihar. Uttar Pradesh is the highest producer of wheat (25.6 million tonnes) followed by Punjab (14.5 million tonnes) and Haryana (9.1 million tonnes) respectively. In India, 2.2 million ha area is adversely affected by waterlogging due to seepage in canal command areas and an additional 2.5 million ha are affected in unspecified area due to alkalinity and undulating topography. Large areas of waterlogging occur in the irrigated rice-wheat rotation systems used throughout South and South East Asia including Pakistan, India, Bangladesh, Nepal and China. Wheat is experiences waterlogging in these area due to sub soil compaction during puddling for rice planting (Samad *et al.,* 2001).

During waterlogging, the gas exchange between soil and air decrease as gas diffusion in water is decreased 10,000 fold slower that than the air. O_2 in the soil is rapidly depleted and the soil may become hypoxic or anoxic within a few hours. Moreover, some waterlogged soils become rich in Mn^{+2} and Fe^{+2}, devoid of NO_3^- and SO_4^{-2} and anaerobic microbial metabolities may accumulate. These effects become more pronounced during prolonged periods of waterlogging. The effects on wheat of waterlogging in soil, or of exposure to low O_2 concentration in culture solutions, are well documented. Seminal roots cease to grow, whereas adventitious root formation is promoted, but the final lengths of these adventitious roots are restricted (Malik *et al.,* 2001; Mc Donald *et al.,* 2001). Waterlogging tolerance of wheat may

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differ depending upon the stage of growth and other environmental factors. Variable results have been reported for yield loss versus stage of waterlogging. Watson *et al.* (1976) reported larger reduction in grain yield of wheat, barley and oat when 6 weeks of continuous waterlogging started at 2 weeks after sowing in comparison to waterlogging started at 6 weeks or 10-14 weeks after sowing.

Normal effect of waterlogging

Experiments were conducted in petri-dishes with two wheat genotypes; NW 1014 and HD 2329 were studied for responses to individual and combined effects of alkalinity and WL during germination and early seedling growth. WL imposed for four days, both on neutral and alkali soils. Soil redox potential declined during WL and recovered gradually in the subsequent 11 days upon removal of standing water (Sharma *et al.*, 2005b). Sharma *et al.* (2004) worked on waterlogging tolerance of wheat genotypes in neutral and sodic soils. Wheat genotypes were incubated for 0, 1, 2, 4, 6 and 8 days. These treatments were applied at seed germination stage. They observed that redox-potential of the soil progressively reduced with the increase duration of waterlogging *i.e.* 1, 2, 4, 6 and 8 days. Higher reduction values were observed at pH 9.1 than pH 7.8. Lee *et al.* (2004) determined the effect of soil waterlogging on oriental melons.

The soil was waterlogged for 1, 3 and 5 days during the early vegetative and late fruit stages. They found that oxygen concentration in the soil rapidly decreased while the carbon dioxide concentration rapidly increased after waterlogging. Malik *et al.* (2003) worked on two experimental systems (1) Plants in soil waterlogged at 200 mm below the surface (2) A nutrient solution system with only the apical region of a single root exposed to deoxygenated stagnant agar solution with the remainder of the root system in aerated nutrient solution. It aims to investigate aerenchyma formation and function in adventitious roots of wheat, only a part of the root system was exposed to O_2 deficiency. They found that porosity increased two-to-three fold along the entire length of the adventitious roots that grew into the water-saturated zone 200 mm below the soil surface and also increased in roots that grew in the aerobic soil above the water saturated zone. Likewise adventitious roots with only the tips growing into deoxygenated stagnant agar solution developed aerenchyma along the entire main axis. Ram *et al.* (1999) characterized the flood water throughout field survey over 3 years in rainfed lowland and flood water areas of Eastern India and reported that concentration of O_2 ranged between 0.00 to 0.60 mol m^{-3} (0-2.5 times air saturated water at 30^0C), while CO_2 from 0.14 to 1.96 mol m^{-3} (16-220 times air saturated water). The pH varied from 5.6 to 9.7 over locations and year. Irradiance in the water profile decreased depending on the turbidity of flood water which showed large variability over locations and time of measurements.

The relevance of these measurements of flood water is used to explain the differences in submergence tolerance in the same set of lowland rice genotypes at two different locations of Eastern India. Setter *et al.* (1995) suggested that flood water O_2 of submerged or non-submerged plant was low in the morning and increased to about 0.12 mol m^{-3} during the day (air saturated water contains 0.24 mol m^{-3} O_2) while opposite trends occurred for CO_2. Low O_2 in flood water in fields contrasted with measurements at an experiment station where flood water was supersaturated with O_2 at 0.59 mol m^{-3} (equivalent to more than 50% v/v O_2). Major environmental characteristics of wetland rice field are determined by flooding in the presence of rice plants along with other agriculture practices. Flooding creates anaerobic condition few millimeters beneath the soil surface. This leads to the differentiation of six major environments differing by their physical and chemical properties: (a) Flood water (b) Surface oxidized soil (c) Reduced soil.

Germination & Growth

The complexity of the waterlogging-prone environment would lead one to predict that waterlogging tolerance may be difficult to repeat in different soils or environments. Seedling age difference (30, 40d) in response to three submergence duration 3, 7 and 11 days complete submergence was studied in tolerant (FR 13 A and TCA 85) and intolerant. These authors concluded that older seedlings had better capacity of tolerance in term of survival than younger seedlings in all submergence duration. Seedlings submergence for three days had no negative effect on plant growth in both tolerant and intolerant genotypes. Sharma *et al.* (2005 b) studied for responses to individual and combined effects of alkalinity and WL during germination and early seedling growth of wheat genotypes. WL was imposed for four days, both on neutral and alkali soils. It was concluded that germination, fresh and dry weights of seedlings decreased by all the stress treatments. Sharma *et al.* (2005a) observed that waterlogging stagnation for 1, 2, 3, 4 and 6 days significantly reduced plant height, branching, shoot dry weight and root dry matter of pigeon pea.

The above water stagnation was applied at vegetative (35 DAS), flowering (75 DAS) and both vegetative and flowering stages. When 9 soybean cultivars were exposed to partial (50% plant portion) and complete submergence at flowering for 5 and 7 days, respectively. Savita *et al.* (2004) studied the effect of temporary waterlogging on the performance of nine maize genotypes under field condition during monsoon season (June to October). The waterlogging treatment given at knee high stage by keeping 0.05 m continuous submergence for 6 days. They observed reduced plant stand, plant height but increased days taken to 50% tassel and silk emergence, anthesis-silking interval, plant barrenness and mortality. Lee *et al.* (2004) reported that the root viability, leaf net photosynthesis and leaf resistance decreased with increasing duration of waterlogging.

Waterlogging was imposed early vegetative and late fruit stage. Kawano *et al.* (2002) observed that when rice (*Oryza sativa* L.) was submerged for 8 days both tolerant (BKNFR) and intolerant (Mahsuri and IR 42) cultivars showed a decrease in ascorbate concentration during submergence. After 3 days of desubmergence, the tolerant cultivar showed a higher survival, rapid recovery of total ascorbate and reduced ascorbic acid where as intolerant cultivars showed a slow recovery with an increase in malonidialdehyde formation and low survival rate (30%). Rahman *et al.* (2001) reported that the mature plant had reduced survival when submerged in water and exposed to anoxia, suggesting than AOH plays an essential role in seed germination and plant survival in the absence of O_2. Adak and Gupta (2000) reported that the photosynthesis and related leaf characters were adversely affected in rice varieties when subjected to high water stress by submergence. The duration of submergence concomitantly decreased the photosynthetic rate, stomatal conductance, intercellular CO_2 concentration etc. irrespective of varieties as compared to the normal condition.

According to Anderson and Pezeshki (1999) studied three forest species, Bladcypress, Nuttall oak and Swamp chestnut oak under an intermittent flooding and subsequent physiological and growth responses to such conditions were evaluated. They found that Baldcypress showed no significant reduction in stomatal conductance or net photosynthetic rate in response to flood in pulses. However, in Nuttall oak seedlings, stomatal conductance and net photosynthetic rate were significantly decreased during the periods of inundation, but recovered rapidly following drainage. Singh *et al.* (1997) also observed a spectacular decrease in dry weight of a number of lowland rice cultivars during submergence. The age of the seedling at the time of submergence has a marked influence on their survival and productivity. The survival and productivity of rice increased with the age of seedling at the time of submergence. Chaturvedi *et al.* (1995) also reported that in low land rice genotypes, survival during submergence increased with the age of seedling at the time of submergence and decreased with the increase in duration of submergence. They also reported that unlike deep-water rice, lowland cultivars with greater elongation during submergence suffered the most, thus lower elongation in lowland rice is associated with tolerance (Mallik *et al.*, 1995; Singh *et al.*, 1997). Malik *et al.* (2001) conducted a pot trial on wheat cultivars where plants were subjected to waterlogging to the soil surface for 0, 3, 7, 14, 21 or 28 d at 3-weeks old wheat plants and then drained to allow recovery for up to 25 d. During waterlogging, the seminal root system stopped growing. Adventitious roots grew to a maximum length. When waterlogged pots were drained, seminal root mass did not recover to control values. At the end of the experiment, shoot mass remained two-to three folds lower in plants from all waterlogged treatments compared with continuously drained controls, due to lower tiller numbers and shorter final leaf lengths in previously waterlogged plants. They further reported that the growth reduction of wheat after waterlogging stress depends on the depth of water from the soil surface. During waterlogging, the RGR of roots decreased more than that of shoot. Plant growth was reduced proportionally as the water level was increased. Light saturated net photosynthesis was reduced by 70-80% for the two most severe waterlogging treatments. Adventitious root porosity was enhanced up to 10 fold for plant growth in waterlogged soil. Some observed that tolerant wheat genotypes have lower elongation rate as compared to intolerant wheat genotypes when submerged at early vegetative stage for 4 and 7 days, respectively.

He also reported that tolerant wheat genotypes have higher soluble sugar and starch content in shoots before and after submergence (4 and 7 days) compared to intolerant genotypes. Lizaso and Ritchie (1997) conducted a field experiment in which saturated conditions were imposed for 4 or 8 days in early or late vegetative growth of maize. Shoot growth measurements included leaf extension, biomass, leaf area, leaf senescence, stomatal conductance and photosynthesis. Roots were also counted at several soil depths. They found that root zone saturation had a major impact on all aspects of plant growth. Biomass growth was reduced through reduced leaf area expansion, increased leaf senescence and reduced photosynthesis. Phenotypic variation in morphological traits *viz*. plant height, leaf length and number of internodes in twenty low land rice varieties were studied by Awasthi *et al.* (1997).

It was concluded that these morphological traits associated with flood tolerance could serve as important criteria for screening germplasm for suitability for use as lowland rice cultivars. Minimizing elongation growth by growth regulators enhanced submergence tolerance in 14 days old seedling of rice genotypes (Setter and Laureles, 1996). Armstrong *et al.* (1994) also reported that submergence tolerant genotypes have moderate elongation ability and most elongation genotypes showed less tolerance for submergence and has low survival value. Ethylene a powerful inhibitor of elongation in most plant is largely responsible for promoting fast extension under water. Kutschera *et al.* (1993) concluded that rapid coleoptile elongation under water is caused by an inhibition of the formation of phenolic cross linkage between matrix polysaccharides via diferulate, which results in a mechanical stiffening of the cell wall, in the air grown coleoptile. Loaiza and Ramirez (1993) conducted a pot trial with maize cultivars Tunapuy and Agna Blanca, susceptible and tolerant respectively to flooding which were flooded for 6 days. It was found that the reduction in root growth was most marked when waterlogging occurred early in growth.

Assimilate distribution to the root significantly increased under stress in cultivars Agna Blanca. Gill *et al.* (1993) reported that 4, 8 and 12 days of flooding at crown root initiation, flowering and grain filling stage, decreased dry weight of shoot and crown root initiation stages were more sensitive to flooding. The grain filling and flowering was more adversely affected than other stages. Greenway and Setter (1996) reported that adverse effects of flooding on plant growth and survival is multiple and complex. The adverse effects during submergence could be due to mechanical damage, low light, siltation, soil leaching increased susceptibility to pest and diseases and limited gas diffusion. Vartapetian *et al.* (1993) discussed in particular reference to maize, rice and pea plant adaptation to anaerobic environments by avoidance of anaerobiosis in root cells and metabolic adaptation in the absence of oxygen. Growth rate, oxygen uptake, cellulase activity, intracellular pH shifts, porosity and aerenchyma formation in maize roots exposed to flooding were studied by Grinieva and Bragina (1993).

They reported that cellulase activity in adventitious roots started rising from the first days of flooding, reaching a maximum after 6-8 days and also observed the enhanced development of aerenchyma and porosity. Flooding also promoted higher acidity in root tissues and enhanced respiration in adventitious roots and in stem base. Under flooding aerenchymatous adventitious roots are of great physiological importance as growth of main roots are inhibited. The main adaptive responses in maize due to flooding were increased shoot-root dry weight ratio and gas space formation. Gill *et al.* (1992) found that wheat (*Triticum aestivum* L.) was more affected at tillering and flowering stages due to flooding. Slower growth rate under complete submergence condition in tolerant genotypes had also been reported by many workers (Setter *et al.,* 1994; Chaturvedi *et al.,* 1995).

Yield and yield attributes

Sharma *et al.* (2005a) reported that waterlogging stagnation for 1, 2, 3, 4 and 6 days significantly reduced number of pods and grain yield in pigeon pea. The above stagnations were applied at vegetative, flowering and both vegetative and flowering stages. Prasad *et al.* (2004) have found that application of waterlogging 5 days and 8 days at 30 DAS of four maize genotypes, reduced in grain yield under waterlogging condition. The effect of temporary waterlogging on maize genotypes under field condition was studied by Savita *et al.* (2004). The waterlogging treatments given at knee-high stage by keeping 0.05 m continuous submergence for 6 days reduced ear length and grain yield. Condon and Giunta (2003) worked on the commercial variety of wheat namely Bodallin and 2 Bodallin backcross derivatives containing the 'tin' gene in 8 field trials grown on shallow, duplex soils. Waterlogging treatments applied before and after anthesis. They observed that waterlogging reduced the number of fertile spikes of RT lines and Bodallin to the same relative extent and differences in grain spike^{-1} and grain size had little effect on relative yields. Even though harvest index of the RT lines was slightly elevated in some environments, biomass production of the RT lines was low in all environments. A field experiment was conducted to investigate the physiology of waterlogging tolerance and associated physiological disorder of rice cultivars. Two water depths (10±5 and 50±5 cm) were maintained continuously up to the flowering stage of the crop. The tolerant varieties (Bogabordhan, IET 10016, IET 10021 and Kushal showed higher grain filling and grain yield while sensitive varieties (IET 11187, IET 11188 and IET 11910) registered reduced grain filling and grain yield under waterlogged condition (Neog *et al.*, 2002).

Biingchyi *et al.* (1994) conducted the field trials with maize cultivars. Tainung 351 subjected to waterlogging for periods of 3 or 5 days at tasselling stage. They reported that yield reduction varied with stage of treatment, season and duration of waterlogging and was in the range of 12-31%. The yield reduction was mainly due to reduction in grain number ear^{-1}. Plant dry weight and linear growth rate of ears were also reduced. Hosono *et al.* (1997) indicated that the relationship between flooding and yield losses of maize, soybean and upland rice was more closely correlated with flood depth than with flood duration. Singh *et al.* (1997) conducted a field experiment with maize cultivar Pratap by flooding for 5, 10, 20 and 30 days after sowing and recorded the grain yield. The grain yield was lowest (1.58 t ha^{-1}) when the crop was flooded for 10 DAS. The control yields were 3.93 t ha^{-1} and 4.21 t ha^{-1}, respectively. It was concluded that flooding decreased nitrogen uptake. Baruah (1996) worked on 10 rice cultivars in field trials for evaluation of tolerance to continuous waterlogged conditions. Some cultivars, despite showing luxuriant vegetative growth, proved to be susceptible to waterlogged conditions. The susceptible cultivars showed yellowing of leaves while many lower leaves had bronzing effect. There was a significant reduction in yield of these cultivars. Lower chlorophyll contents in the leaves and an accumulation of tissue iron in the roots and shoots brought about the physiological disorder reducing the yield.

Torbert *et al.* (1993) imposed waterlogging stress by applying 0, 4 or 6 inches of water to soils at field capacity (0.33 bar) in different types of soil and observed that yield on such soils decreased by 1% for each day soil water tension was below 0.33 bar. Further studies proved that three stress days decreased yield less than 1% but 7 days increased the loss to about 5%. Saha *et al.* (1993) studied 10 elite varieties of rice for yield and yield attributes transplanted and raised under waterlogged conditions. The yield attributes panicles, spikelets and grains m^{-2} and 1000-grains weight decreased under waterlogged conditions by 48, 52, 70 and 21%, respectively. Poluektor and Vasilinko (1993) determined that water dynamics in a soil plant/ soil air continum stimulated the plant growth and yield with the influence of water deficit and excess. They also showed that alternating waterlogged and drought conditions showed that stimulated and actual yields were similar. Muhammad *et al.* (2004) showed that the interactive effects of soil compaction, salinity and waterlogging on wheat cultivars waterlogging treatments applied at tillering and booting stages for 21 days.

They concluded that waterlogging did not change grain yield significantly due to compaction. Rather waterlogging mitigated the effect of compaction for most of the yield components except number of spike plant^{-1}. Lee *et al.* (2004) observed that the application of soil waterlogging on oriental melons for 1, 3 and 5 days during the early vegetative and late fruits stages. The extension of waterlogging duration at any crop growth stage decreased the number and marketable fruit and soluble solids content.

Conclusion

Plant height increased in all wheat varieties under drained conditions at different growth stages but it decreased under waterlogging treatments as compared to the control. Plant height was more reduced under combined stress followed by vegetative and boot stress. The plant height was reduced maximum in HD 2009 and minimum in NW 1014 with respect of all waterlogging treatments. Number of tillers plant^{-1}, number of leaves plant^{-1}, leaf area plant^{-1} and biomass plant^{-1} in all the wheat varieties decreased due to waterlogging treatments as compared to control. However, maximum number of tillers plant^{-1}, number of leaves plant^{-1}, leaf area plant^{-1} and biomass plant^{-1} were observed in NW 1014 while minimum in HD 2009. The number of tillers plant^{-1}, number of leaves plant^{-1} and leaf area plant^{-1} were slightly decreased after 75 DAS while bio-mass plant^{-1} increased till the maturity. An increase in root length, root volume and root dry weight plant^{-1} until 75 DAS was observed in all the wheat varieties but decreased in waterlogged as compared to the control, While root length was slightly reduced after 75 DAS. Maximum increase in root length, root volume and root dry weight plant^{-1} in NW 1014 followed by PBW 343 and HD 2329, While minimum in HD 2009, pH, EC and soil redox potential decreased in all waterlogging treatments. Plant survival, plant height, number of tillers, number of leaves, leaf area, biomass, root length, root volume and root dry weight plant-1 decreased in comparison to control due to lack of oxygen in waterlogged soil. Mineral N, P, K and Na content in shoot were also reduced in all wheat varieties under waterlogging treatments except sodium (Na). Na content in shoot increased with increasing waterlogging treatments.

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