International Journal of Water Resources and Environmental Sciences 1(4): 113-120, 2012
ISSN XXXX-XXXX

DOI: 10.5829/idosi.ijwres.2012.1.4.11119

A Review: Water Logging Effects on Morphological, Anatomical, Physiological and Biochemical Attributes of Food and Cash Crops

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Abstract: In order to investigate the effects of waterlogging on physiological, anatomical, morphological and biochemical attributes of food and cash crops, we conducted a review of literature i.e. Effects of waterlogging on different attributes of cash and food crops. For this purpose many papers were studied to understand the changing brought about by waterlogging. Saturation of any soil with water is known as waterlogging or flooded soil. Excess of water present in soil do not allows the crops to grow expediently. In such conditions some varieties cannot exist and some becomes tolerant or resistant.Hereby we study some crops and their different features that how they grow under such stresses and what changes they brought in them to survive. It was seen that leaf area ratio, root and shoot growth and photosynthesis rate are reduced by waterlogging in some crops. So these changes are similar among them but in some crops like wheat, cotton,sunflower there are some distinguished changes occur i.e. arenchyma formation, genotypic changes to become resistant or tolerant, electrical conductivity etc. The more burning issue is to study comprehensively energy and cash crops and their resistant varieties to solve the worldwide problem of starvation. For this purpose genotypic changes play important role. We collected reasonable,comprehensive and astonishing data that covers all the aspects mentioned above.

Key words: Waterlogging · *Sorghum bicolor* · Physiological · Photosynthesis · Arenchyma · UOG

INTRODUCTION

When soil is completely saturated with water is in general referred to the water logging. In this situation ground water is too high that it does not allow convenient agricultural activities [1]. Above than one third of the global irrigated regions suffer irregular or more recurrent waterlogging [2]. Waterlogging conditions drastically alter the soil properties, these changes in soil adversely affect the capability of a plant to survive in such situations [3]. Permanentflooding offers a positive water and nutrient availability under anaerobic circumstances. But the conservative system consumes a huge quantity of water [4]. Plants growing under waterlogged conditions affected by numerous stresses for example restrictions to gas insufficiency of mineral nutrients and microelements poisoning [5]. When crop plants are grown in waterlogging conditions, or in anaerobic situations, their shoot and root systems counter differently. A multiple of anatomical and morphological modifications build up in the root system. Lessening in the root respiration rate had been reported in both species i.e. tolerant or intolerant to waterlogging. Roots in anoxic conditions are also depressed suppliers of mineral nutrients for the shoot systems and for themselves as well. Closing of stomata and non-stomatal metabolic changes are liable for the decrease in leaf CO_2 integration. In regulation of maintenance of physiological adaptations mostly plant hormones are involved. Roots of any plant, as a result of waterlogging, undergo hypoxia or anoxia. In flood-tolerant plants, the development of arenchyma and adventitious roots in the surrounding area of cotyledonary nodes is a marker of the existence of adaptive characteristics [6].

Permanent flooding offers a positive water and nutrient availability under anaerobic circumstances. But the conservative system consumes a huge quantity of water [4]. Temporary; transitory waterlogging can also have significant influences on growth and production of dry land crops. The harshness of the upshots of waterlogging depends upon thedevelopmental stage of the plant [7]. The waterlogging effects are most prevalent in the irrigated rice-wheat areas of South and Southeast Asian [8].

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Approximately 10-15 million hectors of the global wheat growing regions are affected by waterlogging every yearrepresenting 15-20% of the 70 million ha annually cultivated for wheat production [5]. The responses of wheat plant to waterlogging limited growth of root, too early senescing of leaves, decline in accumulation of dry matter, wilting, declined tillering, lesser kernel weights and infertile florets and also reduced grain yield [9]. Rice can forbear waterlogging because of its constitutive adaptations which may be physiological, morphological or anatomical for example higher ratio of Aerenchyma i.e. gas filled spaces [10]. In view of the fact that 90 % of the world's rice (throughout the growing period) is cultivated in waterlogged soils [11].

Sweet sorghum which is also known as (*Sorghum bicolor*) is a very towering energy crop as it also produces seeds,so known as food crop as well. The sugar is present in the stem of plant. This plant is utilized to make sugar, syrup and wine as well. Due to the production of bio-fuel this crop is known as energy crop. While the production of sorghum advances the development of agriculture, energy, processing of sugar and averts air pollution.

Of all the painstaking manipulating factors, it is important that agriculture yield is positive in renewable energy project. Mortification by redirecting crops from food to bio-fuel feedstock causing resource competition and malnutrition worldwide. Indigenous plant species which are capable of fast growth and tremendous yield are studied intensively for research purpose i.e. sugar cane (*Saccharum officinarum* L.), switch grass (*Penicum virgatum* L.) [12]. One impending energy crop is (*Sorghum bicolor* L.) in tallying rotation of food crop with energy crop is the best solution to lower the worldwide energy and food crisis with less disease and competition. Most of the crops grown in summer are expected to suffer long term waterlogging due to heavy rains. Waterlogging has particularly profound effect on the crops. Shattering of capillary pores, trimming down void ratio, devastation of soil aggregates and heading off clay particles etc. are caused by waterlogging in sorghum. Therefore information related to sorghum effected by waterlogging is important because it is energy as well as food crop. Growth and physiological aspects in sorghum are hit by waterlogging and is injurious to it.

We attempted here to review the morphological, anatomical and physiological and biochemical responses of important crop plants as a consequence of waterlogging. We discussed here food crops and cash crops i.e. wheat, rice, sorghum, sunflower, cotton, maize etc. Review also emphasizes on tolerant and in tolerant behaviors and certain modifications plants develop under waterlogging conditions. The overall study describes how plants generally suffer internally as well as externally under waterlogged conditions.

Alteration in Soil Chemical Composition Due to Waterlogging Is the Initial Influence: Decline in yield carried out by waterlogging probably caused by plentiful aspects acting upon the crop plants, for example variation in chemistry of soil. Waterlogging grounds of changes in soil i.e. chemical and biological changes [13]. It also perturb physiological chattels by changing water and nutrient uptake, preventing shoot and root growth [14, 15]. For example, denitrification of soil nitrogen as a consequence of flooding may have an effect on the quantity of nitrogen that accumulates in the higher leaves of the plants, which will ultimately have a harmful effect on grain production [16]. Declined soil oxygen level usually greater at higher temperatures [17]. Denitrification of both organic and inorganic soil N [18]. Volatile or unstable fatty acids and phenol compounds concentrated in soils high in organic matter effect metabolism and growth of root [19]. Mineral (Fe) covering of epidermal surface of roots during waterlogging is also reported by Ding and Musgrave [20]. Sparrow and Uren [21] told that amplified Mn accumulation that can be poisonous to plant development.

Attributes Effected by Waterlogging:

Morphological: The most unpleasant consequence of the water logging is hypoxia i.e. shortage of oxygen or anoxia i.e. total lack of oxygen in the soil medium which causes the reduced growth, inhibits the metabolic processes and finally reduces the yield of the wheat [22]. When waterlogging is functional for the duration of seed sowing or on sprout stage it causes the fatality of seedling and no further growth take place. Because seeds or seedling root or radicle is not adapted to waterlogging at once and it is most vulnerable to certain diseases caused by flooding of water [17]. Mostly the forbearance of wheat plant enhances as it grows older and adverse effect is that production reduces [8].

The growth of seedlings of sorghum is also effected by short-range waterlogging is pointed by high death rate of seedlings, decline in NAR, LAR, RGR. Lower nitrogen concentration in main stem of wheat plant results in minimized yield of tiller and adversely affect RGR[23]. The ultimate lengths of adventitious roots are restricted [10]. Eventually, mutually root and shoot dry weight is decreased [24]. Leaf lengthening rates and total size of leaf become decreased [25]. Under water logged condition the transpiration rate is also affected unless wheat roots regain their normal activity i.e. when aerobic conditions return or adjust to the anaerobic environment. However, prolonged water logging will result in death of the root. Water logging also restricts the wheat plant's uptake of nutrients by reducing transpiration and restricting root function [26]. Water logging highly reduces plants height in sorghum. These effects may be unpleasant with increase in extent [27]. Water logging prevents growth of sorghum and causes permanent injury. The degree of inclination differs from specie to specie [28]. Water logging prevents shoot growth; dry matter accretion and final acquiesce. Water logging significally reduces nodulated roots as well as longest root length and ensuing root [29]. Water logging causes leaf peeling,flaccidity, reduced nodulation and leaf epinasty [30]. The only crop rice have ability to germinates under conditions of limited or lacking oxygen so, it acts as a representative plant for proper adaptation to anoxia (absence of oxygen) [31]. These adaptations take in coleoptile lengthening, when these are exposed to hypoxic state they develop thick adventitious roots, the number of adventitious roots also increased, in well oxygenated flooded conditions growth of surface roots increased, enhanced leaf area and reduced relative root length and shoot length. Though, the rice plants grown in hypoxic conditions by constant exclusion with nitrogen, it was observed in them that there were no alterations in hypoxic circumstances but there was a decrease in root dry weight in accordance to shortening and enhanced branching of roots [32]. A major developmental feature of rice is an improved rate of rising extension, allowing coleoptiles and shoots to raise contact to oxygen, light and carbon dioxide [33]. This takes place in the pressure of ethylene, jointly with an accumulation of carbon dioxide and partial availability, but not an entirety deficiency of, oxygen [34]. Water logging decreases the yield rate in maize. The other changes brought about by water logging in maize are reduction in leaf growth root growth [35].

Anatomical: Flooding stimulates alterations in roots and shoots of wheat. In roots, the emergence of adventitious roots is noticed as a general response of tolerant species. These adventitious roots possess have greater porosity, help plants to resume with water and nutrient uptake during water logged conditions [36]. Ethylene and auxin interaction is vital for the stimulation of adventitious root development [37].While seminal roots fail to develop further [24]. Some genotypes of wheat possess nodal and adventitious roots that initiate arenchyma formation in wheat. Arenchyma are gas filled channels that carryout transportation of oxygen from leaves to roots under the limited supply of oxygen during water logging condition to carryout root respiration. The formation of arenchyma occurs when the temperature is high or elevated to certain degrees [38]. Water logging also causes shrinkage of metaxylem and protoxylem vessels of the nodal roots of wheat [39]. In sorghum root, cortex and stalk is formed [15]. As well as there is also formation of adventitious roots occurs in sorghum due to water logging. [40, 41]. All this is accepted to crop up due to adaptive retort to water logging stress and is found to be very slammed to the growth of plant shoot and capitulate [41]. The same response i.e. response of shoot, root and capitulate to water logging conditions are shown by grain sorghum as well [42, 43]. The arenchyma in sorghum are recognized by the lysigeneousarenchyma (The gas spaces which occur due to the bursting of cell wall). Arenchyma formation is a natural characteristic in rice. It serves as a model plant plants to study the formation of uneven lysigenicaerenchyma amongst the monocot. These are formed as a product of break downing of cortical cells. The existence of arenchyma in the roots of rice has been accounted to be consequence of genetic control. So, the arenchyma always found in roots of rice, apart from environmental situations [44]. Apart from being a constitutive feature, arenchyma formation has been found to enhane in hypoxic conditions [45]. Conversely, some studies point out that no considerable increase in the percentage of arenchyma with little oxygen root region aeration treatment occurs [44]. Consequently an enhancement in the ratio of arenchyma is reliant on the rice cultivar and the growth period of the plant [46]. In spite of this, the development of air spaces or pore spaces is not limited to the roots only in rice. The cortical arenchyma extends up roots and in the shoots that is in leaves and tillers and maintain well-organized bidirectional transportation of gases between the roots and the aerial parts, both from the atmosphere and from the oxygen produced by photosynthesis as soon as the shoots are flooded, with a few level of resistance among the root-soil, root-shoot and shoot-atmosphere gas transport [46]. The matter of tillers at the root-shoot transition zone is a chief blockage for smooth inner airing [47].

Physiological: In anoxia condition, oxidative phosphorylation of mitochondria is stopped; cells unavoidably suffer anaerobic fermentation, thus substituting Krebs cycle in satisfying the demand for ATP in cells [48]. Throughout alcoholic fermentation, for the glycolysis progression to prolong ADH is accountable for the reprocessing of NAD^+ required [49]. The stimulation for the formation of ADH that goes together with ethanol manufacture has been considered in the course of distinguishes flood-intolerant and tolerant plants [50]. Elevated levels of ADH activity and ethanol assembly all through anaerobiosis have been accounted for flood-tolerant flora [51]. The activity of ADH was absolutely linked with the scale of flood damage in various genotypes [52] and as compared to tolerant species the other varieties were less tolerant to flooding that had high ethanol production [53].

It has been anticipated that the concentrated ethanol may have a "self-poisoning role" in flood-intolerant plants. On the other hand, other studies did not hold up to this idea [54]. Davies [48] proposed a pH stat theory to clarify the short-term water logging tolerance of some plants in which ethanol relatively than lactate is not as much of weakening end product of fermentation. A buildup of lactate encourages acidification of the cytoplasm of anoxia(absence of O_2) intolerant plants, for example maize, barley and wheat. The pH stat hypothesis is also supported by the inspection of alkalinity of the cytoplasm in "pH opposing" plants, that is rice [55].

In eliminated roots of *Oryza sativa* L. and *Cucurbitapepo* L., the reliability of mitochondria was found to be extremely reliant on oxygen accessibility [31]. In wheat chief reaction of the root to the water logging condition is the decrease of respiration, no matter whether the plant is tolerant or not [56]. A greatest oxygen utilization rate in root tips is linked with respiration, which is required for linked metabolic actions, for example formation of ATP. Under waterlogged conditions, plant roots are in a condition of hypoxia (shortage of oxygen) their metabolic activity wassuppressed and ATP production decreased [49]. The decreased ATP production restricts the supply of energy for root growth, thus reducing vegetative growth.Under hypoxia conditions reduction in normal photosynthetic rate occur which mainly due to reduced stomatal aperture. In this case reduction in chlorophyll content and leaf senescence occur and shrinking of leaves may also complete inhibition of photosynthesis. [57]. Lower nitrogen amount causes loss of chlorophyll content and early senescence of leaves. This loss in chlorophyll content ultimately leads to the reduction in photosynthetic rate. Photosynthesis inhibition initiates many days before the chlorophyll content declined [21]. Nitrogen concentrations in leaves, stems and seminal roots decrease with increasing water logging conditions. But nitrogen concentration increases in adventitious roots [25]. The greater amount of N in adventitious roots as compared to seminal roots is due to upholding of the capability for nutrient uptake in the arenchyma possessing adventitious roots [58].

Reduced photosynthetic rate and leaf gas exchange are the characteristic features of water logging in sorghum as well. Increase in intensity occurs with increase in duration of water logging [27]. Sorghum species are severely susceptible to water logging specially germinating seeds. i.e. the seedlings do not possess enough of the oxygen due to water logging [42]. Due to insufficient oxygen respiration and electron transport chain are inhibited, thus the rate of production of ATP reduces in sorghum as well. Membrane permeability in sorghum increases when the rate of production of ATP becomes reduce due to the absence of oxygen.Nutrient uptake photosynthesis rate is also reduces in maize plants [35]. The changes brought about by water logging in cotton includes reduction of stomatal conduction, leaf potential and the rate of photosynthesis [59]. Water logging can also hasten leaf and root senescence. In cottonwater logging also amends the accessible nutrients through various means [43].

Biochemical: Hormones regulation is depend upon an increase of the amount of ethylene, which cooperate with gibberellins and auxins[60]. Auxins and gibberellins are fundamentals for ethylene activity and play activating rather than regulatory roles. Gas flow into the plant is obstructed and lead to little oxygen partial pressure.

This low partial pressure initiate's synthesis of ethylene by rising 1-aminocyclopropane-1-carboxylic acid (ACC) synthase activity so further increasing the amount of ethylene in stem [61]. The effect of water logging is to arouse the production of definite plant hormones in wheat. During anaerobic conditions these hormones are released out from the roots in larger amount and most likely affect responses of root and leaf. Roots and microorganisms present waterlogged soils usually produce ethylene. The hormonal activity of ethylene released during water logging is of great interest. Water acts as a blockade to the ethylene which is produced in roots and other tissues and water also prevent it from escaping. Ethylene is known to be a non-promoter or trigger of senescence of leaf [26]. In sorghum Senescence is delayed by Endogenous cytokinins and promote protein synthesis to advance plant establishment i.e. *Sorghum bicolor* L. [30].

Amongst the biochemical variations experiential in plants under water logging, an elevated level of fermentative metabolism in roots has been revealed to be significant for plant continued existence for the reason that it provides a high adequate energy that can maintain metabolism in roots [44]. Thus, keeping enough levels of fermentable sugars in roots is undeniably vital for long-standing survival of plants throughout water logging conditions. A number of studies demonstrated that the starch levels in whole roots of rice and alfalfa did not considerably diverge under enlarged durations of water logging, telling that starch of root is not freely activate and transformed to substrates which is fermentable [62].

Perata *et al*., [63] described that germinating seeds of rice could degrade accumulated starch under anoxia, while seeds of wheat did not sprout and were not capable to degrade the starch. These separate behaviors are because of the successful introduction of á-amylase in anoxia in rice seeds however not in wheat seeds. Accumulated starch in roots is believed to be simply assembled all through flooding and supply sugars for anaerobic metabolism in roots.Under water logged conditions accumulation of Total non-structural Carbohydrates (TNC) had been well studied in wheat [64]. During flooding TNC accumulated in all parts of plants [21]. Accretion of starch has been found in leaves of a variety of waterlogged plants, e.g., *H. annuus*. During root hypoxia, accumulation of starch in the leaves has been credited to a declined rate of shifting of carbohydrates from leaves to roots [53] and to delayed growth and a lesser level of metabolism of roots, which in fact causes the carbohydrate requirement to reduce [65].

Under water logging, the composition and amount of amino acids, proteins and the activities of associated enzymes are essential. Glutamine synthetase and nitrate reductase, the two important enzymes for ammonia assimilation and nitrate reduction effect the entire nitrogen balance, are severely influence by water logging [66]. Lambers [56] proposed that the performance of nitrate reductase in roots of water logging tolerant plants improved swiftly during water logging so as a consequence amino acid synthesis ability also enhanced.

Tolerant varieties: Rice (*Oryza sativa*L.), distinct from other cereals, can cultivate well in paddy lands and is extremely tolerant to overindulgence of water, from either submergence or water logging. Rice tolerates submergence by internal airing and development power [67].

Sweet sorghum (*Sorghum bicolor* L.) is the resistant variety of sorghum which tolerates the destructions of water logging. Underwater logging the aptitude to continue the production of sorghum is indispensable. The appraisal of the effects of water logging on capitulate parameters and plant growth is the imperative feature to select the most suitable location for every variety of sweet sorghum. Water logging is the reason of string of physiological, chemical and biological amends in soil [13]. It also comprise of hinders root and shoot growth, changing water and nutrient uptake and the changing of physiological possessions. The unsympathetic effects of water logging on plant growth and succumb mostly depends on a species or genotype of sweet sorghum [42]. When the wheat crop is established and maintained many genotypes of wheat can tolerate the water logging up to 10 days maintaining the standard yield under water logging conditions. If wheat crop is treated with extra nitrogen it can make a splendid recovery against the early water logging stress [26]. Susceptible genotype: *Triticumaestivumcvs. Gamenya and Kite*; Tolerant genotype: *Triticosecale cv. Muir* [68].

CONCLUSION

Consequences of waterlogging impart adverse changes in different characteristics of crop plants. Some varieties however are resistant to waterlogging but susceptible varieties undergo vast range of damages. A major portion of country's economy base upon cash crops, waterlogging can decline the overall yield of crops ultimately leading to financial loss. Our study can be used as the basic tool for analyzing the physiological, morphological and anatomical and biochemical attributes of plants under waterlogging. Rice grows well in waterlogged soils because it exhibits some constitutive internal features which make it resistant to waterlogging. On the other hand wheat, sorghum, maize, cotton and other plants do not show efficient growth under waterlogging; however some resistant varieties have ability to grow in such a condition, because they develop certain type of modifications which help them to adapt waterlogging conditions.

REFERENCES

1. Sharma, D.P. and A. Swarup, 1988. Effect of short term water logging on growth, yield and mineral composition of wheat in sodic soils under field condition. Plant and Soil, 107: 137-143.
2. Donmann, W.W. and C.E. Houston, 1967. Drainage related to irrigation management. In: Drainage of Agricultural Lands.
3. Dat, J., N. Capelli, H. Folzer, P. Borgead and P.M. Bado, 2004. Sensing and signaling during plant flooding. Plant physiology and biochemistry, 42: 273-282.
4. Nguyen, H.T., K.S. Fischer and S. Fukai, 2009. Physiological responses to various water saving systems in rice. Field Crops Research, 112, 2(3): 189-198.
5. Settler, T.L. and I. Waters, 2003. Reviews of prospects forgermplasm improvement for water logging toleranceinwheat, barley and oats. Plant Soil, 253: 1- 34.
6. Kawase, M., 1981. Anatomical and morphological adaptation of plants to water logging. Hort Sci., 16: 30-34.
7. Leyshon, A.J. and R.W. Sheard, 1974. Influence of short-term ?ooding on the growth and plant nutrient composition of barley. Canadian Journal of Soil Science, 54: 463-473.
8. Meyer, U.S. and H.D. Barrs, 1988. Response of wheat to single short-term water loggingduring and after stem elongation. Australian Journal of Agricultural Research, 39: 11-20.
9. Cannell, R.Q., R.K. Belford, K. Gales, C.W. Dennis and R.D. Prew, 1980. Effects ofwater logging at different stages of development on the growth and yield of winter wheat. J. Sci. Food Agric., 31: 117-132.
10. Armstrong, W., 1979. Aeration in higher plants. Advances in Botanical Research, 7: 226-332.
11. Vlamis, J. and A.R. Davis, 1944. Effects of oxygen tension on certain physiological responses of rice, barley and tomato. Plant Physio., pp: 19-33.
12. Schmer, M.R., K.P. Vogel, R.B. Mitchell and R.K. Perrin, 2008. Net energy of cellulosic ethanol from switchgrass. PNAS, 105(2): 464-469.
13. Zaidi, P.H., S. Rafique and N.N. Singh, 2003. Response of maize (Zea mays L.) genotypes to excess moisture stress: morpho-physiological effects and basis of tolerance. Eur. J. Agron., 19: 383-399.
14. Liao, C.T. and C.H. Lin, 1995. Effect of flood stress on morphologyandaerobic metabolism of Momordicacharantia. Environ. Exp. Bot., 35: 105-113.
15. Pang, J., M. Zhou, N. Mendham and S. Shabala, 2004. Growth and physiological responses of six barley genotypes to water logging and subsequent recovery. Aust.J.Agr. Res., 55: 895-906.
16. Samad, A., C.A. Meisner, M. Saifuzzaman and M. van Ginkel, 2001. Water loggingtolerance. In: Reynolds MP, Ortiz -Monasterio J. I., McNab A. (eds) Application of Physiology in wheat breeding. CIMMYT, Mexico, pp: 136-144.
17. Belford, R.K., R.Q. Cannell and R.J. Thomson, 1985. Effect of single and multiple water logging on the growth and yield of winter wheat on a clay soil. Journal of the Science of Food and Agriculture, 36: 142-156.
18. Feigenbaum, S., N.G. Seligman and R.W. Benjamin, 1984. Fate of nitrogen-15 appliedto spring wheat grown for three consecutiveyears in a semiarid region. Soil Science Society of America Journal, 48: 838-843.
19. Lynch, J.M., 1978. Production and phytotoxicityof acetic acid in anaerobic soils containingplant residues. Soil Biol. Biochem., 10: 131-135.
20. Ding, N. and M.E. Musgrave, 1995. Relationship between mineral coating on roots and yieldperformance of wheat under water loggingstress. Journal of Experimental Botany, 46: 939-945.
21. Sparrow, L.A. and N.C. Uren, 1987. The role of manganese toxicity in crop yellowing onseasonally waterlogged and strongly acidic soils in northeastern Victoria. Australian Journal of Experimental Agriculture, 27: 303-307.
22. Hossain, A. and S.N. Uddin, 2011. Mechanisms of water logging tolerance in wheat: Morphological and metabolic adaptations under hypoxia or anoxia. Australian journal of crop sciences, 5(9): 1094-1101.
23. Malik, A.I., T.D. Colmer, H. Lambers and M. Schortemeyer, 2001. Changes in physiological and morphological traits of roots and shoots of wheat in response to different depths of water logging. Australian Journal of Plant Physiology, 28: 1121-1131.

24. Trought, M.C.T. and M.C. Drew, 1980. The development of water logging damage in wheat seedlings (TriticumaestivumL.) Shoot and root growth in relation to the changes in the concentrations of dissolved gases and solutes in the soil solution. Plant and Soil, 54: 77-94.
25. Malik, A.I., T.D. Colmer, H. Lambers, T.L. Setter and M. Schortemeyer, 2001. Short-term water logging has long-term effects on the growth and physiology of wheat. Phytologist.
26. Dong, J.G., Z.W. Yu and S.W. Yu, 1983. Effect of increased ethylene production duringdifferent periods on the resistance of wheat plants to water logging. Acta.Phyto.physiologiaSinica, 9: 383-389.
27. Promkhambut, A., A. Younger, A. Polthanee and C. Akkasaeng, 2010. Morphological and physiological responses of sorghum (Sorghum bicolor L. Moench) to water logging. Asian J Plant Sci., 9: 183-193.
28. Clifford, A. and H.L. Henson, 1957. Some effects of temporary flooding on coniferous trees, J. Forest, 55: 647-650.
29. Bhan, S., 1977. Effect of water logging resistance. India J. Agric. Res, 11: 147-150.
30. Bughwat, K.K., G.R. Sandhya and B. Gyatri, 1986. Water logging injury in sorghum seedlings and their kinetin effected rapid recovery. Plant growth regulation, 1: 23-31.
31. Vartapetian, B.B., I.N. Andreevaand and N. Nuritdinov, 1978. Plant cells under oxygen stress. Plant Life in Anaerobic Environments, Biolgia. Plantarum, 2: 13-88.
32. Jayahar, R.P., 2012. Physiological and Anatomical Implications of Salinity on Rice as a Semi-Acquatic Species. Cambridge Scholars Publishing, pp: 1-5.
33. Jackson, M.B. and D.M.E. Pearce, 1991. Hormones and morphological adaptation to aeration stress in rice. Plant Life under Oxygen Deprivation. Publ., Hague, Netherlands, pp: 47-67.
34. Jackson, M.B., R.W. Brailsford and M.A. Else, 1993. Hormones and plant adaptation to poor aeration: A review. In: Adaptation of Food Crops to Temperature and Water Stress Publ., Taipei, Taiwan: pp: 231-243.
35. Jensen, C.R., L.H. Stolzy and J. Letey, 1967. Tracer studies of oxygen diffusion through roots ofbarley, corn and rice. Soil Sci., 103: 23.
36. Kozlowski, T.T. and S.G. Pallardy, 1984. Effects of flooding on water, carbohydrate and mineral relations. In Flooding and plant growth. T.T. Kozlowski (ed). Academic Press Inc., Orlando, Florida, pp: 165-193.
37. McNamara, S.T. and C. A. Mitchell, 1989. Differential flood stress resistance of two tomato genotypes. J. Am. Soc. Hort. Sci., 105: 751-755.
38. Cao, Y., S.B. Cai, Z.S. Wu, W. Zhu, X.W. Fang and E. H. Xion, 1995. Studies on genetic features of water logging tolerance in wheat. Jiangsu Journal of Agricultural Sciences, 11: 11-15.
39. Huang, B.R., J.W. Johnson, S. Nesmith and D.C. Bridges, 1994. Growth, physiological and anatomical responses of two wheat genotypes to water logging and nutrient supply. Journal of Experimental Botany, 45(271): 193-202.
40. Pardales, J.R., Y. Kono and A. Yamauchi, 1991. Response of the different root system components of sorghum to incidence of water logging. Environ Exp. Bot., 31: 107-115.
41. Zaidi, P.H., S. Rafique, P.K. Rai, N.N. Singh and G. Srinivasan, 2004. Tolerance to excess moisture in maize (Zea mays L.): Susceptible crop stages and identification of tolerant genotypes. Field Crop Res., 90: 189-202.
42. Orchard, P.W. and R.S. Jessop, 1984. The response of sorghum and sunflower to short term water logging. Effects of stage of development and duration of water logging on growth and yield. Plant soil, 81: 119-132.
43. Orchard, P.W. and R.S. Jessop, 1985. The response of sorghum and sunflower to short term water logging. II. Root growth effects. Plant Soil, 88: 421-430.
44. Jackson, M.B. and M.C. Drew, 1984. Effects of flooding on growth and metabolism of herbaceous plants. In: Flooding and Plant Growth, pp: 47-128.
45. Armstrong, W., 1971. Radial oxygen losses from intact rice roots as affected by distance from the apex, respiration and water logging. Physiologia Plantarum, 25: 192-197.
46. Butterbach-Bahl, K., C. Li, J. Aber, F. Stange and H. Papen, 2000. A process oriented model of N_2O and NO emissions from forest soils: 1, Model development. J. Geophys. Res., 105: 4369-4384.
47. De Groot, N.S., I. Pallares, F.X. Aviles, J. Vendrell and S. Ventura, 2005. Prediction of "hot spots" of aggregation in disease-linked polypeptides. BMC Structural Biology, 5: 18.

48. Davies, D.D., 1980. Anaerobic metabolism and the production of organic acids. In: The Biochemistry of Plants, Vol. 2. Academic Press, NY, U.S.A., pp: 581-611.
49. Saglio, P.H., P. Raymond and A. Pradet, 1980. Metabolic activity and energy charge of excised maize root tips under anoxia. Plant Physiol., 66: 1053-1057.
50. Crawford, R.M.M., 1967. Alcohol dehydrogenase activity in relation to flooding tolerance in roots. J. Exp. Bot., 18: 458-464.
51. Avadhani, P.N., H. Greenway, R. Lefroy and L. Prior, 1978. Alcoholic fermentation and malate metabolism in rice germinating at low oxygen concentrations. Aust. J. P1ant Physiol., 5: 15-25.
52. Francis, C.M., A.C. Devitt and P. Seele, 1974. Influence of flooding on the alcohol dehydrogenase activity of roots of Tifoliumsubterraneum L. Aust. J. Plant Physiol., 1: 9-13.
53. Barta, A.L., 1984. Ethanol synthesis and loss from flooded roots of Medicagosativa L. and Lotus cotniculatus L. Plant Cell Environ., 7: 187-191.
54. Jackson, M. B., B. Herman and A. Goodenough, 1982. An examination of the importance of ethanol in causing injury to flooded plants. Plant CellEnviron., 5: 163-172.
55. Menegus, F., L. Cattaruzza, A. Chersi and G. Fronza, 1989. Differences in the anaerobic lactate succinate production and in the changes of cell sap pH for plants with high and low resistance to anoxia. Plant Physiol., 90: 29-32.
56. Lambers, H., 1976. Respiration and NADH-oxidation of the roots of flood-tolerant and flood-intolerant Senecia species as affected by anaerobiosis. Physiol. Plant., 37: 117-122.
57. Haung, B., J.W. Johnson and D.S. Nesmith, 1997. Responses to root zone CO_2enrichment and hypoxia of wheat genotypes differing in water logging tolerance. Crop Science, 37: 464-468.
58. Drew, M.C. and L.R. Saker, 1986. Ion transport to the xylem in aerenchymatous roots of Zea mays L. Journal of Experimental Botany, 37: 22-33.
59. Meyer, W.S., H.D. Barrs, A.R. Mosier and N.L. Schaefer, 1987. Response of maize to three short term periods of water logging at high and low nitrogen levels on undistributed and repacked soil, Irrigation soil, 4: 257-272.
60. Cookson, C. and D.J. Osborne, 1978. The stimulation of cell extension by ethylene and auxin in aquatic plants. Planta, 144: 39-47.
61. Pearce, D.M.E., K.C. Hall and M.B. Jackson, 1992. The effects of oxygen, carbon dioxide and ethylene on ethylene biosynthesis in relation to shoot extension of rice (Oryza sativa) and barnyard grass (Echinochloaoryzoides). Ann. Bot., 69: 441-447.
62. Barta, A.L., 1988. Response of field grown alfalfa to root water-logging and shoot removal. I. Plant injury and carbohydrate and mineral content of roots. Agron. J., 88: 889-892.
63. Perata, P., J. Pozueta-Romero, T. Akazawa and J. Yamaguchi, 1992. Effect of anoxia on starch breakdown in rice and wheat seeds. Planta, 188: 611-618.
64. Barrett-Lennard, E.G., P.D. Leighton, F. Buwalda, J. Gibbs, W. Armstrong, C.J. Thomson and H. Greenway, 1988. Effects of growing wheat in hypoxic nutrient solutions and of subsequent transfer to aerated solutions. I. Growth and carbohydrate status of shoots and roots. Australian Journal of Plant Physiology, 15: 585-598.
65. Wample, R.L. and R.W. Davis, 1983. Effect of flooding on starch accumulation in chloroplasts of sunflower (Helianthus annuus L.). Plant Physiol., 73: 195-198.
66. Buwalda, F., E.G. Barrett-Lennard, H. Greenway and B.A. Davies, 1988. Effects of growing wheat in hypoxic nutrient solutions and of subsequent transfer to aerated solutions. II. Concentrations and uptake of nutrients and sodium in shoots and roots. Aust. J. Plant Physiol., 15: 599-612.
67. Shunsaku, N., T. Yamauchi, H. Takahashi, L. Kotula and M. Nakazono, 2012. Rice, 5: 2doi: 10.1186/1939-8433-5-2.
68. Thomson, C.J., T.D. Colmer, E.L.J. Watkin and H. Greenway, 1992. Tolerance of wheat (Triticumaestivumcvs.Gamenyaand Kite) and triticale (Triticosecalecv. *Muir*) to water logging. Phytol., 120: 335-344.