WATERLOGGED SOILS: CAUSES, CHALLENGES AND MANAGEMENT STRATEGIES

Abstract

Waterlogged soils pose significant challenges to agricultural productivity and environmental sustainability. This abstract provides an overview of the causes, challenges, and management strategies associated with waterlogged soils. Waterlogging occurs when the soil becomes saturated with water, leading to poor aeration and impeded drainage. Several factors contribute to waterlogging, including heavy rainfall, high water table levels, poor soil structure, and inadequate drainage systems. Climate change exacerbates these conditions, making waterlogging a pressing issue in many regions. The challenges posed by waterlogged soils are multifaceted. Oxygen deficiency in waterlogged soil hinders root respiration and nutrient uptake, leading to reduced crop yields. Additionally, anoxic conditions promote the growth of anaerobic bacteria, which produce harmful substances like methane and hydrogen sulfide. These gases can contribute to greenhouse gas emissions and negatively impact soil health. To manage waterlogged soils effectively, a combination of preventive and remedial strategies is necessary. Prevention involves improving soil drainage through proper land leveling, constructing drainage systems, and implementing controlled irrigation practices. Additionally, maintaining good soil structure through proper organic matter and nutrient management can enhance soil drainage capacity. Remedial strategies focus on reducing the immediate effects of waterlogging. These include using soil amendments to enhance soil aeration and drainage, such as applying gypsum to improve soil structure or incorporating organic materials to increase microbial activity. Crop selection is also crucial, as certain plant species exhibit better

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waterlogging tolerance than others. Addressing the challenges posed by waterlogged soils is crucial for achieving sustainable agriculture and conservation of environment. By understanding the causes and implementing appropriate management strategies, we can focus towards ensuring food security, minimizing environmental impact, and promoting the resilience of agricultural systems in waterlogged areas.

Keywords: Drainage, Flood, Greenhouse gases, Soil, Waterlogging

I. INTRODUCTION

Waterlogging is simply the temporary or permanent soaking of soil with water. When there is an excess of water in a region, the soil is unable to absorb it as it should.

Waterlogging due to rain or floods has long been a natural occurrence that has resulted in the largest loss of human life and economic devastation around the planet. In the case of over-irrigation, waterlogging occurs when the water table rises to the root zone; repeated incorrect irrigation creates a shallow impermeable layer that prevents water from infiltrating down.

Waterlogging limits plant development and output under anaerobic circumstances, causing certain crops and plants to die (Najeeb *et al.* 2015). Furthermore, as a result of the excess water in the soil profile, plant roots become weak and die or fall (Pan *et al.* 2021).

Thus,management of excess water either due to rain or over-irrigation in agriculture is a major challenge globally as well as in India, where approximately 11.6 million ha area is under waterlogged condition. Waterlogging or severe soil drainage restrictions impact an estimated 10-12% of agricultural land worldwide (Shabala 2011). Many forecasts indicate that flood risk for many river basins will grow significantly in the twenty-first century, owing not only to climate change but also to industrial expansion and land use changes (O'Donnell *et al.* 2020; Tariq *et al.* 2021). Waterlogging inhibits gaseous exchange with the atmosphere, and biological activity uses up available oxygen in the soil air and water – also called anaerobiosis, anoxia or oxygen deficiency. Such conditions have a number of effects on agricultural plants, *e.g.,* toxicities or nutrition deficits and slow root death. In the winter, these conditions can cause deeper roots to die, resulting in spring dryness and early senescence of annual crops.

Most field crops, such as wheat, rice, maize, and barley, are affected by waterlogging conditions. Waterlogging during the seedling, flowering, and grain filling phases of wheat reduced grain yield by 50-70% due to poor seed development and fewer spikes per unit area (Misra *et al.* 1992; Ding *et al.* 2020).

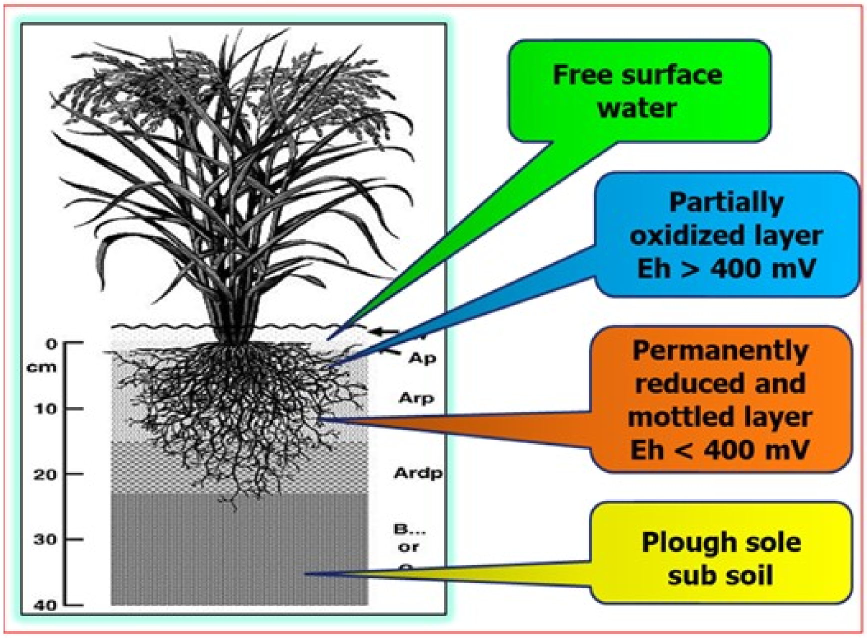

Figure 1: Different Layers under Waterlogged Soils

Water logging in maize reduces output in tropical and subtropical areas. Waterlogging affects 15% of South-East Asia's maize-growing regions, resulting in annual output losses ranging from 25-70% (Rathore *et al.* 2000; Tian *et al.* 2019). It promotes chlorophyll, protein, and RNA degradation in barley, as well as decreases in the concentrations of nutrients such as nitrogen, phosphorus, metal ions, and minerals in the shoot. After the commencement of flood leaf chlorosis (Wang *et al.* 1996; Buchanan *et al.* 2003), root and shoot development was also impaired, resulting in a drop in dry matter accumulation and, ultimately, yield (Malik *et al.* 2002). Based on plant damage, an average yield loss of 20-25% can occur; it may exceed 70% due to waterlogging (Setter *et al.* 1999). In the present scenario, when the climate is variable and the incidence of flooding has increased, it is important to understand the mechanism by which crops are resilient to this stress and other management practices that help crops to perform better. With the above mentioned aim, this book chapter has been designed in different sections that will discuss the problem, causes, and impact of waterlogging in major field crops with the future prospects and scope in water management for these crops.

II. CAUSES OF WATERLOGGING

1. **Climatic Variability:** Excessive rainfall in a short span of time exceeds the soil storage capacity and makes the area waterlogged. Climate change scenarios have made such incidences more frequent, hence leading to frequent waterlogging situations. Higher air temperatures encourage evaporation of water in rivers and seas and, as a result, cloud formation. Higher temperatures allow the air to store more moisture, which may cause an increase in precipitation intensity, duration and/or frequency. As global warming raises the chance of additional extreme weather occurrences, dangers will spread beyond the established high-risk zones. More severe flooding is to be predicted, and for towns and cities where flooding has already occurred, it will no longer be a "once in a lifetime" risk

but will become considerably more frequent. The truth is that we live in a planet that is warming by 1.1°C. These record temperatures and floods are not anomalies; they represent the start of new standards, and the new records will be broken year after year.

2. **Irrigation:** Irrigation of soil without considering the soil infiltration capacity, soil storage ability and soil structure often leads to accumulation of water beyond desired, making the soil unsuitable for agricultural activity. Excessive irrigation often leads to the accumulation of water above the soil surface, creating an anaerobic environment (Irmak *et al.* 2014).

3. **Drainage:** Drainage can be considered the single most important factor that can lead to waterlogging (Balun 2020). Lack of proper drainage allows the excess water to remain on the soil surface for a longer period of time. The use of heavy machinery, a lack of organic matter addition, and other factors contribute to the formation of compacted layers in the subsurface region, resulting in poor drainage (Gurovich and Oyarce 2015; Kaur *et al.* 2020).

4. **Topography:** Topography has a significant effect on the occurrence of floods in an area (Valeo and Rasmussen 2000; Sendek *et al.* 2021). Lowland soils are more prone to waterlogging than upland soil, where free drainage is available. Uneven or unlevelled land creates waterlogged patches across the field as the water remains accumulated in small patches for a longer period of time.

5. **Ground Water Table:** Shallow ground water table regions are more prone to waterlogging, as high rainfall brings the water level close to the plant roots quickly, resulting in a longer anaerobic environment around the root regions.

III. PROBLEMS OF WATERLOGGING

Waterlogging can cause multiple problems, which have been discussed briefly under the following heads

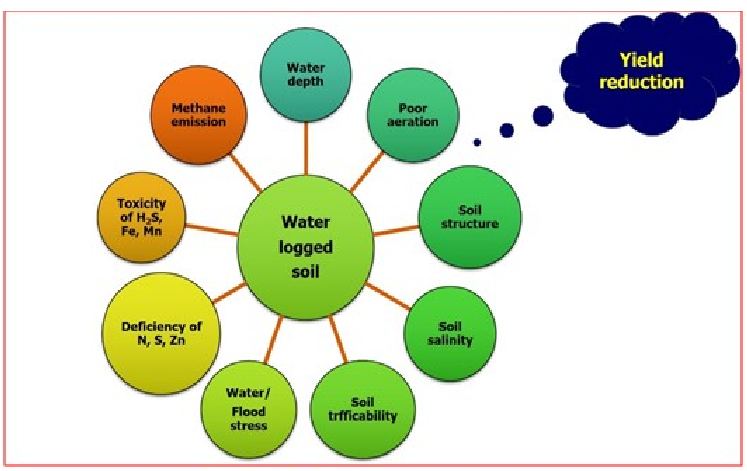

Figure 2: Effects of Waterlogging on Soil Physicochemical and Biochemical Properties

1. **Poor Crop Performance:** Waterlogged soil causes an anaerobic environment in the root zones, which leads to lower root respiration. Lower root respiration generates less ATP, which is required for regular crop metabolic activity such as photosynthesis and absorption of nutrients:- lower ATP generation makes nutrient absorption poorer, which leads to lower crop growth and productivity. The production of some toxic gases in anaerobic environments also lower root permeability, making both nutrient and water absorption increasingly difficult.

2. **Destruction of Soil Structure:** Excess soil moisture makes soil aggregates weaker. Tillage during excessive moisture, as practiced by many farmers, especially under paddy cultivation, destroys the soil structure and creates subsurface compaction that restricts root movement of subsequent crops.

3. **Emissions of Greenhouse Gases:** An anaerobic environment lowers the redox potential, which results in the formation of greenhouse gases such as methane and nitrous oxide. Lowering redox potential also increases the toxicity of iron and manganese as their availability increases under reduced conditions.

Table 1: Different Chemical Species and Their Transformation Under Waterlogging Conditions and Their Redox Potentials

Reduction Reactions under Waterlogging		
Oxidized species	**Reduced species**	**Redox potential (mV)**
O_2	H_2O	+380 to +320
NO_3^-	N_2	+280 to +220
Mn^{4+}	Mn^{2+}	+280 to +220
Fe^{3+}	Fe^{2+}	+180 to +150
SO_4^{2-}	S^{2-}	-120 to -180
CO_2	CH_4	-200 to -280
H_2O	H_2	-200 to -420

4. **Deficiency of Nutrients:** Waterlogging leads to nutrient deficiencies through different mechanisms. Leaching of nutrients is one of the most common mechanisms of nutrient loss under a waterlogged environment in which soluble nutrients move beyond the root zone with water. Nutrients such as nitrogen may also be lost through denitrification under a waterlogged anaerobic environment. Zinc is the most limiting micronutrient under water logged conditions, as its availability is reduced because of the formation of sparingly soluble salt.

5. **Diseases and pest incidence:** Rising humidity developed under waterlogged conditions provides a congenial environment for the development of diseases and pest incidence.

Table 2: Effect of Waterlogging on Different Crops

Crop	Effect Due to Waterlogging	References
Corn	Cause of disease like Smut, Leaf spot and downy mildew	Urban *et al.* (2015)
Corn	Yield reduction	Singh *et al.* (2016)
Cotton	Effect on growth and yield attributes	Wang *et al.* (2017)
Cotton	Yield reduction	Zhang *et al.* (2016)
Wheat	Wheat scab disease	Urban *et al.* (2015)
Wheat	Yield loss	Arguello *et al.* (2016)
Soybean	Sudden death	Urban *et al.* (2015)
Soybean	Yield reduction	Singh *et al.* (2016)
Arabidopsis	Root cell death	Guan *et al.* (2019)

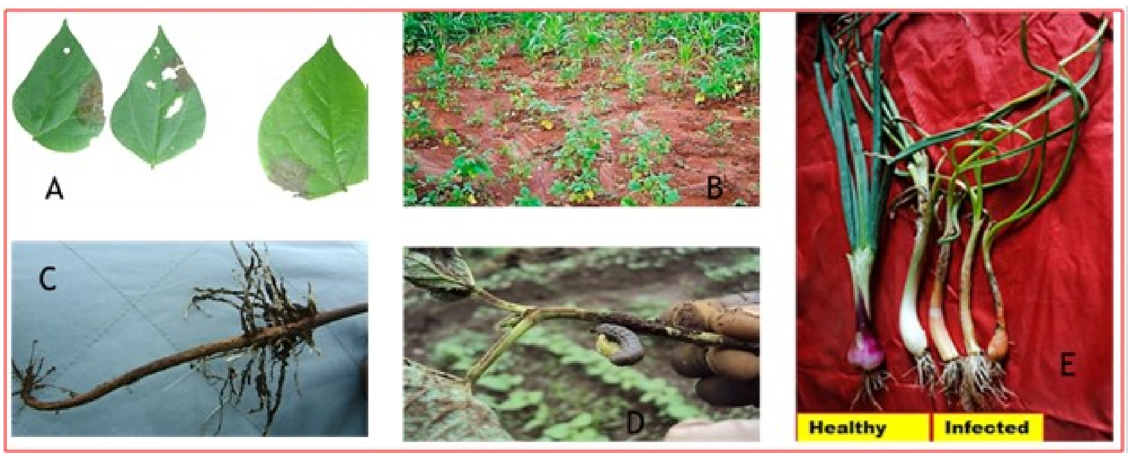

Figure 3: Incidence of Diseases and Pests under Waterlogging in Crops

- Ascochyta blight of common bean (Athanase *et al.* 2013)
- Phythium root rot of common bean (Eke *et al.* 2020)
- Rhizoctonia root rot of common bean (Athanase *et al.* 2013)
- Cutworm in common bean (Athanase *et al.* 2013), and
- Anthracnose twister in onion (Salunkhe *et al.* 2022)

IV. EFFECT OF WATER LOGGING ON PLANT PHYSIOLOGICAL PARAMETERS

Plants can suffer significant damage from the excessive synthesis of several ROS (reactive oxygen species) in waterlogged conditions, such as superoxide radicals, hydroxyl radicals, hydrogen peroxide, and singlet oxygen observed in hypoxia-stressed leaf and root tissues. In wet soil, ethylene is a potentially hazardous compound that inhibits root extension development. Additionally, the leftover ethanol in anoxic cells will be converted into acetaldehyde during the reintroduction of oxygen during the recovery phase, which may result in cell damage. All of these factors result in constrained root development, early leaf withering, and the formation of sterile florets, which all reduce yield. Due to a combination of factors, including a decreased photosynthetic rate, a decreased stomatal conductance, a decreased root hydraulic conductivity, and a decreased translocation of photo-assimilates, carbohydrate production was drastically reduced during complete submersion or subsequent de-submergence. The decrease in stomatal conductance is one of the earliest reactions of plants to waterlogging. Abscisic acid (ABA) transit from older to younger leaves or de novo synthesis of the hormone was suggested as the cause of stomatal closure. Waterlogging also lowers the chlorophyll concentration of leaves (Manik *et al.* 2019). The capacity of plants to photosynthesize is either directly or indirectly impacted by this decrease in chlorophyll. Stomatal closure, which limits CO_2 flow, is to blame for the decline in transpiration and photosynthesis.

V. MANAGEMENT PRACTICES

1. **Alternate Crop:** Growing crops suitable under waterlogged conditions can be the single most effective strategy to tackle the issue of yield reduction under waterlogged environments. Varieties of particular crops suitable for waterlogged conditions can be further effective in reducing the negative impact of waterlogging.

2. **Alteration in Cropping Pattern:** Developing cropping patterns that facilitate growing water logging-tolerant crops or growing crops in such a time that can escape waterlogging at critical stages can be an effective strategy for alleviating waterlogging issues.

3. **Sowing Time:** Adjusting the sowing time can be useful in escaping waterlogging. Sowing rice in late April or early may help rice escape early season floods. Moreover, this facilitates the early sowing of wheat. Adjusting the planting time should be done in such a way that the most susceptible stage of the crop does not coincide with the peak waterlogging period.

4. **Raised Bed Planting:** Growing crops such as maize, wheat, mustard, etc., on raised beds has been found to be effective in minimizing the negative effect of waterlogging to a great extent. Crops planted on raised beds are less exposed to waterlogging. Moreover, the furrows formed between the raised bed serve as a channel for the drainage of excess water.

5. **Drainage:** Provision of surface and subsurface drainage can help minimize waterlogging issues. Subsurface drainage is especially useful in alleviating the issue of rising water tables. Surface drainage can be useful for conditions where excess water accumulates over the soil surface. Bio-drainage can also be effective in lowering the water table. This can be especially useful where the water table is shallow, resulting in frequent issues of waterlogging.

6. **Genetic Approach:** Breeding for waterlogging tolerance can be an effective strategy for better adaptation under waterlogging conditions. Varieties such as Sarjoo–52 and Swarna sub 1 have been highly effective under waterlogged conditions. Finding landraces or germplasm and screening for their waterlogging tolerance ability can be the first step in developing such varieties. Bringing water logging tolerance genes from wild parents can also be useful in this aspect.

VI. CONCLUSION

Flood/waterlogging is an important and serious threat to agriculture, as is evident in many research works. There is a need to develop a comprehensive and spatially explicit risk evaluation framework to predict and investigate how floods impact crop production. Additionally, it is necessary to develop climate-resilient agriculture techniques that not only save crops but also protect soil from erosion. A risk-based approach should be frame that would lead to an economic, social, and environmental balance between gains and losses.

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