Zoo Botanica
ISSN: 3007-2050 (E), 3007-2042 (P)

Check for updates

ROOTS PRESS

Research Article

Effect of waterlogging on seed germination and growth of selected tree species in Dharabi watershed, district Chakwal

Muhammad Saqlain Sarfraz[1], Bisma Shahbaz[1], Sabeeqa Usman Malik[1], Mah Jabeen[1]

Department of Forestry and Range Management, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi 46300, Pakistan.

ABSTRACT

The purpose of this research in the Dharabi watershed region was to investigate the seed germination and growth potential of selected (04) tree species (*Ziziphus mauritiana*, *Melia azedarach*, *Acacia modesta*, *Acacia nilotica*). The study was conducted to identify the effect of waterlogging on seed germination and growth of selected species that can develop at the fastest pace under waterlogging stress. The research was based on Pot experiments and field experiments. Four treatments (T0, T1, T2, and T3) were utilized, and germination and mortality percentages were investigated. Growth parameters consisted of height, stem diameter, and leaf number. The data was analyzed using CRD (Complete Random Design) and R Studio for Windows, using a statistical test (ANOVA). The results showed that the means of significant effects were separated using the LSD at a 5% probability. Being planted in waterlogged environments, *Acacia nilotica* had the highest average percentage of seed germination out of selected species, regardless of the degree of waterlogging stress that was applied. In comparison to other species, the *Acacia nilotica* plant's height was noticeably greater and had a significantly larger stem diameter. *Ziziphus mauritiana* also progressed very well; however, the results produced by *Acacia modesta* were unsatisfactory. These results will help in the plantation of the best-suited plants in the waterlogged areas in the future.

Keywords: *Acacia nilotica*; *Acacia modesta*; *Melia azedarach*; *Ziziphus mauritiana*; growth potential; mortality percentage; waterlogging tolerance.

OPEN ACCESS

Correspondence
Bisma Shahbaz
bismashahbaz4@gmail.com

Article History
Received: May 27, 2025
Accepted: August 02, 2025
Published: August 31, 2025

INTRODUCTION

Waterlogging is a significant problem globally, affecting approximately 10% of the land area and significantly reducing vegetation yield. In the United States, where waterlogging affects 16 % of the cultivated area, it poses serious threats to cultivated lands in Russia, Pakistan, Bangladesh, China, and India (Shaheen, Ahmad, Khan, & Munir, 2021).

Around 11 million hectares of land in Pakistan are flooded to a depth of between 5 and 10 feet. In Pakistan, waterlogging is predicted to harm more than 2.8 million hectares of irrigated land. Major consequences of waterlogging include a reduction in drainage capacity and fertility, a loss of biodiversity, and a decrease in agricultural output. Moreover, this issue consistently contributed to the deterioration of land (Babur, Ali & Baig, 2013; Qureshi, 2021). According to WAPDA, the waterlogged area in KPK is 400000 hectares with a water level of 3 to 5 feet (Quereshi & Sarwar, 2009). Some studies indicate that around 25% of the irrigated land in Punjab is extremely flooded (Bhutta & Smedema, 2007). The total waterlogged area of Sindh province is 50%. There is waterlogging on 60% of the irrigated land in Sindh province, resulting in 31% of the crop's annual loss due to waterlogging. An area is declared as waterlogged when the water table reaches such a level that soil pores present in the crop's root zone get saturated, oxygen level declines, and the level of carbon dioxide rises over an extended period (Khan & Shafiq, 2003). Waterlogging is a significant kind of abiotic stress that inhibits the plant's growth and development (Dat et al., 2006). Waterlogging causes nutrient loss and the loss of beneficial bacteria, resulting in chemical degradation due to the buildup of salt at the soil's surface, which in turn leads to an ecological imbalance (Shah et al., 2013). When waterlogging occurs, it may be very difficult for seeds to germinate and for seedlings to get established. As a consequence of waterlogging, growth, maturation, and the continued existence of species are affected (Dat et al., 2006). The physiological and physiochemical characteristics of tree species and soil may both be influenced negatively by waterlogging (Shaheen et al., 2021). Most of the pore spaces are filled with water when the soil gets waterlogged. Due to this metabolism of the root system, different microorganism starts consuming available oxygen and produce carbon dioxide. The diffusion rate of gases in water is 1000 times slower in waterlogged conditions than in air (Armstrong, 1979). The production of carbon dioxide and consumption of oxygen are also imbalanced. In soil, the concentration of harmful gases is enhanced due to the slow movement of gases in the soil solution (Haj-Amor et al., 2022).

Plants are unable to reach their full potential when grown in waterlogged soil, as there is not enough oxygen in it to support healthy plant growth (Rangamsi et al., 2022). The growth of the plants, as well as their germination and development, is negatively impacted by these variations (Armstrong, 1980). The delay in root production in waterlogged conditions has a deleterious effect on the growth of nearly all terrestrial plants (Kozlowski and Pallardy, 1997; Ramos & Maranon, 2009). If the leaves of a plant grow on soil that has proper drainage rather than poor soil that is deficient in important plant nutrients, the circumstances will be considerably different. Because nitrogen is transferred from old leaves as they turn yellow to new ones, as the plant matures (Parmanik et al., 2022). There is a spectrum of waterlogging tolerance for every plant, which has a considerable impact on the age of the plant, the amount of water it can hold, and how quickly it can transfer water around (Kozlowski and Pallardy, 1997). One of the harmful effects of waterlogging is the reduction in the amount of oxygen that is present in the root systems of plants. The strength of the root system is directly proportional to how well it can withstand flooding (Kreuzwieser, Papadopoulou & Rennenberg, 2004). Waterlogging causes a decrease in the root biomass of plant species, as well as a drop in the root-to-shoot ratio (Possen et al., 2011).

Morphological changes such as the formation of adventitious roots are a common response of waterlogging-tolerant species (Malik et al., 2001). Adventitious roots have high porosity, which helps plants in water and nutrient uptake when they are in waterlogged conditions. Adventitious roots replace the older basal root system with a new root system (Dat et al., 2006). These roots are found near the basal area of the stem or in the region of lenticels. The growth of these roots is lateral and relatively close to the surface of the soil (Steffens et al. 2006). The formation of adventitious roots occurs when an older root system becomes unable to supply the required minerals and water to the shoot. It is understood that the main root system would deteriorate to provide energy for the growth of a root system that is well-adapted (Amesalu & Kebede, 2020). Hypertrophied lenticels production is another response of plants against waterlogging (Yamamoto et al., 1995). It helps in delivering oxygen downward and eliminating anaerobic metabolic byproducts from roots. Lenticels are water-permeable and help the plants maintain water homeostasis during flooding by replacing root systems and allowing the shoot to absorb water (Groh et al., 2002). Many soil physiochemical properties are affected by flooding, including soil pH, redox potential, and oxygen level. As a result, plants growing in waterlogged soil must contend with hypoxia (a lack of oxygen) or anoxia (absence of O2). It reduces plant growth and stops all metabolic processes, which causes a reduction in crop yield. It also causes fatality and stops the seedling growth as seedling roots are not adapted to waterlogging, causing immediate death of the plant (Amesalu & Kebede, 2020; El-Yazel et al., 2022; Ashraf, 2012; Clarie et al., 2008).

Pakistan's undulating landscape is usually unsuited for crop cultivation due to soil degradation and waterlogging challenges, erratic rainfall, exacerbated by a water and energy crisis. Using eucalyptus may be the best solution because it may grow in soils that are no longer utilized (But et al., 2022). Both salinity and waterlogging are major contributors to crop growth reductions and yield losses, particularly in irrigated lands, as seed germination is inhibited, biomass accumulation and photosynthetic rate are slowed, and plant water relations are disrupted (Hussain et al., 2022). Seeds will not germinate in waterlogged soil under relay sowing due to a lack of oxygen. This is most likely due to slower imbibition rates that leak fewer electrolytes during germination than faster imbibition rates. However, small seeds can germinate in waterlogged soil by utilizing the limited oxygen available on the soil's surface (Wirguna, 2022). This study aims to investigate the effect of waterlogging on seed germination of selected tree species and determine the influence of waterlogging on the growth potential of selected tree species in the Dharabi watershed area.

MATERIALS AND METHODS

Study Area

A waterlogged site in the Dharabi watershed area (Figure 1), Pipli, located near Dharabi Dam, Pakistan, was selected. The experiment was conducted in an open area starting from March 2021. The Dharabi watershed is bounded by latitudes 32° 42′ 36″ N and 32° 55′ 48″ N, and longitudes 72° 35′ 24″ E and 72° 48′ 36″ E. It drains an area of 196 km^2. Within the watershed, there are twenty villages, including the town of Kallar Kahar. It also features one lake, two tiny dams, 12 mini-dams, and a forest reserve. The geography is dominated by low to medium hills with elevations ranging from 466 m to 800 m above sea level. The steepness of the slope ranges from 2% in the plains to more than 30% in the slopes. A gullied region accounts for more than half of the overall area. The low temperature ranges from -0.5°C in January to 16°C in July and August. Maximum temperatures ranged from 24°C in January to 48°C in June. The yearly rainfall is around 630 mm. The most common land types are wasteland/bad lands (40%), harsh grazing land (20%), dry farming (12%), and wetlands (8 %). Built-in and irrigated regions account for less than 5% of the total area (Oweis & Ashraf, 2011).

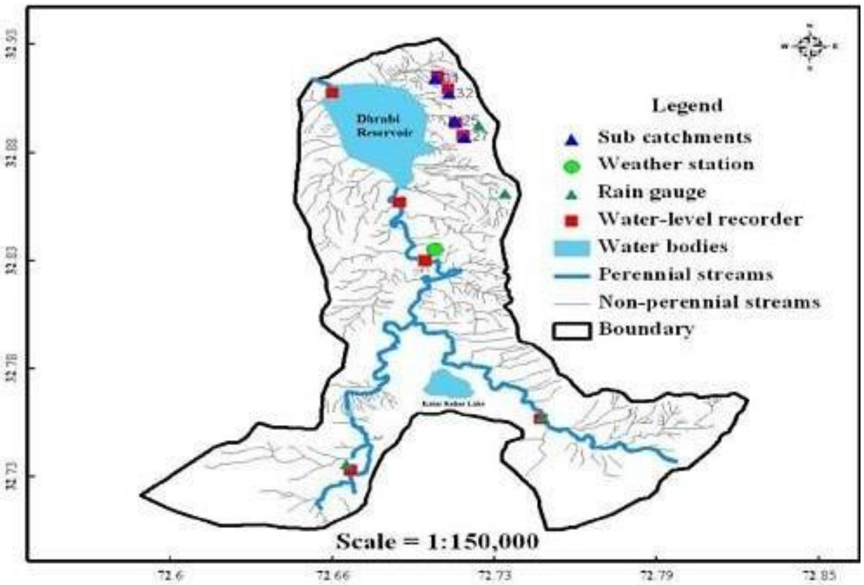

Figure 1. Map of Dharabi watershed area.

Plant Material

Ziziphus mauritiana (Ber) is a shrub that can be either deciduous or evergreen and is intolerant, thriving without specific soil preferences and adapting to various environments. This tree originates from South Asia, particularly Pakistan, and has been successfully grown in numerous regions worldwide. It is found throughout Pakistan, with optimal growth occurring at lower elevations in Punjab, KPK, Sindh, and Balochistan. *Melia azedarach* (bakain) is a deciduous tree that is intolerant and flourishes in different types of well-drained soils found in valleys and ravines. This shorter tree is native to the Himalayas, including regions in Pakistan and Nepal. In Pakistan, it is widely planted in the plains of Punjab and KPK, and it has also been successfully introduced in many other parts of the globe. *Acacia modesta* (phulai) is a deciduous tree that is moderately intolerant and can withstand drought, thriving in various soil types, including dry and shallow ones. Its native regions include Pakistan, Afghanistan, and India. In Pakistan, it can be found at elevations below 1200 meters in the foothill ranges of the Himalayas, Salt Range, Sulaiman Hills, Baluchistan, and Kirthar Range, as well as in the plains adjacent to these mountains. *Acacia nilotica* (kikar) is an evergreen tree that is intolerant and drought-resistant, capable of growing in a wide range of locations. It can endure saline and sodic conditions if there is sufficient soil moisture. Native to Pakistan, it is present in Sindh, Punjab, Baluchistan, and KPK. It occurs both in the wild and is extensively cultivated worldwide, typically at elevations below 600 meters (Trees of Pakistan).

Experimental Design

The research was based on two experiments, i.e., the Pot Experiment and the Field Experiment. Four treatments were established per the multiple degrees of stress as described in Table 1. To analyze field data, a randomized complete block design was used. 3 plots of normal soil & 3 plots of waterlogged soil were taken. One plot of waterlogged soil & one plot of normal soil were considered replications. R1, R2, and R3 were three replications. Data was collected from R1, R2, and R3 (6 plots, 3 waterlogged and 3 normal).

Methodology

In March 2021 (spring season), seeds were sown. Growth data was taken every month for 1 year (2021-2022). Plastic pots having dimensions of 2*1 feet were used in the study. Waterlogged soil was collected from the selected site of the Dharabi watershed area. Pots were filled with an equal volume of soil according to stress levels. Seeds of the 4 selected tree species were sown in each pot. 6 seeds of each tree species were sown at equal distances in each pot. These pots were placed under sunlight and watered regularly according to field capacity % T0, T1, T2, and T3 (Table 1). Seed germination was noticed till 60 days after the date of sowing.

Table 1. Layout for seed sowing in pot.

Field Capacity 70-90% T0		Field Capacity 100-110 % T1		Field Capacity 110-120% T2		Field Capacity 120-130% T3	
Replications	No of seeds	Replications	No of seeds	Replications	No of seeds	Replications	No of seeds
R1	6	R1	6	R1	6	R1	6
R2	6	R2	6	R2	6	R2	6
R3	6	R3	6	R3	6	R3	6

Germination data were collected weekly. The mortality percentage was evaluated after germination was completed. After complete germination, the germination percentage was calculated to check the germination rate of selected tree species under different stress levels by the following formula:

GP = Total number of seeds that germinated x 100
Number of seeds sown _____ Eq. 1

After seed germination, the mortality percentage was calculated to estimate the death rate of selected tree species under different stress conditions to examine the performance.

MP = Number of seeds that died after germination x 100
Total number of seeds germinated ______ Eq. 2

Where,

GP = Germination Percentage, MP = Mortality Percentage

After 3 months, at the sapling stage saplings of selected tree species grown in the pot experiment after applying different waterlogging stress treatments were selected. 6 plots having size of 28 X 22 were taken in the selected site. 3 plots in normal soil and 3 plots in waterlogged soil were selected for the site. Row-to-row distance between plants was 10ft. Plant-to-plant distance was 6ft 6 saplings were planted in each plot (2 plants per species). Saplings were planted in a randomized design. 2 plots of each waterlogged and normal soil (Table 2) were considered as 1 Replication (R).

Table 2. Layout for saplings plantation.

Normal Soil				Waterlogged Soil			
S1	S2	S3	S4	S1	S2	S3	S4
S4	S3	S2	S1	S4	S3	S2	S1

Plant growth metrics, such as the quantity of leaves, plant height, and stem diameter, were assessed. The leaves of chosen tree species were counted manually over a period of four months, from June to September. A Vernier Caliper and measuring tape were utilized to measure the height and diameter of all plants. The diameter of the plant stem was calculated using the following formula.

Diameter = Girth /π _______ Eq. 3

Where, π = 3.14 and Girth = Circumference of plant stem (Ullah et al., 2019; Zafar et al., 2021).

Data Analysis

The data was examined using R Studio version 2022 on Windows 10. A statistical test (ANOVA) was employed to ascertain the most notable influence of seed treatment and waterlogging on the morphological parameters. Significant means were differentiated using the LSD method at a 5% probability level.

RESULTS AND DISCUSSION

In general, waterlogging produced a negative effect on different aspects of seed germination, mortality percentage, and growth potential in the selected tree species, although the impact on each of them differed slightly.

Waterlogging and Seed Germination

The results (Figure 2) describe the effects of four different treatments on seed germination of *Ziziphus mauritiana*, *Acacia nilotica*, *Melia azedarach*, and *Acacia modesta*. The germination percentage of seeds of selected tree species was statistically different in all treatments. Maximum germination percentage was examined in seeds of selected 04 species treated with controlled soil T0 with values of (77, 94, 88, and 83%) followed by germination in waterlogging stress T1 (66, 88, 83, 72%), T2 (55, 77, 55, 38%), & T3 was (27, 55, 22, 11%). Data illustrated in Table 3 shows the effects of different treatments on seed germination. Differences among treatments were further compared using an LSD test at a 5% probability level.

Treatments	Seed germination percentage			
	Ziziphus mauritiana	*Acacia nilotica*	*Melia azedarach*	*Acacia modesta*
T0	77%	94%	88%	83%
T1	66%	88%	83%	72%
T2	55%	77%	55%	38%
T3	27%	55%	22%	11%
LSD	0.94*	1.08*	0.94*	0.786*

Table 3. Mean germination percentage of selected tree species.
*Statistically significant at P < 0.05

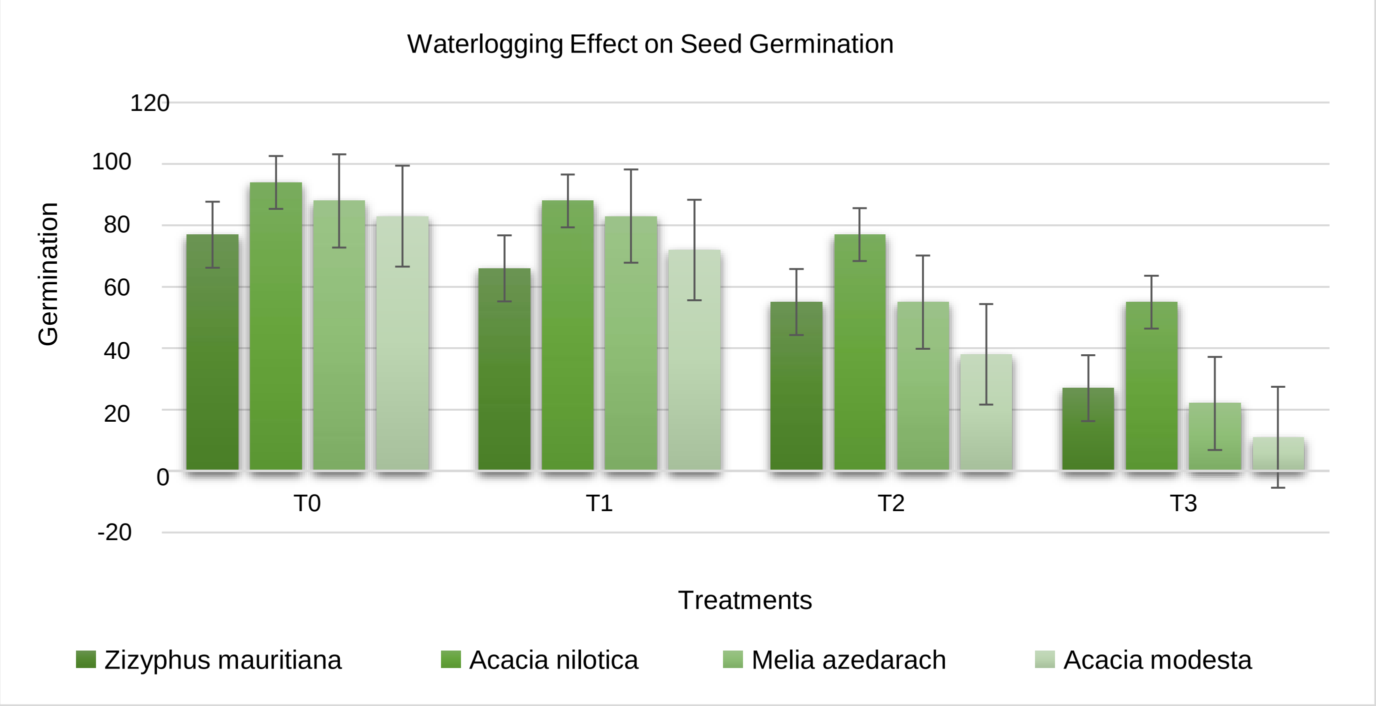

Figure. 2. Seed germination percentage of selected tree species.

Waterlogging and Mortality Percentage

The results for Figure 3 describe the mortality percentage of *Ziziphus mauritiana*, *Acacia nilotica*, *Melia azedarach*, and *Acacia modesta*. Maximum morality % was recorded in T3, which is (60, 30, 50, 50%), followed by (30, 22, 28, 53%) in T2, (25, 7, 20, 24%) in T1, and (15, 6, 13, 22%) in T0. Table 4 illustrates the death rate hike in treatment T3 with higher stress levels, which indicates that the seeds of selected tree species were not able to perform exceptionally under higher stress conditions.

Table 4. Mean mortality percentage of selected tree species.

Treatments	Mean mortality percentages			
	Ziziphus mauritiana	*Acacia nilotica*	*Melia azedarach*	*Acacia modesta*
T0	15%	6%	13%	22%
T1	25%	7%	20%	24%
T2	30%	22%	28%	53%
T3	60%	30%	50%	50%

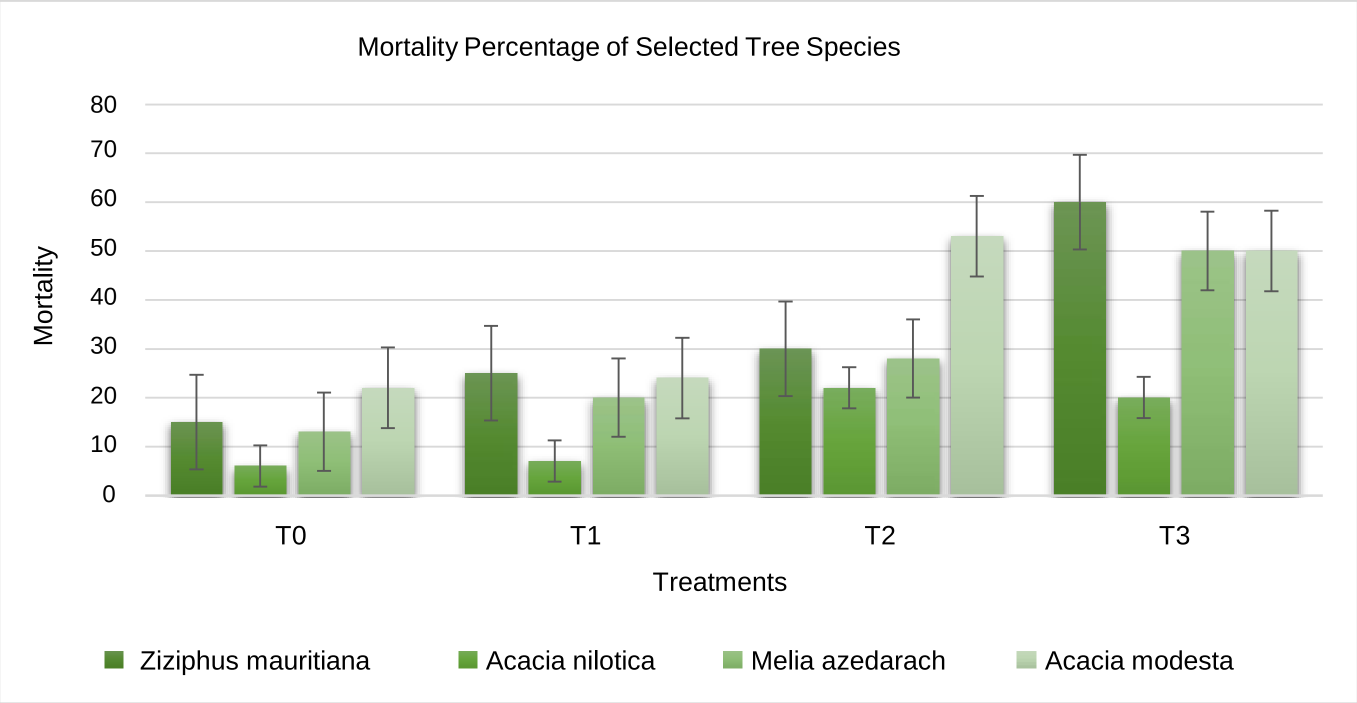

Figure 3. Mortality percentage of selected tree species.

Waterlogging and Plant Height

The mean height of *Ziziphus mauritiana*, *Acacia nilotica*, *Melia azedarach*, and *Acacia modesta* is described in Figure 4. The height of the plants differs significantly in both normal and waterlogged soil conditions. The mean plant height in normal soil, which is recorded after one year of growth, is 95, 111.33, 136.6, and 47 cm. On the other hand, in waterlogged soil, the selected tree species attain a mean height of 90, 94.6, 86, and 40.3 cm. The tallest plant in normal soil conditions was 137 cm (*Melia azedarach*), and the tallest plant in waterlogged conditions was 95 cm (*Acacia nilotica*). The bar chart of both soil conditions' effects on the growth of the selected tree species is illustrated in Table 5. Differences among treatments were further compared using the LSD test at a 5% probability level.

Table 5. Mean plant height of selected tree species

Plant species	Plant Height		LSD	
	Treatments			
	Waterlogged Soil	Normal Soil	Waterlogged Soil	Normal Soil
Ziziphus mauritiana	90 cm	95 cm	1.372*	3.444*

Acacia nilotica	94.6 cm	111.33 cm	1.372*	3.444*
Melia azedarach	86 cm	136.6 cm	1.372*	3.444*
Acacia modesta	40.3 cm	47 cm	1.372*	3.444*

*Statistically significant at P < 0.05.

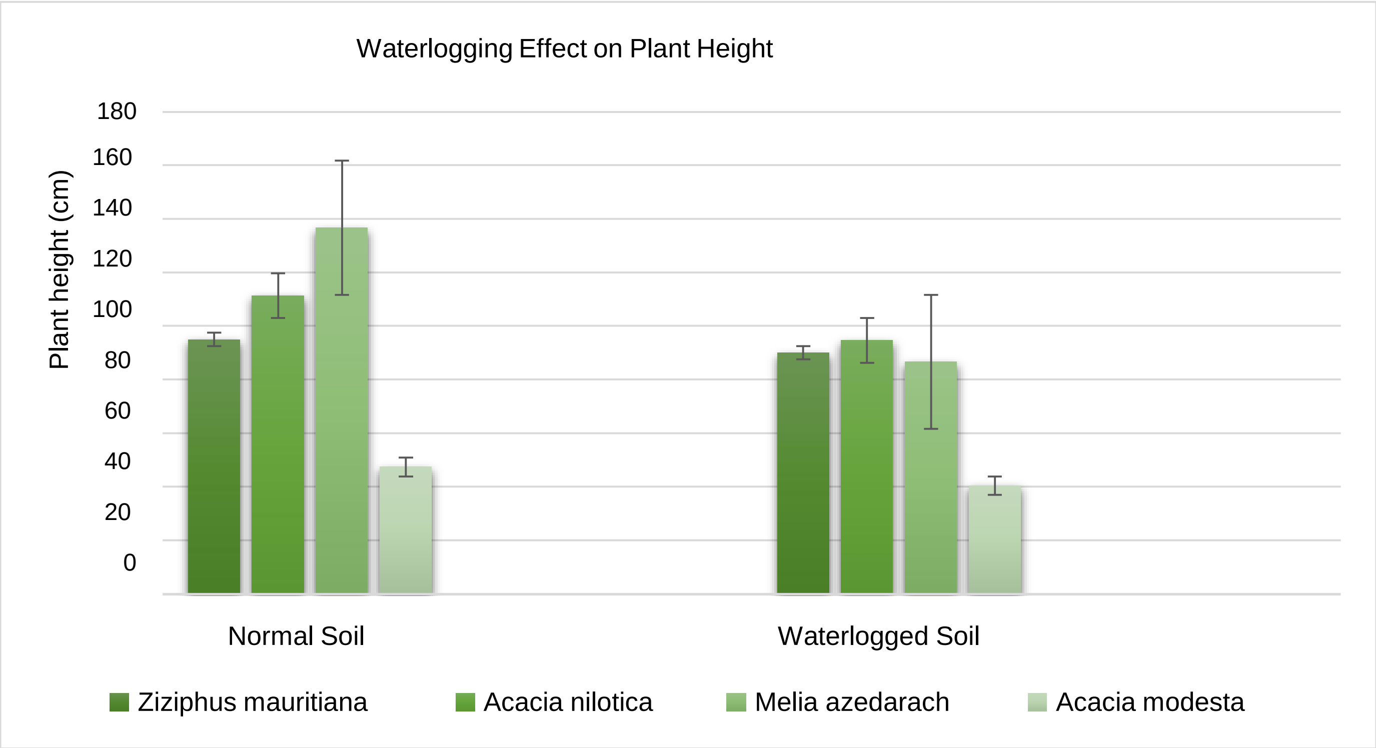

Figure 4. Plant height of selected tree species

Waterlogging Effect and Stem Diameter

The diameter of *Ziziphus mauritiana*, *Acacia nilotica*, *Melia azedarach*, and *Acacia modesta* is represented in Figure 5. There was a statistical difference recorded regarding data for the stem diameter of the selected tree species in the field. Diameter measurements were taken every month, and after one year of growth, the mean diameter of the species was calculated. In normal soil, the maximum mean diameter was reported as 10.9 mm (*Acacia nilotica*), and in waterlogged conditions, the maximum diameter was recorded as 9.3 mm (*Acacia nilotica*). The highest diameter observed in normal soil was 11 mm (*Acacia nilotica*), and in waterlogged soil was 9.4 mm (*Acacia nilotica*). Differences among treatments were further compared using the LSD test at a 5% probability level (Table 6).

Table 6. Mean stem diameter of selected tree species.

Plant species	Stem Diameter		LSD	
	Treatments			
	Waterlogged Soil	Normal Soil	Waterlogged Soil	Normal Soil
Ziziphus mauritiana	8.6 mm	10.73 mm	0.185*	0.115*
Acacia nilotica	9.3 mm	10.9 mm	0.185*	0.115*
Melia azedarach	6.1mm	9.4 mm	0.185*	0.115*
Acacia modesta	5.1 mm	7 mm	0.185*	0.115*

*Statistically significant at P < 0.05.

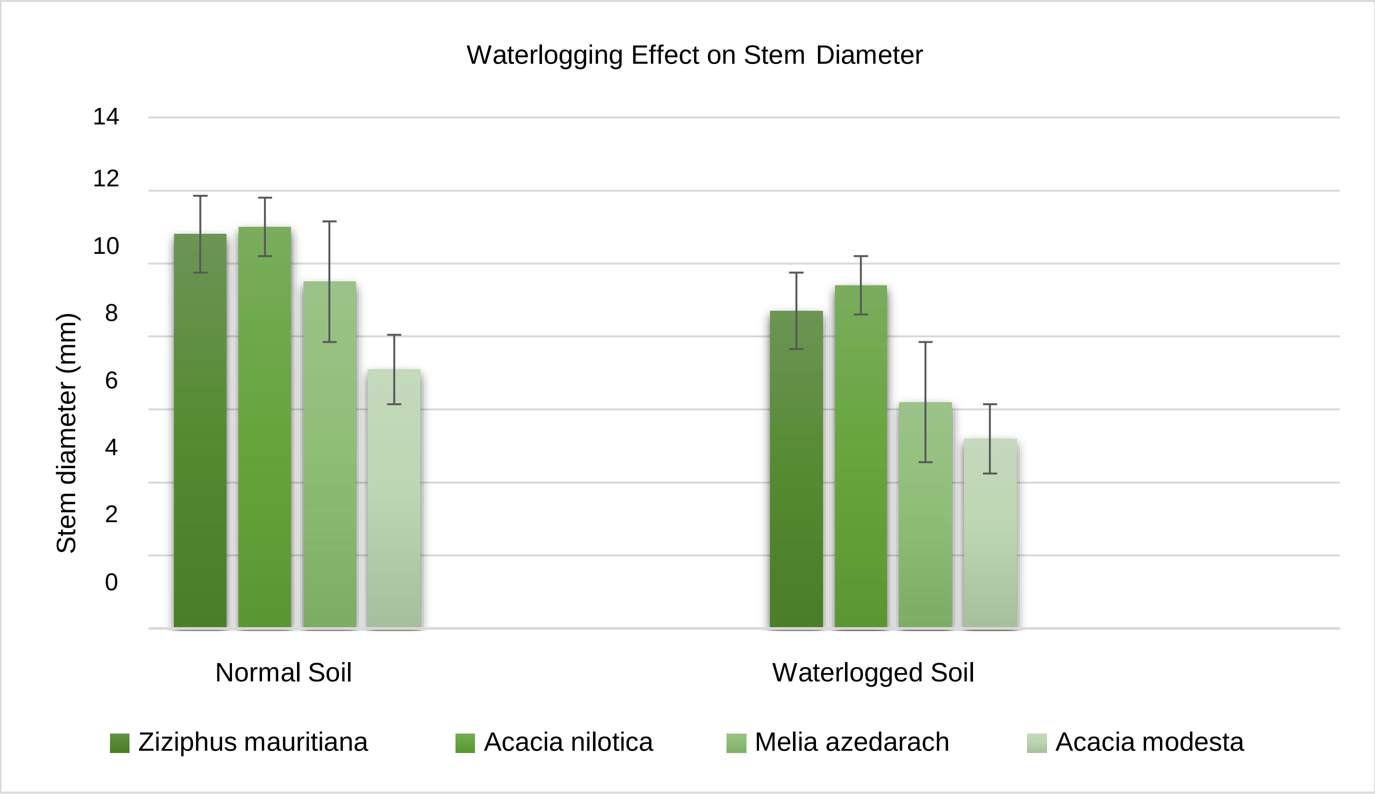

Figure 5. Stem diameter of selected tree species.

Waterlogging Effect and the Number of Leaves

Statistical analysis shows that the number of leaf counts of *Ziziphus mauritiana*, *Acacia nilotica*, *Melia azedarach*, and *Acacia modesta* differed significantly in both waterlogged and normal soil conditions. Figure 6 demonstrates the data regarding the number of leaves. In normal Soil conditions, the highest mean leaf count was 160.33 (*Acacia nilotica*), and in waterlogged soil conditions, the highest mean leaf count was 129.66 (*Acacia nilotica*). The highest leaf count on a plant in normal soil was recorded as 139 leaves (*Acacia nilotica*), and in waterlogged conditions, the highest leaf count was 165 (*Acacia nilotica*). Differences among treatments were further compared using the LSD test at a 5% probability (Table 7).

Table 7. Mean number of leaves of selected tree species.

Plant species	No. of Leaves		LSD	
	Treatments			
	Waterlogged Soil	Normal Soil	Waterlogged Soil	Normal Soil
Ziziphus mauritiana	81.3	111.6	4.328*	3.069*
Acacia nilotica	129.66	160.33	4.328*	3.069*
Melia azedarach	39.3	56	4.328*	3.069*
Acacia modesta	85	103	4.328*	3.069*

*Statistically significant at $P < 0.05$.

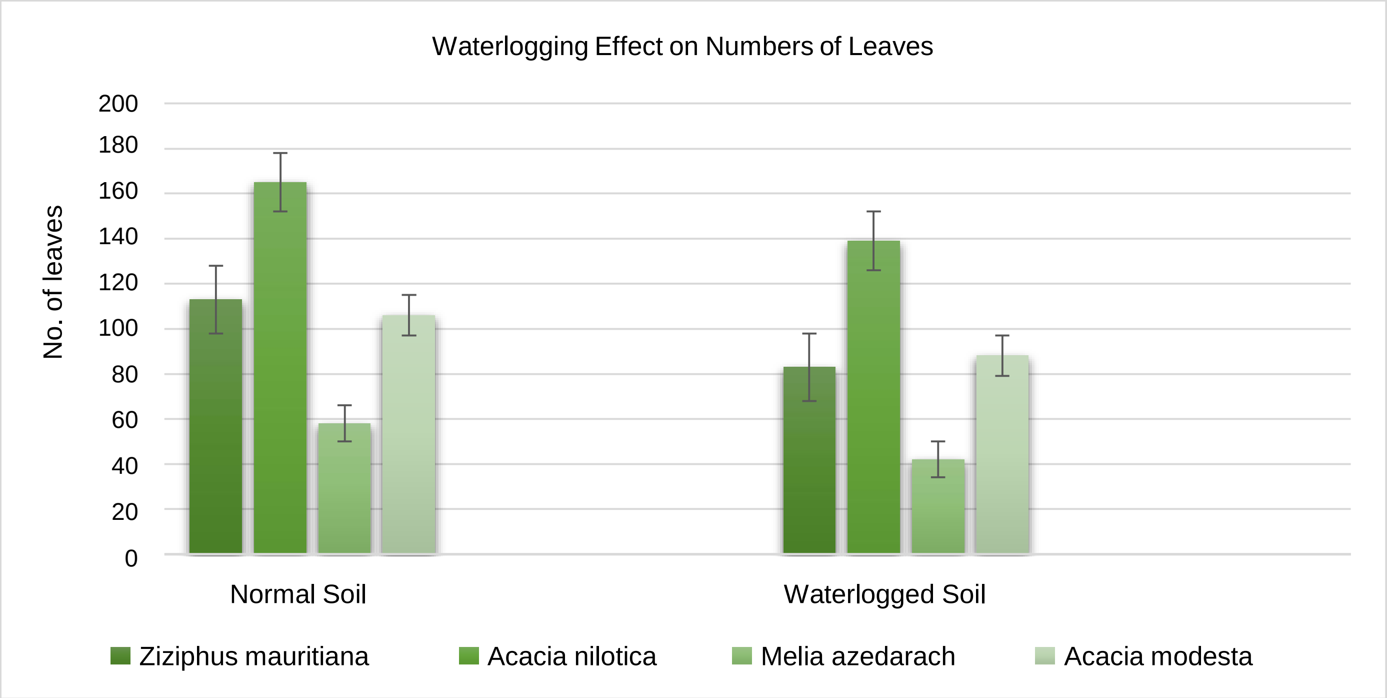

Figure 6. Number of leaves of selected tree species

DISCUSSIONS

Waterlogged soil is a common phenomenon in nature. Waterlogging affects the soil redox potential, pH, and oxygen concentration. The oxygen supply to plant roots is usually insufficient. This is harmful to the plant's growth, survival, and development. Plants commonly transition from aerobic respiration to anaerobic fermentation when their roots are submerged in water (Luo et al., 2024). The goal of this study was to determine which tree species are the most successful in avoiding waterlogging while allowing them to thrive. This was done to evaluate the seed germination and growth potential of selected tree species. The purpose of this research was to investigate the effects of waterlogging on the germination rate of seeds and the capacity for the development of a variety of tree species that were subjected to varying degrees of waterlogging stress. The proportion of seeds that were able to germinate under various degrees of stress was one of the variables that was investigated in this research. The results of the experiment showed that *Acacia nilotica* performed noticeably better in seed germination than any other species. *Acacia nilotica* had the highest germination mean percentage among all the species studied when exposed to waterlogged conditions. In waterlogged circumstances, the germination rate of *Acacia modesta* seeds has the lowest percentage; *Melia azedarach* progressed modestly, but *Ziziphus mauritiana* did very well. Our results are supported by the study of (Zhou et al., 2020) who examined seed germination under waterlogging stress conditions. The mortality rate of many different tree species is significantly affected by using waterlogging stress treatments. The mortality rate is calculated by taking the total number of plants that germinate and go on to survive and dividing that number by the number of plants that perish. The value of this proportion is expressed as a percentage of the overall quantity of plants. After the seeds had fully germinated their potential, the mortality rate was calculated. The average number of dead *Acacia modesta* plants was much higher than that of any other plant that was assessed when the plants were exposed to a range of waterlogging stress conditions. The high mortality rate is a direct result of the stress caused by waterlogging. Waterlogging stunts plant development by creating stressful conditions such as delayed growth, damaged root tips, and adventitious roots forming at the base of the stem. These conditions contribute to the high mortality rate. *Ziziphus mauritiana* and *Melia azedarach* have the overall average mortality rate, followed by *Acacia nilotica*, which has the lowest mean mortality rate. The results of mortality percentage are supported by the findings of Craig et al (1990). Damage to the stems of plants is one of the illuminating signs of waterlogging that may be seen with the naked eye. These symptoms include a reduction in growth rate and wilting. The plant's height may be adjusted in several different ways, all of which are contingent on the method that is used to alleviate the waterlogging. If a plant's height is diminished because of waterlogging, it will have a far more difficult time withstanding the stresses caused by waterlogging and reaching its full potential. This is because a waterlogged plant will develop more slowly than one that is not. It has been examined that the mean plant height of *Acacia nilotica* was noticeably greater than other selected species, whilst the mean plant height of *Acacia modesta* is stunted. When compared to those of *Acacia modesta*, the average heights of *Ziziphus mauritiana* and *Melia azedarach* are rather impressive. The results of this study are supported by research conducted by Xu et al. (2024). Waterlogging treatments have a significant impact on the growth of the stem diameter. Certain tree species grow well under normal soil circumstances, but their diameter growth is severely inhibited when subjected to waterlogging stress treatments. In waterlogged conditions, *Acacia nilotica* has the highest mean stem diameter, followed by the species *Ziziphus mauritiana*. Under waterlogged conditions, the *Melia azadrach* plant had the lowest mean stem diameter, followed by the *Acacia modesta* plant, which had the smallest mean stem diameter. The stem diameter reduces as the stress level rises, since waterlogging stunts plant development. The results of this study are supported by the results of Xu et al. (2024). Visual symptoms of waterlogging damage the downward curvature of leaves, chlorosis, premature senescence and leaf drop. Leaf growth in stress conditions is affected badly by waterlogging. The highest mean leaf count was reported in *Acacia nilotica* which is followed by *Acacia modesta*. The leaf count of *Ziziphus mauritiana* was relatively low. The results of this study were supported by Kreuzwieser & Rennenberg (2014).

CONCLUSION

The findings indicate that waterlogging significantly influences seed germination rates and alters the growth potential of the studied tree species. *Acacia nilotica* exhibited greater resilience to waterlogging, displaying relatively higher seed germination rates and maintaining growth under waterlogged conditions. In contrast, *Acacia modesta* showed reduced germination and growth rates in response to waterlogging stress. *Melia azadirach* behaved modestly and *Ziziphus mauritiana* fared very well.

These results highlight the need for management strategies when planting tree species in areas prone to waterlogging. Our study contributes to the understanding of the ecological responses of these tree species to waterlogging stress, offering insights that can inform land management practices, conservation efforts, and reforestation initiatives in the Dharabi watershed and similar environments. Considering key ecological factors such as soil aeration, hydrology, and species-specific tolerance to flooding is crucial for selecting suitable species. Future research should focus on long-term monitoring of waterlogging impacts to enhance resilience in vulnerable landscapes.

AUTHOR'S CONTRIBUTION

MSS: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing. BS: Conceptualization, Data curation, Visualization, Review & editing. SUM: Conceptualization, Visualization, Data curation, Review. MJ: Review & editing.

FUNDING

No funding was received for the study.

AVAILABILITY OF DATA AND MATERIAL

All the data is provided in the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All Authors have consented to participate in the publication.

CONSENT FOR PUBLICATION

All Authors have consented to participate in the publication.

CONFLICT OF INTERESTS

The authors have no conflict of interest.

ACKNOWLEDGEMENT

We acknowledge the Department of Forestry & Range Management for providing the opportunity to conduct this research.

REFERENCES

Aamir Saeed, (2015). Waterlogging and salinity threaten farmlands along the Indus. Available...online;https://www.thethirdpole.net/en/regionalcooperation/waterlogging-and- salinity/ The Third Pole Retrieved on 11, August 2021

Amesalu, F., & kebede, G., (2020). Influence of Waterlogging on Anatomical, Morphological and Physiological Responses of Plants. Academic Journal of Plant Sciences 13 (3): 78-93, 2020 ISSN 1995-8986

Armstrong, W. (1980). Aeration in higher plants. In Advances in botanical research (Vol. 7, pp. 225-332). Academic Press.

Babur, Z. U., Ali, A., & Baig, M. N. (2013). Desertification in Pakistan, Challenges and Opportunities. Journal of Environmental Treatment Techniques, 1(1), 13-18.

Bhutta, M. N., & Smedema, L. K. (2007). One hundred years of waterlogging and salinity control in the Indus valley, Pakistan: a historical review. Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 56(S1), S81-S90. But, N. I., Saleem, A., Mirza, S. N., & Haneef, M. (2022). Potential of Eucalyptus camaldulensis for agroforestry and energy plantation on problem soils. International Journal of Agricultural Extension, 10(1).

Choi, B. H., Bhusal, N., Jeong, W. T., Park, I. H., Han, S. G., & Yoon, T. M. (2020). Waterlogging tolerance in apple trees grafted on rootstocks from G, CG, and M series. Horticulture, Environment, and Biotechnology, 61(4), 685-692.

Craig, G. F., Bell, D. T., & Atkins, C. A. (1990). Response to salt and waterlogging stress of ten taxa of Acacia selected from naturally saline areas of Western Australia. Australian Journal of Botany, 38(6), 619-630.

Dat J, Folzer H, Parent C, Badot P-M, & Capelli N (2006) Hypoxia stress: Current Understanding and Perspectives. In: Teixeira da Silva JA (Ed) Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues (Vol 3), Global Science Books, Isleworth, United Kingdom, pp 664- 674

Dat, J., Folzer, H., Parent, C., Badot, P. M., & Capelli, N. (2006). Hypoxia stress. Current understanding and perspectives. Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues, 3, 664-674.

El-Yazel, M. A. S., EI-Shewy, A. A., & Matter, F. M. A. (2022). Impact of waterlogging condition on seedling of five timber tree species. Hortic. Int. J, 6, 37-45.

Groh B, Hubner C, Lendzian KJ (2002) Water and oxygen permeance of phellems isolated from trees: The role of waxes and lenticels. Planta 215, 794-801

Gujar, Z., Kandhar, I. A., Channa, A., & Azam, M. (2019, July). Removal of bulk pollutants from wastewater through river sand during gravity and suction flow process. In AIP Conference Proceedings (Vol. 2119, No. 1, p. 020025). AIP Publishing LLC.

Haj-Amor, Z., Araya, T., Kim, D. G., Bouri, S., Lee, J., Ghiloufi, W & Lal, R. (2022). Soil salinity and its associated effects on soil microorganisms, greenhouse gas emissions, crop yield, biodiversity and desertification: A review. Science of The Total Environment, 156946.

Hook, D. D. (1984). Waterlogging Tolerance of Lowland Tree Species of the South[1]. Southern Journal of Applied Forestry, 8(3), 136-149.

Hussain, S., Mehmood, U., Ashraf, U., & Naseer, M. A. (2022). Combined salinity and waterlogging stress in plants: limitations and tolerance mechanisms. In Climate Change and Crop Stress (pp. 95-112). Academic Press.

Irfan, M., Qadir, A., Habib, A., Nadia, J., & Ahmad, S. R. (2019). Vulnerability of environmental resources in Indus Basin after the development of irrigation system. In Irrigation-water productivity and operation, sustainability and climate change. IntechOpen.

Iqbal, Z, (1990) Effects of soil salinity on the early development of three important forest tree species and two provenances of Acacia nilotica. " Tree Production from Saline, Sodic. & Waterlogged Soils, 6.

Jackson, M. B., & Colmer, T. (2005). Response and adaptation by plants to flooding stress. Annals of botany, 96(4), 501-505.

Kawase, M., & Whitmoyer, R. E. (1980). Aerenchyma development in waterlogged plants. American Journal of Botany, 67(1), 18-22.

Khan, A. A., & Shafiq, M. (2003). Water Logging and Salinization: A serious threat for our agriculture. Pakistan Geographical Review, 58(1), 2.

Kozlowski, T. T., & Pallardy, S. G. (1997). Growth control in woody plants. Elsevier.

Kreuzwieser, J., & Rennenberg, H. (2014). Molecular and physiological responses of trees to waterlogging stress. Plant, cell & environment, 37(10), 2245-2259.

Kreuzwieser, J., Papadopoulou, E., & Rennenberg, H. (2004). Interaction of flooding with carbon metabolism of forest trees. Plant Biology, 6(03), 299-306.

Luo, Z. Q., Shi, X. Q., Wang, X. Y., Yang, Q. L., Pan, X., Pan, W. X., ... & Zhang, X. M. (2024). Waterlogging in soil restricts the growth of Gleditsia sinensis seedlings and inhibits the accumulation of lignans and phenolic acids in thorns. PeerJ, 12, e17137.

Lytton, L., Ali, A., Garthwaite, B., Punthakey, J. F., & Saeed, B. (2021). Groundwater in Pakistan's Indus Basin.

Malik AI, Colmer TD, Lambers H & Schortemeyer M (2001) Changes in physiological and morphological traits of roots and shoots of wheat in response to different depths of waterlogging. Australian Journal of Plant Physiology 28, 1121-1131

Mergemann H & Sauter M (2000) Ethylene induces epidermal cell death at the site of adventitious root emergence in rice. Plant Physiology 124, 609-614

Mihir Shah, Himanshu Kulkarni., Tushaar Shah, Karam Singh & S.C. Dhiman, (2013). Report of the high-level expert group on water logging in Punjab.Available.online.https://niti.gov.in/planningcommission.gov.in/docs/reports/genrep/rep_wate rpunjab2702.pdf Government of India planning commission. Retrieved on 9, August 2021.

Muhammad, A. A. (2012). Waterlogging stress in plants: A review. African Journal of Agricultural Research, 7(13), 1976-1981.

Murphy, M., Laiho, R., & Moore, T. R. (2009). Effects of water table drawdown on root production and aboveground biomass in a boreal bog. Ecosystems, 12(8), 1268-1282.

Nema, A. G., & Khare, A. K. (1992). Effect of waterlogging on some forest plants. Journal of
Tropical Forestry, 8(2), 187-188.

Nicoll, B. C., & Coutts, M. P. (1998). Timing of root dormancy and tolerance to root waterlogging in clonal Sitka spruce. Trees, 12(4), 241-245.

Nurul-Nasyitah, S., Hazandy, A. H., Arifin, A., & Mohd-Kamil, I. (2014). Waterlogging effects on growth and physiological characteristics of Azadirachta excelsa seedlings. American Journal of Plant Physiology, 9(3), 78-94.

Oweis, T. (2011). Assesments and options for improved productivity and sustainability of natural resources in Dhrabi watershed, Pakistan. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas (ICARDA)

Pérez-Ramos, I. M., & Marañón, T. (2009). Effects of waterlogging on seed germination of three Mediterranean oak species: ecological implications. Acta Oecologica, 35(3), 422-428.

Possen, B. J., Oksanen, E., Rousi, M., Ruhanen, H., Ahonen, V., Tervahauta, A., ... & Vapaavuori,
E. (2011). Adaptability of birch (Betula pendula Roth) and aspen (Populus tremula L.) genotypes to different soil moisture conditions. Forest Ecology and Management, 262(8), 1387-1399.

Pramanick, K. K., Kashyap, P., Shukla, A. K., Watpade, S., & Kumar, J. (2022). Water & neutrient management in stone fruites. Natural Resource Management in Horticultural Crops (2022): 93- 121

Quereshi, A. S., & Sarwar, A. (2009). Managing salinity in the Indus Basin of Pakistan.
International Journal of River Basin Management, 7(2), 111-117.

Qureshi, A. S., & Perry, C. (2021). Managing water and salt for sustainable agriculture in the Indus Basin of Pakistan. Sustainability, 13(9), 5303.

Qureshi, A. S., McCormick, P. G., Qadir, M., & Aslam, Z. (2008). Managing salinity and waterlogging in the Indus Basin of Pakistan. Agricultural Water Management, 95(1), 1-10.

Rangasami, S. S., Murugaragavan, R., Rakesh, S. S., Prabu, P. C., Ramesh, A. R., & Elangovan, R. (2022). Chemistry of flooded soils: A review.

Rizwan, Z. S., Khan, T. A., Rizvi, S. A., Aziz, A., & Alam, M. (2018) . An implementation of waterlogging and salinity management control using solar tube wells. Journal of Xi'an Shiyou University, Natural Science Edition ISSN :1673-064X

Setter, T. L., & Waters, I. (2003). Review of prospects for germplasm improvement for waterlogging tolerance in wheat, barley, and oats. Plant and soil, 253(1), 1-34.

Shaheen, H. M. F., Ahmad, I., Khan, S. H., & Munir, H. (2021). Screening of five multipurpose tree species for waterlogging tolerance using morphological and physiological response as effective indicators. Pakistan Journal of Agricultural Sciences, 58(2).

Steffens B, Wang J, Sauter M (2006) Interactions between ethylene, gibberellin and abscisic acid regulate emergence and growth rate of adventitious roots in deepwater rice. Planta 223, 604- 612

Ullah, S., Fahad, S., Latif, N., Mirza, S. N., Shahzad, H., Rizwan, M., & Khan, M. A. (2019). 84. Growth potential of primed Moringa oleifera varieties under nursery and field conditions of Potohar Region-Pakistan. Pure and Applied Biology, 8(1), 813-819.

Van der Moezel, P. G., Watson, L. E., Pearce-Pinto, G. V. N., & Bell, D. T. (1988). The response of six Eucalyptus species and Casuarina obesa to the combined effect of salinity and waterlogging. Functional Plant Biology, 15(3), 465-474.

Wiraguna, E. (2022). Adaptation of Legume Seeds to Waterlogging at Germination. Crops, 2(2), 111-119.

Xu, Z., Ye, L., Shen, Q., & Zhang, G. (2024). Advances in the study of waterlogging tolerance in plants. Journal of Integrative Agriculture, 23(9), 2877-2897.

Yamamoto F, Sakata T, Terazawa K (1995) Physiological, morphological and anatomical response of Fraxinus mandshurica seedlings to flooding. Tree Physiology 15, 713-719

Ye, Y., Tam, N. F., Wong, Y. S., & Lu, C. Y. (2003). Growth and physiological responses of two mangrove species (Bruguiera gymnorrhiza and Kandelia candel) to waterlogging. Environmental and Experimental Botany, 49(3), 209-221.

Zhou, W., Chen, F., Meng, Y., Chandrasekaran, U., Luo, X., Yang, W., & Shu, K. (2020). Plant waterlogging/flooding stress responses: From seed germination to maturation. Plant Physiology and Biochemistry, 148, 228.