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Research article

Germination and Growth response of *Albizia lebbeck* (L.) Benth to different soil moisture levels at seedling stage

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ABSTRACT

Albizia lebbeck (L.) Benth., is one of the widely used agroforestry species in Bangladesh for its timber, nitrogen fixing capacity and adaptability. Current study examined the impact of different soil field capacities (FC) on early establishment of this species including germination and seedling growth. A completely randomized design (CRD) was used for monitoring germination and randomized complete block design (RCBD) to study growth for sixty (60) days considering the field capacity (25%, 50%, and 100%). The experiment found a significant difference among the field capacities ($p<0.05$) where highest germination was recorded at 50% FC (78%), followed by 100% FC (76%) and only 15% germination in 25% FC. The height growth was significantly ($p<0.05$) higher at 50% FC than 100% FC but diameter growth did not differ significantly ($p<0.05$) among the treatments. The findings indicated that 50% FC provided better germination and height growth than 25% FC and 100% FC. These findings also highlighted the optimization of soil water in plant nurseries for developing a climate-resilient seedling stock for drought-prone regions.

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Introduction

Albizia lebbeck (Benth.), also known as the lebbeck tree, which is locally named Kala Koroi, is one of the fastest-growing tree species native to the tropical and subtropical climates of Asia and Africa. (Jin *et al*., 2023; Thakur *et al*., 2024). *A. lebbeck* is comparatively advantageous over many agroforestry species because of its fast growth, nitrogen-fixing ability, multipurpose use, adaptability to tropical environments, and value for timber, fodder, shade, and soil improvement (Yadav *et al*., 2023). In early stages of this species, it is strongly influenced by soil moisture and other site factors which are critical in developing successful plantation from seedling (Thakur *et al*., 2024). Moisture availability is widely calculated based on field capacity (FC), which is defined as the amount of water retained by soil after excess water has drained (Bhattacharya, 2021). Therefore, examining the impacts of soil moisture, particularly at different field capacities, on *A. lebbeck* during the nursery stage is essential for optimizing plantation practices.

Consistent with regional trends across South Asia, Bangladesh has emerged as a focal point of environmental concern; specifically, several of its regions are experiencing a marked escalation in water-related stressors. These climatic shifts pose significant challenges for reforestation efforts and agroforestry plantations (Wilson & Witkowski, 1998; FAO, 2022). To overcome these constraints, research on related issues, such as climate-resilient forestry, is increasing significantly; however, most recent studies have focused on mature trees and agricultural crops, and very limited attention has been given to the germination and early development of native trees (Khurana & Singh, 2004; Rahman et al., 2023).

In addition to other site conditions and microclimatic parameters, soil moisture is a critical factor for seedling establishment, as it regulates germination, nutrient uptake, and overall plant health (Patel *et al*., 2025; Silva *et al*., 2023). Therefore, deficit or excessive moisture in the soil can restrict seedling development, including growth (Farhan *et al*., 2024; Sharma *et al*., 2021). First of all, germination represented the most significant stage and was highly influenced by soil moisture. Studies have indicated that soil moisture is essential for seed imbibition and the initiation of germination (Campos *et al*., 2020; Muthukumar *et al*., 2022). Specifically, deficit or excessive moisture in the soil can impact root and shoot development, resulting in poor development and increased susceptibility to disease (Hassan *et al*., 2023; Silva *et al*., 2023). Patel *et al*. (2025) also concluded that optimized soil moisture levels enhance seedling height, biomass

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accumulation, and root development, and deviation from the optimal quantities resulted in reduced growth and death of the seedlings.

Similar to other agroforestry species, *Albizia* species demonstrate superior growth outcomes by maintaining optimal field capacity (60–80%) compared to conditions of excess or deficient moisture (Sharma *et al*., 2021). However, research on *A. lebbeck* is limited, and evidence from other related species suggests effective moisture regulation during the nursery stage to produce healthy seedlings (Yadav *et al*., 2023; Thakur *et al*., 2024). Considering this gap, this study aimed to investigate the effects of soil moisture levels (Field capacity) on the germination and growth of *A. lebbeck* seedlings at the nursery stage. The primary objectives were to determine the optimal field capacity (FC) that promotes germination and growth of *A. lebbeck* seedlings. By evaluating these relationships, this study will contribute to better management practices for *A. lebbeck* seedlings in nurseries, with implications for enhancing reforestation and agroforestry efforts.

We hypothesized that intermediate soil moisture would maximize germination and early seedling growth of *A. lebbeck*, whereas both low moisture (25% FC) and saturated moisture (100% FC) would reduce performance due to water deficit and reduced root zone aeration, respectively.

Materials and Methods

Experimental Site

The study was conducted at the Forest Nursery of Khulna University, located in the southwestern coastal region of Bangladesh (Figure 1). The general climate of the district is tropical monsoon, which is mostly characterized by hot summer, mild winter, and monsoonal rain. The growing season starts in April and continues until November (BBS, 2013; Rahman *et al*. 2018). To eliminate climatic fluctuations the experiment was conducted in a glasshouse environment (FAO, 1998; Gardner *et al*., 2018).

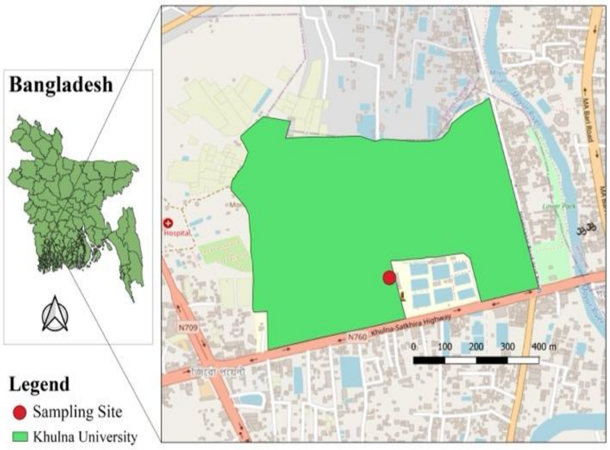

Figure 1: Map of the experimental site

Soil Preparation and Seed collection

Soil was collected from a plantation site and mixed thoroughly to homogenize and used as a growth medium for both germination and growth study. A 6×4 inch polybag was used in the experiment, and each polybag had two perforations just above the bottom of the polybag. Soil enough to fill five polybags were oven dried at 105°C. Five soil filled polybags were weighed separately for the control treatment, and the average weight of the five soil samples was used to fill the polybags for the experiment. To determine the 100% field capacity of the soil, five polybags were fully watered with tap water and kept until the last drop drained out due to the gravitational force. The wet polybags were weighed, and the oven-dry weight was deducted from the soil sample, and the resulting amount of water was 100% FC. The average value of the water from five samples were considered as the required water for 100% field capacity (FC) for the experiment. Later on, the required amount of water for 50% and 25% FC were calculated. Soil moisture was maintained through weight-based irrigation by calculating the average evaporation rate using five control polybags without seedlings throughout the experiment.

For seed collection, mature pods were harvested manually between March and April by climbing and using long sticks from trees within Khulna University and the surrounding areas of Khulna district. After seed extraction from the pods, the seeds were sun-dried for one week and carefully screened to remove damaged seeds.

Experimental Setup

There were two experimental designs used. Completely Randomized Design (CRD) was used for Germination study and Randomized Block Design (RCBD) was used for growth study in a glass house.

Seed Germination: The experiment was set up using Completely Randomized Design (CRD) with three levels of Field Capacity (FC) (25%, 50% and 100 %) as treatments. Each treatment contained four replications and each replication consisted 45 seeds. No chemical pre-treatment or sterilization was applied to the seeds before sowing. However, seeds were soaked for 24 hours before sowing. Seed germination was monitored daily.

Seedling Growth: Considering the microclimatic variation especially light intensity, and air circulation of the uncontrolled glasshouse, the growth experiment was arranged in a Randomized Complete Block Design (RCBD), where each block represented a glasshouse position to account for possible micro-environmental variation. Due to poor germination and subsequent complete (100%) mortality of sprouts, 25% FC was excluded from the growth experiment. Therefore, there were two treatments: 50% FC and 100 % FC, three blocks. 10 seedlings were considered as replications per treatment per block. Therefore, each treatment per block contained 30 seedlings. The experiment was monitored daily for moisture adjustment and conducted from July to September in a glasshouse, with daytime temperatures ranging from 24 to 45 °C (Table 1).

***Data collection*:** The cumulative germination data was recorded at two-day intervals for 60-day period. For seedling growth, height and diameter increment was considered as explanatory perimeter. Height growth was measured from collar region (just above the soil surface) to the tip of the shoot in cm. Diameter increment was measured at the collar region of the seedling using slide calipers.

Table 1: Basic properties of homogenized soil used in the study

pH	7.87
EC	2.36 mS/cm
Available N	2310^{-3} (.003) mg/gm
Available P	1.210^{-4} (.00007) mg/gm
Available K	13.9910^{-2} (.003) mg/gm
Available Na	18.810^{-2} (.079) mg/gm

Data analysis

Seed Germination: Germination was recorded based on radicle emergence. The Germination percentage and Mean germination Time (MGT) for each treatment was calculated using the following formula:

Germination percentage (%) = (Number of germinated seeds)/ (Total number of seeds planted) ×100

MGT = (∑nxD)/(∑n)

Where:

- n: Number of seeds newly germinated on day D.
- D: Number of days from the beginning of the germination test.
- ∑n: Total number of seeds germinated at the end of the test.

Statistical test: Python program (version 3) and appropriate python libraries (panda, statmodels and scipy packages) were used to perform all statistical analyses and graphical outputs. Differences among treatments were analyzed using one-way analysis of variance (ANOVA) and Tukey Test for post-hoc test.

Result

Germination

The germination of A. lebbeck differed significantly among the soil moisture regimes (25%, 50%, and 100% FC). Higher germination percentage was found for 50% FC (78%) and for 100% FC (76%) and 25% FC (15%) (Fig. 02). One-way ANOVA for germination percentage showed significant difference ($p<0.05$). Germination percentage of 25% FC was significantly different from 50% FC and 100% FC (Figure 2). However, there was no significant ($p>0.05$) difference between 50% FC and 100% FC (Annexure A1). The Mean Germination Time (MGT) was highest for 50% FC (12.09 days) which indicate longer time for germination and was significantly ($p<0.05$) different from 100% FC (5.5 days) and 25% FC (2.5 days). However, germination percentage (15%) was poor at 25% FC though MGT was low (Figure 3). Seed soaking prior to sowing could have triggered germination for all treatments but 100% mortality of seedling at 25% FC within 7 days shows irreversible moisture stress for survival.

Height and Diameter Growth

Seedling growth were assessed using height and diameter. mean height was calculated 8.956 cm ± 0.929 cm (SE) for 50% FC and 5.511cm ± 0.571 cm (SE) for 100% FC. The Two-Way ANOVA showed significant ($p<0.05$) effect on height growth. It justifies blocking in design and indicating soil moisture level and microclimatic influence growth variation (Annexure A2).

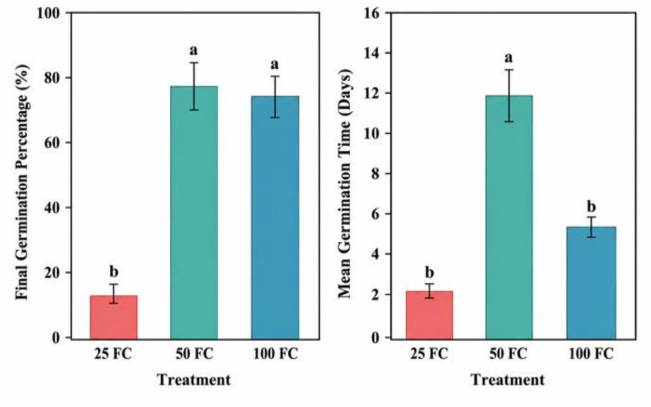

Figure 2: Germination percentage and Mean Germination Time (MGT) at different field capacities

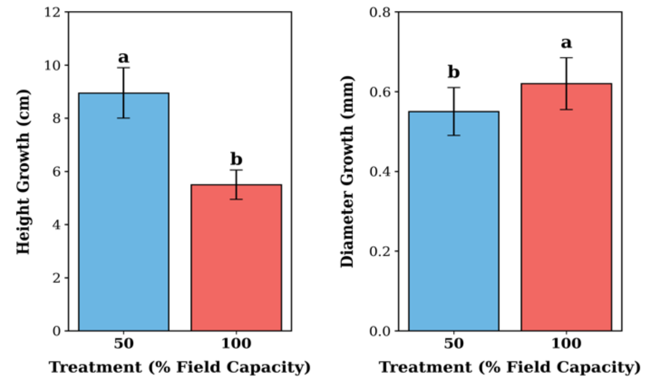

Figure 3: Comparison of growth performance (height and diameter) in different field capacities

Diameter growth was measured at collar diameter (CD), which increased progressively over time under both FCs. Over the period, the mean diameter was recorded as 0.551 cm ± 0.057 cm (SE) for 50% FC and 0.620 cm ± 0.064 cm (SE) for 100% FC. The both treatments and block significantly ($p<0.05$) influenced diameter growth. However, diameter growth at 100% FC was significantly ($p<0.05$) higher than 50% FC. Though ANOVA showed a significant effect, Tukey test yielded a p=0.4279 value and fails to reject null hypothesis and confirms subtle effect on dimeter growth. The result indicates seedlings prioritize shoot elongation significantly under favorable moisture conditions, while diameter growth develops more gradually over time.

Discussion

Soil moisture availability is a primary factor determining seed germination and early seedling development of *A. lebbeck* (L.) Benth. The results indicate 25% FC represent unfavorable for both germination and survival. This is consistent with Bradford (1990) who found a sharp germination decline in *Acacia nilotica* and *Leucaena leucocephala*, under reduced moisture. Such moisture deficits delay enzymatic activation, reduce metabolic flux, and prevent radicle emergence (Bewley *et al*., 2013; Shahid *et al*., 2008; Taiz *et al*., 2015). While 100% FC showed better germination percentage, short MGT, and balanced height and diameter growth indicating ideal condition for the species in comparison to 50% FC. However, 50% FC does show highest germination percentage and the longest MGT which indicate the adaptability of the species with the moisture limiting environment. Though diameter growth is not as sensitive as height growth which is a common and well-documented trend in woody species (Wilson & Witkowski, 1998; Kozlowski & Pallardy, 2002), the taller height but thinner diameter at 50% FC indicates morphological plasticity to allocate more to height growth than diameter growth in comparison to 100% FC.

50% FC likely created a favorable balance between water availability and air supply, supporting both germination and shoot growth. These results are in agreement with previous studies on other related species, where moderate moisture content (60-80% FC) adequately imbibed the embryo without restricting oxygen diffusion and resulted in significant growth (Chakraborty *et al*., 1992; Khurana & Singh, 2001). Additionally, the study supports the stress-gradient theory, which suggests that plant performance declines under both resource scarcity (drought) and excess (waterlogging), and optimal performance can be achieved in between (Grime, 1973).

In general, the outcomes of this study are a perfect example of optimal partitioning theory, which predicts that plants allocate biomass toward organs that maximize the acquisition of the most limiting resources, such as light and water (Bloom *et al*., 1985). *A. lebbeck* showed adaptive capacity to moisture stress but the threshold level is 50% FC at seedling stage in the context of the experiment. Therefore, 100% FC is beneficial to produce healthy seedlings in a nursery. However, 50% FC can be considered to harden the seedling before planting in the wild.

Conclusion

This study shows that soil moisture plays a significant role in regulating the germination and early seedling growth of *A. lebbeck*. Germination of *A. lebbeck* was constrained under moisture deficit condition. Better adaptation for germination was observed at 50% FC. The findings are also consistent with the ecological theories of optimal resource allocation and stress-gradient theory which can help nurseries produce healthy seedlings for plantation.

Limitations

This study was conducted on a single species, at one location, and during one growing season under glass house conditions. Therefore, the findings may not fully represent field-level responses under varying soil types, climatic conditions, and seasonal patterns. Future studies should include multiple locations, different soil textures, longer observation periods, and physiological or biomass measurements to better understand the moisture response of *A. lebbeck* seedlings.

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Conflict of Interest

The authors do not have any conflicts of interest, financial or personal, or professional issues regarding the publication of this manuscript.

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Annexure

Annexure A1: One-Way ANOVA for Germination Percentage and Mean Germination Time

	Metric	F-statistic	p-value
0	Germination Percentage	162.3462	8.69E-08
1	Mean Germination Time	24.94793	2.13E-04

A1.1: Germination Percentage - Tukey's HSD:

	Group1	Group2	Mean diff	*p*-adj	Lower	Upper	Reject
0	100 FC	25 FC	-61.6667	0	-72.8519	-50.4814	TRUE
1	100 FC	50 FC	1.6667	0.9099	-9.5186	12.8519	FALSE
2	25 FC	50 FC	63.3333	0	52.1481	74.5186	TRUE

A.1.2: Mean Germination Time - Tukey's HSD:

	Group1	Group2	Mean diff	*p*-adj	Lower	Upper	Reject
0	100 FC	25 FC	-3.3	0.1027	-7.2597	0.6597	FALSE
1	100 FC	50 FC	6.5415	0.0033	2.5818	10.5012	TRUE
2	25 FC	50 FC	9.8415	0.0002	5.8818	13.8012	TRUE

Annexure A2: Two-way ANOVA for Height and diameter growth

	Variable	Sum of sq	df	*F*	PR(>F)
C(Treatment)	Height Growth	177.9515	1	61.02372	1.58E-10
C(Block)	Height Growth	871.0489	2	149.3515	3.57E-23
Residual	Height Growth	163.3018	56	NaN	NaN
C(Treatment)	Diameter Growth	0.070727	1	5.433472	2.34E-02
C(Block)	Diameter Growth	5.707803	2	219.2468	3.26E-27
Residual	Diameter Growth	0.728943	56	NaN	NaN

A.2.1: Tukey HSD: Height Growth

Multiple Comparison of Means - Tukey HSD, FWER=0.05						
Group1	Group2	Mean diff	*p*-adj	Lower	Upper	Reject
50	100	-3.4443	0.0025	-5.6269	-1.2617	TRUE

A.2.2: Tukey HSD: Diameter Growth

Multiple Comparison of Means - Tukey HSD, FWER=0.05						
Group1	Group2	Mean diff	*p*-adj	Lower	Upper	Reject
50	100	0.0687	0.4279	-0.1035	0.2408	FALSE