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Influence of Substrate Type and Water Level on the Germination and Growth of Three Agroforestry Species

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Authors' contributions

This work was carried out in collaboration among all authors. Authors YSFM, YTJ and BHR designed the study and performed the statistical analysis. The protocol was written by Author YSFM, as was the first draft of the manuscript. Authors YSFM, YTJ and BHR conducted the literature search. All authors read and approved the final manuscript.

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Abstract

Background: Leguminous species play a vital role in agroecosystems, particularly in semi-arid regions, due to their capacity for biological nitrogen fixation, soil restoration, and contribution to sustainable farming systems. However, despite the ecological and socio-economic importance of key species such as *Faidherbia albida*, *Gliricidia sepium*, and *Pterocarpus erinaceus*, limited knowledge on low-cost and reproducible germination conditions constrains their regeneration and conservation efforts.

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Aims: This study examines the interaction between substrate and water availability in order to identify the optimal conditions for seedling production of *Faidherbia albida* (Del.) A. Chev, *Gliricidia sepium* (Jacq.) Walp, and *Pterocarpus erinaceus* Poir.

Study Design: The study material consisted of seeds from the three species. The treatments comprised three substrates combined with four irrigation regimes. The substrate formulations were as follows: 1/2 manure + 1/2 clay (M1), 1/2 manure + 1/2 sand (M2), and 1/2 manure + 1/2 sawdust (M3). Water availability was the second factor with the field capacity (FC) to have four irrigation levels: 100% FC, 75% FC, 50% FC, and 25% FC. In total, 12 treatments were studied for each species.

Place and Duration of Study: The study was conducted in Gampéla, located in the municipality of Saaba, Burkina Faso, West Africa. It was conducted in 2024 over a period of four months.

Methodology: The study consisted of the establishment of a completely randomized factorial design with three replications. The pots were filled with the different substrates, and sowing was carried out at a rate of two seeds per pot. Starting two days after sowing, the number of germinated seeds was recorded every two days, while growth parameters were measured every seven days, beginning thirty days after sowing.

Results: The results show that substrate M3 offers the best germination rates: 76.7% (*G. sepium*), 79.2% (*P. erinaceus*), and 69.6% (*F. albida*), unlike M1 and M2 which are less effective, with germination rates below 50% regardless of the species. Watering at 50% and 75% of field capacity optimized germination, excess water (100%) reduced the germination performance of the species. The interaction between substrate and water volume does not reveal any significant difference in the growth parameters of *Faidherbia albida* ($P > 0.05$). For seedling growth, *F. albida* shows a clear preference for substrate M1 (manure + clay) combined with a low water volume (25% CC), without any notable interaction. In *G. sepium*, the substrate influences height and foliage, with an optimum at 25% CC for both height and diameter, but significant substrate-water interactions emerge. Finally, *P. erinaceus* is highly dependent on substrate M3 for diameter and foliage, shows low sensitivity to water regime, and exhibits significant interactions.

Conclusion: This study provides essential data for improving agroforestry species regeneration techniques. It reveals the potential of sawdust as a substrate component and the importance of precise watering control to maximize seedling germination and growth. The combined management of substrate and water regime, adapted to the Eco physiological needs of the species, is crucial for maximizing production.

Keywords: Substrate; field capacity; germination; growth; tree legumes.

1. Introduction

Legumes include a wide variety of trees, shrubs, vines, and herbaceous plants that play a central role in agricultural and pastoral systems. Their importance is particularly notable in semi-arid areas, where they contribute to the restoration of degraded soils and the sustainability of farms (Nabaloum et al., 2022; Meng et al., 2025). Approximately 90% of species in this family are distinguished by their ability to fix atmospheric nitrogen through symbiosis with nodular bacteria (Lu et al., 2018). Among them, the tree species *Faidherbia albida*, *Gliricidia sepium*, and *Pterocarpus erinaceus* play an important ecological and socio-economic role for Sahelian populations. *G. sepium* is a fast-growing exotic species that provides both wood and nitrogen-rich foliage used as green manure to improve soil fertility (Rahman et al., 2019) and as fodder (Silva et al., 2024). It is used in alley cropping systems or as living hedges to protect soils from erosion in agroforestry (Bayala et al., 2009). The species *F. albida* and *P. erinaceus* play similar roles in ecological and socioeconomic terms. Indeed, *P. erinaceus* is one of the species with high cultural and economic value, prized for its wood used in crafts (Segla et al., 2015; Rabiou et al., 2015, 2017). Its increasing exploitation by local populations has made it a priority in conservation programs (Nacoulma et al., 2011) as it is highly endangered and locally extinct in certain areas (Diakite et al., 2024). As for *F albida*, emblematic of agroforestry parks in West Africa, its presence contributes to improved cereal yields, soil and mineral enrichment, and better soil water availability (Bayala et al., 2015). The foliage of *P. erinaceus* and the pods of *F. albida* are excellent fodder for livestock (Rabiou et al., 2017). Despite their importance, *F. albida* and *P. erinaceus* populations are aging and struggling to regenerate (Rabiou et al., 2015; Tougiani et al., 2021). Although these species have been the subject of multiple studies on domestication (Ky-Dembele et al., 2016; Bamba et al., 2018; Tchatchoua et al., 2019; Diémé et al., 2025), there is still insufficient data on the optimal conditions for seed germination under conditions that are reproducible by the producer and at low cost. Indeed, the conservation and sustainable exploitation of a species necessarily require knowledge of its regeneration techniques (Houphouet et al., 2022). Among these techniques, controlling watering and substrate type are essential to the germination process (DuPont, 2025;

Iroko et al., 2021). It is in this context that the present study contributes to understanding the effect of substrates and water availability on the establishment process of these species. More specifically, it aims to evaluate the effect of substrates and water level on seed germination and seedling growth of the three species.

2. Material and Methods

2.1 Plant Material

The plant material used in this study consists of seeds from *Faidherbia albida*, *Gliricidia sepium*, and *Pterocarpus erinaceus*. These seeds were obtained locally from the National Forest Seed Center (CNSF) in Ouagadougou and the INERA research station in Farakoba, Bobo-Dioulasso. These seeds belong to the category of seeds known as orthodox seeds. These are seeds that can withstand dehydration and low-temperature storage while retaining their germination capacity.

2.2 Study of Germination

Germination tests were carried out in plastic pots (20 cm of height and 15 cm of diameter). To do this, formulations were made with ½ manure + ½ clay (M1), ½ manure + ½ sand (M2) and ½ manure + ½ sawdust (M3). The field capacity (FC) of each formulation was then determined using re-draining of the soil column method (Bourdon and Henin 1950). After determining the field capacity, four watering levels were defined: 100% FC, 75% FC, 50% FC, and 25% FC. A total of 12 treatments, resulting from the combination of three types of substrates and four water volume levels, were applied for each species (Table 1). The pots were then filled with the different substrate formulations. These pots were arranged in a factorial design with three replicates. The statistical unit consisted of 10 pots. Each treatment comprised 30 pots, for a total of 380 pots per species. In total, the experiment was conducted using 1,140 pots across all three species studied.

Table 1. Details of the experimental treatments in the study

Substrates	Treatments	Description	Code
M1	100% of FC	½ manure + ½ clay with	T1
	25 % of FC	½ manure + ½ clay with 25% of the substrate field capacity	T2
	50% of FC	½ manure + ½ clay with 50% of the substrate field capacity	T3
	75 % of FC	½ manure + ½ clay with 75% of the substrate field capacity	T4
M2	100% of FC	½ manure + ½ sand with 100% of the substrate field capacity	T5
	25 % of FC	½ manure + ½ sand with 25% of the substrate field capacity	T6
	50% of FC	½ manure + ½ sand with 50% of the substrate field capacity	T7
	75 % of FC	½ manure + ½ sand with 75% of the substrate field capacity	T8
M3	100% of FC	½ manure + ½ sawdust with 100% of the substrate field capacity	T9
	25 % of FC	½ manure + ½ sawdust with 25% of the substrate field capacity	T10
	50% of FC	½ manure + ½ sawdust with 50% of the substrate field capacity	T11
	75 % of FC	½ manure + ½ sawdust with 75% of the substrate field capacity	T12

2.3 Chemical Parameters of Substrates

The chemical parameters of the substrates were determined in the laboratory (Table 2) and reveal that substrate M3 is distinguished by very high levels of organic matter (587.4%), total nitrogen (14.4%), total phosphorus (2455.77 mg/kg), and total potassium (9218.32 mg/kg), indicating a high content of essential nutrients and well-humified, stable organic matter (C/N ratio = 24). Substrates M1 and M2 have lower values and slightly higher C/N ratios (25 and 27), suggesting slower mineralization and lower organic and nutrient content.

2.4 Data Collection

The data collected included the number of germinated seeds, height, diameter, and number of leaves of the seedlings. The height of the young plants was measured using a tape measure, while the collar diameter was measured using a caliper. The number of germinated seeds was recorded every two days, and growth parameters were measured every seven days for 30 days after seeds germination. This data was used to determine:

Table 2. Chemical parameters of substrates

Substrates	pH	Organic Matter (g/kg)	Total Nitrogen (g/kg)	Total Phosphorus (g/kg)	Total Potassium (g/kg)	C/N
M1	7.69	149.3	3.58	715.95	531.52	25
M2	8.71	105.3	2.37	623.52	934.53	27
M3	8.42	587.41	4.42	4557.79	218.32	24

Legend: M1 = ½ manure + ½ clay, M2 = ½ manure + ½ sand, M3 = ½ manure + ½ sawdust

Germination Rate (GR) expressed as a percentage, is used to assess the germination potential of seeds. It was calculated using the following equation:

$$\text{GR} = \frac{\text{The number of germinated seeds per traetment}}{\text{The total number of seeds sown per traetment}} \text{X } 100 \tag{1}$$

Hmoy (the average height of the plants) was determined using equation 2:

$$Hmoy = \frac{\text{The sum of the heights of the plants per traetment}}{\text{The total number of plants per traetment}} \tag{2}$$

Dmoy (the average diameter of the plants) was determined using equation 3

$$\text{Dmoy} = \frac{\text{The sum of the diameters of all plants per traetment}}{\text{The total number of plants per traetment}} \tag{3}$$

NFmoy (the average number of leaves per plant) was also determined using equation 4:

$$\text{NFmoy} = \frac{\text{The sum of leaves off all plants per traetment}}{\text{The total number of plants per traetment}} \tag{4}$$

2.5 Data Analysis

All statistical analyses were performed using R Studio software version 10.2. The significance threshold was set at 0.05 for all analyses. Data normality was verified using the Shapiro-Wilk test, and when data distribution did not follow a normal distribution, a nonparametric approach was used. Thus, the main effects of the “substrate” and “water volume” factors, and their interaction, were evaluated using Aligned Rank Transform ANOVA (ART-ANOVA), implemented in the ARTool package. This method, which is suitable for situations where the parametric assumptions of ANOVA are not met, allows factorial effects to be analyzed using non-parametric tests equivalent to ANOVA. In the case of a significant effect ($p < 0.05$), Bonferroni's post-hoc multiple comparison test was conducted to identify differences between modalities.

3. Results and Discussion

3.1 Effect of Substrate Type on Species Germination Rates

Analysis shows significant differences between substrates for the species *G. sepium* and *P. erinaceus* ($P < 0.05$) but not for *F albida* (P=0.07) (Fig. 1). Substrate M3 (½ manure + ½ sawdust) showed the highest germination rates, 80±9,33% and 81.70±5.48% for *G. sepium* and *P. erinaceus*, respectively. The lowest germination rates were observed in substrate M1 (½ manure + ½ clay), at 7.5±2.57% and 12.91±2.08% for *G. sepium* and *P. erinaceus*, respectively.

The germination rate in substrate M3 is higher than that observed in substrates M1 and M2 for all three species. These results could be explained by the fact that sawdust has high porosity, which promotes water absorption and good air circulation, preventing waterlogging (Mapongmetsem et al., 2012). Its properties facilitated embryo germination, root emission, and root anchoring in the substrate. Furthermore, Buba et al. (2023) emphasize that the physical properties of the substrate that promote respiration for optimal germination are water retention and air circulation. Our results corroborate those of Aka et al. (2022), who argued that germination parameters vary depending on the substrate and that substrates composed of sawdust and rice husks have high germination rates.

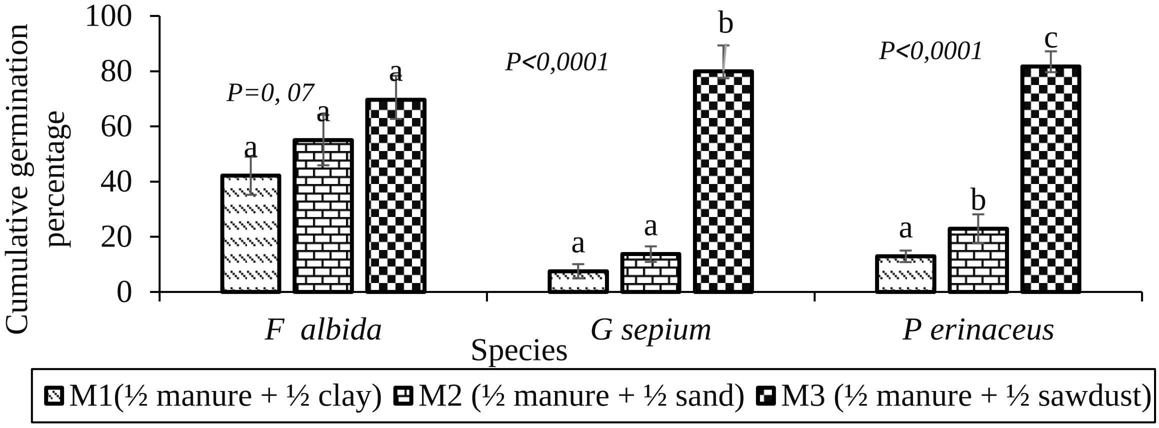

Fig. 1. Effect of substrate type on the germination rate of the three species

3.2 Influence of Water Volume on Species Germination Rates

Fig. 2 shows the germination rates of species as a function of water volume received and reveals a significant effect of water volume on the germination rate of *P. erinaceus* (p < 0.001). However,the ent water volumes did not show any significant effect on germination rates for the species *F albida* and *G sepium* (P > 0.05). In fact, the 50%CC volume shows the highest germination rate, i.e., 51.7 ± 11.63%, while the lowest germination rate is obtained with the 100%CC volume, i.e., 32.80 ± 11.47%.

This suggests species-specific responses to water availability. This variability highlights the importance of considering the hydrological needs of each species when planning restoration efforts (Fogliani, 2002). These differential responses highlight the complex interaction between water availability and germination success (Gao et al., 2021). Some species have variable germination rates and require specific environmental conditions, beyond simple water availability, to establish themselves successfully (Nogueira et al., 2014). Indeed, the germination potential of some species is highly variable, influenced by factors such as temperature, storage duration, and seed moisture content (Mota et al., 2017). This interspecific variation requires a thorough understanding of the ecophysiological requirements of each species for optimal germination, particularly when considering the challenges posed by changing environmental conditions. Furthermore, the high germination rates obtained with volumes of 50% FC and 75% FC would represent the optimum water requirements of substrates for plant production. Indeed, according to Buba et al. (2023), moisture must be maintained between 50% and 75% of the substrate's field capacity in order to avoid both drying out and saturation, which could reduce germination by damaging the seeds.

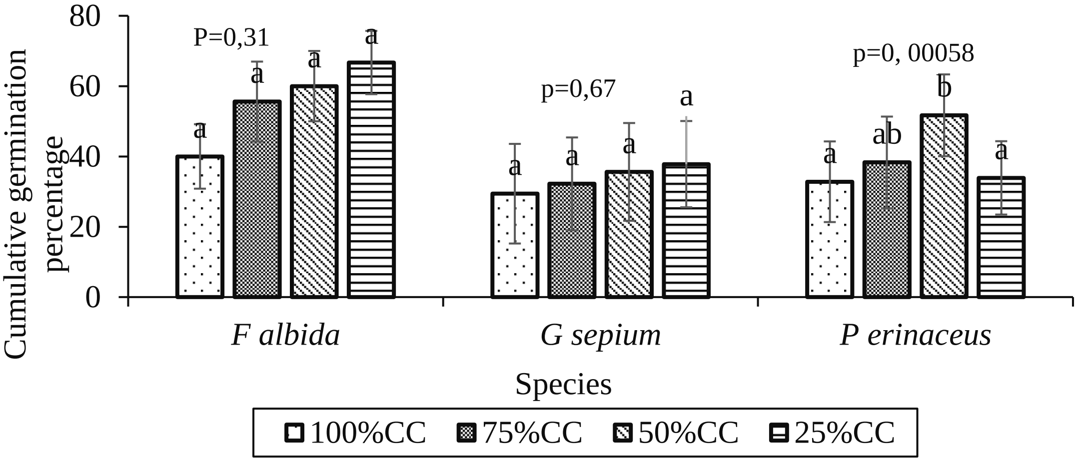

Fig. 2. Effect of volume on the germination rate of the three species

3.3 Effect of the Interaction Between Water Volume and Substrate Type on Seed Germination Rates

Analysis shows that there is a significant interaction between substrate and water level on germination rate only for the species *P erinaceus* (Table 3). Indeed, M3 +50% FC has the highest germination rate, at 90 ± 10%, followed by M3 +75% FC and M3 +100% FC with 88.33 ± 11.67% and 75 ± 25% respectively. In contrast, the lowest rate was observed with M1 +100% FC at 6.67 ± 1.67%. Furthermore, the germination rates of *G. sepium* and *P. erinaceus* are low in substrates M1 and M2 with watering volumes of 100% FC and 75% FC. These seeds appear to be sensitive to both heavy substrates and high-water supply. Indeed, water saturation reduces the aeration necessary for germination metabolism, as already pointed out by Buba et al. (2023). In addition, sand and clay are composed of very fine particles compared to sawdust, which, when saturated with water, form a dense and compact structure that significantly reduces the pore space available for air. Indeed, the lack of aeration in certain substrates most often leads to root mortality, usually due to attacks by phytopathogenic fungi.

The type of substrate and water level did not significantly affect the germination rate of F albida seeds. This could be explained by the high dormancy of *F albida* seeds. Indeed, unlike Pterocarpus and Gliricidia seeds, which have a less rigid seed coat, *F albida* possesses a hard shell responsible for dormancy. This characteristic generally necessitates dormancy-breaking operations to optimize germination. This impermeability is frequently cited as the main cause of dormancy in Fabaceae species, where the hard seed coat acts as a physical barrier limiting water absorption and embryonic development (Toumi et al., 2017). Other research indicates that this physical dormancy may also be associated with the presence of inhibitory chemical compounds, such as polyphenols, which are released during hot water treatment and significantly influence the germination process (Cavallaro et al., 2021). Pretreatment with sulfuric acid, scarification, and soaking in hot water aim to soften the seeds or create a pathway for water to reach the embryo and trigger the germination process (Yandou et al., 2019; Buba et al., 2023; Diémé et al., 2025).

Table 3. Effect of substrate and volume interaction on seed germination rate

	Germination rate (%)		
Interaction substrats and Water	***Faidherbia albida***	***Gliricidia sepium***	***Pterocarpus erinaceus***
M1(100%FC)	31.67±10.14**a**	-	6.67±1.67**bc**
M1(25%FC)	55±2.89**a**	18.33±1.67**a**	18.33±3.33**abc**
M1(50%FC)	58.33±19.22**a**	5±2.89**a**	13.33±6.01**a**
M1(75%FC)	23.33±10.93**a**	6.67±6.67**a**	13.33±3.33**ab**
M2(100%FC)	28.33±13.02**a**	6.67±4.41**a**	16.67±1.67**abc**
M2(25%FC)	58.33±22.5**a**	13,33±4.41**a**	10±2.89**ab**
M2(50%FC)	66.67±13.64**a**	21.67±3,33**a**	51.67±4.41**c**
M2(75%FC)	66.67±22.05**a**	13.33±8.33**a**	13.33±3.33**ab**
M3(100%FC)	60±20.82**a**	81.67±18.33**a**	75±14.43**abc**
M3(25%FC)	86.67±13.33**a**	81.67±18.335**a**	73.33±10.14**abc**
M3(50%FC)	55±24.6**a**	88.33±11.67**a**	90±10**abc**
M3(75%FC)	76.67±12.02**a**	68.33±31.67**a**	88.33±11.67**abc**
P	*0.65*	*0.98*	*0.046*

Values affected by the same letters in the same column are not statistically different in the Art ANOVA test at the 0.05 level

3.4 Effect of Substrate, Volume and their Interaction on the Growth Parameters of Seedlings of the Three Species

Statistical analysis indicate that substrate type has no significant effect on height ($P=0.22$), but revealed a significant effect on collar diameter and leaf number of *F. albida* ($P < 0.05$). Indeed, substrate M1 produced seedlings with larger diameters (2.91 ± 1.32 mm) and a higher number of leaves (59±6 leaves) compared to substrates M2 and M3. Water regime, on the other hand, has a significant effect on height and stem diameter (P = 0.02 and P = 0.03, respectively), with no significant effect on the number of leaves. Indeed, the 25% field capacity (FC) watering level simultaneously maximized height (33.11 ± 2,21 cm), collar diameter (2.58±0.15 mm), and leaf number (54 ±5.35). Nevertheless, the interaction between factors showed no significant effect on the measured growth parameters (P > 0.05) (Table 5).

For *Gliricidia sepium*, the analysis indicated that substrate had no significant effect on seedling collar diameter (P = 0.65). However, it had a significant effect on height and mean leaf number (P = 0.025 and P < 0.001, respectively). Regarding water level, the analyses showed a significant effect on height and collar diameter but not for leaf number (Table 4). The 25% FC watering level produced the tallest seedlings (63.28 ± 3.04 cm) with the largest diameters (9.77 ± 0.36 mm) (P < 0.001 and P < 0.01). In contrast, abundant watering at 100% FC resulted in the lowest heights and diameters (43.02 ± 2.7 cm and 7.29 ± 0.46 mm) but promoted a higher leaf number (16 ± 0.86 leaves). Furthermore, the interaction between factors showed significant differences across all growth parameters (Table 6). Greater heights and leaf numbers were obtained with M1 (50% FC) and M3 (25% FC). The largest diameters were recorded with M3 (75% FC) (14.2 ± 0.49 mm) and M2 (25% FC) (11.6 ± 0.67 mm), whereas treatments M3 (100% FC) and M1 (50% FC) produced the highest leaf numbers respectively 17.4±0.52 and 16±1 (Table 6).

Regarding *P. erinaceus*, analysis showed that water volume had no significant effect on seedling growth parameters (P > 0.05) (Table 4). In contrast, substrate exhibited a significant effect on diameter (P < 0.001) and leaf number (P < 0.001). Substrate M3 produced seedlings with the largest diameter (2.27±0.08 mm), followed by M2 (1.87 ± 0.13 mm) and M1 (1.33 ±0.31 mm). Moreover, the interaction between factors also showed a significant effect on all growth parameters (Table 7). The treatments M1 (25%FC) (20.50 ± 4.5 cm) and M1 (50%FC) (18.50 ± 2.5 cm) show the greatest heights. Regarding the number of leaves, the combination M2 (50%FC) has the highest average (11.60 ± 0.74 leaves). M1 (100%FC) et M2 (25%FC) show the lowest number of leaves, which is 7 leaves.

Table 4. Effect of substrate type and water volume on seedling development

	Settings	**M1**	**M2**	**M3**	***P***	
F albida	Hmoy (Cm)	31.8±2.2**a**	27.64±2.33**a**	27.02±1.72**a**	*0.219*	
	Dmoy (mm)	2.91±1,32**a**	1.99±0.78**b**	2.20±0.79**b**	*0.008*	
	Nfmoy	59±6**a**	37±5**a**	38±4b	*0.02*	
G sepium	Hmoy (Cm)	48±6.28**a**	52.5±2.19**ab**	57.9±1.61**b**	*0.025*	
	Dmoy (mm)	8.18±0.99**a**	9.02±0.48**a**	8.47±0.19**a**	*0.657*	
	Nfmoy	13.1±1.52**ab**	13.6±0.45**b**	14.9±0.25**a**	*<0.001*	
P erinaceus	Hmoy (Cm)	12.7±3.06**a**	14.8±0.87**a**	14.7±0.33**a**	*0.31*	
	Dmoy (mm)	1.33±0.31**b**	1.87±0.13**ab**	2.27±0.08**a**	*<0.001*	
	Nfmoy	6.2±1.48**b**	11±0.63**a**	9±0.19b	*<0.001*	
	Settings	**100%FC**	**75%FC**	**50%FC**	**25%FC**	***P***
F albida	Hmoy (Cm)	24±2.5**ab**	23.2±1.89**a**	30.7±2.27**ab**	33.1±2.21**b**	*0.02*
	Dmoy(mm)	2.47±0.27**ab**	1.89±0.1**b**	2.48±0.2**ab**	2.58±0.15**a**	*0.03*
	Nfmoy	42±6.95**a**	32±4.8**a**	47±5.07**a**	54±5.35**a**	*0.08*
G sepium	Hmoy (Cm)	43.02±2.7**b**	61.4±2.1**a**	55±2.12**a**	63.3±3.04**a**	*< 0.001*
	Dmoy (mm)	7.29±0.46**b**	8.62±0.28**ab**	8.27±0.28**b**	9.77±0.36**a**	*0.009*
	Nfmoy	16±0.86**a**	14±0.4**a**	14±0.3**a**	14±0.26**a**	*0.05*
P erinaceus	Hmoy (Cm)	13.17±0.56**a**	14.12±0.93**a**	15.36±0.61**a**	15.48±0.63**a**	*0.42*
	Dmoy (mm)	1.86±0.13**a**	1.84±0.15**a**	2.21±0.12**a**	2.69±0.15**a**	*0.06*
	Nfmoy	8±0.35**a**	8±0.53**a**	9±0.4**a**	9±0.39**a**	*0.63*

Values affected by the same letters on the same line are not statistically different in the Art ANOVA test at the 0.05 significance level

Table 5. Effect of substrate and volume interaction on the growth parameters of *Faidherbia albida* seedlings

Interaction substrates and Water	**Hmoy (Cm)**	**Dmoy (mm)**	**NFmoy**
M1 (100%FC)	20.2±3.23**a**	3.18±0.83**a**	46±18**a**
M1 (25%FC)	36.9±3.18**a**	3.06±0.25**a**	72±8**a**
M1 (50%FC)	31.4±3.92**a**	2.83±0.4**a**	55±10**a**
M1 (75%FC)	21.7±1.67**a**	2.01±0.39**a**	26±11**a**
M2 (100%FC)	30.2±5.05**a**	2.41±0.61**a**	45±9**a**
M2 (25%FC)	23.6±5.13**a**	1.84±0.27**a**	32±10**a**
M2 (50%FC)	34.6±4.62**a**	2.1±0.31**a**	43±8**a**
M2 (75%FC)	24.3±3.18**a**	1.91±0.16**a**	35±9**a**

Interaction substrates and Water	Hmoy (Cm)	Dmoy (mm)	NFmoy
M3 (100%FC)	24.1±3.75**a**	2.19±0.25**a**	40±9**a**
M3 (25%FC)	34.1±3.42**a**	2.49±0.2**a**	47±8**a**
M3 (50%FC)	26.3±3.02**a**	2.35±0.23**a**	39±7**a**
M3 (75%FC)	22.7±2.78**a**	1.86±0.13**a**	31±6**a**
P	*0.17*	*0.45*	*0.21*

Values affected by the same letters in the same column are not statistically different in the Art ANOVA test at the 0.05 significance level

Table 6. Effect of substrate and volume interaction on the growth parameters of *Gliricidia sepium* seedlings

Interaction substrates and Water	Hmoy (Cm)	Dmoy (mm)	NFmoy
M1 (100%FC)	-	-	-
M1 (25%FC)	55.3±4.31**e**	9.33±0.61**bc**	15.3±0.52**e**
M1 (50%FC)	68±2**d**	10.7±0.14**bc**	16±1**cde**
M1 (75%FC)	49.7±10.16**abcd**	9.26±0.79**a**	14.7±0.88**abcde**
M2 (100%FC)	38.3±1.67**abcd**	6.4±0.28**abc**	11.7±1.45**abcd**
M2 (25%FC)	47.6±5.19**ab**	11.6±1.82**abc**	12.4±0.25**abcde**
M2 (50%FC)	56.9±2.91**cd**	8.49±0.44**abc**	14.5±0.67**abcde**
M2 (75%FC)	54±4.07**abc**	9.36±0.61**abc**	13.5±0.96**abcde**
M3 (100%FC)	46.4±2.3**bcd**	7.87±0.39**abc**	17.4±0.52**bde**
M3 (25%FC)	67.8±3.76**d**	9.58±0.38**abc**	14.5±0.3**abcde**
M3 (50%FC)	53.4±2.85**bc**	8.01±0.35**ab**	13.5±0.31**ac**
M3 (75%FC)	64.1±2.25**bcd**	14.2±0.49**c**	14.2±0.49**abcde**
P	*0,01*	*0,01*	*<0,0001*

Values affected by the same letters in the same column are not statistically different in the Art ANOVA test at the 0.05 significance level

Table 7. Effect of substrate and volume interaction on the growth parameters of *Pterocarpus erinaceus* seedlings

Interaction substrates and Water	Hmoy (Cm)	Dmoy(mm)	NFmoy
M1 (100%FC)	12**abcde**	1.44**b**	7abc
M1 (25%FC)	20.5±4.5**de**	2.23±0.38**b**	10.5±2.5**bc**
M1 (50%FC)	18.5±2.5**e**	1.86±0.11**b**	8.5±0.96**bc**
M1 (75%FC)	-	-	-
M2 (100%FC)	12.5±1.85**bcde**	1.29±0.16**ab**	9±1.23**abc**
M2 (25%FC)	11**ab**c	1.83**ab**	7**abc**
M2 (50%FC)	15.8±1.07**bcd**	1.97±0.16**b**	11.6±0.74**abc**
M2 (75%FC)	13±2.**abcde**	2.37±0.54**b**	8.5±2.1.5**abc**
M3 (100%FC)	13.3±0.62**bcd**	1.97±0.15**b**	8.31±0.38**abc**
M3 (25%FC)	15.3±0.56**b**	2.76±0.15**b**	9.35±0.40**abc**
M3 (50%FC)	14.6±0.75**b**	2.42±0.19**b**	7.96±0.32**ab**
M3 (75%CC)	15,6±0.64**cde**	1.99±0.14**b**	9.13±0.35**c**
P value	*0,0004*	*0,02*	*0,0001*

Values affected by the same letters in the same column are not statistically different in the Art ANOVA test at the 0.05 significance level

Regarding seedling growth, the optimum growth of seedlings is achieved with clayey substrate. This performance could be attributed to the physicochemical properties of clay, particularly its ability to retain water and nutrients (Alghamdi et al. 2023). These results corroborate those of Gachuiri et al. (2016), who demonstrated that clay soils offer better nutrient availability to *F. albida* seedlings, which invest more resources in developing aerial parts to capture light. Furthermore, Geiger et al. (1992) showed that areas of good growth for young *Faidherbia albida* were associated with higher clay content in the soil. However, this observation needs to be nuanced. Indeed, a high clay content in the soil can lead to a low survival rate, hence the need to add amendments (Kedir et al. 2025). Furthermore, a substrate that is unfavorable for germination can nevertheless support satisfactory post-germination growth, underscoring the importance of distinguishing between these phases. Indeed, Maghdouri et al. (2021) found that, in kiwifruit, the best substrate for growth is not necessarily the one that maximizes germination. This could be explained by the fact that the germination and growth phases do not have the same physiological requirements. A water deficit or excess, or a substrate that is too compact or waterlogged, can slow down or prevent germination, whereas an already formed seedling is more resistant to such conditions (Rocha et al. 2022). Moreover, the optimization of growth under a water regime of 25% field capacity could be explained by the presence of arbuscular mycorrhizal fungi, which, in case of water stress, help the plant absorb water and nutrients. Indeed, inoculation with these fungi significantly improved plant growth, especially when water was more available (Hailemariam et al. 2017).

In the species *Gliricidia sepium*, diameter growth is not affected by substrate type. Indeed, studies have shown that the substrate does not significantly impact stem diameter, while influencing height and leaf number (Bayala et al., 2009). The plant may direct its growth towards increased height and leaf development to access the sunlight necessary for photosynthesis. However, observations made with volumes corresponding to 25% and 100% of field capacity (FC) could reflect an adaptive strategy. Under conditions of low water availability, the plant invests in height and diameter growth to optimize light capture and resource access, while excess water could trigger a survival response resulting in increased leaf production, potentially for transpiration. Unlike *F. albida*, the interaction of factors revealed significant differences for all growth parameters. These complex results highlight that, for *G. sepium*, optimizing growth requires integrated management of the substrate and water regime, with each factor's effect depending on the other. This interaction is crucial for producing quality seedlings in nurseries.

Regarding *Pterocarpus erinaceus*, the water volume did not have a significant effect on the growth parameters of the seedlings. This suggests a relatively high tolerance of this species to variations in the water regime under the conditions of the study. Indeed, it is one of the slow-growing species in semi-arid zones. The interaction of factors also showed a significant effect on all growth parameters, implying that the specific combination of substrate and water regime is essential to optimize growth. Furthermore, a multitude of interdependent environmental factors influence the growth and development of plants, each having an optimal range (Hwang et al., 2020; Carotti et al., 2021). These include water availability, supply of essential nutrients, light intensity and quality, oxygen and CO_2 concentration, and temperature. This information is crucial for establishing effective nursery protocols aimed at producing robust seedlings adapted to reforestation conditions. Temperature and light levels are also recognized as factors that can influence species growth and may have contributed to the observed variability. These factors control photosynthesis, respiration, stem elongation, and leaf expansion, resulting in differences in biomass and morphology between treatments and among species (Kong et al., 2021).

4. Conclusion

This study highlighted the influence of substrate type and water regime on the germination and and early growth of three Sahelian tree legume species: *Faidherbia albida*, *Gliricidia sepium*, and *Pterocarpus erinaceus*. Substrate M3 (manure + sawdust) exhibited the highest germination rates (>69%) and good tolerance to a high water regime (100% FC), while moderate watering (50-75% FC) optimized the germination rate. Conversely, substrate M1 yielded generally poorer results except for *Faidherbia albida*. However, the combined effect of substrate and water volume on growth varies depending on the parameter considered and the species. For seedling growth, *F. albida* showed a clear preference for substrate M1 (manure + clay) with a low water volume (25% FC), without any notable interaction. substrate-water interactions were significant, with an optimum at 25% FC for both plant height and collar diameter, Finally, height and leaf number development in *P. erinaceus* depended strongly on substrate M3, though with significant substrate-water interactions. Overall, this study identified growing conditions conducive to improving seedling production, while promoting the use of local materials, such as sawdust, combined with rational water management, thereby contributing to the promotion of sustainable land management practices beneficial to researchers, farmers, and land-use planners.

Disclaimer (Artificial Intelligence)

Author(s) Hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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