Effect of Simulated Drought and Rainfall Fluctuation on Seedling Growth of Two Savannah Trees Species in Sudan: An Experimental Exploration

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Abstract – Climate change scenarios project that several regions, especially in dryland areas of sub-Saharan Africa, will undergo increasing aridity and, subsequently, expanding land degradation. The study aims to investigate the effect of two drying treatments on establishing and growing Hashab (*Acacia senegal*) and Boabab (*Adansonia digitata*) in nursery conditions. Through a 2×2 factorial experiment, seedlings grown in a mixture of silt and sand soil (2:3) were treated by irrigation intervals of one or two liters every three days for 14 weeks to simulate rainfall fluctuation patterns. Seedling germination rate, leaf number, stem height, and diameter were measured weekly; taproot length, shoot, and root dry weights were also assessed. The results showed that neither drying treatment significantly affected *A. senegal* and *A. digitata* seedling growth parameters. However, an interaction effect was found in the height and diameter for *A. senegal* and shoot dry weight for *A. digitata*. The study concluded that *A. senegal* and *A. digitata* seem tolerant to drying treatment. Therefore, the two species are recommended for afforestation programs in areas with relatively harsher conditions. Also, exposing the seedlings of these studied species to similar, extended periods of simulated drought (e.g., 6 – 12 months) is recommended for future studies.

***Acacia senegal* / *Adansonia digitate* / climate change / dryland / Savannah /Sudan**

Kivonat – Szimulált aszály és csapadék ingadozás hatása két szavannai fafaj csemetéinek növekedésére Szudánban: egy kísérleti felfedezés. Az éghajlatváltozási forgatókönyvek szerint több régió, különösen a száraz területek a szubszaharai Afrikában, egyre szárazabbá válnak és ennek következtében a talajdegradáció is terjedni fog. A tanulmány célja a Hashab (*Acacia senegal*) és a

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Boabab (*Adansonia digitata*) két szárítási kezelésnek a csemetekerti körülmények közötti kialakulására és növekedésére gyakorolt hatásának vizsgálata. Egy 2×2 faktoriális kísérleten keresztül, amelyben magoncokat neveltünk homokos és iszapos talajkeverékben (2:3) öntözési intervallumokkal, amelyek 1 vagy 2 literes vízmennyiségeket kaptak minden 3. napon 14 hétig, hogy szimuláljuk a csapadék-ingadozásokat. A magoncok csírázási aránya, a levél- és a szár magassága, valamint átmérőjük hetente mérve lett, majd a hosszú gyökér, a hajtás és a gyökér száraz tömegeit értékeltük ki. Az eredmények azt mutatják, hogy egyik szárítási kezelés sem volt hatással az *A. senegal* és az *A. digitata* magoncok növekedési paramétereire. Azonban interakciós hatást találtunk az *A. senegal* magasságára és átmérőjére, valamint az *A. digitata* hajtás száraz tömegére. A tanulmány arra a következtetésre jutott, hogy mind az *A. senegal*, mind az *A. digitata* toleránsnak tűnik a szárítási kezeléssel szemben, ezért mindkét faj ajánlható az erdősítési programokhoz olyan területeken, ahol viszonylag szélsőségesebbek a körülmények. A jövőbeni vizsgálatok során érdemes volna a vizsgált fajok csemetéit hosszabb ideig (pl. 6-12 hónap) szimulált aszálynak kitenni.

***Acacia senegal* / *Adansonia digitate* / klímaváltozás / száraz területek / Szavanna / Szudán**

1 INTRODUCTION

Climate change poses a grave threat to the planet and its inhabitants. The Intergovernmental Panel on Climate Change (IPCC) reports that if global temperatures continue to increase at the current rate of 0.2 °C per decade, it will result in a 1.5 °C increase between 2030 and 2052 compared to the preindustrial levels (IPCC 2018). Global and regional climatic changes are expected to increase the frequency and severity of other natural hazards, such as droughts, heavy precipitation, floods, and monsoons (Grillakis 2019, Gebrechorkos et al. 2020, Carvalho et al. 2022, Aibaidula et al. 2023). According to the IPCC (2014), Sudan is projected to experience increasing temperatures, with summer averages expected to rise by 1.5 to 3.0 °C and winter averages by 1.1 to 2.1 °C by 2100. Additionally, there will be changes in precipitation patterns, characterized by a decrease in overall precipitation and increased variability, ranging from 15 % to 190 % coefficient of variation (CV). Rainfall shifts of up to 6mm and changes in the timing and length of the rainy season are anticipated. Reduced water availability will likely increase this risk and worsen land degradation (Roy et al. 2022, Chaudhuri et al. 2023). Africa has been identified as exceptionally vulnerable to the impacts of climate change; however, impacts are worse in dryland ecosystems, particularly sub-Saharan Africa (IPCC 2014, Hoffmann 2022, Ntali et al. 2023).

Drylands cover 43% of land in Africa and about 65% of the countries are dryland (Gebremeskel et al. 2021, Ren et al. 2022, Kuyah et al. 2023). Sudan is classified as a dryland country; more than half of the area is desert, 23% is a savannah ecosystem, 10% is forested, 13% is grasslands, 13% is agricultural lands, and 1% is water resources. The remainder is other (i.e., urban areas) (FAO 2013). The Savanna ecosystem in Sudan is a source of several ecosystem services, including providing livelihood and support for rural life. However, it is also a vital host of great biological diversity (Abdel Magid 2001, Siddig et al. 2019, Mohamed 2022, Mulatu et al. 2022).

Climate change is a major environmental threat to Sudan’s dryland biodiversity because it reduces overall ecosystem productivity, composition, function, and vegetation diversity (Stavi et al. 2023, Abdoelmoniem et al. 2023). Savannah ecosystems are more fragile to soil erosion and lower rainfall levels. Climate extremes (e.g. drought) are highly expected in Sudan because rainfall patterns in savannas link directly to climate change, rising temperatures, and the El Nino phenomenon. Subsequently, tree species will likely suffer from water scarcity, reflected in species distribution and patterns in savannas and woody land (Huang et al. 2022, Delgado et al. 2022, Dahan et al. 2023). Desertification is likely to complicate the impacts of climate change on savannah ecosystems as the Sahara Desert expands rapidly southwards (Ardi 2013).

Hashab (*Acacia senegal*) is a priority dryland species, a crucial component of traditional dryland agroforestry resilience systems, and a source of livelihood in Sudan (Mohamed et al. 2015, Deng et al. 2017, Gadallah et al. 2022, Hasoba et al. 2020, Hemida 2023). *A. senegal* is a multi-purpose tree that produces gum arabic, a high-value export commodity in Sudan and other African countries (Peroches et al. 2022). The tree also provides animal fodder, multiple timber products, intercropping, firewood, food, and medicines (Fadl – El Sheikh 2010, Peroches et al. 2022). Furthermore, it is one of the most significant sub-Saharan African trees inhabiting savannah systems to be threatened by ongoing anthropogenic and climate-mediated degradation, leading to substantial losses of natural habitats (Marchant 2022, Abdoelmoniem et al. 2023). The tree is found to be more responsive to its limited growth factors, especially by availing water in the seedling stage (Abdoelmoniem et al. 2023).

The Baobab tree (*Adansonia digitata*) is widely distributed in Africa, forming a belt in central Sudan (Elamin 1990, Adesina – Zhu 2022, Elsayed et al. 2023). *A. digitata* is a valuable savanna tree for food, fodder, and medicine it provides animals and humans (Leakey et al. 2022, Bosch et al. 2004, Saeed et al. 2023). The European Union approved the species as a novel food in 2008, granting African farmers access to a billion-dollar industry (Hermann 2009, Meinhold et al. 2022, Leakey et al. 2022). Nicknamed the *Tree of Life*, the endangered baobabs play a significant role in their ecosystem by keeping soil conditions humid, promoting nutrient recycling, and preventing soil erosion. Additionally, they are a vital source of food, water, and shelter for various animals, birds, reptiles, and insects (Nayak et al. 2022).

Drought stress at germination and seedling emergence stages may have a series of disastrous consequences on the dynamics of species. For instance, a lack of natural regeneration and the decline of *A. senegal and A. digitata* populations have been commonly observed in Sudan (Fischer 2020, Mohammed 2021). However, the link between drought resistance and plant distribution and diversity of the two species needs to be better understood. The present study focuses on the effects of simulated drought and rainfall fluctuations on seedling growth, providing insights into how changing environmental conditions can affect tree species. This study is relevant because it explores the tree seedling responses to simulated drought and rainfall fluctuations within a savanna setting. Understanding the influence of these factors on seedling growth can provide valuable insights into the resilience and adaptability of tree species, which is relevant not only in Sudan but also in other ecosystems, including those in Central Europe. This paper aims to experimentally investigate drought impacts on the establishment and development of these two species.

2 MATERIALS AND METHODS

2.1 Seed source

A. senegal and *A. digitate* seeds were collected from trees growing naturally in the Elain Natural Forest Reserve (12º 52´ -13º 04´ N and 30º 10´-30º 24´ E), 26 km south of Elobeid, the capital of North Kordofan State, Sudan. The forest falls under savannah low rainfall and receives annual rainfall between 300-600 mm.

2.2 Study site and settings

The experiment was conducted in the nursery facility in the Faculty of Forestry at the University of Khartoum, Shambat Area (latitude 15º40 N, longitude 32º 32 E and height 380 m above sea level) (*Figure 1*) from December 2017 to March 2018. Annual precipitation of 14.28 mm, annual temperatures (min. 24.76ºC, max. 37.25 ºC), relative humidity of 22.53 %, and dense vegetation adjacent to the eastern bank of the river Nile characterize the region.

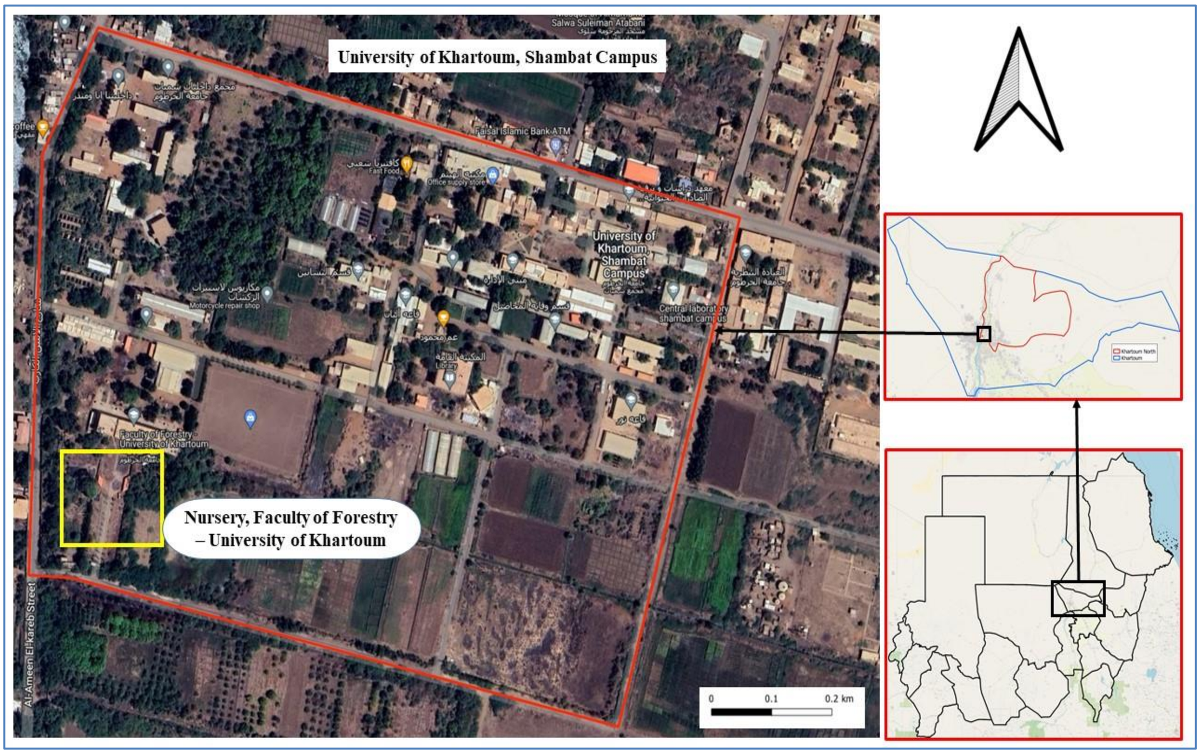

Figure 1. Map of the study area.

2.3 Experimental design and treatments

The study simulated drought and rainfall fluctuation effects on the seedling growth of two savannah tree species in an area with annual rainfall between 300-600 mm. The experiment design was through a 2×2 factorial study. The treatments were drought occurrence (i.e., drought occurs or does not occur) and drought pattern (i.e., occurs regularly or randomly).

The study collected 250 grams of *A. senegal* and *A. digitata* seeds from the Kordofan region and sowed three seeds of each species in 24 pots (six seeds per pot; 72 seeds). Irrigation in the first three weeks was two liters in three-day intervals, assigned to normal condition (no drought) units. An irrigation interval of one liter every three days was assigned to drying units (drought conditions). From week four to week 14, irrigation intervals used to simulate rainfall fluctuations were assigned randomly to the pots by adopting two weeks of irrigation breaks. Consultations with hydrology and climatology experts determined the water amounts used for irrigation in the experiment. The study also considered natural rainfall patterns in the low-rainfall Savannah, which typically ranges between 300 and 600 mm.

2.4 Measured variables

The study monitored seedling germination, growth, and survival weekly. Germination was observed for the presence or absence of newly germinated seeds, seedling height, diameter, and number of leaves. Then plants were harvested and separated into shoot and root, where the tap root lengths were measured. Shoot and root dry weight was determined by oven drying for 24 hr at 105 ºC. Soil characteristics were also assessed by conducting before and after treatments following the same sample quantity. In particular, Electric Conductivity (EC) pH, Sodium Adsorption Ratio (SAR), and Field Capacity (FC) were measured (Pachepsky – Rawls 2005).

2.5 Statistical methods

The Analysis of Variance (ANOVA) procedures and Duncan's Multiple Range Test were applied to separate means of the same factor that were performed using the R open-source software program (R core team 2021), and simple summary descriptive statistical methods were used.

3 RESULTS

3.1 Effect of simulated drying and rainfall fluctuation pattern on the development and growth of *A. senegal* seedlings

Drying and rainfall fluctuation patterns did not significantly affect *A. senegal* seedling height, diameter, leaf number, taproot length, and shoot and root dry weights ($P < 0.05$, *Table 1*). However, the interaction effect of drying and fluctuation was significant on seedling height and diameter ($F_{1, 20} = 5.522$, $P < 0.05$) and ($F_{1, 20} = 4.902$, $P < 0.05$), respectively.

Table 1. Results of ANOVA test for effects of simulated drying and rainfall fluctuation pattern on A. senegal seedling growth

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Shoot Height					
Drying	1	20.17	20.17	2.817	0.1088
Fluctuation	1	11.48	11.48	1.604	0.2199
Drying: Fluctuation	1	39.53	39.53	5.522	0.0292 *
Residuals	20	143.16	7.16		
Number of Leaves					
Drying	1	40	39.8	0.207	0.6539
Fluctuation	1	3	3.2	0.016	0.8993
Drying: Fluctuation	1	727	727.1	3.786	0.0659
Residuals	20	3841	192.0		
Root Length					
Drying	1	65	65.0	0.333	0.5704
Fluctuation	1	53	52.5	0.269	0.6098
Drying: Fluctuation	1	721	720.5	3.689	0.0692
Residuals	20	3907	195.3		
Biomass					
Drying	1	63	63.1	0.309	0.5844
Fluctuation	1	49	49.0	0.240	0.6293
Drying: Fluctuation	1	734	733.7	3.596	0.0724
Residuals	20	4080	204.0		
Plant Diameter					
Drying	1	0.02667	0.02667	3.137	0.0918
Fluctuation	1	0.01500	0.01500	1.765	0.1990
Drying: Fluctuation	1	0.04167	0.04167	4.902	0.0386 *
Residuals	20	0.17000	0.00850		
Root Dry Weight					
Drying	1	0.015	0.0150	0.091	0.766
Fluctuation	1	0.060	0.0600	0.363	0.553
Drying: Fluctuation	1	0.060	0.0600	0.363	0.553
Residuals	20	3.303	0.1652		
Shoot Dry Weight					
Drying	1	0.0417	0.04167	0.725	0.4047
Fluctuation	1	0.0017	0.00167	0.029	0.8665
Drying: Fluctuation	1	0.2400	0.24000	4.174	0.0545
Residuals	20	1.1500	0.05750		

3.2 Effect of simulated drying and rainfall fluctuation pattern on the development and growth of *A. digitata* seedlings

Drying and rainfall fluctuation patterns did not significantly affect the *A. digitata* seedling height, diameter, leaf number, taproot length, and shoot and root dry weights. However, a significant interaction effect was found on shoot dry weight ($F_{1, 20} = 4.17$, P = 0.05; *Table 2*), root length (P= 0.06), and biomass (P=0.07).

Table 2. Results of ANOVA test for effects of simulated drying and rainfall fluctuation pattern on A. digitata seedling growth.

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Shoot Height					
Drying	1	2.34	2.344	0.293	0.594
Fluctuation	1	0.01	0.010	0.001	0.972
Drying: Fluctuation	1	0.84	0.844	0.105	0.749
Residuals	20	160.13	8.007		
Number of Leaves					
Drying	1	5.42	5.423	1.036	0.321
Fluctuation	1	0.46	0.459	0.088	0.770
Drying: Fluctuation	1	0.46	0.459	0.088	0.770
Residuals	20	99.43	5.233		
Root Length					
Drying	1	65	65.0	0.333	0.5704
Fluctuation	1	53	52.5	0.269	0.6098
Drying: Fluctuation	1	721	720.5	3.689	0.0692
Residuals	20	3907	195.3		
Biomass					
Drying	1	77	63.2	0.312	0.5855
Fluctuation	1	50	49.22	0.250	0.6288
Drying: Fluctuation	1	735	733.7	3.595	0.0722
Residuals	20	4090	204.0		
Plant Diameter					
Drying	1	0.0104	0.010417	0.652	0.429
Fluctuation	1	0.0012	0.001157	0.072	0.791
Drying: Fluctuation	1	0.0012	0.001157	0.072	0.791
Residuals	20	0.3194	0.015972		
Root Dry Weight					
Drying	1	0.0150	0.01500	0.0908	0.7663
Fluctuation	1	0.0600	0.0600	0.363	0.553
Drying: Fluctuation	1	0.0600	0.0600	0.363	0.553
Residuals	20	3.3033	0.16517		
Shoot Dry Weight					
Drying	1	0.0412	0.04157	0.721	0.4027
Fluctuation	1	0.0015	0.00144	0.025	0.8625
Drying: Fluctuation	1	0.2200	0.2477	4.17	0.0542
Residuals	20	1.1700	0.05780		

3.3 Effect of simulated drying and rainfall fluctuation pattern on soil conditions of the two studied species

Drying significantly affected SAR ($F_{1, 20} = 13.91$, P < 0.01) but not on other variables. Further, rain fluctuation patterns showed no significant effects on any measured variables (FC, EC, pH, and SAR). On the other hand, the interaction effect was marginal on soil pH ($F_{1, 20} = 3.689$, P = 0.06, *Table 3*).

Table 3. Results of ANOVA test for the effect of simulated drying and rainfall fluctuation pattern on soil

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Field Capacity (FC)					
Drying	1	2.60	2.600	0.372	0.549
Fluctuation	1	0.77	0.770	0.110	0.743
Drying: Fluctuation	1	0.07	0.070	0.010	0.921
Residuals	20	139.91	6.995		
Electrical Conductivity (EC) – Salinity					
Drying	1	0.0067	0.00667	0.087	0.772
Fluctuation	1	0.1067	0.10667	1.385	0.253
Drying: Fluctuation	1	0.1067	0.10667	1.385	0.253
Residuals	20	1.5400	0.07700		
pH					
Drying	1	65	65.0	0.333	0.5704
Fluctuation	1	53	52.5	0.269	0.6098
Drying: Fluctuation	1	721	720.5	3.689	0.0692
Residuals	20	3907	195.3		
Sodium Adsorption Ratio (SAR)					
Drying	1	0.20167	0.20167	13.91	0.00132 **
Fluctuation	1	0.00667	0.00667	0.46	0.50550
Drying: Fluctuation	1	0.00667	0.00667	0.46	0.50550
Residuals	20	0.29000	0.01450		

3.4 Trend of growth and development factors of two studied species:

The trend of seedling response to drying and rain fluctuation treatments was moderate and varied between the species. As the following figures show (Figures 2, 3, 4, and 5), the number of leaves on Hashab seedlings increased in the first seven weeks for all treatments before decreasing in the last three weeks. The interaction of drying and fluctuations significantly increased the number of leaves compared to the independent (main) treatment (*Figure 2*). The results are as expected if the drying fluctuations are discounted; however, the drying fluctuations influenced the results unexpectedly.

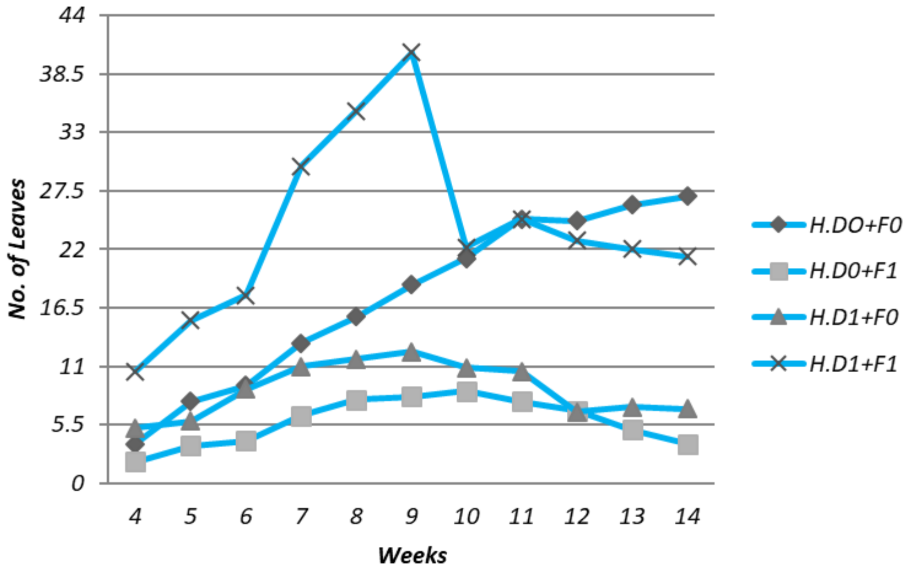

Figure 2. The trend of weekly changes in the number of leaves for Acacia senegal (H) seedlings. D = Drying treatment & F = Drying fluctuation pattern treatment; 1 = treatment present; 0 = treatment absent.

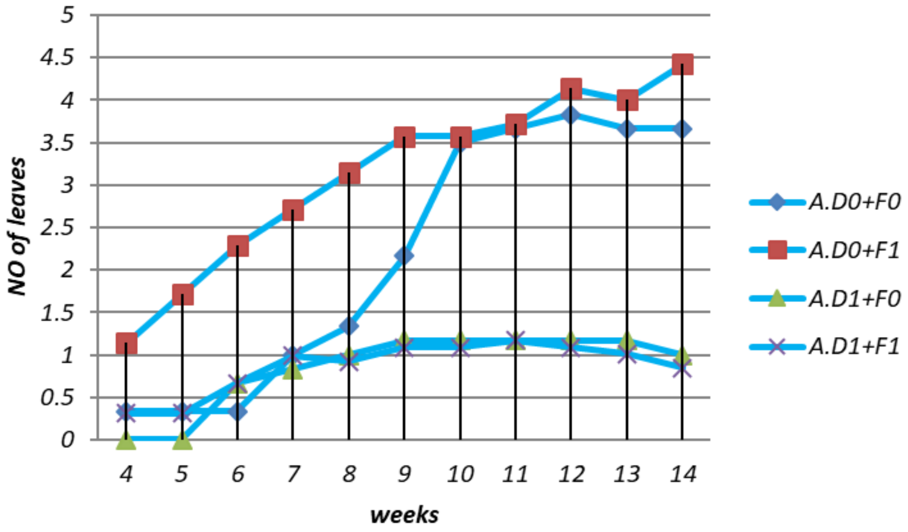

Figure 3. The trend of weekly changes in the number of leaves for Adansonia digitata (A) seedlings. D = Drying treatment & F = Drying fluctuation pattern treatment; 1 = treatment present; 0 = treatment absent.

Adansonia seedlings responded negatively to the drying and fluctuation treatments, as the number of leaves in the treated pots showed a declining trend compared to the control (*Figure 3).* Seedling height for Hashab trees showed an increasing trend because the interaction effects of the two treatments seemed higher than the control (*Figure 4*). On the other hand, the height of Adansonia seedlings in the interactive treatments showed a steady, stable trend compared to the control treatment (*Figure 5*).

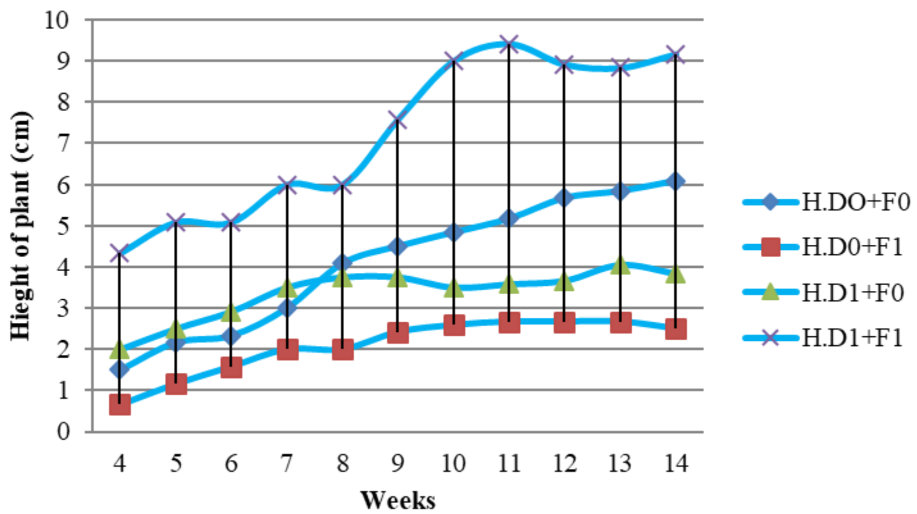

Figure 4. The trend of weekly changes in seedling height for Acacia senegal (H). D = Drying treatment & F = Drying fluctuation pattern treatment; 1 = treatment present; 0 = treatment absent.

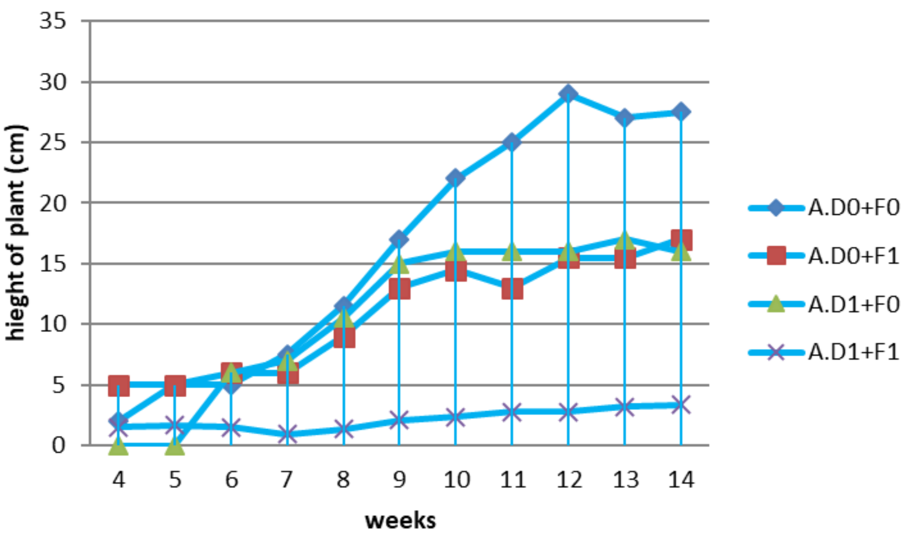

Figure 5. The trend of weekly changes in seedling height for Adansonia digitata (A). D = Drying treatment & F = Drying fluctuation pattern treatment; 1 = treatment present; 0 = treatment absent.

4 DISCUSSION

The present study tested the effect of the simulated drought and drying pattern on *Acacia senegal* and *Adansonia digitata* seedling establishment in nursery conditions. It provides valuable information about these species' potential for adapting to future climate change scenarios by exposing them to controlled environmental stressors. Sustainable reforestation and afforestation programs can benefit from the findings because they can aid in selecting tree species that do well in varying climates. The study's rigorous experimental design ensures accurate results and adds to our knowledge of how to preserve the savannah ecosystems of Sudan. The findings also help with climate-resilient land use planning and provide insight into broader ecological implications.

Our results showed some significant effects and varied impacts of drying and watering fluctuation patterns within and between the two species in some of the parameters investigated. Seedling growth of the two species, as measured by the number of leaves and plant shoot height, showed some negative responses to the treatments. Results were consistent with our early assumptions and literature about plant responses to environmental changes in dryland (Schreiner-McGraw et al. 2020, Sun et al. 2021, Wang et al. 2022). Studies have also reported that trees native to arid environments often have a high root/shoot ratio; the higher the exposure to drought, the more the ratio between root and shoot mass shifted further in favor of root growth (Larcher 1995, Lozano et al. 2022, Wu et al. 2023) and was found in many dry zone plants, including *Acacia tortilis*, *Acacia senegal*, and *Acacia mellifera* (Elmagboul 2002, Musa 2005, Retta et al. 2022, Zwarts et al. 2023).

Many studies proved that a lack of rainfall is the main reason for low Baobab seedling survival in several countries (Sanchez 2011, Hellion–Gusted 2004, Venter – Kwiatkowski 2013, Fischer et al. 2020). However, Schweiger et al. (2020) have projected that efficient Baobab recruitment may occur every 100–150 years. Thus, in the absence of Baobab regenerations, episodic recruitment could maintain Baobab populations (Sanchez 2011, Venter 2012, Venter – Kwiatkowski 2013, Msalilwa et al. 2020, Orina et al. 2021).

Acacia senegal seedlings were more tolerant than *Adansonia digitata* seedlings in response to drying and drying fluctuation patterns suggesting that plants can adapt to drought conditions by shedding older leaves. Drought resistance differences in species may be a crucial factor influencing species distributions in the dry tropics. However, the link between species drought resistance and plant distribution and diversity needs to be better understood, mainly because comparative quantitative assessments of the effects of drought on plant growth and survival are largely missing. We use drought resistance as "the capacity of a plant to withstand periods of dryness" (Larcher 2000), i.e., the ability to survive drought while minimizing reductions in growth and, ultimately, fitness.

On the other hand, increasing drying conditions affected the total plant dry weight for both studied species. Although *Acacia senegal* seedlings showed higher total plant weight, the two species no significant weight differences during the experiment. Indeed, this indicates the tolerance of *Acacia senegal* to survive arid conditions with reasonable growth performance and biomass buildup. Furthermore, the observed higher root/shoot ratio in *Acacia senegal* indicates that this species is more prone to survive dry conditions.

Both species can withstand drying and watering fluctuations, indicating their resistance against anticipated drought conditions. However, *Acacia senegal* seedlings seem more tolerant to drought and rain breaks than Adansonia digitata seedlings.

5 CONCLUSIONS

This study concludes with significant insights regarding the effects of simulated drought and drying patterns on the growth and development of *Acacia senegal* and *Adansonia digitata* seedlings. The findings suggest that the two species have different tolerance levels to drying treatments, with *Acacia senegal* seedlings demonstrating greater tolerance than *Adansonia digitate* seedlings. The drought resistance differences between the two species may significantly influence their distributions in the dry tropics. The study also highlights the importance of water harvesting techniques and protection from browsing animals and humans during afforestation projects involving these two species. Additionally, the results suggest that further research is needed to assess the impacts of longer drying intervals on the growth and development of both seedlings and to investigate their sensitivity to other climate change factors, such as heat waves and temperature rises. In light of the findings, the study recommends prioritizing *Acacia senegal* for afforestation programs in areas with more arid conditions and that special programs be developed for Baobab afforestation focusing on drying tolerance for seedlings and protection from browsing. Nevertheless, the results of this study warrant caution as they are of only are from only one experiment with relatively low replications. Overall, this study contributes to our understanding of the effects of drying on seedling survival and dynamics and provides valuable insights into the management of afforestation projects in dry tropics.

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