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Effect of water stress on morphological characteristics of *Vachellia tortilis* (Forssk.) Galasso & Banfi, *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. and *Senegalia senegal* (L.) Britton seedlings in Maiduguri, Nigeria

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Abstract

This study investigated the effect of water stress on three species *Vachellia tortilis* (Forssk.) Galasso & Banfi, *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb., and *Senegalia senegal* (L.) Britton to varying degrees of water stress in Maiduguri, Borno State, Nigeria. The experiment assessed key morphological parameters such as shoot length, root length, shoot and root dry weights, total dry matter, and root-to-shoot ratio at 60, 90, and 120 days after sowing. A split-plot design was employed with four watering regimes: control (M0), slight (M1), moderate (M2), and severe moisture stress (M3). The results revealed significant interspecific differences in growth responses under water stress, with *S. senegal* exhibiting superior shoot biomass across treatments, while *V. tortilis* showed the highest root-to-shoot ratio, especially under severe stress. These adaptive morphological traits highlight the species' resilience strategies in arid and semi-arid ecosystems. The findings have implications for afforestation and agroforestry programs in drought-prone areas. These findings suggest *Senegalia senegal* may be better adapted to arid environments.

Keywords: Drought, Ecological, Moisture, Plasticity, Tolerance

1. Introduction

Water stress remains one of the most significant constraints on plant development, especially in arid and semi-arid ecosystems where water availability is inherently limited. The ability of plant species to withstand or adapt to such conditions is crucial to the success of afforestation, restoration, and agroforestry initiatives in these environments. In particular, members of the genera *Vachellia* and *Senegalia* are known for their ecological and economic importance, due to their drought tolerance, nitrogen-fixing ability, and multipurpose utility.

The morphology of seedlings under stress provides key insights into their survival strategy. Traits such as shoot and root biomass, root-to-shoot ratio, and total dry matter accumulation often shift in response to water availability, revealing physiological trade-offs and adaptive plasticity (Anjum et al., 2011). Morphological traits are known to reflect adaptation strategies to specific habitats, as highlighted by Mehrotra et al., (1999), who linked differences in morphology to habitat conditions in Central Himalayan pine forests. Understanding these responses is essential for selecting suitable species for arid land management.

Previous studies have documented that certain plant species display morphological changes in response to moisture gradients in their natural habitats (Mehrotra et al., 1998), suggesting that differential allocation to roots versus shoots may confer a competitive advantage under specific moisture regimes. This study was therefore conducted to evaluate the morphological responses of three species *V. tortilis*, *V. nilotica*, and *S. senegal*, to varying degrees of water stress in nursery conditions in Maiduguri, Borno

State, Nigeria. The objective was to identify species with favorable adaptive traits that can be recommended for ecological restoration and afforestation in drought-prone areas of the Sahel and Sudan savanna regions.

2. Materials and Methods

The study was conducted in Maiduguri, Borno State, located in the North-Eastern region of Nigeria. Maiduguri lies between latitudes 11°442 503 and 11°552 253 N and longitudes 13°022 253 and 13°162 003 E. The state is predominantly agrarian and has a projected population of 6.65 million (Borno State Population by Local Government, 2025). Laboratory experiments were carried out in the Department of Biological Sciences, Faculty of Science, University of Maiduguri, while nursery trials were conducted from August 2017 to January 2018 at Imam Malik Botanical Garden, Wulari Ward, Maiduguri.

Seeds of three species *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* were collected from the Borno State Ministry of Environment's Afforestation Project Office. To enhance germination, seeds were soaked in boiled water for 10 minutes, following RMRDC (2004) protocol and Ghassali et al. (2012). Plastic pots (32 × 40 cm^2) were filled with a soil mixture composed of topsoil, cow dung, and riverbed sand in a 3:2:1 ratio (Jackson et al., 1974). Dry leaves were placed at the base of each pot to maintain drainage. A total of 144 pots were used, with two seeds of each species sown directly per pot. After germination, seedlings were thinned to one per pot.

To simulate water stress, four watering regimes were applied post-germination; daily watering for 30 days, followed by either four times per week (control), three times (slight stress), twice (moderate stress), or once per week (severe stress). Each pot received one liter of water per watering event. The experimental layout followed a Randomized Complete Block Design in a split-plot arrangement. Destructive sampling was performed at 60, 90, and 120 days after sowing. Ten randomly selected seedlings from each species and replicate were harvested at each interval for morphological assessment.

Morphological parameters measured included shoot length (cm), root length (cm), and leaf area (cm^2), following FAO (1983). Leaf area was calculated using a graph sheet tracing method. Shoot and root dry weights were determined after oven drying samples at 70°C for 72 hours. The root-to-shoot ratio and total dry matter accumulation (sum of leaf, stem, and root dry weights) were also computed, the latter following Hashim et al. (2012).

Descriptive statistics were used for laboratory data analysis. Nursery data were subjected to analysis of variance (ANOVA), and treatment means were compared using the Least Significant Difference (LSD) test at $P < 0.05$.

3. Results and Discussion

Shoot length was markedly influenced by the watering regime across all three species (Table 1). For *V. tortilis*, shoot length decreased consistently with reduced watering frequency. At 120 days, shoot length declined significantly by 21%, 31%, and 43% under M1, M2, and M3 treatments respectively, compared to the control (M0). Similar reductions were observed in *V. nilotica* and *S. senegal*, indicating a strong sensitivity of shoot elongation to water availability. These reductions align with findings by Farooq et al. (2009), who reported that drought stress significantly inhibits cell expansion and division in shoot tissues. Notably,

S. senegal exhibited relatively better tolerance, maintaining 88-96% of its shoot length under mild stress (M1 and M2), suggesting higher drought resilience at 120 days.

Table 1. Shoot length (cm) of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

	Treatments				
Days	M_0	M_1	M_2	M_3	LSD 5%
Vachellia tortilis					
60	40.53 ± 2.34^d	30.63 ± 2.87^c (-24%)	25.63 ± 0.76^b (−37%)	21.07 ± 0.80^a (−48%)	0.71
90	51.56 ± 1.31^d	46.43 ± 1.45^c (-10%)	41.83 ± 0.81^b (-19%)	30.27 ± 2.03^a (-41%)	0.73
120	68.67 ± 1.66^d	54.07 ± 2.49^c (-21%)	47.07 ± 1.95^b (-31%)	38.90 ± 4.52^a (-43%)	1.77
Vachellia nilotica					
60	76.90 ± 2.45^a	66.57 ± 2.48^c (-13%)	51.03 ± 0.71^b (-34%)	31.07 ± 1.81^a (-58%)	0.74
90	88.87 ± 4.14^d	73.90 ± 2.67^c (-17%)	67.80 ± 2.44^b (-24%)	30.27 ± 2.10^a (-54%)	2.65
120	101.01 ± 4.36^d	88.23 ± 0.06^c (-13%)	74.43 ± 2.63^b (-21%)	51.70 ± 2.03^a (-49%)	1.05
Senegalia senegal					
60	33.07 ± 1.71^d	27.43 ± 1.71^c (-17%)	25.03 ± 1.42^b (-24%)	19.83 ± 1.46^a (-40%)	2.10
90	40.13 ± 0.81^d	35.83 ± 1.39^c (-11%)	33.77 ± 1.76^b (-16%)	32.37 ± 1.75^a (-19%)	0.44
120	50.17 ± 1.78^d	47.97 ± 1.83^c (-4%)	44.03 ± 1.80^b (-12%)	42.63 ± 3.72^a (-15%)	1.22

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress).Mean ± Standard Deviation (SD)
The figures within parenthesis indicates the % reduction (-) and % increase (+) in the shoot length with respect to control

Root length varied in response to water stress but showed a general trend of significant reduction under severe (M3) drought conditions in comparison to control (Table 2). For instance, *V. tortilis* exhibited a 50% decrease in root length at 120 days under M3. In contrast, *S. senegal* displayed anomalous increases under the moderate draught condition (M2). The percent

increase in root length showed maximum (87%) at 60 days while, it decreased 68% to 60% from 90 to 120 days. The anomalous increase in treatment M2, potentially due to adaptive root proliferation a common xerophytic response under limited moisture conditions (Chaves et al., 2003).

Table 2. Root length (cm) of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

Days	Treatments M_0	M_1	M_2	M_3	LSD 5%
Vachellia tortilis					
60	39.80 ± 3.40^{d}	28.67 ± 2.11^{c} (-28%)	24.70 ± 3.02^{b} (-38%)	15.77 ± 0.81^{a} (-60%)	0.92
90	40.63 ± 1.12^{d}	36.97 ± 0.91^{c} (-9%)	26.63 ± 2.25^{b} (-34%)	21.33 ± 0.90^{a} (-47%)	0.33
120	61.70 ± 1.22^{d}	54.90 ± 2.88^{c} (-11%)	38.50 ± 2.12^{b} (-38%)	31.33 ± 0.91^{a} (-50%)	0.98
Vachellia nilotica					
60	43.00 ± 4.32^{c}	$23.47 \pm 3.72^{a}2$ (-45%)	39.7 ± 3.19^{a} (-44%)	25.8 ± 2.70^{b} (-40%)	1.73
90	43.87 ± 2.48^{c}	36.10 ± 1.74^{b} (-18%)	29.43 ± 2.08^{a} (-33%)	30.73 ± 1.46^{a} (-30%)	2.44
120	67.3 ± 4.13^{c}	40.70 ± 3.02^{ab} (-40%)	59.17 ± 3.30^{b} (-12%)	42.70 ± 4.19^{a} (-37%)	0.91
Senegalia senegal					
60	29.83 ± 1.10^{c}	19.47 ± 1.53^{a} (-35%)	55.83 ± 4.26^{b} (+87%)	21.67 ± 2.20^{a} (-27%)	2.19
90	38.86 ± 1.62^{d}	30.53 ± 6.04^{c} (-19%)	63.20 ± 4.53^{b} (+68%)	15.7 ± 3.33^{a} (-22%)	0.34
120	47.76 ± 0.96^{d}	35.57 ± 1.37^{c} (-25%)	76.90 ± 3.99^{b} (+60%)	39.40 ± 1.31^{a} (-18%)	0.76

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress). Mean ± Standard Deviation (SD)
The figures within parenthesis indicates the % reduction (-) and % increase (+) in the root length with respect to control

Among the species, *S. senegal* demonstrated the most plasticity in root architecture, suggesting a survival advantage under intermittent drought. This response is consistent with the work of Padilla and Pugnaire (2007), who emphasized root elongation as a key drought avoidance strategy in arid zone plants.

Shoot dry weight decreased with increasing water stress across all species (Table 3). However, *S. senegal* exhibited the least percentage reduction in shoot dry weight compared to *V. tortilis* and *V. nilotica*, particularly under mild and moderate water stress conditions. For example, at 60 days, shoot dry weight of *S. senegal* decreased by only 4% under treatment M1 and M2 while, *V. tortilis* experienced a reduction of 44% and 72% under the same conditions. This suggests that *S. senegal* maintains higher biomass stability under drought, possibly due

Table 3. Shoot dry weight (g) of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

Days	Treatments M_0	M_1	M_2	M_3	LSD 5%
Vachellia tortilis					
60	1.43 ± 0.06^{c}	0.80 ± 0.10^{b} (-44%)	0.40 ± 0.31^{a} (-72%)	0.38 ± 0.02^{a} (-73%)	0.07
90	1.87 ± 0.06^{c}	1.63 ± 0.06^{b} (-13%)	0.83 ± 0.06^{a} (-56%)	0.52 ± 0.06^{a} (-72%)	0.67
120	2.30 ± 0.10^{a}	1.80 ± 0.10^{ab} (-22%)	1.43 ± 0.15^{ab} (-38%)	1.07 ± 0.06^{b} (-53%)	1.15
Vachellia nilotica					
60	9.13 ± 1.36^{cd}	9.43 ± 0.90^{c} (+3%)	5.70 ± 0.72^{b} (-38%)	1.97 ± 0.15^{a} (-78%)	0.34
90	12.13 ± 1.12^{d}	11.6 ± 0.50^{c} (-4%)	7.73 ± 1.11^{b} (-36%)	2.77 ± 0.74^{a} (-77%)	0.12
120	20.27 ± 1.00^{d}	15.40 ± 1.20^{c} (-24%)	10.03 ± 1.03^{b} (-50%)	3.77 ± 0.65^{a} (-81%)	0.33
Senegalia senegal					
60	0.93 ± 0.06^{c}	0.90 ± 0.10^{b} (-3%)	0.90 ± 0.06^{b} (-3%)	0.63 ± 0.00^{a} (-32%)	1.97
90	1.40 ± 0.10^{d}	1.17 ± 0.06^{c} (-16%)	0.90 ± 0.10^{b} (-36%)	0.53 ± 0.06^{a} (-62%)	1.04
120	2.23 ± 0.21^{d}	1.83 ± 0.06^{c} (-18%)	1.20 ± 0.20^{b} (-46%)	0.87 ± 0.06^{a} (-61%)	1.60

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress).Mean ± Standard Deviation (SD)
The figures within parenthesis indicates the % reduction (-) and % increase (+) in the shoot dry weight with respect to control

to better water retention or efficient carbon allocation. These findings are consistent with the reports by Anjum et al. (2011), who stated that lower biomass reduction under drought is a sign of physiological robustness and better stress mitigation.

Water stress had a profound effect on root biomass. *V. tortilis* and *V. nilotica* suffered the highest reductions under M3 (up to 80%). Conversely, *S. senegal* showed a significant increased (15%) in 60 days old root dry weight under Slight water stress (M0), while under Moderate water stress (M2) root weight increased 29% and 14% with increasing the age from 90 to 120 days respectively in comparison to control. The increasing root length of *S. senegal,* highlighting its capacity to allocate more biomass to roots in response to drought (Table 4). Such plastic allocation patterns are common in arid-adapted species and confer survival advantages during prolonged water scarcity (Hsiao & Xu, 2000). The data underscore the adaptability of *S. senegal* in dry conditions through enhanced below-ground investment.

Table 4. Root dry weight (g) of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

Days	Treatments M_0	M_1	M_2	M_3	LSD 5%
Vachellia. tortilis					
60	1.20 ± 0.52^{a}	0.53 ± 0.08^{a} (-56%)	0.47 ± 0.08^{a} (-61%)	0.33 ± 0.08^{a} (-72%)	1.03
90	1.60 ± 0.10^{b}	0.83 ± 0.05^{a} (-48%)	0.70 ± 0.00^{a} (-56%)	0.37 ± 0.06^{a} (-77%)	1.02
120	1.97 ± 0.21^{d}	1.33 ± 0.06^{c} (-32%)	1.03 ± 0.15^{b} (-47%)	0.67 ± 0.15^{a} (-66%)	0.27
Vachellia nilotica					
60	2.60 ± 0.20^{b}	2.80 ± 0.56^{b} (+8%)	2.10 ± 0.10^{a} (-19%)	1.9 ± 0.10^{a} (-65%)	0.32
90	1.60 ± 0.10^{b}	0.83 ± 0.05^{a} (-48%)	0.70 ± 0.00^{a} (-56%)	0.37 ± 0.06^{a} (-77%)	1.02
120	9.00 ± 0.26^{d}	5.93 ± 0.91^{c} (-34%)	5.00 ± 0.10^{b} (-44%)	1.80 ± 0.26^{a} (-80%)	0.01

Senegalia senegal

60	3.40 ± 0.46^{b}	3.73 ± 0.15^{a} (+15%)	2.17 ± 0.21^{a} (-51%)	1.13 ± 0.15^{a} (-74%)	0.32
90	3.73 ± 0.15^{b}	2.43 ± 0.32^{a} (-35%)	4.80 ± 0.10^{a} (+29%)	2.30 ± 036^{a} (-38%)	1.12
120	5.83 ± 0.25^{d}	2.03 ± 0.06^{c} (-65%)	6.67 ± 0.32^{a} (+1 4%)	2.73 ± 0.25^{b} (-53%)	1.43

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress).Mean ± Standard Deviation (SD)
The figures within Parenthesis indicates the % reduction (-) and % increase (+) in the root dry weight with respect to control

The root-to-shoot ratio increased significantly with drought severity in most cases, especially in *S. senegal*, where ratios surged by up to 650% at 90 days under M2. This indicates an adaptive shift toward root development to enhance water uptake (Table 5). *V. nilotica* also showed high plasticity in this trait, while *V. tortilis* had a more moderate response. The increase in root-to-shoot ratio is a common adaptation in xerophytes to mitigate drought effects (Lambers et al., 2008). The results suggest *S. senegal* possesses a superior drought adaptation mechanism.

Table 5. Root to shoot ratio of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

	Treatments				
Days	M_0	M_1	M_2	M_3	LSD 5%
Vachellia tortilis					
60	0.84 ± 0.03^{d}	0.66 ± 0.07^{c} (-21%)	1.18 ± 0.03^{b} (+41%)	0.87 ± 0.04^{a} (+36%)	0.03
90	0.86 ± 0.02^{d}	0.05 ± 0.01^{c} (-41%)	0.84 ± 0.02^{b} (-2%)	0.71 ± 0.01^{a} (-17%)	0.02
120	0.86 ± 0.04^{c}	0.74 ± 0.05^{b} (-14%)	0.72 ± 0.04^{b} (-16%)	0.63 ± 0.03^{a} (-27%)	0.04
Vachellia nilotica					
60	0.28 ± 0.03^{d}	0.30 ± 0.04^{c} (+7%)	0.37 ± 0.02^{b} (+32%)	0.96 ± 0.06^{a} (+243%)	0.05

90	0.13 ± 0.01^{a}	0.07 ± 0.01^{c} (-46%)	1.09 ± 0.01^{b} (+31%)	10.13 ± 0.02^{a} (0%)	0.02
120	0.44 ± 0.04^{c}	0.39 ± 0.02^{b} (-11%)	0.50 ± 0.02^{a} (+14%)	0.48 ± 0.07^{a} (+9%)	0.03
Senegalia senegal					
60	3.66 ± 0.12^{c}	1.14 ± 0.40^{c} (-13%)	2.41 ± 0.20^{b} (-34%)	1.79 ± 0.20^{a} (-51%)	0.50
90	0.71 ± 0.04^{d}	2.08 ± 0.20^{c} (+193%)	5.33 ± 0.60^{b} (+650%)	4.34 ± 0.50^{a} (+511%)	0.81
120	2.61 ± 0.10^{d}	1.11 ± 0.10^{c} (-57%)	5.56 ± 0.50^{b} (+113%)	3.14 ± 0.40^{a} (+20%)	0.12

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress).Mean $\pm$ Standard Deviation (SD)
The figures within parenthesis indicates the % reduction (-) and % increase (+) in the root to shoot ratio with respect to control

Leaf area is a critical morphological trait influenced by water availability, as it directly affects the plant's photosynthetic capacity and transpiration rates. In this study, water stress significantly affected the leaf area of all three species over time (Table 6). For *V. tortilis*, leaf area decreased consistently with increasing water stress. At 60 days, leaf area under M1, M2, and M3 was reduced by approximately 38%, 56%, and 69%, respectively, compared to the control (M0). This trend continued through 90 and 120 days, with up to 63% reduction under M3 at 90 days. These reductions indicate a sensitivity of *V. tortilis* to water deficit, likely reflecting a strategy to limit water loss by reducing leaf surface area under stress conditions. In contrast, *V. nilotica* exhibited a mixed response under different watering regimes. At 60 days, the leaf area decreased by 50% under M1 but increased by 25% and 50% under M2 and M3, respectively, compared to the control (M0). This initial variability may reflect an adaptive morphological response or compensatory growth under moderate stress. However, as stress progressed over time, the trend shifted toward consistent reductions. By 120 days, leaf area declined steadily under M1, M2, and M3 by approximately 17%, 25%, and 42%, respectively, indicating that prolonged water stress negatively impacted foliage development in *V. nilotica*.

Table 6. Leaf area (cm^2) of *Vachellia tortilis, Vachellia nilotica* and *Senegalia senegal* at different watering regimes over days

Days	Treatments M_0	M_1	M_2	M_3	LSD 5%
Vachellia tortilis					
60	0.16 ± 0.01^c	0.10 ± 0.11^b (-38%)	0.07 ± 0.07^b (-56%)	0.05 ± 0.05^a (-69%)	0.04
90	0.19 ± 0.01^c	0.15 ± 0.01^b (-21%)	0.14 ± 0.03^b (-26%)	0.07 ± 0.01^a (-63%)	0.15
120	0.21 ± 0.02^c	0.16 ± 0.01^b (-24%)	0.10 ± 0.01^a (-52%)	0.09 ± 0.01^a (-57%)	1.51
Vachellia nilotica					
60	0.04 ± 0.06^{bc}	0.02 ± 0.06^b (-50%)	0.05 ± 0.06^{bc} (+25%)	0.06 ± 0.07^{bc} (+50%)	0.04
90	0.07 ± 0.01^a	0.059 ± 0.01^a (-14%)	0.05 ± 0.06^a (-29%)	0.039 ± 0.00^a (-42%)	0.04
120	0.12 ± 0.01^a	0.10 ± 0.00^a (-17%)	0.09 ± 0.01^a (-25%)	0.07 ± 0.01^a (-42%)	0.07
Senegalia senegal					
60	0.09 ± 0.01^a	0.08 ± 0.01^a (-11%)	0.08 ± 0.00^a (-11%)	0.07 ± 0.01^a (-22%)	0.04
90	0.12 ± 0.00^b	0.13 ± 0.01^b (+8%)	0.10 ± 0.02^a (-17%)	0.11 ± 0.01^a (-8%)	0.06
120	0.15 ± 0.01^a	0.16 ± 0.02^a (+7%)	0.17 ± 0.00^a (+13%)	0.16 ± 0.01^a (+7%)	0.08

M0 = watered four times a week (control)
M1= watered three times a week (slight moisture stress)
M2 = watered two times a week (moderate moisture stress)
M3 = watered once in a week (severe moisture stress). Mean ± Standard Deviation (SD)
The figures within parenthesis indicates the percentage (-) and (+) in the leaf area with respect to control

S. senegal showed the least reduction and even marginal increases in leaf area under mild and moderate stress. At 120 days, leaf area under M1, M2, and M3 increased by 7%, 13%, and 7%, respectively, compared to the control. This suggests an adaptive advantage of *S. senegal*

in water-limited conditions, potentially due to efficient stomatal regulation or higher water use efficiency. These observations align with the findings of Anjum et al. (2011) and Chaves et al. (2003), who reported that drought-tolerant species often maintain or increase leaf area through osmotic adjustment and structural resilience.

Overall, *S. senegal* demonstrated the highest degree of morphological stability in leaf area under drought conditions, further supporting its suitability for dryland afforestation programs.

4. Conclusion

This study highlights the impact of varying watering regimes on the growth and biomass accumulation of three species. It was observed that water stress led to a decrease in the overall growth performance of the species, but *Senegalia senegal* exhibited a higher degree of resilience compared to *Vachellia tortilis* and *Vachellia nilotica*. Among the species, *S. senegal* had the least reduction in root biomass, suggesting its superior adaptability to water stress conditions. The experiment also demonstrated that severe water stress significantly impaired plant growth across all species, with root and shoot biomass reductions being most pronounced under such conditions. Therefore, *Senegalia senegal* appears to be a more promising candidate for afforestation initiatives in semi-arid regions where water availability is a concern.

These results provide valuable insights into species selection for afforestation efforts aimed at combating desertification and improving soil fertility in dryland areas. Future research could focus on more detailed physiological mechanisms of drought tolerance in these species and explore their potential for large-scale agroforestry practices.

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