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Full Length Research

Influence of differential watering regimes on root traits and productivity of *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* in the Semi-Arid Zone of Maiduguri, Borno State, Nigeria

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ABSTRACT: Understanding the dynamics of root productivity under drought stress is critical for selecting resilient tree species for dryland forestry. This study examines the impact of various watering regimes on root growth and Net Primary Productivity (NPP) of three leguminous species: *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* under semi-arid conditions in Maiduguri, Nigeria. Seedlings were subjected to four watering regimes (control: four times a week, slight stress: three times a week, moderate stress: two times a week, and severe stress: once a week), and their root length, dry weight, and NPP were measured at 30, 90, and 120 days after planting. Results revealed species-specific responses, with *S. senegal* consistently maintaining higher root biomass and NPP under moderate stress, indicating strong drought adaptation. The degree of positive relationship between NPP and watering regime at 90 days was stronger in *S. senegal* (27%) than in *V. nilotica* (11%), highlighting superior physiological plasticity. Although *V. tortilis* was resilient under severe drought, it showed a strong negative correlation between NPP and watering frequency, indicating an inverse relationship between water availability and root productivity. These findings underscore the value of root-based metrics like NPP in identifying drought-tolerant species. *S. senegal* and *V. nilotica* emerge as promising candidates for reforestation and ecosystem restoration in arid and semi-arid zones.

Keywords: Drought stress, ecophysiological response, net primary productivity, root adaptation, soil moisture deficit, semi-arid reforestation.

INTRODUCTION

Water availability is a critical factor influencing plant growth, productivity, and survival, particularly in arid and semi-arid regions such as northeastern Nigeria. These ecosystems face increasing threats from prolonged droughts and erratic rainfall patterns due to climate change, which significantly hampers natural vegetation regeneration and reforestation efforts (FAO, 2022; IUCN, 2023). In such contexts, understanding species-specific responses to water stress is essential for selecting drought-resilient tree species for afforestation, agroforestry, and ecological restoration.

Although several studies have examined biomass allocation and drought responses in dryland tree species, there is a noticeable gap in the literature regarding the direct quantification of correlations between root Net Primary Productivity (NPP) and watering regimes. This study aims to bridge that gap by analysing species-specific root NPP/day responses to varying water availability in *Vachellia* and *Senegalia* seedlings.

Drought is one of the primary limitations to seedling establishment in drylands, with its impact on root development drawing increasing attention in dryland forestry research (Comas *et al*., 2013; Sarr *et al.,* 2024). Root systems play a central role in water acquisition, thrust roots such as length, dry biomass, and Net Primary Productivity (NPP) are key indicators of a plant’s drought resilience. Enhanced root biomass allocation under water-limited conditions enables plants to access deeper soil moisture and improve survival (Poorter *et al.*, 2012a). Moreover, species that maintain higher root NPP during stress are often more capable of sustaining overall plant growth and productivity (Comas *et al*., 2013).

The genus *Acacia*, recently reclassified into *Vachellia* and *Senegalia*, includes several native multipurpose species vital for ecological and socio-economic functions in drylands. *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* are among the most widely distributed in the Sahel and sub-Saharan Africa, valued for their roles in soil stabilisation, fodder provision, gum arabic production, and carbon sequestration (Sinare and Gordon, 2015; Sarr *et al*., 2024**;** Cory *et al.,* 2022). However, these species vary in their drought adaptation strategies, especially at the seedling stage—the most vulnerable period of plant development.

In addition to drought-focused studies, earlier research has investigated root growth responses under other environmental stressors. For instance, Saquib (2009, 2012) explored root development in *Melilotus indicus* and *Anagallis arvensis* under coal smoke pollution, while Khan and Ghouse (1988) examined air pollution effects on *Anagallis* root growth. These studies emphasised root sensitivity as a key indicator of environmental stress and adaptation, laying a foundation for examining root responses under abiotic challenges like drought.

Building on this foundation, the present study evaluates how varying watering regimes influence root Net Primary Productivity (NPP) in *V. tortilis*, *V.nilotica*, and *S.senegal* seedlings in a semi-arid environment. The objective is to identify root-based traits that contribute to drought resilience and inform species selection for dry land afforestation and restoration in northeastern Nigeria. The results demonstrate species-specific differences in root responses to water stress, thereby achieving the aim of quantifying NPP trends and identifying traits associated with drought adaptation.

MATERIALS AND METHODS

Study area and experimental setup

The study was conducted in Maiduguri, Borno State, Nigeria (Lat. 11°44′50″–11°55′25″N, Long. 13°02′25″–13°16′00″E). Laboratory work took place at the University of Maiduguri, while nursery experiments were carried out at Imam Malik Botanical Garden, Maiduguri.

Plant materials and pre-treatment

Seeds of *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* were sourced from the Borno State Ministry of Environment. To break dormancy, seeds were soaked in boiled water for 10 minutes before sowing.

Soil and potting

Plastic pots (32 cm wide × 40 cm long) were filled with a 3:2:1 mixture of topsoil, cow dung, and river sand. Dry leaves were placed at the bottom for drainage.

Experimental design

A total of 144 pots were used, with two seeds sown per pot. After germination, seedlings were thinned to one per pot. The experiment followed a Randomised Complete Block Design in split-plot format with four watering regimes:

M0: Four times/week (control)
M1: Three times/week (slight stress)
M2: Twice/week (moderate stress)
M3: Once/week (severe stress)
Each pot received 1 litre of water per watering.

Data collection

Root morphological data (length and dry weight) were recorded at 60, 90, and 120 days after sowing on 10 randomly selected seedlings per species. Root length was measured with a meter rule, and dry weight was determined after oven-drying at 70°C for 72 hours (Poorter *et al*., 2012b)**.**

Net primary productivity (NPP)

NPP was calculated as the increase in root biomass divided by the age of the plant in days. Fine root hairs lost during measurement were not included. Both the plant age and initial biomass were considered negligible at the starting point of 60 days (Saquib, 2012).

Statistical analysis

Descriptive statistics and ANOVA were performed using SPSS. Mean comparisons were conducted using the Least Significant Difference (LSD) test at a significance level of $p<0.05$. Pearson correlation analysis was used to assess the relationships between NPP per day and watering regimes. Biomass of the embryo at the seedling stage was considered to be zero.

RESULTS

Root length

Root length responses varied across species, watering regimes, and seedling age (Table 1). In general, reduced watering frequency led to a decline in root length for most treatments, although exceptions were observed.

Table 1. Root Length (cm) of *Vachellia tortilis, Vachellia. nilotica and Senegalia senegal* at different watering regimes over days (The figures within parentheses indicate the % reduction (-) & % increase (+) in the root length with respect to the control).

Days	Treatments				
	M0	M1	M2	M3	LSD 5%
V. 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
V. nilotica					
60	43.00±4.32^{c}	23.47±3.72^{a}(-45)	39.70±3.19^{a}(-44)	25.80±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	67.30±4.13^{c}	40.70±3.02^{ab}(-40)	59.17±3.30^{b}(-12)	42.70±4.19^{a}(-37)	0.19
S. 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)	15.70±3.33^{a}(-22)	0.34
120	47.76±0.96^{a}	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 a week (severe moisture stress). Means ± SD with different superscript letters within the same row are significantly different at $p<0.05$ based on the LSD test.

For *Vachellia tortilis*, root length decreased progressively with increasing moisture stress. At 60 days, root length was highest under the control treatment (M0), with significant reductions of 28%, 38%, and 60% under M1, M2, and M3, respectively. By 90 days, root length under M0 reached 40.63 cm, with reductions of 9%, 34%, and 47% recorded for M1, M2, and M3. A similar trend was maintained at 120 days, where reductions of 11%, 38%, and 50% were observed under the respective stress treatments.

In *Vachellia nilotica*, root length at 60 days was highest in the control (43.00 cm), with notable reductions of 45%, 44%, and 40% under M1, M2, and M3. At 90 days, root length also declined, though the reductions were less severe—18%, 33%, and 30% under M1, M2, and M3, respectively, compared to the control (43.80 cm). At 120 days, root length declined by 40%, 12%, and 37% under M1, M2, and M3, respectively.

Senegalia senegal exhibited a markedly different pattern. At 60 days, root length was lowest under M1 (35% reduction) and M3 (27% reduction), but showed a significant increase (87%) under M2 relative to the control ($p<0.05$). At 90 days, root length under M2 remained elevated with a 68% increase, while M1 and M3 showed 19% and 22% reductions. At 120 days, root length was again significantly higher under M2 (60% increase), whereas M1 and M3 caused 25% and 18% reductions, respectively.

The Least Significant Difference (LSD) at 5% confirms that these changes were statistically significant ($p<0.05$), particularly for treatments showing sharp increases or declines. Notably, *S. senegal* exhibited a distinct adaptive response under moderate water stress, contrasting with the consistent decline observed in *V. tortilis* and *V. nilotica*.

Root biomass

Root biomass, measured as root dry weight, was significantly influenced by watering regimes, seedling age, and species (Table 2). Overall, root dry weight declined with increasing water stress, although some species showed distinct deviations from this trend.

In *V. tortilis*, root biomass decreased progressively under increased stress across all growth stages. At 60 days, the control (M0) recorded the highest root dry weight (1.20 g), with reductions of 56%, 61%, and 72% under M1, M2, and M3, respectively. At 90 days, compared to the control (1.60 g), root dry weight declined by 48%, 56%, and 77% under increasing stress. By 120 days, reductions of 32%, 47%, and 66% were recorded under M1, M2, and M3, respectively.

V. nilotica displayed a more complex pattern. At 60 days, root biomass slightly increased by 8% under M1 relative to the control (2.60 g), while M2 and M3 caused reductions of 19% and 65%. However, at 90 days, a consistent decline was observed, with 48%, 56%, and 77% reductions under M1, M2, and M3. At 120 days, root biomass dropped significantly under stress, with M1, M2, and M3 reducing biomass by 34%, 44%, and 80%, respectively, compared to the control (9.00 g).

S. senegal again demonstrated a distinct response. At 60 days, root biomass increased by 15% under M1 (relative to the control at 3.40 g), while M2 and M3 resulted

Table 2. Root dry weight (g) of *Vachellia tortilis, Vachellia nilotica and Senegalia senegal* at different watering regimes over days (The figures within parentheses indicate the % reduction (-) & % increase (+) in the root weight with respect to the control).

Days	Treatments				LSD 5%
	M0	M1	M2	M3	
V. 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
V. nilotica					
60	2.60 ± 0.20^{b}	2.80 ± 0.56^{b}(+8)	2.10 ± 0.10^{a}(-19)	1.90 ± 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
S. 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 ± 0.36^{a}(-38)	1.12
120	5.83 ± 0.25^{d}	2.03 ± 0.06^{c}(-65)	6.67 ± 0.32^{a}(+14)	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 a week (severe moisture stress). Means ± SD with different superscript letters within the same row are significantly different at $p < 0.05$ based on the LSD test.

Table 3. Root Net Primary Productivity (mg root^{-1}day^{-1}) of *Vachellia tortilis, Vachellia nilotica and Senegalia senegal* at different watering regimes over days (The figures within parentheses indicate the % reduction (-) & % increase (+) in the NPP with respect to the control).

Days	Treatments			
	M_0	M_1	M_2	M_3
V tortilis				
60	0.0200	0.0088 (-56)	0.0078 (-61)	0.0055 (-72)
90	0.0100	0.0077 (-25)	0.023 (+ 42)	0.0013 (-90)
120	0.0123	0.0167 (+36)	0.0110 (-11)	0.0100 (-19)
V. nilotica				
60	0.0433	0.0467 (+8)	0.0350 (-19)	0.0317 (-27)
90	0.0333	0.0657 (+97)	0.0467 (+40)	0.0510 (+53)
120	0.2467	0.1700 (-31)	0.1433 (-42)	0.0477 (-81)
S. senegal				
60	0.0567	0.0622 (+10)	0.0362 (-36)	0.0188 (-67)
90	0.1110	0.0433 (+294)	0.0877 (+698)	0.0390 (+255)
120	0.0700	0.0133 (-119)	0.0623 (- 11)	0.0143 (-80)

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 a week (severe moisture stress).

in 51% and 74% reductions. At 90 days, a substantial 29% increase in root biomass occurred under M2 (relative to 3.73 g in the control), whereas M1 and M3 led to 35% and 38% reductions. At 120 days, M2 again induced a biomass increase of 14%, while M1 and M3 produced declines of 65% and 53%, respectively, compared to the control (5.83 g).

Net Primary Productivity (NPP/day)

Net Primary Productivity (NPP/day) varied significantly with species, watering regimes, and seedling age (Table 3). Although reduced watering generally decreased NPP, species-specific responses were evident, especially in *S. senegal*, which showed notable increases under certain stress conditions.

For *V. tortilis*, NPP declined consistently with increased water stress at 60 days. The control (M0) recorded the highest NPP (0.0200 g/day), while M1, M2, and M3 showed declines of 56%, 61%, and 72%, respectively. At 90 days, similar trends continued, with reductions of 25%, 42%, and 90% under M1, M2, and M3 (relative to 0.0133

Table 4. Correlation Coefficient (r), Per cent Dependence (d), and Linear Regression Equation (Ŷ) between Net Primary Productivity (NPP) and watering regime of three plant species (*Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal*) at different seedling ages.

Species	Age (days)	Correlation Coefficient (r ± SE)	Per cent Dependence (d%)	Linear Regression Equation (Ŷ = a + bx)
V.tortilis	60	–0.89 ± 0.07	79*	Ŷ = 0.017 – 0.004x
	90	–0.98 ± 0.03	96*	Ŷ = 0.014 – 0.004x
	120	–0.55 ± 0.04	30*	Ŷ = 0.014 – 0.001x
V.nilotica	60	–0.86 ± 0.03	74*	Ŷ = 0.046 – 0.005x
	90	+0.33 ± 0.15	11*	Ŷ = 0.044 + 0.003x
	120	–0.98 ± 0.03	96*	Ŷ = 0.245 – 0.062x
S.senegal	60	–0.91 ± 0.07	83*	Ŷ = 0.064 – 0.014x
	90	+0.52 ± 0.15	27*	Ŷ = 0.026 + 0.013x
	120	–0.50 ± 0.03	25*	Ŷ = 0.058 – 0.012x

SE = Standard Error, * = significant at 5% level.

g/day in control). Interestingly, at 120 days, NPP increased by 36% under M1 compared to the control (0.0123 g/day), while M2 and M3 still showed declines of 11% and 19%, respectively.

In *V. nilotica*, NPP at 60 days increased slightly (+8%) under M1 (0.0467 g/day) compared to the control (0.0433 g/day), while it declined by 19% and 27% under M2 (0.0350 g/day) and M3 (0.0317 g/day). At 90 days, NPP increased across all treatments relative to the control (0.0333 g/day), with +97% under M1 (0.0657 g/day), +40% under M2 (0.0467 g/day), and +53% under M3 (0.0510 g/day). However, by 120 days, NPP declined significantly, with reductions of 31%, 42%, and 81% under M1 (0.1700 g/day), M2 (0.1433 g/day), and M3 (0.0477 g/day), respectively, relative to the control (0.2467 g/day).

S. senegal exhibited a remarkable response to stress. At 60 days, NPP increased slightly (+10%) under M1 compared to the control (0.0567 g/day), while M2 and M3 led to 36% and 67% reductions. At 90 days, NPP increased dramatically under all stress levels, with gains of 294% (M1), 698% (M2), and 255% (M3) relative to the control (0.0110 g/day). However, at 120 days, NPP declined by 119% under M1 and 80% under M3, while M2 showed only a modest 11% decline.

Correlation analysis

Correlation analysis (Table 4) revealed species-specific relationships between NPP and watering regimes. In *V. tortilis*, a strong negative correlation was observed at all growth stages (r = –0.86 to –0.98), indicating that increasing water stress consistently reduced productivity. *V. nilotica* showed a more variable response, with a strong negative correlation (r = –0.98) at 120 days, but a weak positive correlation (r = +0.33) at 90 days. In contrast, *S. senegal* showed moderate to strong negative correlations at 60 and 120 days (r = –0.91 and –0.50), but a positive correlation (r = +0.52) at 90 days, aligning with the dramatic increases in NPP observed under stress.

DISCUSSION

This study investigated the effects of different watering regimes on root length, root biomass, and root Net Primary Productivity (NPP/day) in *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* seedlings under semi-arid conditions in Maiduguri, Nigeria. The findings reveal species-specific differences in morphological and physiological responses to water stress, which are crucial for selecting drought-resilient species in afforestation and restoration programs.

Root length and biomass responses to water stress

Across all species, water stress generally reduced root length and root biomass, with the most severe declines observed under the longest watering interval (M3: every 7 days). However, the magnitude and pattern of decline varied among species. *V. tortilis* showed the most consistent and linear reduction in both root length and biomass with increasing stress, indicating a low tolerance to moisture limitation. This supports earlier observations that *V. tortilis* is relatively sensitive to prolonged drought (Raddad and Luukkanen, 2006).

V. nilotica displayed a more complex pattern. Although root length and biomass generally declined under stress, there were occasional increases at moderate stress levels (M1), suggesting some degree of adaptability or compensation. A similar tolerance mechanism was noted by Madnee *et al.* (2025), who reported improved root allocation in *V. nilotica* under intermediate drought.

Notably, *S. senegal* exhibited a distinct adaptive response under moderate stress (M2), where both root length and biomass increased significantly compared to the control. This suggests a capacity for compensatory root growth under water-limited conditions, possibly as a drought avoidance strategy. Enhanced root elongation and biomass accumulation under moderate stress could help *S. senegal* access deeper soil moisture, consistent with the findings of Comas *et al.* (2013) and Walters *et al.* (2023), who reported stress-induced root proliferation in drought-adapted legumes and tree seedlings.

Net primary productivity (NPP/day) and its correlation with water stress

Previous studies have documented the effects of drought stress on biomass allocation and root growth (Bachofen *et al.,* 2024 and Guasconi *et al*., 2023). However, very few have statistically quantified the relationship between Net Primary Productivity (NPP) and watering frequency, especially at the root level in tree seedlings. Most existing research presents generalised trends or regression models linking water availability to total biomass or shoot development (Poorter *et al*., 2012b; Sarr *et al.,* 2024), but lacks direct correlation coefficients that specifically relate root NPP/day to watering regimes. This study fills that gap by offering a detailed correlation analysis, including r-values and regression equations that reveal species-specific responses in root productivity to varying drought intensities. In particular, the positive correlation observed in *Senegalia senegal* under moderate stress (r = +0.52 at 90 days) highlights an adaptive physiological mechanism that may be overlooked in broader biomass studies. These findings underscore the value of root-based metrics like daily NPP in accurately identifying drought-resilient species for dryland forestry.

NPP trends paralleled the root biomass responses, with *V. tortilis* showing a consistent decline in productivity under stress across all stages. The correlation analysis confirmed this, revealing a strong negative correlation between NPP and water stress at 60, 90, and 120 days (r = –0.55 to –0.98), confirming its sensitivity to moisture reduction. This aligns with findings by Khan and Ghouse (1988) and Saquib (2009, 2012), who reported declining root productivity on weed plants under industrial air pollution stress, another environmental stressor that can affect physiological function.

In contrast, *V. nilotica* exhibited a positive correlation between NPP and watering regime at 90 days (r = +0.33), indicating that moderate stress temporarily enhanced productivity. This could reflect a phase of compensatory growth or improved resource-use efficiency during early developmental stages. However, this effect was not sustained at 120 days, when a strong negative correlation re-emerged (r = –0.98), indicating that prolonged stress ultimately hindered productivity.

Senegalia senegal again showed the most remarkable physiological resilience. At 90 days, NPP increased under all watering regimes compared to the control, with the correlation analysis revealing a moderate positive relationship (r = +0.52). Notably, the degree of positive correlation at this stage was substantially higher in *S. senegal* (27% increase in NPP) than in *V. nilotica* (11% increase), highlighting *S. senegal*'s superior performance under moderate drought. This finding is particularly important for afforestation efforts in semi-arid zones, as it demonstrates the species' capacity to maintain or even enhance productivity under intermediate water stress.

These positive correlations at 90 days suggest a temporal window during which seedlings may activate adaptive growth mechanisms, such as efficient carbon allocation to roots or enhanced root respiration and nutrient uptake. Such responses are consistent with the theory of hormesis in plant stress physiology, where low to moderate stress can trigger beneficial responses (Calabrese and Baldwin, 2001).

Implications for drought tolerance and afforestation

The differential responses among the three species underscore the importance of selecting appropriate species for dryland restoration. *V. tortilis* appears less suited to prolonged drought due to its sharp decline in root growth and NPP. *V. nilotica* shows moderate adaptability but lacks sustained productivity under extended stress. In contrast, *S. senegal* emerges as the most drought-resilient species in this study, with the ability to maintain or enhance root growth and NPP under moderate stress. Its adaptive growth under M2 conditions suggests that it can survive and even thrive in environments with infrequent rainfall—an essential trait for semi-arid reforestation programs.

These results also validate the importance of root-based indicators like root NPP and root biomass in assessing drought tolerance. Root growth reflects the capacity of seedlings to explore deeper soil layers and sustain physiological activity during dry periods (Uni *et al*., 2023). The superior root performance of *S. senegal* under moderate stress reinforces its ecological plasticity and supports its use in dryland agroforestry systems.

Conclusion

This study reveals distinct species-specific differences in root development and root Net Primary Productivity (NPP) among *Vachellia tortilis*, *Vachellia nilotica*, and *Senegalia senegal* seedlings under varying water availability in the semi-arid conditions of Maiduguri, Nigeria. *S. senegal* demonstrated the strongest drought adaptation, consistently maintaining higher root biomass and NPP under moderate water stress. This highlights its suitability for dryland afforestation and ecosystem restoration programs.

V. nilotica showed a delayed but positive response at 90 days, with increased NPP across all watering regimes, suggesting some adaptive capacity during early drought exposure. However, its productivity declined under prolonged severe stress, indicating limited long-term drought tolerance.

In contrast, *V. tortilis* exhibited a continuous decline in root length, biomass, and NPP with increasing water stress, reflecting low resilience under drought conditions. Despite its reputation for hardiness, these results suggest that *V. tortilis* may be less suitable for areas with prolonged or intense water scarcity.

These findings reinforce the value of root traits and NPP as reliable indicators of drought resilience in leguminous tree species. The superior performance of *S. senegal* and, to a lesser extent, *V. nilotica* under moderate stress conditions positions them as priority species for reforestation and agroforestry initiatives in arid and semi-arid zones.

As climate change intensifies drought pressures, incorporating root-based metrics like NPP into species selection and management strategies offers a robust pathway to enhance the effectiveness and sustainability of dryland forestry. Future research should expand on these insights through long-term field trials and integrative physiological or molecular approaches to elucidate the underlying mechanisms of drought adaptation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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