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Original Article

Growth Performance and Carbon Sequestration potential of Planted *Albizia versicolor* and *Albizia harveyi* in Morogoro, Tanzania

Milka Elieza Musana[1], Shaban Athuman Chamshama[1], Eliakimu Zahabu & Wilson Mugasha[1]*

[1] Sokoine University of Agriculture, P. O. Box 3010, Morogoro, Tanzania.
[*] Correspondence Email: musanamilka@gmail.com

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Miombo Woodlands, Monoculture Growth Performance, Carbon Sequestration, Albizia Harveyi, Albizia Versicolor.

ABSTRACT

This study assessed the growth performance and Carbon sequestration potential of 21-year-old Albizia versicolor Welw ex. Oliver. (Av) and Albizia harveyi Fourn (Ah) planted in 2003 at Maseyu village, Morogoro, Tanzania. These species are among the species preferred for wood fuel in Tanzania and other countries within African savanna ecosystems. Seedlings of the two species were planted at a spacing of 2 x 2 m with 25 trees per plot (8 x 8 m) using a completely randomized block design with three replications. In 2024, measurements were taken for diameter at breast height (Dbh) and height. Data was analyzed to get means for Dbh, height, volume, annual increment (MAI), above-ground biomass (AGB) and above-ground Carbon stock (AGC). An independent t-test was used to analyze differences in species parameters using R-studio. Results showed significant differences in stocking density ($p < 0.001$), Dbh ($p < 0.001$) and height ($p < 0.001$) between species, with Albizia versicolor exhibiting larger mean Dbh (8.82 ± 1.36 cm) and height (7.46 ± 1.47 m) but relatively lower stocking density (1,188 ± 407 stems/ha) compared to Albizia harveyi (7.33 ± 1.16 cm,6.63 ± 2.28 m and 2,230 ± 1046 stems/ha respectively). However, no significant differences were found in volume, AGB, and AGC. Volume increments were 2.41 m^3/ha/yr for Albizia versicolor and 2.58 m^3/ha/yr for Albizia harveyi, while AGB increments were 1.23 and 1.17 t/ha/year for Albizia versicolor and Albizia harveyi respectively. Above-ground Carbon (AGC) stock increments (0.58 and 0.62 tC ha^{-1} $year^{-1}$) for Albizia versicolor and Albizia harveyi respectively under monoculture were consistent with studies on mature Miombo woodlands. These findings suggest that both Albizia species perform well in monoculture growth, demonstrating their potential for sustainable Miombo woodland management and Carbon sequestration, despite lower biomass accumulation rates compared to natural Miombo ecosystems.

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INTRODUCTION

Savanna is the world's largest ecosystem, occupying about 50% of Africa's land area and 20% of the global land area (Morales-Rincon *et al.,* 2021; Osborne *et al.,* 2018). The Miombo woodlands in Southern Africa are a portion of the southern hemisphere of the African savanna covering two-thirds of the Sudan Zambezian phytoregion (about 2.7 million km^2) (Jinga & Palagi, 2020; Mukwada, 2018; Syampungani *et al.,* 2010) with about 8500 species of plants, common ones being *Jubernadia* species, *Brachystegia* species, *Pseudilachnostylis maprouneifolia*, *Burkea africana* and *Diplorhynchus condylocarpon* (Ribeiro *et al.,* 2020b).

These woodlands are a major source of energy for fuelwood in portions of Angola, the Democratic Republic of the Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe and a vital supply of subsistence items for daily living, such as food, medicine, poles and building materials, lumber, and construction products (Bulusu *et al.,* 2021; Chiteculo *et al.,* 2018). In addition, the woodlands support biodiversity, preserve soil fertility, manage soil erosion, provide shade, maintain Carbon stocks (which in turn regulate climate), and govern hydrological cycles; all of which are crucial ecosystem services (Gumbo & Dumas-Johansen, 2021; Jew *et al.,* 2019). In Tanzania, almost 91% of the country's forested area equivalent to 44 million hectares (ha) is covered by this type of vegetation with a diverse understory of shrubs, grasses, and other vegetation (Mwakalukwa *et al.,* 2024; Manyanda *et al.,* 2021; Lupala *et al.,* 2015).

Despite their ecological and socio-economic significance, the Miombo woodlands in Tanzania face multiple threats from anthropogenic factors which include late wildfires, shifting cultivation and unsustainable harvesting for firewood, charcoal and timber (Ribeiro *et al.,* 2020a; Catarino *et al.,* 2021). To ensure the long-term sustainability and benefits of these woodlands, effective management strategies are essential (Campbell *et al.,* 2007). One such strategy involves the establishment of woodlots, on-farm plantings, and plantations using tree species native to the Miombo woodlands (Vyamana *et al.,* 2021; Kimambo *et al.,* 2020). These alternatives can supplement high-value tree species needed for domestic and external markets.

While studies on the growth performance of Miombo tree species under agroforestry systems exist, little has been documented on their performance when planted in monoculture. Therefore, the specific objectives of this paper are to evaluate the growth performance of *Albizia harveyi* and *Albizia versicolor* in terms of volume, biomass, and carbon sequestration potential 21 years after their establishment in monoculture at Maseyu Village, Morogoro, Tanzania. These two

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species are recognized as being among the preferred species for wood fuel in Tanzania and other African savanna ecosystems, as highlighted by Vyamana *et al*., (2021) and Kaschula *et al*., (2005).

MATERIALS AND METHODS

Study site description

The study was conducted at Maseyu village near Kitulang'halo forest reserve about 50 km east of Morogoro municipality ($6^0$41' S and $37^0$57' E). This area was chosen due to its suitable soil types ranging from alfisols to mollisols and inceptisols depending on the altitude of the specific area (Msanya *et al.*, 1995) and environmental conditions. The predominant natural vegetation is regrowth open Miombo woodland with few scattered *Julbenardia globiflora*, *Brachystegia spp* and *Pterocarpus rotundifolia* in the upper story reaching a height of 15-20 m alongside *Themeda triandra* grasses which can reach up to 1.5 m high.

The area experiences tropical and sub-humid climates with two distinct seasons i.e. wet and dry seasons. The wet season is characterized by long and heavy rains from February to May which can reach up to 1000 mm per annum. The weather is warm and arid during the dry season from June to October. There are occasional showers during the dry season especially the month of July and August. Between the wet and dry seasons, there are often short rains which are normally light and sporadic, occurring from November to December. The temperature varies between 18^0C and 30^0C and the mean annual temperature is 24.3^0C (Njoghomi, 2021). The inhabitants of Kitulang'halo practice agriculture and poultry keeping as important economic activities.

Study design

This study utilized an experimental setup that was established in March 2003 and later documented by Vyamana *et al*. (2007) when assessing the effects of nursery treatments such as shade, polythene diameter, tube height, and soil mixtures on the survival and growth of five Miombo tree species: *Albizia harveyi*, *Albizia versicolor*, *Diplorhynchus condylocarpon*, *Pericopsis angolensis*, and *Pterocarpus angolensis*. Seedlings were raised in the nursery using standard nursery techniques and field planted in March 2003. Square plots measuring 8 x 8 m were used, with distances between plots and blocks set at 2.5 m and 3 m, respectively. Seedlings of *Albizia harveyi* and *Albizia versicolor* were planted at a spacing of 2 x 2 m, with 25 trees per plot (5 rows by 5 columns) using a randomized block design with four replications. For each species, each plot had one surrounding row of trees planted at a spacing of 2 x 2 m. The trial was kept clean by weeding three times during the rainy season and twice during the dry season using hand hoes.

Field assessments and analysis

Tree measurements were conducted on 36 plots for *Albizia versicolor* and 26 plots for *Albizia harveyi*. The reduced number of plots for *Albizia harveyi* was due to some plots being completely empty, a result of illegal harvesting observed in the field. Measurements of Dbh and height were taken on all surviving non-border trees within each plot using a caliper and a Suunto Clinometer respectively. Data analysis was conducted using R Studio Software version 4.2.3 to compute mean Dbh, height, volume, AGB, and AGC, utilizing existing allometric models for Miombo woodland species. MAI was computed by dividing above-ground biomass, Carbon stock and volume production by tree age. A Welch Two-Sample t-test was employed to compare variable means between the two species in terms of Dbh, height, volume, MAI, AGB and AGC.

Model selection

In this study, the applicability of existing models for volume and AGB estimation in the Miombo woodlands of Kitulang'halo forest reserve was evaluated. Two models developed by Chamshama *et al.* (2004), as well as more recent models by Mugasha *et al*. (2013) and Mauya *et al*. (2014) were

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considered. To validate these models, field measurements on selected trees representative of small, medium and large diameter were conducted.

The validation process involved felling sample trees, measuring their total height and Dbh, and sectioning them into 1.5 m billets. The length, mid-diameter, and green weight of each billet were recorded directly in the field. Wood disc samples were extracted to determine dry-to-green weight ratios for biomass calibration. Total tree biomass was calculated by summing the dry weights of all billets of a given tree and compared with estimates from the general AGB model equation. For volume estimation, Huber's formula was applied to individual billets of a given tree and compared the summed volumes with predictions from the general volume model equation. Then a t-test was conducted to determine if the two sets of models were statistically significantly different and how closely they aligned with the values obtained directly from the field.

The validation process resulted in the selection of the following models:

Volume (cm^3) = $0.00016*Dbh^{2.463}$ (Mauya *et al.*, 2014).

AGB (tons) = $0.0625*Dbh^{2.553}$ (Chamshama *et al.*, 2004).

RESULTS

Stocking, Diameter at Breast Height, and Height

The analysis revealed significant differences in stocking density, Dbh, and height between *Albizia versicolor* and *Albizia harveyi*, as shown in **Table 1**. *Albizia harveyi* displayed a higher stocking density, which likely contributed to the differences in Dbh. On the other hand, *Albizia versicolor* reached a greater mean height compared to *Albizia harveyi*, with the height difference also confirmed as statistically significant.

Table 1: Stocking Density, Diameter at Breast Height, and Height of *Albizia versicolor* and *Albizia harveyi*

Variable	Species		p-value
	Albizia versicolor	***Albizia harveyi***	
Stocking (Stem/ha)	$1,188 \pm 407^a$	$2,230 \pm 1046^b$	< 0.001
Diameter (cm)	8.82 ± 1.36^a	7.33 ± 1.16^b	< 0.001
Height (m)	7.46 ± 1.47^a	6.63 ± 2.28^b	< 0.001

Note: within the same row, mean ± standard deviation followed by different letters indicate significant differences, p-value < 0.001

Volume and Mean Annual Increment

Despite differences in Dbh and height, no significant difference was observed in volume per ha between the two species, as presented in **Table 2**. The mean volumes for *Albizia versicolor* and *Albizia harveyi* were statistically similar. Similarly, MAI in volume did not differ substantially between the two species.

Table 2: Volume and Mean Annual Increment of *Albizia versicolor* and *Albizia harveyi*

Variable	Species		p-value
	Albizia versicolor	***Albizia harveyi***	
Volume (m^3/ha)	50.57 ± 23.3^a	54.17 ± 27.8^a	0.6242
MAI (m^3/ha/year)	2.41 ± 1.11^a	2.58 ± 1.32^a	0.6242

Note: within the same row, mean ± standard deviation followed by the same letter are not significantly different, p-value > 0.001

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Above-Ground Biomass and Carbon Stocks

As shown in **Table 3**, the analysis of AGB and AGC stocks revealed no significant differences between *Albizia versicolor* and *Albizia harveyi*. Both species demonstrated comparable AGB and AGC values, with no statistically significant difference in increments.

Table 3: Above-Ground Biomass, Above-Ground Carbon, and Mean Annual Increment of *Albizia versicolor* and *Albizia harveyi*

Variable	Species		p-value
	Albizia versicolor	***Albizia harveyi***	
AGB (tons/ha)	24.59 ± 11.6^{a}	25.76 ± 13.5^{a}	0.7449
MAI in AGB (t/ha/yr)	1.17 ± 0.55^{a}	1.23 ± 0.64^{a}	0.7449
AGC (tons/ha)	12.29 ± 5.82^{a}	12.88 ± 6.73^{a}	0.7449
MAI in AGC (tC/ha/yr)	0.58 ± 0.27^{a}	0.62 ± 0.32^{a}	0.7449

Note: within the same row, mean ± standard deviation followed by the same letter are not significantly different, p-value > 0.001

DISCUSSION

Stocking density had a direct impact on growth parameters such as Dbh, volume, AGB, and AGC with no effect on height. In this study, the higher stocking density of *Albizia harveyi*, nearly double that of *Albizia versicolor*, led to smaller Dbh values due to intense competition for resources like light, water, and nutrients, hence restricted lateral growth. In contrast, the lower density of *Albizia versicolor* reduced competition, allowing more resources to be allocated to diameter growth. This aligns with Grundy and Grundy, (1995), who found that reduced competition promotes larger individual growth in Miombo woodlands. Since height was not directly affected by stocking density, the selective removal of larger trees contributed to the lower mean height of *Albizia harveyi* compared to *Albizia versicolor*. As a result, the overall height distribution is skewed toward smaller trees for *Albizia harveyi*, making its height performance appear lower despite potentially similar genetic growth potential.

Despite *Albizia harveyi*'s smaller individual tree sizes, its higher number of stems per ha compensated, resulting in comparable total volume, AGB, and AGC to *Albizia versicolor*. These findings suggest that while *Albizia harveyi* achieves biomass and Carbon stock through high-density stocking, *Albizia versicolor* attains similar levels via increased individual tree growth. Thus, both species contribute similarly to Carbon sequestration under monoculture conditions, with *Albizia harveyi* relying on cumulative density and *Albizia versicolor* on greater growth per tree.

So far there are no reported research on the performance of *Albizia harveyi* and *Albizia versicolor* under monoculture. MAI values of this study fall within the typical range reported for Tanzanian Miombo woodlands, from 0.8 to 3.3 m³/ha/yr, with an average of 1.6 ± 0.2 m³/ha/yr (Manyanda *et al.*, 2020; Treue *et al.*, 2014; Zahabu *et al.*, 2005). Similar increments have been reported in other studies, with annual volume growth rates ranging between 0.57 and 4.35 m³/ha/yr (Ek, 1994). This alignment suggests that the growth rates of both species are consistent with the typical patterns observed in Miombo woodlands, even though they are grown under monoculture conditions.

AGB, values observed in this study align with those reported by Malimbwi *et al.*, (2001) which range from 0.58 to 3 tons/ha. Similarly, Ek, (1994) recorded AGB increments between 0.57 and 2.97 t/ha/year over a period of 13 to 16 years in Morogoro, Tanzania. Additionally, research on younger Miombo woodlands reported higher AGB increments, ranging from 0.7 to 4.2 t/ha/year, depending on factors such as disturbance levels and fire protection (Grundy & Grundy, 1995). On the

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other hand, AGC increments recorded for *Albizia versicolor* and *Albizia harveyi* are also consistent with increments documented by Stromgaard, (1985) who observed 0.5 tC/ha/year in 16-year-old stands; Chidumayo (1997), who reported 0.9 tC/ha/year in 35-year-old Miombo stands and Williams *et al*., (2008) who reported an increment of 0.4 to 0.9 tC/ha/year for 50-year-old Miombo woodlands.

The relatively lower biomass and Carbon stock increments observed in this study may be partly due to illegal harvesting activities, which likely reduced stocking density and contributed to the observed decreases in biomass and Carbon stock. Despite this, other factors such as site-specific conditions and inherent species traits also played a significant role (Bulusu *et al*., 2021). Environmental factors like soil fertility, water availability, and management practices are also known to further influence biomass accumulation rates (Sakala & Vinya, 2020). Additionally, stand age tends to impact growth rates, with younger Miombo species often showing higher biomass growth due to active nutrient cycling, whereas mature or minimally disturbed stands tend to accumulate biomass more slowly (Lusambo, 2016; Lupala *et al*., 2015). Overall, Miombo woodland species are characterized by inherently slow growth rates, which is why relatively low values are observed in this study.

CONCLUSION AND RECOMMENDATIONS

This study provides insights into the monoculture growth of *Albizia versicolor* and *Albizia harveyi* as a strategy for Miombo woodland management. Both species demonstrated comparable growth performance with no significant interspecific variations in volume, AGB, or Carbon stock, suggesting adaptability to monoculture systems and potential for sustainable Miombo woodland management.

The findings have practical implications for sustainable woodland management. The higher stocking density of *Albizia harveyi* and its capacity for volume accumulation, even with smaller diameters, suggest that this species could be prioritized in areas focused on rapid biomass production. In contrast, *Albizia versicolor*, with its larger individual diameters, may be more suited for applications where larger tree structure is preferred, such as timber production or habitat restoration. Such species-specific selection, guided by the study's findings, could enhance the resilience and productivity of Miombo woodland restoration efforts.

Further research is necessary to determine optimal rotation ages and maximum biomass and Carbon sequestration potential for these species in monoculture settings. Expanding studies to include a broader range of Miombo species, with an emphasis on silvicultural practices, species-environment interactions, and genetic diversity, would deepen the understanding of growth dynamics across different Miombo species. This comprehensive approach could lead to optimized management strategies for sustainable woodland restoration and more effective Carbon sequestration. Comparative analyses between monoculture and mixed-species plantings would provide valuable insights into ecosystem function and resilience in managed Miombo systems, ultimately informing best practices for large-scale restoration and climate change mitigation efforts.

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