Journal of Agroforestry and Environment
Volume 19, Issue 1, 2026
Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Morphological and Physiological Growth of *Terminalia superba* Seedlings as Influenced by Different Planting Depths, Width and Urea Application

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Received: 03/03/2026
Accepted: 10/06/2026
Available online: 22/07/2026

Abstract: Optimum survival, growth and development of cultivated tree species are of great importance especially to timber species of high value like *Terminalia superba*. Poor planting technique and inadequate nutrient supply contribute to low survival and growth rate. This study examined the field response of T. *superba* seedlings to different planting depths, widths and urea application. Using split - plot experimental design, at 3m x 3m spacing, seedlings were subjected to Fertilizer treatments (F_0 and F_1), planting depths of 10cm, 15cm and 20cm levels (D_1, D_2 and D_3) and planting width of 10cm and 15cm (W_1 and W_2). Each treatment was replicated ten (10) times. Seedling height, collar diameter and number of leaves were assessed fortnightly for 6 months while biomass was assessed after the end of experiment. Relative Growth Rate (RGR), Absolute Growth Rate (AGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Relative Water Content (RWC) and Leaf Turgidity were estimated using appropriate formula. The result showed that seedlings planted without urea,15cm width and 20cm depth planting hole ($F_0W_2D_3$) had the highest mean height (66.94cm), mean collar diameter (10.28mm) and number of leaves but lower values in dry matter weights and R/S ratio (0.13). Seedlings planted with fertilizer in 10cm width and 10cm depth ($F_1W_1D_1$) recorded the highest RWC value of 54.05%, highest positive NAR and RGR values (0.007 gcm^{-2}/ day^{-1} and 0.305$gg^{-1}day^{-1}$ respectively). Therefore, seedlings subjected to zero urea application, wider and deepest holes ($F_0W_2D_3$) had highest values for height, collar diameter and number of leaves whereas those subjected to 5g urea application, shallow and narrow holes ($F_1W_1D_1$) were physiologically superior though they recorded average morphological values. The findings hereby justified the need for optimizing planting techniques and nutrient management to enhance seedling growth and also support sustainable forest management in Nigeria. It is therefore recommended that forest managers utilize wider and deeper planting holes ($F_0W_2D_3$) to maximize initial physical growth, while incorporating strategic urea application in standard planting holes (F1W1D1) when high physiological resilience and early assimilation rates are prioritized for *T. superba* establishment in Nigeria.

Keywords: *Terminalia superba*; Planting width; Planting techniques; Urea application; Planting width.

INTRODUCTION

Natural forests are complex ecosystems that have evolved over centuries, providing a foundation of biodiversity, environmental stability and human well-being (FAO, 2020). These forests house array of flora and fauna which many of them are endemic and play critical roles in maintaining ecological balance (Gardner *et al.*, 2009). Beyond their biological richness, natural forests deliver essential ecosystem services such as carbon sequestration, water regulation, soil conservation and climate modulation (Bonan, 2008; Thompson *et al.*, 2013) which are vital for mitigating climate change and preventing desertification (Lal, 2004). Forests also offer cultural, aesthetic and recreational values that enrich human societies and contribute to mental and physical well being (Botequim,2025). Another value derived from forests include non-timber forest products which are depended on by most rural populace for livelihood (Shackleton *et al.,* 2015).

Nigerian forests have been blessing to her populace and vital part of the country's ecosystem and economy. These forests are diverse with composition ranging from tall indigenous trees, shrubs, herbs, lianas and epiphyte of different important values. Some indigenous trees are valued for their timber production and one of such is *Terminalia superba*. *T. superba*, commonly known as Afara or Korina, is a deciduous tree species native to tropical Africa, including Nigeria. It is a member of the Combretaceae family and can grow up to 50 meters tall, straight cylindrical bole with large buttresses and spreading crown. It is valued for furniture, joinery, and plywood due to its lightweight, pale-yellow wood. Its bark and leaves are used for various ailments in traditional medicine.

Due to the importance of *T. superba*, there have been attempts to conserve the species which have been threatened through cultivation/plantation establishment, hence the need for appropriate silvicultural practices such as planting depth, width and fertilizer application in plantation establishment for optimum survival, growth and development. Giblin *et al.,* (2011) stated that planting depth affects root development and seedling survival, with optimal depths varying among species while width of planting which is often overlooked, can impact soil moisture retention and aeration, influencing root growth (Larcher, 2003). Fertilizer applications, particularly urea, is known to enhance plant growth by providing essential nitrogen (Xu *et al.* 2021). However, excessive or inadequate application can be detrimental to plant growth and the environment (Sharma *et al.*,2021).

Studies on T. *superba* have focused on few silvicultural practices such as spacing (Okojie *et al.*,1988; Ola-Adams 1990), mulching, fertilizer application and weed control (Nzala and Moussounghou, 2006) but there is a dearth of information on combined effects of planting depth, width, and urea application on its growth. This study aims were to assess the morphological and physiological growth of *T. superba* as influenced by different planting depths, widths, and urea application, providing insights for optimizing planting techniques in Nigerian agroecosystems. The cultivation of *T. superba*, a valuable timber species in Nigeria, requires optimization of planting techniques to enhance growth and productivity. Planting depth, width, and fertilizer application are critical factors influencing seedling establishment and development as adoption of wrong planting practices (planting excessively deep or planting hole too narrow or wide) can cause as high as 30-50% death rate in plantation establishment (Arnold *et al.*, 2007).

Considering its economic importance, there is need for information on the morphological and physiological responses of *T. superba* to varying planting depths, widths, and urea application for optimizing its cultivation, timber yield and enhancing plantation management practices in Nigeria forest reserves

Therefore, the Null hypothesis of the study was- Morphological and physiological growth of *T. superba* would not be affected by different planting depths, widths and urea application.

MATERIALS AND METHODS

Study area

The study was conducted at the Arboretum of the Forestry Research Institute of Nigeria (FRIN), Jericho Hill, Ibadan, Nigeria. It is situated at Jericho area in Ibadan Northwest Local Government Area of Oyo State. Figure showed the map of the study area. The area lies between latitude 7º 23' 18″ N and 7º 23' 43″ N and longitude 3º 51' 20″ E and 3º 51' 43″ E.

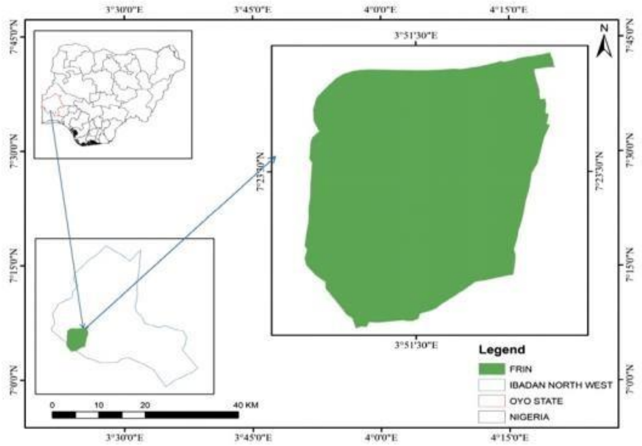

Figure 1. Map of the study area.

The climatic condition of the area is tropically dominated by rainfall pattern from 1400mm 1500mm with relative humidity of about 85% and average temperature is about 31.2°C. The area experiences two distinct seasons, the dry season usually commence from November to March while the rainy season from April to October. The soil is lateritic alluvial soil (FRIN Meteorological Report, 2015).

Experimental design

The experimental design used was split - plot. Fertilizer treatments (F_0 and F_1) were main plots while combinations of planting depths of 10cm, 15cm and 20cm levels (D_1, D_2 and D_3) and planting width of 10cm and 15cm (W_1 and W_2) were sub-plots. This gives 12 treatment combinations and each treatment was replicated ten (10) times using single plant replicate.

Experimental layout

F_0	**W_1D_1**	**W_2D_2**	**W_2D_3**	**W_1D_2**	**W_2D_1**	**W_1D_3**
F_1	**W_1D_1**	**W_2D_2**	**W_2D_3**	**W_1D_2**	**W_2D_1**	**W_1D_3**

DOI: https://doi.org/10.55706/jae1924

F0= No fertilizer application, F1= 5g Urea application, W1=10cm,W2,=15cm, D1=10cm, D2=15cm, D3=20cm

Experimental plot establishment

Soil samples were taken from the identified genetic horizons of the 3 soil profiles within FRIN Arboretum, starting from the lowest to the uppermost, in order to prevent cross-contamination. Samples were also collected at 0-15 cm and 15-30 cm depth across the area. The soil samples were bagged and taken to the laboratory for analysis.

The experimental plot was manually cleared with minimum disturbance to reduce impacts on the soil. Pegging was carried out to mark out the planting space according to the treatments. Each marked spot was prepared using digging hoe to make holes according to depth and width designated and gauge sticks prepared according to each combination was used to validate the holes. One hundred and twenty (120) healthy and relatively uniform *T. superba* seedlings of three (3) month old were obtained from Tree Improvement nursery of FRIN and were planted according to experimental design in 3m by 3m espacement to encourage healthy competition and reduce weed suppression. Fertilizer treatment using 5g Urea was carried out at 4 weeks after planting. Seedlings were planted during raining season which aided high rate of survival (100%).

Data Collection

Morphological parameters

Morphological parameters such as seedling height, collar diameter, number of leaves produced were taken fortnightly for 7 months. Biomass was assessed by harvesting the seedlings and these were separated into roots, stems and leaves. These parts were air dried for 3 weeks and their weights been taken till constant weights were obtained.

Physiological Parameters

The physiological parameters such as Relative Growth Rate, Absolute Growth Rate, Net Assimilation Rate, Leaf Area Ratio and Leaf turgidity were estimated from the data collected with the formula below:

Relative Growth Rate (RGR) = $\frac{\log_e H_2 - \log_e H_1}{T_2 - T_1}$ (gg $^{-1}$ day $^{-1}$)……………………….…… .equation 1

Absolute Growth Rate (AGR) = $\frac{H_2 - H_1}{T_2 - T_1}$ (cm day $^{-1}$)…………………………………… equation 2

Net Assimilation Rate (NAR) = $\frac{RGR}{LAR}$ (gcm^{-2} day $^{-1}$)………..…………………………equation 3

Leaf Area Ratio (LAR) (m^{2}Kg^{-1}) = $\frac{A}{W}$… ……………………………………..…….equation 4

Leaf Turgidity = $\frac{\text{Leaf weight in water} - \text{Initial fresh weight}}{\text{Initial Fresh Weight}} X100$ ……………………………..….equation 5

Where:

H = Plant Height (cm)

T = Time (days)

A = Plant Leaf Area (m^2)

W = Plant Dry Weight (Kg)

Relative water content % = $\left\{\frac{(FW - DW)}{(TW - DW)}\right\} \times 100$…………………………………………equation 6

Where, FW = fresh weight

DW = dry weight

TW = turgid weight (fully hydrated)

Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using SPSS and the significantly different means were separated using LSD.

RESULTS AND DISCUSSIONS

Elemental analysis of soil

Tables 1 and 2 expressed the physical and chemical properties of the project site. The prominent textural classes of soil are sandy loam and sandy clay loam. These two classes are appropriate for *T. superba* as it prefers soils that are well drained with moderate fertility (Orwa *et al*., 2009) Profile 1 (depth 31-62) had 71% of gravel which is the highest while lowest was observed in profile 3 depth 0-17 (1%). Percentage of sand ranged from 57% to 76% with the highest observed in profiles 1 (depth 0-10) and 2 (depth 0-17). Generally in the soil profiles, sand content decreased with depths while silt and clay increased. This may be due to a process known as clay migration which results in having coarser textured surface horizon (Schaetzl and Thompson, 2015). This sandy topsoil helps with easy root penetration and aeration but getting to the subsoil comprising of denser clay, may have restricted root elongation. Highest bulk density was observed in profile 2 (depth 72-132) while lowest was recorded in profile 2 (depth 0-18). the pH ranged from 5.6 to 6.8 which is slightly acidic to near neutral. This is appropriate for *Terminalia* as it prefers pH 5.5- 6.5 (Lorenzi, 2022).

DOI: https://doi.org/10.55706/jae1924

Table 1. Physical properties of soils from the profiles in the study area

Horizon	Depth (cm)	Gravel %	Sand %	Silt %	Clay %	Silt/clay %	Textural class
(Profile 1)							
	0-10	22	76	6	18	0.33	Sandy loam
	10-39	55	74	7	19	0.78	Sandy loam
	39-62	71	59	7	34	0.21	Sandy clay loam
	62-105	60	57	9	34	0.26	Sandy clay loam
(Profile 2)							
	0-17	5	76	9	15	0.60	Sandy loam
	17-39	13	74	11	15	0.73	Sandy loam
	39-55	13	68	12	20	0.60	Sandy clay loam
	55-120	2	59	14	27	0.52	Sandy clay loam
(Profile 3)							
	0-17	1	73	20	7	2.86	Sandy loam
	17-28	5	70	22	8	2.75	Sandy loam
	28-53	3	70	21	9	2.33	Sandy clay loam
	53-112	5	63	27	10	2.70	Sandy clay loam

Table 2. Selected physical and chemical properties of soils from the profiles in the study area

Horizon	Depth (cm)	BD g/cm^3	pH ($H_2$0)	O.M (%)	Total N. (%)	Avail. P. mg/kg	Exchangeable Bases (CmolKg$^-$)				Exch. Acidity (Cmol Kg$^-$)		Sum of Bases	ECEC Cmol Kg$^-$	Micronutrient (mg/kg			
							Ca^{2+}	Mg^{2+}	Na^+	K^+	Al^{3+}	H^+			Cu^{2+}	Fe^{2+}	Zn^{2+}	Mn^{2+}
Profile 1	0-18	1.06	6.9	2.20	0.10	6.99	7.2	4.86	0.21	0.30	0.4	0.2	12.57	12.97	2.9	156.2	5.0	32.1
	18-24	**1.54**	**6.8**	**1.10**	**0.09**	**5.82**	**6.6**	**4.86**	**0.26**	**0.26**	**0.2**	**0.3**	**11.98**	**12.18**	**2.1**	**209.5**	**2.6**	**0.8**
	24-51	1.62	6.5	0.30	0.09	3.58	6.7	4.10	0.25	0.30	0.3	0.3	11.30	11.60	3.0	223.1	1.4	0.7
	51-70	**1.59**	**6.0**	**0.30**	**0.80**	**3.55**	**5.8**	**3.20**	**0.20**	**0.24**	**0.7**	**0.3**	**9.44**	**10.10**	**2.6**	**159.4**	**2.1**	**1.1**
Profile 2																		
	0-18	1.01	6.5	2.30	0.10	4.10	5.3	4.86	0.19	0.24	0.4	0.2	10.58	10.98	2.3	113.9	1.5	0.8
	18-28	1.57	6.4	1.90	0.07	5.83	4.9	4.05	0.19	0.22	0.4	0.3	9.35	9.75	2.4	85.2	1.5	0.1

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28-72	1.63	6.2	1.60	0.08	3.21	5.5	1.62	0.21	0.28	0.1	0.4	7.69	7.79	2.1	78.4	0.7	0.1
72-132	1.68	6.1	1.30	0.08	2.15	5.3	5.67	0.19	0.26	0.4	0.3	11.42	11.82	2.5	166.1	4.2	15.7
132-185	1.73	5.9	1.40	0.08	5.08	5.3	4.05	0.20	0.26	0.1	0.3	9.81	9.91	1.7	95.5	0.6	3.1
185-210	1.48	5.6	1.20	0.07	4.51	5.0	4.86	0.17	0.26	0.2	0.2	10.29	10.49	1.7	35.9	0.3	0.2
Profile 3																	
0-18	1.34	6.8	1.70	0.09	6.94	4.0	7.29	0.14	0.22	0.4	0.3	11.64	12.04	1.4	187.3	0.3	3.7
18-33	1.42	6.7	1.80	0.09	8.51	4.9	4.05	0.19	0.24	0.3	0.3	9.38	9.68	2.0	237.2	2.7	1.8
33-65	1.45	6.6	1.40	0.08	5.08	5.3	1.62	0.21	0.30	0.2	0.2	7.44	7.64	4.0	198.8	5.3	1.3
65-120	1.65	6.4	1.20	0.07	4.51	4.1	6.48	0.14	0.20	0.2	0.3	10.91	11.11	2.2	162.9	0.6	1.0
120-200	1.40	6.7	1.20	0.05	3.20	3.1	10.53	0.11	0.22	0.3	0.2	13.96	14.26	1.8	175.2	2.4	1.8

BD= Bulk density, OM= Organic Matter, Avail. P.= Available Phosphorous, N= Nitrogen, ECEC= Effective Cation Exchange Capacity

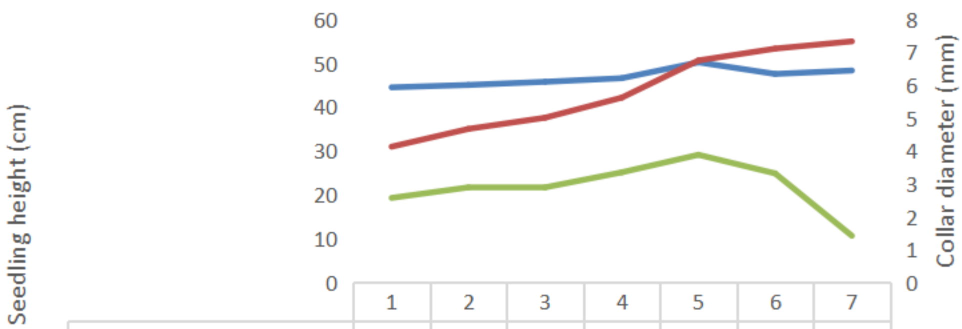
Effects of fertilizer application, planting widths and depths on Morphological parameters of *Terminalia superba* seedling growth

Grand mean values for seedling growth parameters are shown in Figure 1. This revealed that at MAP 7, *Terminalia* seedlings either with or without 5g of Urea may grow up to 48.33cm, with collar diameter 7.33mm. Mean values of seedling growth parameters over the months of assessment was expressed in Table 3. First Month After Planting (MAP 1), F_0 had mean height value of 44.8cm while F_1 had 44.3cm, not significantly different from each other. This trend was observed through out the month of assessment but at MAP 5, there was significant variations in the seedling height with F_0 having 51.96cm while F_1 had 48.45 cm. Collar diameter for both treatments (F_0 and F_1) at MAP 1 was 4.1mm but F_1 recorded non significant higher mean value (5.05mm) at MAP 3 while at MAP 5, F_0 recorded higher mean value (6.77mm). At MAP 7, F_0 recorded higher mean value with 7.75mm while least was observed in F_1 (6.92mm). Leaf number followed similar trend with seedling height as F_0 produced more leaves than F_1 throughout the month of assessment. At MAP 7, leaf number was significantly higher in F_0 (12.28). This results implied that 5g of Urea did not significantly affect the seedling growth positively. This may be due to fast rate at which urea turns quickly to ammonia. Urea being most used fertilizer is readily available to plant but is vulnerable to loss through volatilization and ammonia formed can scorch roots of young seedlings causing stunted growth (Motasim *et al*., 2024; Skorupka and Nosalewicz, 2021).

DOI: https://doi.org/10.55706/jae1924

Width of planting did not significantly affect seedling growth of T. *superba* though W_2 recorded higher mean seedling height (45.54cm and 45.13cm respectively) at MAP 1 and 2 but at MAP 3, W_1 had higher mean value of 46.82cm. W_1 continued to have taller seedlings for the rest of the month of assessment. Similar trend was observed in collar diameter as W_2 recorded higher mean value initially. W_1 overtook to have higher mean values till MAP 7 as W_2 recorded higher mean height value. Similar trend was observed in collar diameter. W_2 recorded higher mean value from MAP 1 but W_1 overtook to have higher mean value of 5.67mm while W_2 had the least (5.57mm). But at MAP 7, W_2 had higher mean value of 7.34mm. Leaf number was affected by width though not significantly as W_2 recorded higher mean values from MAP 1 till 5 while W_1 overtook and continued till MAP 7 with mean value 10.70 while W_2 had 10.60. This initial advantage by wide width (W_2) having higher values in seedling parameters may be due to greater resource availability especially the root space, where access to water and nutrients were available due to larger soil volume exploration which promoted early seedling vigour (Lynch, 2013; Hodge 2004). However the trend reversed as the month of assessment progressed where narrow width (W_1) outgrew seedlings in wide width (W_2) as roots of the seedlings had adjusted using their smaller but more concentrated root zone more efficiently (Freschet *et al*., 2018). But at MAP 7, the pattern shifted in favour of seedlings planted wide width which may be that their root system had tapped into broader soil layers assessing water and nutrients beyond reach of seedlings planted in narrow width (Schenk and Jackson, 2002; Lynch and Brown 2012). This pattern underscores the dynamic role of root system width in mediating seedling growth as wide root space confers long term resource capture benefits but may incur mid-term competition costs, whereas narrow root space optimizes early resource use efficiency but limit later exploration potential.

Planting depth also influenced seedling growth in this study. At MAP 1, depth significantly affected seedling height as tallest seedlings were observed in D_1 (45.7cm) and short ones in D_3 (43,2cm) until MAP 7 where highest mean value was recorded in D_3 (49.1cm) while D_2 had the least (47. 5cm). Assessing seedling collar diameter with respect to depth, highest mean value was recorded in D_3 at MAP 1 with 4.15mm, followed by D_1 (4.13mm) while least was observed in D_2 (4.10mm). D_3 overtook and recorded highest mean values from MAP 4 to 7 while D_1 had least. Number of leaves produced was also affected though not significantly as D_2 produced more leaves with mean leaf number 19.7 which was followed by D_3 (19.6). but at MAP 7 D_3 produced higher leaf number (11.9) while D_1 recorded the least (9.7). Deep planting initially may result in reduced seedling height compared to shallow planting as observed in this study. This is because seedlings must expend additional energy to grow through a greater soil profile, delaying shoot emergency and early height development (Lynch and Brown, 2012). However, once established, the seedlings will eventually attain greater final height. This long-term advantage is attributed to deeper root placement, which allows access to more stable moisture and nutrient reserves in lower horizons thereby enhancing overall growth potential (Schenk and Jackson, 2002). in contrast, collar diameter remains higher in deep-planted seedlings. This reflects an early investment in secondary growth and structural reinforcement, which supports future height increment and improves resistance to environmental pressure (Freschet *et al*., 2018; Hodge, 2004). Though planting shallow may favour initial early seedling growth but for field establishment, deeper planting may pay off as sturdy seedlings with better anchorage will be produced.



	1	2	3	4	5	6	7
Height (cm)	44.5	45.04	45.76	46.58	50.2	47.55	48.33
Leaf number	19.3	21.7	21.7	25.13	29.13	24.88	10.67
Collar diameter (mm)	4.13	4.67	5.01	5.62	6.75	7.11	7.33

Figure 2. Grand means values of seedling parameters of *Terminalia superba* subjected to fertilizer application, planting widths and depths on the field

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Table 3. Mean values of seedling growth parameters of *Terminalia superba* as affected by fertilizer application, planting depths and widths over 1, 3, 5 and 7 months of assessment

Treatments		Months of Assessment											
		1			3			5			7		
		Ht (cm)	CD (mm)	LN	Ht	CD	LN	Ht	CD	LN	Ht	CD	LN
Fertilizer	F0	44.8	4.1	19.8	46.3	5.0	22.3	52.0[a]	6.8	31.0	50.1	7.8	12.3[a]
	F1	44.3	4.1	18.8	45.2	5.1	21.2	48.5[b]	6.4	27.2	46.6	6.9	9.1[b]
	S.E	0.9	0.51	0.5	0.96	0.1	0.8	1.1	0.2	1.6	2.6	0.4	1.1
Width	W1	44.5	4.1	19.1	46.8	5.0	21.7	50.7	6.6	28.5	49.0	7.3	10.7
	W2	44.5	4.2	19.6	44.7	5.0	21.9	49.7	6.6	29.8	47.7	7.3	10.6
	S.E	0.5	0.1	0.5	1.0	0.1	0.8	1.1	0.2	1.6	2.6	0.4	1.1
Depth	D1	45.7[a]	4.1	18.8	46.5	4.9	20.5	50.5	6.4	27.5	48.5	7.1	9.7
	D2	44.7[bc]	4.1	19.7	45.1	5.1	23.0	50.3	6.7	31.2	47.5	7.5	10.4
	D3	43.2[c]	4.2	19.6	45.7	5.1	21.8	49.9	6.7	28.7	49.1	7.4	11.9
	S.E	0.6	0.1	0.6	1.2	0.2	1.0	1.4	0.3	1.9	3.2	0.5	1.3

F0- no urea application; F1-5g urea application; W1-10cm width; W2-15cm width; D1-10cm depth, D2-15cm depth. D3- 20cm depth; Ht- height;CD- collar diameter; LN-leaf number

Interaction effects of fertilizer application, planting widths and depths on seedling growth parameters of *Terminalia superba*

Interaction effects of fertilizer application, planting widths and depths on seedling growth parameters of *T. superba* was observed in Table 5. $F_0W_2D_3$ had the highest mean height (66.94cm), mean collar diameter (10.28mm) and number of leaves but lower values in dry matter weights and R/S ratio (0.13). Least mean collar diameter value was recorded in $F_1W_1D_3$ (48.08cm) while $F_1W_1D_2$ had least total foliar weight (0.30g). Highest mean LAE, leaf, stem and root dry weight were observed in $F_0W_2D_2$ with 2254.33 cm^2, 5.54g, 4.33g, and 3.38g respectively while $F_1W_2D_1$ had least value in stem and root dry weight as $F_1W_1D_2$ recorded least value of 0.12 in leaf dry weight. Seedlings subjected to $F_0W_1D_2$ have highest R/S ratio (0.79) while least value was observed in $F_0W_2D_3$ (0.13). Seedlings planted in wider and deeper pits without urea showed higher height, collar diameter, and leaf number, but lower dry weight and root-to-shoot ratio. This pattern can be explained by resource allocation and nutrient availability as wider and deeper pits provide greater soil volume for root exploration, improving access to water and nutrients. This stimulates aboveground growth (height, leaves, stem thickness) as seedlings invest in capturing light and expanding canopy area (Lynch and Brown, 2012; Schenk and Jackson, 2002). This was observed by Yisau (2018) in *Synsepalum dulcificum* as leafiness, seedling height and collar diameter increased with increasing planting depth regardless of fertilizer application. However, without urea (nitrogen supply), seedlings lack sufficient nitrogen for biomass consolidation. As a result, while they grow taller and produce more leaves, their tissues remain less dense and lower in dry matter accumulation (Freschet *et al*., 2018; Hodge, 2004). The lower root-to-shoot ratio indicates that seedlings allocate more energy to shoot growth (for light capture) at the expense of root development, a common strategy under low nitrogen conditions (Lynch, 2013). This makes the seedlings top-heavy and potentially more vulnerable to drought or lodging. Hence to optimize planting, pit modification should be combined with nitrogen fertilization to balance shoot and root growth, ensuring both vigor and resilience.

Table 5. Interaction Effect of fertilizer application, depth and width of planting on morphological growth of *Terminalia superba* seedlings

Experimental treatment	Seedling height (cm)	Collar diameter (mm)	Leaf Number	Leaf area estimate (cm^2)	Total foliar weight (g)	Dry weights (g)			R/S ratio
						leaf	Stem	Root	
$F_0W_1D_1$	51.41	7.48	13.9	1057.07	6.38	0.92	2.64	1.75	0.23
$F_0W_1D_2$	51.46	8.26	12.5	1416.78	10.96	4.81	3.91	3.11	0.79
$F_0W_1D_3$	48.80	7.89	11.2	651.0	3.42	1.22	1.34	1.33	0.29
$F_0W_2D_1$	48.52	6.95	10.1	373.68	7.79	2.37	3.98	3.04	0.56
$F_0W_2D_2$	41.24	6.76	10.5	2264.33	12.36	5.54	4.33	3.38	0.35
$F_0W_2D_3$	58.84	9.14	15.5	1390.99	1.91	0.74	1.32	2.82	0.13
$F_1W_1D_1$	52.52	8.15	10.3	508.48	10.07	5.39	4.07	2.19	0.41
$F_1W_1D_2$	46.16	6.46	6.8	539.05	0.30	0.12	1.41	2.22	0.37

DOI: https://doi.org/10.55706/jae1924

$F_1W_1D_3$	43.74	5.70	9.5	351.54	2.98	0.96	1.17	1.56	0.32
$F_1W_2D_1$	41.30	5.75	4.6	293.08	1.76	0.58	0.88	0.73	0.34
$F_1W_2D_2$	51.11	8.50	11.6	868.01	6.51	2.04	3.48	1.80	0.27
$F_1W_2D_3$	44.84	6.95	11.5	923.64	8.89	4.53	2.03	3.38	0.47
S.E	6.30	1.06	2.65	121.32	3.42	2.94	1.62	1.14	0.13

F0- no urea application; F1-5g urea application; W1-10cm width; W2-15cm width; D1-10cm depth, D2-15cm depth. D3- 20cm depth;R/S= Root to Shoot

Effects of fertilizer application, planting widths and depths on Physiological parameters of *Terminalia superba* seedling growth

Effect of fertilizer application, depth and width of planting on physiological parameters of *T. superba* seedlings as revealed by Figures 3-7. Relative Water Content (RWC) and leaf turgidity serve as primary indicators of cellular water status, reflecting a balance between root water uptake and leaf transpiration. In this study, RWC ranged from 25 to 54.05% with $F_1W_1D_1$ recording the highest value of 54.05%, this implies that the seedlings were well hydrated, followed by $F_1W_1D_3$ with 49.44% (Fig. 3). The elevated RWC observed under fertilized and narrow-spaced conditions suggests that early nutrient availability stimulates root proliferation. Enhanced root density improves the hydraulic efficiency of the seedling, permitting optimal water uptake despite closer spatial arrangements. This aligns with findings by Agboola *et al.* (2020), who noted that early NPK fertilizer application improves root hydraulic conductivity and tissue water status in tropical hardwood seedlings by facilitating cellular osmotic adjustment. In Fig. 4, highest leaf turgidity was observed in $F_0W_1D_2$ (0.67) while least value was recorded in $F_1W_1D_3$ (0.33).The inverse relationship between high RWC and reduced leaf turgidity under deep planting (D_3) implies a physiological bottleneck. When seedlings are planted too deeply, the compact nature of deeper soil layers can impair root respiration. This decreases active water transport to the shoots, forcing cells to maintain volume without generating high turgor pressure (Awodun, 2021). The analysis of growth indices reveals complex interactions governing biomass production. Considering NAR as shown by Fig. 5, $F_0W_1D_3$ and $F_1W_1D_2$ had negative values of -0.002 $gcm^{-2}/ day^{-1}$and -0.0019 gcm^{-2}/ day^{-1} respectively while highest positive value was recorded in $F_1W_1D_1$ (0.007 gcm^{-2}/ day^{-1}). Negative NAR indicates growth inefficiency, where the rate of respiratory carbon loss exceeds photosynthetic carbon gain. This occurs because leaves expand structurally without a corresponding accumulation of dry matter. Deep planting (D3) likely restricted root access to oxygen, inducing metabolic stress. This stress forces the seedling to shift from autotrophic accumulation to a survival strategy characterized by high maintenance respiration.This trend mirrors the observations of Poorter *et al*. (2019), who affirmed that negative net assimilation rates often occur under deep soil burying or mechanical stress because of the severe depletion of non-structural carbohydrates during upward etiolation. On the other hand, the high NAR in F1W1D1 confirms that combining shallow planting with targeted fertilization optimizes light interceptive structures and photosynthetic efficiency, accelerating early dry matter accumulation.Similar trend was observed in RGR (fig, 6), as $F_0W_1D_3$ and $F_1W_1D_2$ had negative values but highest positive value was observed in $F_0W_1D_2$ and $F_1W_1D_1$ (0.305$gg^{-1}day^{-1}$). RGR is fundamentally driven by its physiological component, NAR, and its morphological component, Specific Leaf Area (SLA). The strong positive alignment between NAR and RGR under shallow planting confirms that biomass accretion per unit of existing biomass in *T. superba* is heavily governed by photosynthetic gains rather than structural leaf adjustments. This direct relationship between NAR and RGR has been well-documented in tropical forest dynamics by Shipley (2006) and Gibert *et a*l. (2016), who reported that variation in net assimilation rate is the primary driver of relative growth rate during the early nursery stages of tropical silvicultural species. For the Absolute Growth Rate (AGR), a distinct negative value was observed in $F_1W_2D_1$ (-0.823 cm day^{-1}). In contrast, the highest positive value was achieved in $F_0W_2D_3$ (1.937 cm day^{-1}) which was closely followed by $F_0W_1D_2$ with 1.34 cm day^{-1} (fig. 7). Negative NAR values recorded may imply growth inefficiency where leaves are expanding but little dry matter accumulation, which may be due to the depths which are deeper. The high AGR in F0W2D3 represents a classic shade-avoidance or etiolation response. When seedlings are placed at a greater depth without sufficient initial nutrient signals, they prioritize rapid linear stem elongation over dry matter accumulation to clear the soil barrier or outcompete neighboring weeds. This structural elongation explains why AGR (which measures raw dimensional increases like height) was high in treatments where NAR and dry weight-based metrics were severely compromised. As substantiated by Oliet and Jacobs (2021), forest seedlings under deep-planting stresses often divert restricted carbon reserves into rapid structural extension at the expense of root development and mechanical stability, leading to high mechanical growth rates but weak physiological tissue investment.

DOI: https://doi.org/10.55706/jae1924

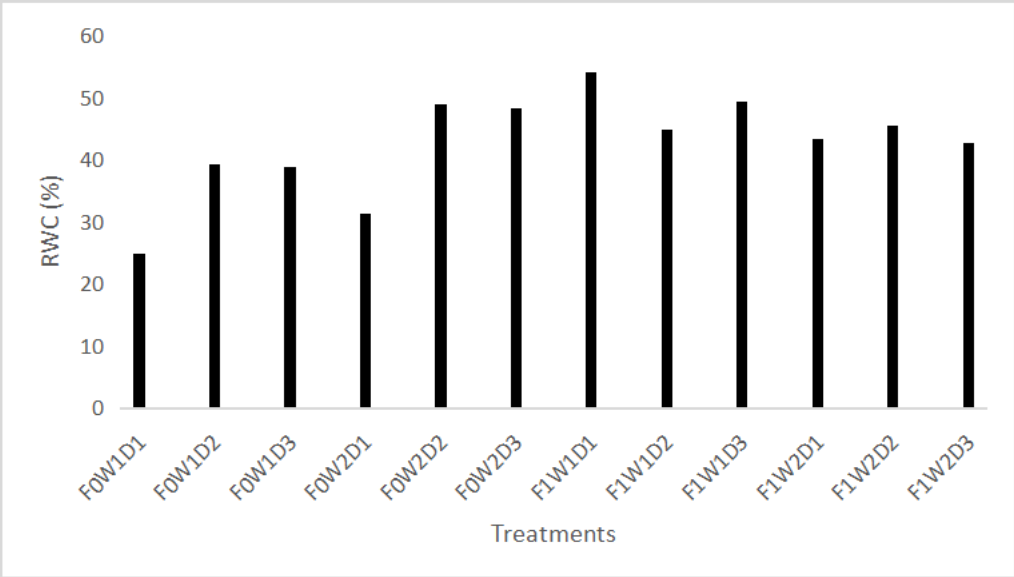

Figure 3: Relative water content of *Terminalia superba* seedlings as influenced by fertilizer application, planting widths and depths

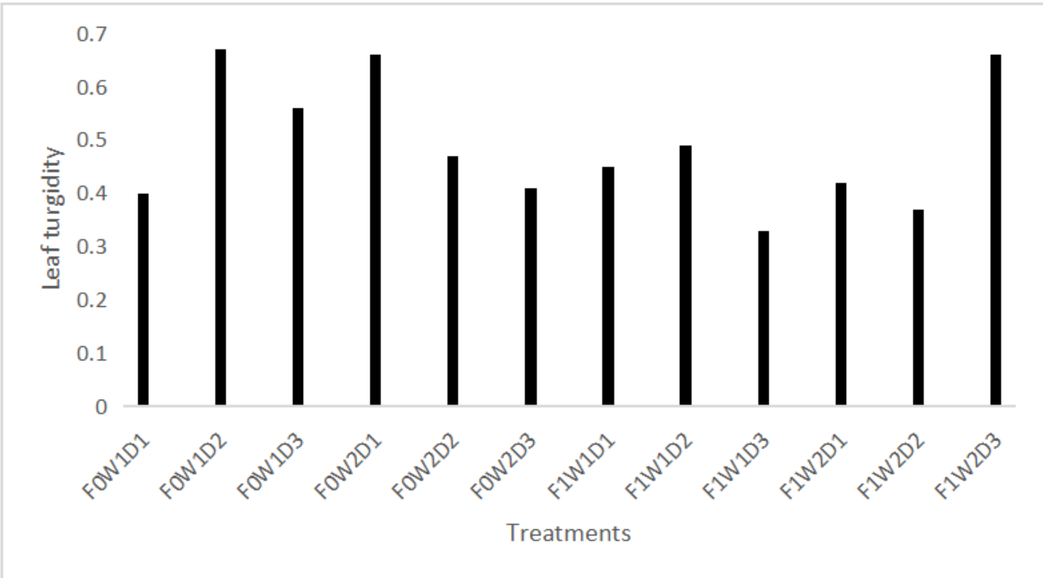

Figure 4. Leaf turgidity of *Terminalia superba* seedlings as influenced by fertilizer application, planting widths and depths

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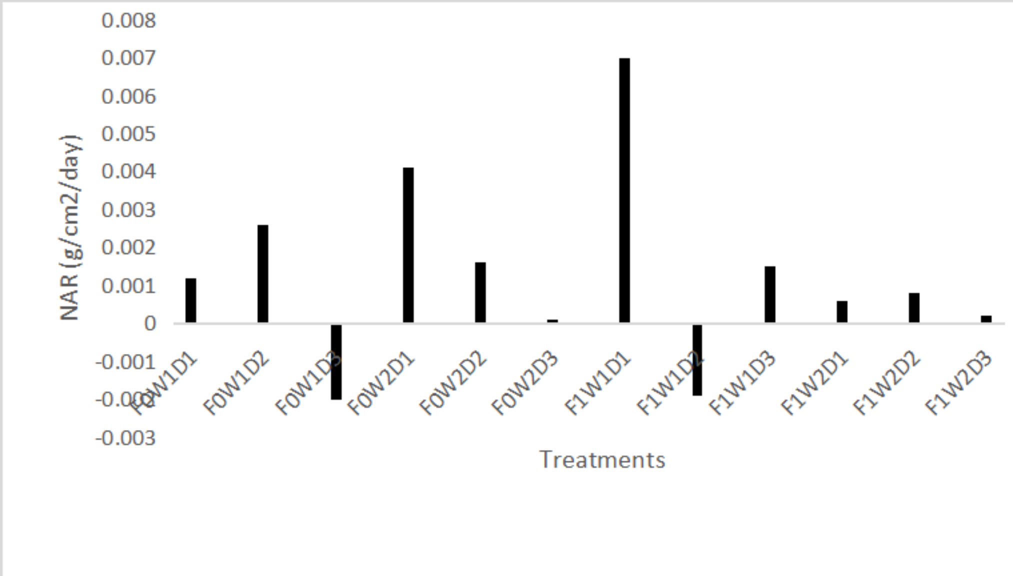

Figure 5. Net Assimilation Rate of *Terminalia superba* seedlings as influenced by fertilizer application, planting widths and depths

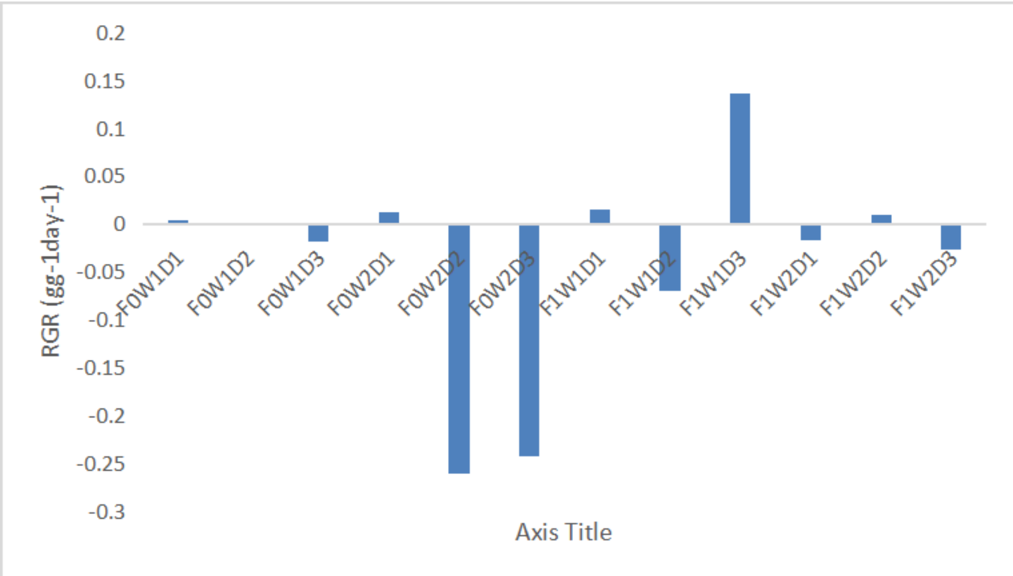

Figure 6. Relative Growth Rate of *Terminalia superba* seedlings as influenced by fertilizer application, planting widths and depths

DOI: https://doi.org/10.55706/jae1924

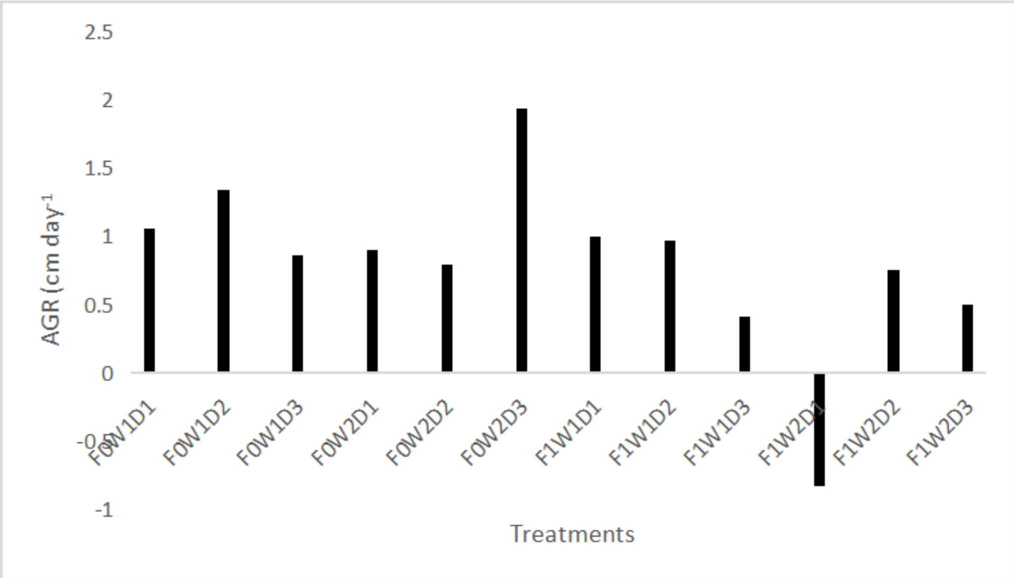

Figure 7. Absolute Growth Rate of *Terminalia superba* seedlings as influenced by fertilizer application, planting widths and depths

CONCLUSION

The study was conducted to determine the appropriate planting practice while suitability of the soils under investigation to produce *Terminalia superba* was also assessed. The result from the study revealed that *Terminalia* seedlings either with or without 5g of Urea may grow up to 48.33cm, with collar diameter 7.33mm. Seedlings subjected to zero urea application, wider and deepest holes ($F_0W_2D_3$) had highest values for height, collar diameter and number of leaves whereas those subjected to 5g urea application, shallow and narrow holes ($F_1W_1D_1$) were physiologically superior though they recorded average morphological values. $F_1W_1D_1$ is therefore recommended to tree farmers as the seedlings in this study photosynthesized and used resources well as balanced input (fertilizer) with output (efficient healthy growth).

Conflict of Interest

The authors declare no competing financial, professional, or personal interests that could have influenced the project reported in this paper.

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