Early Growth Response of *Khaya senegalensis* Seedlings to Fertilizer Types and Seed Sources in the Sudan Savanna of Nigeria

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ABSTRACT: *Khaya senegalensis (*Desr.) is a hardwood tree species from the *Meliaceae* family. The species is an economically important tree species used for different purposes in Africa. The high demand for this species has led to excessive exploitation, thus threatening sustainability in the natural forest. The production capacity is low and does not meet the ever-growing human-use demand. Also, tropical soils are deficient in nitrogen and phosphorus nutrients, and the uptake of these limited quantities of nutrients by plant roots from litter is difficult, thus reducing seedlings' growth. A Completely Randomized Design experiment was used to evaluates the effects of seed source (forest area and urban forest) and fertilizer types (poultry manure, cow dung manure, and NPK 10:10:10) on the early growth rate of *K. senegalensis* seedlings in forestry nursery located in Kano State, the Sudan savanna area of Nigeria, aiming to identify the most suitable fertilizer option. The results show that seed source and fertilizer type exert considerable influence on the early performance of *K. senegalensis* seedlings. Seeds from forest areas showed superior germination, moisture retention, and biomass accumulation, while seedlings from urban forests demonstrated larger leaf areas and greater height under optimal treatments. Organic manure (poultry manure and cow dung) consistently outperformed inorganic fertilizers in promoting growth. It is recommended that *K. senegalensis* seedlings intended for afforestation or reforestation in semi-arid areas of Nigeria should be propagated using seeds sourced from natural forest areas and grown with organic fertilizers (poultry manure or cow dung) to enhance germination success and promote vigorous early growth.

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INTRODUCTION

*Khaya senegalensis (*Desr), commonly known as African mahogany, is a hardwood tree species which belongs to the *Meliaceae* family and grows up to 15–30 m in height and 1 m in diameter. The bark is dark grey to grey-brown while the heartwood is brown with a pink-red pigment made up of coarse interlocking grains (Focho *et al.*, 2011). The *Meliaceae*, which includes the genus *Khaya* are among the most valuable timber species in the world (Opuni-Frimpong *et al*., 2008). *Khaya senegalensis* is one of the most economically important forest tree species in Africa that is used for high-class furniture and construction purposes, and recommended for utilization purposes for which surface quality is of high importance. The species plays a major economic role in the international timber trade, human health and environmental protection because of its many desirable qualities, which include its straight grain (World Agroforestry Centre, 2004). The high demand for this plant's products has led to excessive exploitation, thus threatening the sustainability of its resource base in the natural forest. The production capacity is low and therefore does not meet the ever-growing demand for human use.

Tropical soils are deficient in nitrogen and phosphorus nutrients, and the uptake of these limited quantities of nutrients by plant roots from litter is difficult, thereby leading to a reduction in seedling growth (Kuje *et al.*, 2019). Adequate supply of mineral elements is of importance in the tropics where the soil is poorly formed, and continuous cropping is on the increase (Kartini *et al.*, 2024). For any sustainable plant production, soil fertility amelioration is essential. However, there is inadequate information on the right amount of organic and inorganic fertilizer application for raising this tree species. Most soils in the tropics have organic matter content below one percent, low phosphorus and a highly acidic medium (pH below 5), leading to low productivity.

To address these challenges, this study evaluates the effects of seed source (forest area and urban forest) and fertilizer types (poultry manure, cow dung manure, and NPK 10:10:10) on the early growth performance of *Khaya senegalensis* seedlings in the Sudan savanna region of Nigeria, aiming to identify the most suitable fertilizer option.

MATERIALS AND METHODS

Study location

Kano State is situated between latitudes 12°40′ and 10°30′ N, and longitudes 7°40′ and 9°30′ E. The region

experiences a tropical climate characterized by distinct dry and wet seasons. The dry season ranges from November to April, while the rainy season extends from May to September. The mean annual rainfall is approximately 690 mm, and the mean annual temperature ranges from a minimum of 19°C to a maximum of 33°C (Wakawa *et al.,* 2016).

Vegetation in Kano State is primarily savanna, ecologically classified into the Northern Guinea Savanna and the Sudan Savanna zones (Wakawa *et al.,* 2016). The Northern Guinea Savanna is typified by open woodland or brush vegetation with relatively shorter grasses, while the Sudan Savanna consists of scattered trees interspersed with open grasslands.

Common tree and shrub species native to the region include *Adansonia digitata*, *Vitex doniana*, *Diospyros mespiliformis*, *Tamarindus indica*, *Khaya senegalensis*, *Acacia senegal*, *Acacia nilotica*, *Acacia seyal*, *Faidherbia albida*, *Balanites aegyptiaca*, *Parkia biglobosa*, *Guiera senegalensis*, *Borassus aethiopum*, *Piliostigma thonningii*, *Ziziphus spina-christi*, *Hyphaene thebaica*, and *Anogeissus leiocarpus*.

Experimental design

The experimental design for the research was laid out in a Completely Randomized Design (CRD) with three (3) treatments: poultry manure (PM), cow dung manure (CM), and inorganic fertilizer (NPK 10:10:10) (Imoro *et al.,* 2012). The experiment was conducted using plastic containers filled with 1 kg of soil. Treatments were applied at one gram (1 g) unit. Seeds were collected from two sources: the forest area and the urban forest, from mature mother trees with superior phenotypic traits (Gregorio, *et al.,* 2005). Two seeds of Mahogany (Khaya senegalensis) were sown at an average depth of 2 cm in each plastic pot and later thinned to one stand per pot after germination (Ufere *et al.,* 2013). Germination occurred within 8 to 14 days. One hundred (100) seeds from each seed source were sown in plastic pots perforated at the base to facilitate drainage, with three replications for each treatment. A total of six hundred (600) seeds (100 x 3 treatments x 2 seed sources). Treatments were applied five (5) weeks after germination assessment. Topsoil, organic manure, inorganic fertilizer and other materials used for this work were obtained within Kano State, Nigeria. Seedlings were subjected to the same watering regime (once daily) throughout the experimental period (Imoro *et al.,* 2012).

Data Collection and Analysis

Data on seed germination for each treatment were recorded continuously until the cessation of seedling emergence, which occurred 40 days after sowing. Key growth variables—including seedling height, collar diameter, number of leaves, and leaf area—were measured to assess treatment effects. Seedling height was determined from the collar region to the apex using a standard meter rule, while collar diameter was measured with a vernier calliper. The number of leaves per seedling was obtained by manual counting. Leaf area was estimated by tracing two representative leaves per seedling onto a graduated graph sheet, with measurements taken fortnightly on ten randomly selected seedlings per treatment following the method of Aluko *et al.* (2014).

Biomass weights of the seedlings were also recorded using an electronic weighing scale. Dry weights were obtained after oven-drying the samples at 60°C for 48 hours, following the procedure described by William *et al*. (2012). For dry weight determination, five seedlings per treatment were randomly selected and carefully uprooted from the growing medium to avoid damage, as outlined by Algunaid *et al.* (2013).

All data collected—including germination rate and seedling growth variables—were analyzed using descriptive statistics (means, standard deviations, and percentages) and inferential statistics. A two-way analysis of variance (ANOVA) was employed to assess treatment effects, using SPSS version 25. Where statistically significant differences were observed among treatment means, the Least Significant Difference (LSD) method was applied for mean separation, following the recommendations of William et al. (2012), Imoro *et al*. (2012), and Aluko *et al.* (2014).

RESULTS

Table 1 presents the comparative germination rates of *Khaya senegalensis* seeds collected from two distinct seed sources—forest areas and urban forests —over a 40-day observation period. The germination performance was measured at 10-day intervals. At Day 10, seeds sourced in forest areas recorded a higher germination rate (22.43 ± 0.09) than those from urban forests (19.44 ± 0.19), with a statistically significant difference of $p = 0.050$. At day 20 (27.65 ± 0.05 vs. 26.35 ± 0.09, $p = 0.051$), day 30 (31.54 ± 0.46 vs. 28.32 ± 0.11, $p = 0.066$), and day 40 (37.80 ± 0.20 vs. 36.13 ± 0.15, $p = 0.076$). Although these differences were not statistically significant at the statistical level ($p < 0.05$). The total mean germination rate across all the time shows that the superior performance of seeds from forest areas (29.84 ± 0.20) compared to urban forest seeds (27.27 ± 0.13), with a statistically significant difference, indicating seed provenance influences germination outcomes**.** Thus, seeds sourced from natural forest areas exhibited a consistently higher and statistically different germination rate than the seeds from urban forest areas.

Table 1: Effect of Seed Source on Germination Rate of *K. senegalensis* Seeds in Kano State, Nigeria

Growth in days	Seed source		*T-test value* (variation between seed sources)
	Forest area	Urban forest	
10	22.43±0.09	19.44±0.19	0.050
20	27.65±0.05	26.35±0.09	0.051
30	31.54±0.46	28.32±0.11	0.066
40	37.80±0.20	36.13±0.15	0.076
Mean	29.84±0.20[a]	27.27±0.13	0.055

Means on the same row with different superscripts are statistically significant ($p<0.05$)

Figure 1 illustrates the impact of different fertilizer types—Poultry manure (TP), inorganic Fertilizer (TF) and Poultry manure (TP)—on the moisture content of *Khaya senegalensis* seedlings sourced from forest and urban forest environments in Kano State, Nigeria. For seedlings from forest areas, the highest moisture content was recorded under poultry manure treatment (31.4%), followed by the control (28.9%), and the lowest under inorganic fertilizer (28.0%). However, urban forest seedlings also showed the highest moisture content with poultry manure (29.1%), slightly higher than the NPK treatment (27.8%), while the lowest value was observed in the control group (26.0%). Poultry manure appeared to enhance moisture retention in seedlings from both seed sources, indicating its effectiveness in improving soil water-holding capacity and seedling hydration. The results also reveal that seedlings from forest sources generally retained more moisture than those from urban forests under the same fertilizer treatments, showing the influence of seed provenance and nutrient source on early seedling growth.

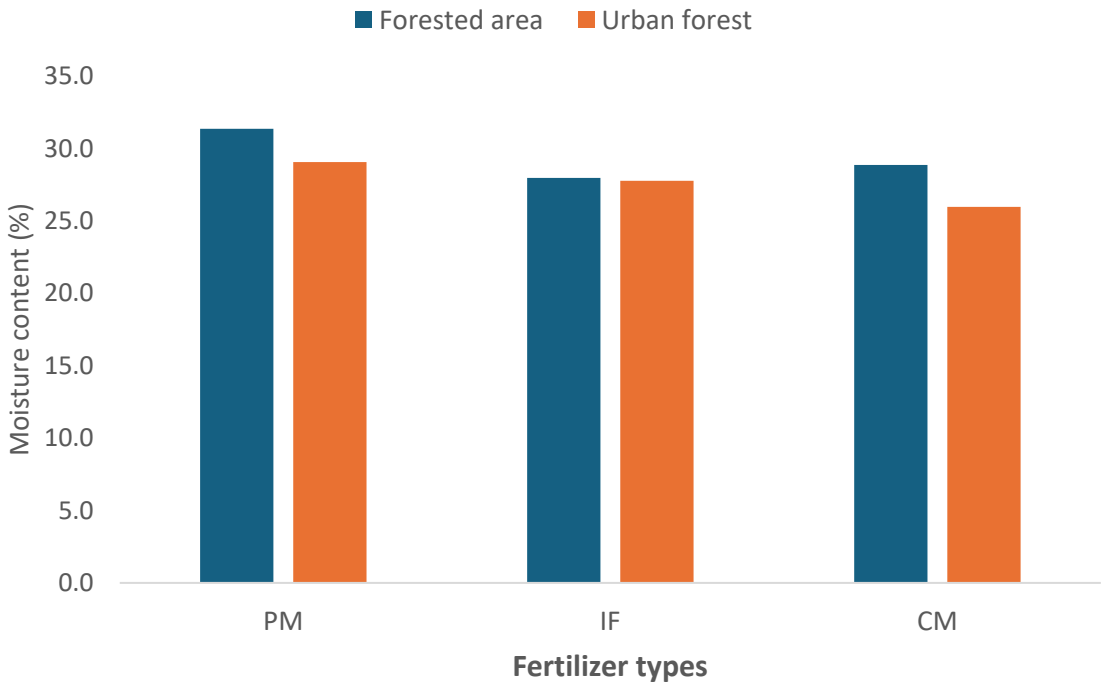

Figure 1. Graphical Comparison on the Effects of Fertilizer Types on the Moisture Content of *Khaya senegalensis* Seedlings in Kano State, Nigeria

Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10)

A comparative analysis of the effect of fertilizer types on the biomass content of *Khaya senegalensis* seedlings raised from urban forest sources in Kano State (Figure 2) shows slight variation across the seed sources of urban forest seedlings. Seedlings treated with poultry manure (PM) had the highest biomass content (8.2 g), followed by cowdung manure (CM) (7.35 g), while inorganic fertilizer (IF) yielded the lowest biomass content (6.35 g). Under forest area, all three treatments produced slightly higher biomass values, with CM showing the highest (8.55 g), followed closely

by PM (8.5 g) and IF (8.25 g). These results reveal that organic fertilizer, such as cow dung and poultry manure, promote greater biomass accumulation in *K. senegalensis* seedlings than inorganic fertilizer. The consistent trend in both observations shows the effect of organic manures in enhancing seedling vigour, growth and development for sustainable forestry management.

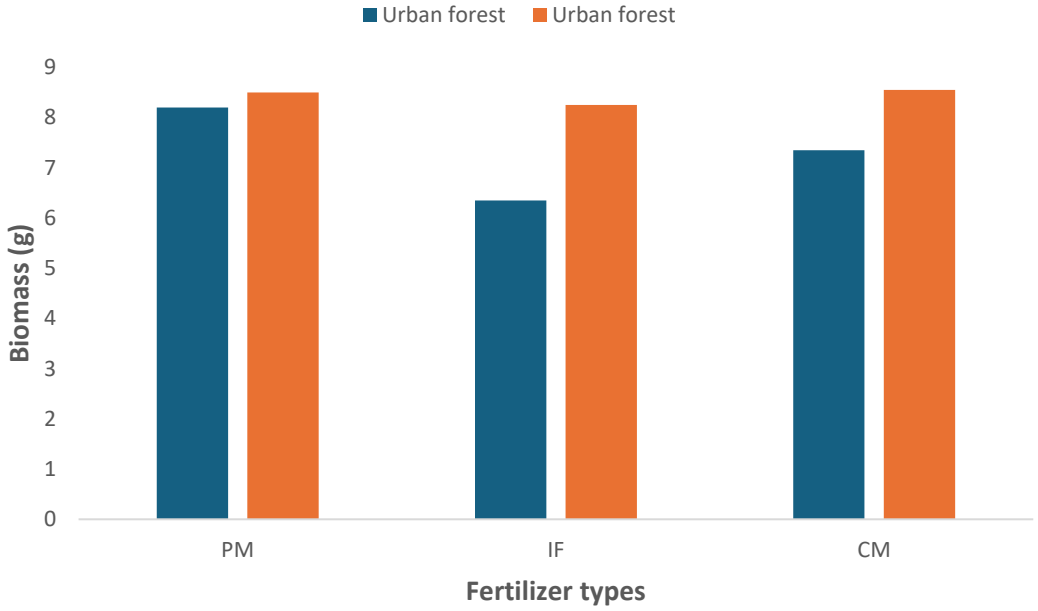

Figure 2: Graphical Comparison of the Effects of Fertilizer Types on the Biomass Content of *Khaya senegalensis* Seedlings in Kano State, Nigeria.
Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10).

Seedlings grown from urban forest seeds consistently recorded higher mean leaf areas than those from forest areas (Table 2), indicating a potential influence of seed source on vegetative development. Poultry manure (PM) resulted in the largest leaf area in urban forest seedlings (48.84 ± 3.33 cm²), which was significantly higher than values recorded for other treatments. Seedlings under forest areas had relatively larger leaf areas with PM = 30.13 ± 4.54 cm² and IF = 29.66 ± 5.42 cm². There was no significant difference between the seedlings, indicating similar performance among these treatments within this seed source. However, Cow dung (CM) produced the smallest leaf area in forest area seedlings (26.63 ± 4.12 cm²), whereas in urban forest seedlings, it yielded a moderately higher value (39.16 ± 5.86 cm²), though not statistically different from IF.
The P-values indicate that differences in leaf area among fertilizer treatments were not statistically significant ($p > 0.05$) across seed sources, except for PM treatment in urban forest seedlings, where the difference was marginally significant ($p = 0.05$). Thus, poultry manure appears to have the most favourable impact on leaf area, particularly in seedlings from urban forest origins, revealing the combined influence of seed source and organic nutrient input on early vegetative growth.

Table 2: Effect of Fertilizer Types and Seed Source on Leaf Area of *K. senegalensis* Seedling Growth

Fertilizer types	**Seed source**		***T-test value* (variation between seed sources)**
	Forest area	**Urban forest**	
CM	26.63±4.12^{ab}	39.16±5.86^{b}	**0.50**
IF	29.66±5.42^{a}	36.78±5.32^{bc}	**0.56**
PM	30.13±4.54^{a}	48.84±3.33^{a}	**0.05**
***P*-value**	**0.50**	**0.55**	**-**

Means on the same row with different superscripts are statistically significant ($p<0.05$); ns = not significant
Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10)

Seedlings grown with cow dung consistently exhibited a mean number of leaves ranging from 9.0 ± 0.22 and 9.0 ± 0.21 for seedlings under forest and urban forest areas, respectively, with a marginal *p*-value of 0.056, indicating no statistically significant difference between seed sources for this treatment (Table 3). Under inorganic fertilizer application, urban forest seedlings produced a slightly higher number of leaves (10.0 ± 0.43) compared to forest area seedlings (9.0 ± 0.21), but the difference was not statistically significant (p = 0.265) between the seed sources. Similarly, poultry manure produced the fewest leaves overall, with both seed sources recording 8.0 leaves, and a non-significant difference (p = 0.176). The result of the analysis of variance between the fertiliser types was not statistically significant (p = 0.062 and p = 0.055 among the treatments). Inorganic fertilizer applied to urban forest seeds showed a trend toward enhanced leaf development, potentially indicating a favourable but not definitive influence.

Table 3: Effects of Fertilizer Types and Seed Source on the Mean Number of Leaves of *Khaya senegalensis* Seedlings

Fertilizer types	Seed sources		*T-test value (*variation between seed sources)
	Forest area	Urban forest	
CM	9.0±0.22	9.0±0.21	0.056
IF	9.0±0.21	10.0±0.43	0.265
PM	8.0±0.03	8.0±0.35	0.176
P-Value	**0.062**	**0.055**	**-**

Means on the same column with different superscripts are statistically significant (p<0.05), ns = not significant
Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10)

Table 4 shows results on how different fertilizer types (cow dung, inorganic fertilizer, and poultry manure) influence the mean height growth of *Khaya senegalensis* seedlings derived from two seed sources (forest area and urban forest in the Sudan savanna area (Kano State) in Nigeria. Based on the result, seedlings' height growth from the urban forest outperformed that from the forest area. For instance, with cow dung, urban forest seedlings had a mean height of 19.14 ± 0.41 cm, significantly higher than the 16.33 ± 0.32 cm recorded for forest area seedlings (T-test p = 0.050). Similarly, poultry manure produced similar mean heights for urban forest seedlings (19.14 ± 0.17 cm), exceeding the growth of forest area seedlings (16.25 ± 0.32 cm), with a highly significant p-value of 0.006.
Variation was observed under inorganic fertilizer, where seedlings from the urban forest grew to 17.21 ± 0.10 cm compared to 14.14 ± 0.31 cm for the seeds from the forest area, and this difference was also statistically significant (p = 0.045). The p-values (0.001 for both seed sources) indicate that fertilizer type significantly influenced height growth, regardless of seed origin. Among fertilizers, poultry manure and cow dung were more effective than inorganic fertilizers, especially when applied to seeds from urban forests. Thus, this finding shows that both fertilizer type and seed source significantly affect the height growth of *K. senegalensis* seedlings. Organic fertilizers, particularly poultry manure, promoted greater height gains, and urban forest seeds consistently demonstrated better growth performance under all fertilizer treatments.

Table 4: Effect of Fertilizer Type and Seed Source on Mean Height Growth of *Khaya senegalensis* Seedlings

Fertilizer types	Seed source		*T-test value (*variation between seed sources)
	Forest area	Urban forest	
CM	16.33±0.32^{ab}	19.14±0.41^{a}	0.050
IF	14.14±0.31^{c}	17.21±0.10^{b}	0.045
PM	16.25±0.32^{a}	19.14±0.17^{a}	0.006
P-Value	***0.001***	***0.001***	**-**

Means on the same column with different superscripts are statistically significant (p<0.05), ns = not significant.
Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10)

The effects of fertilizer types on the collar diameter (stem thickness at the base) of *Khaya senegalensis* seedlings raised from two different seed sources are presented in Table 5. The results show that fertilizer type and seed source had no significant differences in collar diameter, as evidenced by p-values greater than 0.05 across all comparisons. The use of cow dung resulted in similar collar diameters between seedlings from forest areas (3.54 ± 0.13 mm) and urban forests (3.36 ± 0.11 mm), with a non-significant p-value of 0.075.

Similar patterns were observed for inorganic fertilizer and poultry manure, where the diameter values varied slightly between seed sources, however, none of the differences reached statistical significance ($p = 0.183$ and $p = 0.218$, respectively). The results reveal that minor differences in values exist; fertilizer type and seed source did not significantly affect the collar diameter of *K. senegalensis* seedlings. This implies that collar thickness may be less sensitive to the applied treatments than other growth variables such as height.

Table 5: Effect of Fertilizer Type and Seed Source on Mean Collar Diameter of *Khaya senegalensis* Seedlings

Fertilizer types	Seed source		*T-test value* (variation between seed sources)
	Forest area	Urban forest	
CM	3.54±0.13[a]	3.36±0.11[a]	0.075
IF	3.13±0.22 [a]	3.43±0.12[a]	0.183
PM	3.32±0.21[a]	3.55±0.22[a]	0.218
P-Value	***0.135***	***0.261***	**-**

Means on the same column with different superscripts are statistically significant ($p<0.05$), ns = not significant.
Note - PM: Poultry manure; CM: Cow dung, and IF: Inorganic fertilizer (NPK-10:10:10)

DISCUSSION

This finding investigated the germination and early growth performance of *Khaya senegalensis* seedlings derived from two distinct seed sources (forest areas and urban forests) under different fertilizer treatments. The findings show the influence of both seed provenance and fertilizer types on key physiological and morphological seedling variables. The germination rate of *K. senegalensis* seeds was consistently higher for seeds sourced from forest areas than those from urban forest environments throughout the 40-day observation period. The differences were observed during the early stages of germination (Day 10 and Day 20), with *p*-values close to the statistical significance level ($p = 0.050$ and $p = 0.051$, respectively). Although the differences at later stages (Days 30 and 40) were not statistically significant ($p > 0.05$), the overall mean germination rate was at its peak under the forest seed source with a statistically significant difference ($p < 0.05$). This implies that environmental conditions at the seed source level, including soil nutrient status and maternal plant vigour, influence seed viability and initial germination capacity. This result aligns with the report of Nguyen *et al.* (2021), who reported that the maternal environment strongly affects petunia seed germination and subsequent seedling vigour and growth rate.

Poultry manure treatment had the highest seedling moisture content from the two seed sources. Seedlings grown from forest area seeds recorded higher moisture content values than those from urban forests under the same fertilizer treatments. This trend indicates that poultry manure enhances soil water-holding capacity, supporting better water uptake by the seedlings (Okonwu and Mensah, 2012; Hoover *et al.*, 2019). The superior performance of forest-derived seeds reflects their inherent physiological advantages, shaped by adaptation to less disturbed environments (Liu, 2025). The organic fertilizers (poultry manure and cow dung) supported greater biomass accumulation than inorganic fertilizer. Forest area seedlings consistently performed better than urban seed sources across all fertilizer treatments, with cow dung yielding the highest biomass content. This indicates that organic nutrient sources release nutrients more gradually and sustainably, promoting steady biomass development (Khan *et al.*, 2024). The uniform trend across both seed sources reinforces the potential of organic fertilizers in sustainable afforestation programs, especially in semi-arid environments such as Kano State.

The urban forest seedlings exhibited larger leaf areas across all treatments compared to those from forest areas, with the greatest leaf expansion observed under poultry manure application (48.84 ± 3.33 cm²). Although the differences in leaf area were generally not statistically significant ($p > 0.05$), the marginal significance observed for poultry manure treatment in urban seedlings ($p = 0.05$) implies a possible interactive effect between seed source and nutrient type. These results show the importance of nutrient-rich organic inputs in supporting photosynthetic structures essential for plant growth (Shaji *et al.*, 2021). The number of leaves was largely unaffected by fertilizer type or seed source, with no statistically

significant differences observed ($p > 0.05$). However, a slight increase in leaf production was observed in seedlings from the urban forest under inorganic fertilizer treatment. Although not statistically significant, this indicates a tendency for inorganic fertilizer to promote leaf initiation more effectively in certain seed sources. This result is not in line with the report of Kuje *et al.* (2023), who reported that changes in the number of leaves *K. senegalensis* seedlings produced were significant ($p < 0.05$), and the seedlings given the combination of poultry manure and cow dung had more leaves on average. Poultry manure yielded the lowest number of leaves, due to slower nutrient mineralization than in inorganic sources (Purnomo *et al.*, 2017).

Fertilizer type and seed source significantly influenced seedling height (Ghimire *et al.*, 2023; Kuje *et al.*, 2023). Urban forest seedlings consistently exhibited taller growth than those from forest areas under all fertilizer treatments. Among the fertilizers, poultry manure and cow dung proved more effective in enhancing height, with statistically significant differences ($p < 0.05$). This result is linked with slow decomposition and mineralization of these manures, which release nutrients gradually and steadily than inorganic fertilizer (Kuje *et al.*, 2019). Craven *et al.* (2006) and Gbadamosi (2006) reported that for a seedling to grow effectively, it must be given adequate nutrients in the proper amounts. According to Focho *et al.* (2011), seedlings that receive an adequate amount of fertilizer yield more than those that do not.

The superior response of urban forest seeds to organic treatments may be due to their adaptive growth strategies in nutrient-variable environments. This result affirms the role of organic amendments in enhancing vertical growth—a critical attribute for seedling survival and competitiveness in forest ecosystems (Zhang *et al.*, 2022). Unlike other growth variables, collar diameter was not significantly influenced by fertilizer type or seed provenance. Although slight differences were observed, none reached statistical significance ($p > 0.05$), indicating that this variable may be less responsive to early nutrient inputs. Longer-term growth conditions or genetic factors may have a greater impact on collar diameter than does short-term fertilizer application. This result is not in line with the result of Chabbi *et al.* *(*2023), who reported that the organic fertilizer determined a higher growth than an inorganic fertilizer, showing a higher increment in both collar diameter and tree height. Ong *et al.* (2003) reported that the growth performance of some timber seedlings without fertilzer application was shown to be poor.

CONCLUSION

The results show that both seed source and fertilizer type exert considerable influence on the early performance of *K. senegalensis* seedlings. Seeds from forest areas showed superior germination, moisture retention, and biomass accumulation, while seedlings from urban forests demonstrated larger leaf areas and greater height under optimal treatments. Organic fertilizers, (poultry manure and cow dung), consistently outperformed inorganic fertilizers in promoting growth. These findings revealed the ecological and silvicultural value of selecting appropriate seed sources and organic nutrient inputs for successful afforestation and reforestation in the semi-arid Sudan savanna region. Based on the findings, it is recommended that *Khaya senegalensis* seedlings intended for afforestation or reforestation in semi-arid regions such as Kano State should be propagated using seeds sourced from natural forest areas and grown with organic fertilizers (poultry manure or cow dung) to enhance germination success and promote vigorous early growth.

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