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Efficiency of Bio-Fertilizing as One of the Natural Alternatives to Improve the Growth of *Khaya senegalensis* and *Swietenia mahagoni* Trees and for Sustainability

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Abstract

A field experiment was carried out at Ismailia Research Station, Ismailia Governorate from 2020-2022 to improve the growth of *Khaya senegalensis* and *Swietenia mahagoni* by using a combination of mineral fertilizer (NPK) and biological fertilizer (*Azotobacter chroococcum*, *Bacillus megatherium*, and *Bacillus circulant*) as recommended dose under new sandy soils conditions. Split plot designed with four treatments (Control, (50% Mineral fertilizer (M.) + 50% Biological fertilizer (Bio.)), 100% M. and 100% Bio.) of each species. Vegetative growth, leaf area, tree biomass, stored carbon, basal area, tree volume, and in the soil both of microbial account and mineral content were determined. The experimental results showed no significant differences between studied species among the most studied parameters except for *Khaya senegalensis* which gave the highest significant difference in root biomass and below-stored carbon than *Swietenia mahagoni.* Evidently, the highest significant growth parameters were 100% mineral fertilizer followed by (50% M. + 50% Bio.) as compared with control. No significant difference between 100% M. and (50% M. + 50% Bio.) of shoot dry biomass (15.19 and 12.02 kg, respectively) and above-stored carbon (0.28 and 0.22 Mt, respectively). Microbial account and mineral content in soil were improved after cultivation of tree species compared to before planting and control, especially with 50% mineral fertilizer and 50% bio-fertilizer treatment. In conclusion, a treatment containing 50% mineral fertilizer and 50% bio-fertilizer has led to the ideal *Khaya senegalensis* and *Swietenia mahagoni* growth in sandy soil for cheaper and sustainable.

Keywords

Khaya senegalensis, *Swietenia mahagoni*, Mineral Fertilizer, Bio-Fertilizer, Growth Parameters, Tree Biomass, Stored Carbon, Sustainable

1. Introduction

Khaya senegalensis (Desr.) A. Juss. (African mahogany) is the most common species in the mahogany family (Meliaceae) in Egypt. It is a forest tree species of high economic significance in Africa. It is one of the most important timber species in the international timber market. *K. senegalensis* is utilized in making high-quality furniture, construction, flooring, interior trim, railway sleepers, and pulpwood [1]. Additionally, it is a wood of choice with the required high surface quality. Shoot parts of the tree are of immense use in human and livestock traditional medicine. It is cultivated under adverse conditions, especially in low-rainfall regions due to rusticity and relative adaptability [2].

Swietenia mahagoni Jacq belongs to Family Meliaceae [3]. This and several other species of mahogany are used in the timber industry for furniture and fine cabinets due to the color, straight grain, and durability of the wood. *S. mahagoni* is a taller tree with a dominant, straight trunk that could be grown in Florida along the streets [4] and in Egypt.

Applications of fertilizer to the soil are essential to reach full growth, increasing the crop's quantity and quality and promoting health. Fertilization of *Khaya senegalensis* and *Swietenia mahagoni* stand to achieve specific management goals, especially in sandy soils allowing the tree to be more effective at manufacturing. It is essential to attempt generalizations about the response of the different kinds of plants of which it is composed [5]. Nutrient requirements of tree species raised located at various sites also vary since site chemical and physical conditions are not the same [6]. On the other side, the use of excessive chemical fertilizers and pesticides has decreased soil microbial life and destroyed the balance between soil microbes and plants, negatively impacting plant nutrition, production, and soil health [7]. In addition, the high cost of the applicability of mineral fertilizer, FAO [8] indicated that about 53 billion tons of NPK fertilizers are used yearly to supplement the number of nutrients needed for plant growth and yield performance.

Bio-fertilization in agriculture is considered safe and environmentally friendly, it can replace chemical fertilizers and pesticides without any negative impacts on the ecosystem [9] [10]. These are the most advanced biotechnology necessary to support the development of organic agriculture, sustainable agriculture, green agriculture, and non-polluting agriculture. Bio-organic fertilizer can increase the output, and improve the quality and it is responsible for the agricultural environment [11].

Plant Growth-Promoting Rhizobacteria have diverse mechanisms through which support plant growth, like atmospheric nitrogen fixation, solubilization of mineral phosphorus, siderophores production, mineralization of other nutrients, anti pathogenic affects and also can produce IAA, etc. [12] [13].

A number of intellectuals throughout the world started working on alternatives and found that bio-fertilizers can help increase the yield without causing the damage associated with chemical fertilizers. Microorganisms accelerate certain microbial processes. Such microbiological processes can change unavailable forms of nutrients into available ones that can be easily assimilated by plants [14]. Some plant microbes, such as *Rhizobium*, *Bacillus*, and *Pseudomonas*, fix nitrogen to the soil by forming symbioses with the plant root, thus enhancing symbiotic efficiency in shaping plant-bacteria interactions [15]. Adopting biomes for sustainable agriculture can help understand plant-bacteria co-evolvement with promises for a desirable selection of beneficial microbes to improve yield under drought stress [16].

The main object of this study is to improve the growth and productivity of *Khaya senegalensis* and *Swietenia mahagoni* as important woody trees and at the same time are endangered species under new sandy soil conditions by adding mineral and bio-fertilizers.

2. Materials and Methods

2.1. Location

This study was carried out at Ismailia Agriculture Research Station (IARS) located in Ismailia governorate in the eastern parts of the Arab Republic of Egypt (ARE) at the middle part of the Suez Canal at latitudes 30˚36'15N and longitudes 32˚16'20E, from 2020 to 2022 (**Figure 1**).

2.2. Source of Seedlings

Seedlings aged one-year-old of *Khaya senegalensis* and *Swietenia mahagoni* species were obtained from the Nursery of Forestry and Timber Trees Department, Horticulture Research Institute in Giza, Egypt.

2.3. Soil Analysis

Before planting (virgin, sandy texture soil) and at the end of the experiment, soil sample was taken from the surface layer 0 - 30 cm and analyzed for the mechanical and physiochemical properties according to the method of [17] and recorded in **Table 1**.

Table 1. Virgin soil analysis before cultivation of *K. senegalensis* and *S. mahagoni* in February 2018.

Soil Depth (cm)	S.P	pH	EC $dS \cdot m^{-1}$	Cations ($meq \cdot L^{-1}$)				Anions ($meq \cdot L^{-1}$)				Aval. ppm		no. of colonies (10^6)	Avg. CFU/ml (10^6)
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	N	P		
0 - 30	25	8.0	0.88	4.54	1.94	3.20	0.14	--	3.30	2.54	4.0	463.04	11.37	42	5.0E+08

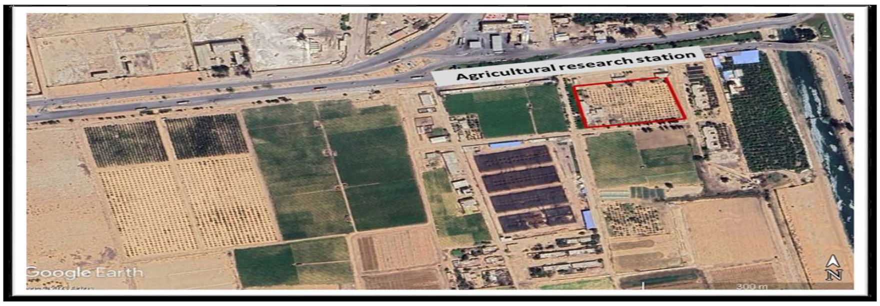

Figure 1. Location of the experiment at red square.

2.4. NPK Estimation

Soil samples before and after planting were analyzed to estimate NPK concentration according to the method of [18].

2.5. Mineral Fertilizer

Eighty grams of mineral soluble fertilizer as recommended dose, which contained 19% of N, 19% of P_2O_5 and 19% of K_2O were applied for each tree twice a year.

2.6. Bacterial Strains Inoculums

Microorganisms in inoculums bio-fertilizer were represented as nitrogen-fixing bacteria (*Azotobacter chroo-coccum*), phosphate-dissolving bacteria (*Bacillus megatherium* var. *Phosphaticum*), and potassium-dissolving bacteria (*Bacillus circulant*)were prepared and provided by Bio-fertilizers Production Unit, Soils, Water and Environmental Research Institute, ARC, Giza, Egypt.

2.7. Microbial Total Count

The total counts of heterotrophic bacteria in the soil samples before and after cultivation with tree species subjected to different fertilizer treatments were determined (serial dilution and pour plate technique) as described by the methods of [19].

$$\text{CFU/mL} = (\text{no. of colonies} \times \text{dilution factor})/\text{volume of culture plate}$$

where: CFU is the colony forming unit.

2.8. Experimental Proceeding

Before transplanting the seedlings in April 2018, 48 holes were prepared by adding 1 kg of animal manure/seedlings in each hole. Then, planted seedlings in permanent land in the Ismailia research station at 3 m × 3 m plant spacing. Seedlings were surface irrigated with fresh water from the Nile canal and the soil moisture content was kept continuously near the field capacity.

Seedlings were irrigated three times a week in summer and twice a week in winter for 4 years till March 2022. Four treatments were applied in March 2020 by adding 100% mineral fertilizer (80 gm/seedling), 100% bio-fertilizer (80 gm/seedling, as recommended dose), 50% of mineral and bio-fertilizer (40 gm 19% NPK + 40 gm bio-fertilizer) and control (without fertilizer). Fertilizer levels were added twice yearly in March and September by dissolving 80 grams of NPK, 80 grams of bio-fertilizer, and 40 gm NPK + 40 gm bio-fertilizer in twenty-liter water and put it for each treatment seedling hole.

2.9. Growth Measurements

Tree height (m) and base diameter (cm) were recorded three times in February, June, and November yearly. Then, calculated the annual increment rate of height and diameter. Diameter at breast height (DBH) in cm was taken at the end of experiment. After that, calculated the tree basal area (m^2), total stored carbon (MT), and tree volume (m^3).

Basal area (m^2/tree) for each tree was calculated according to [20] by the next equation.

$$\text{Tree Basal Area (TBA)} \ (m^2) = \pi \ (DBH/200)^2$$

Tree volume:

Each tree was cut into logs at 10%, 30%, 50%, 70%, 90% of tree's total height.

- Volume of each log was calculated with Smalian equation according to next formula for:

$$V = \frac{g1 + g2}{2} h$$

where: $g1$, $g2$ is lower and upper log base area (m^2), h is log's height (m) [21] [22].

- Upper part of stem was calculated as a cone according to next equation:

$$V = (1/3)\pi r^2 h$$

where: h is log's height (m), r is log base radius.

Total fresh and dry weights were taken at the end of the experiment in March 2022.

Tree height was taken from the collar region to the apical bud of the trees using a meter rule. The collar diameter was measured using a veneer caliper.

Leaf area was measured by putting each leaf on a flat surface, with a length reference scale then scanned for leaf area measurement using Image J software [23].

2.10. Tree Biomass

At the end of the experiment, three trees of each treatment were chosen to determine the total fresh weight of the vegetative parts and root portions, Roots were detached from the soil matrix and cleaned carefully to maintain the fine roots. Each part of the tree was oven-dried at 70˚C until constant weight. The shoot, root, and total fresh and dry biomass were expressed as kilograms per tree by using an electronic weighing scale.

Above & below ground biomass and carbon calculation:

-Biomass

1) Above ground biomass = crown dry weight (kg) + stem dry weight (kg).

2) Below ground biomass = root system dry weight (kg).

3) Total tree biomass (kg) = above ground biomass + below ground biomass.

-Biomass of total area = main of total tree biomass (kg)*trees number/Feddan *planted area (Feddan)

- Carbon:

1) Stored carbon (kg) = Biomass of total area (kg)*0.5

2) Stored CO_2 (kg) = stored C (kg)*3.67

3) Stored CO_2 metric tons = stored CO_2 (kg)*0.001 [24] [25].

2.11. Statistical Analysis

The statistical analysis was performed using a split-plot design, where tree species were the main plot, while the subplot was fertilizer treatments with 3 replicates for each treatment. In addition, the means of the individual factors and their interaction were compared by F-test, and the least significant differences were at a 95% level of confidence (LSD 0.05) using SAS 9.1 system software according to [26].

3. Results and Discussion

3.1. Vegetative Growth

Over-viewing the statistical analysis, all studied parameters showed highly significant differences among fertilizer treatments, while the significance of species and the interaction between fertilizer treatments and species were varied as data explain. Moreover, *Khaya senegalensis* species was supervised *Swietenia mahagoni* for all studied parameters.

Table 2 indicates the effect of fertilizer treatments, species, and the interaction between them at the end of the experiment in 2022. Results showed highly significant differences were obtained in trees height and diameter under fertilizer treatments and for the interaction between (Sp. and Treat.). Mineral fertilizer (M.100 %) recorded the highest value of height and diameter (3.92 m and 11.07 cm, respectively), followed by (M.50% + B.50%) treatment (3.39 m and 9.92 cm, respectively). For the interaction between tree species and fertilizer treatments, *Khaya senegalensis* gave the highest value of height and diameter with (M.100%) treatment followed by *Swietenia mahagoni* with (M.50% + B.50%) treatment.

In addition, the results in **Figure 2** indicated that the yearly height increment of *K. senegalensis* was evident with mineral fertilizer (M.100%) treatment as compared with other treatments. While, *S. mahagoni* gave the highest height increment with 50% mineral fertilizer and 50% bio-fertilizer (M.50% + B.50%)

through the experiment from 2020 to 2022, as shown in **Figure 3**. The yearly diameter increment of *K. senegalensis* was high with bio-fertilizer as compared with other treatments (**Figure 4**). while, *S. mahagoni* gave the highest yearly diameter increment with mineral fertilizer (M.100%), as shown in **Figure 5**.

The results indicated that the absence of mineral NPK in spite of bio-fertilizer was the reason for reducing the effectiveness; as B.100% appeared measurements lower than that of contain mineral NPK. This could be explained by the ability of bio-fertilizer to utilize each mineral NPK fertilizer to be available by plants as a simple material. This indicates the possibility of obtaining better growth due to improved photosynthetic rate if cultivated in sandy soil with the contents of

Table 2. Means of tree height (m), base diameter (cm), leaf Area (cm^2) and total fresh weight (kg) for studied species, treatments and their interaction.

Species Treatments	Height (m)			Diameter (cm)			Leaf Area (cm^2)			Total fresh weight (kg)		
	Khaya senegalensis	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means
Control	2.93 d	1.80 e	2.363 C	7.73 a	5.6a	6.163 D	23.91 c	7.11 d	15.51 C	11.59de	3.27e	7.428 D
M.50% + B.50%	2.98 cd	3.82 ab	3.398 B	12.55a	7.3a	9.925 B	33.49 b	11.69 d	22.59 B	43.32b	14.22cde	28.77 B
M. 100%	4.35 a	3.50 bc	3.925 A	13a	9.15a	11.075 A	48.60 a	14.01 d	31.31 A	68.88a	22.75cd	45.82 A
B.100%	2.98 cd	3.02 cd	2.997 B	10.4a	6.41a	8.405 C	28.65 bc	9.49 d	19.07 BC	23.19c	8.26e	15.723 C
Means	3.308 A	3.034 A		10.919 A	6.865 A		33.67 A	10.58 B		36.75A	12.125A	
LSD.0.05 Treatment	0.402			0.818			4.882			8.026		
LSD.0.05 Species	1.223			5.195			3.091			34.74		
LSD.0.05 Interaction	0.57			7.53			6.9			11.35		

Means with the same Letters are not significant, Capital Letters for species and treatments.

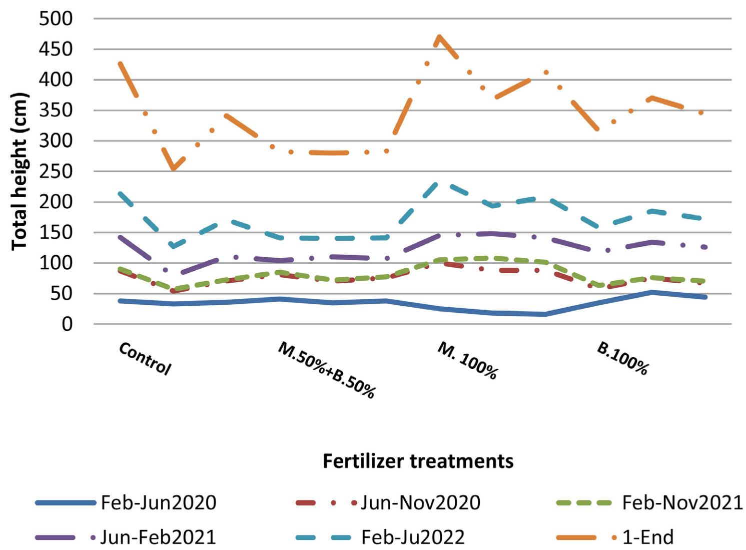

Figure 2. Annual increment total height (cm) of *Khaya senegalensis*.

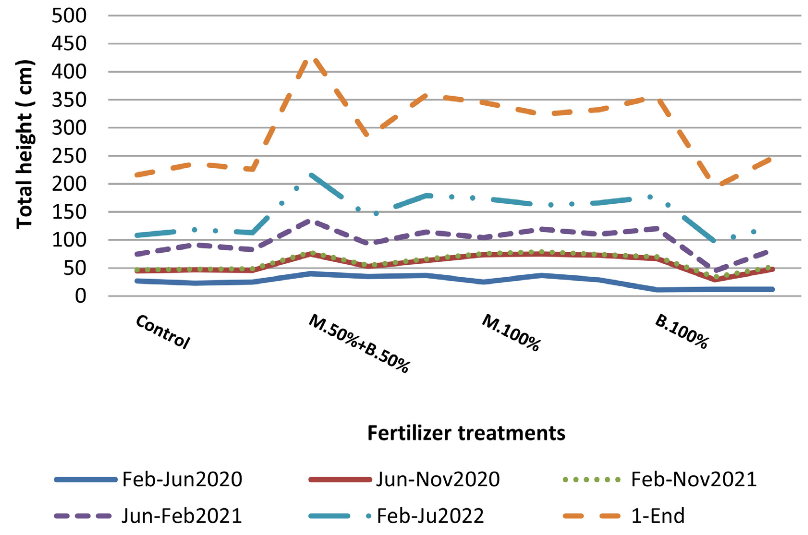

Figure 3. Annual increment total height (cm) of *Swietenia mahagoni*.

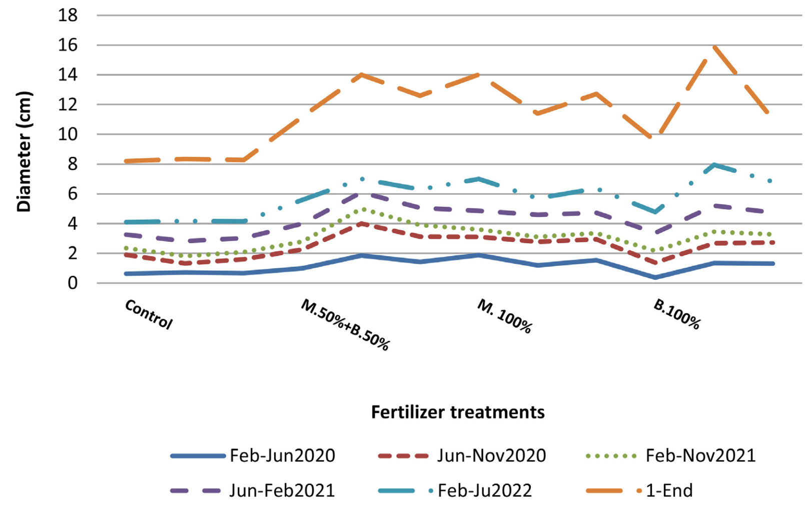

Figure 4. Yearly diameter increment (cm) of *Khaya senegalensis*.

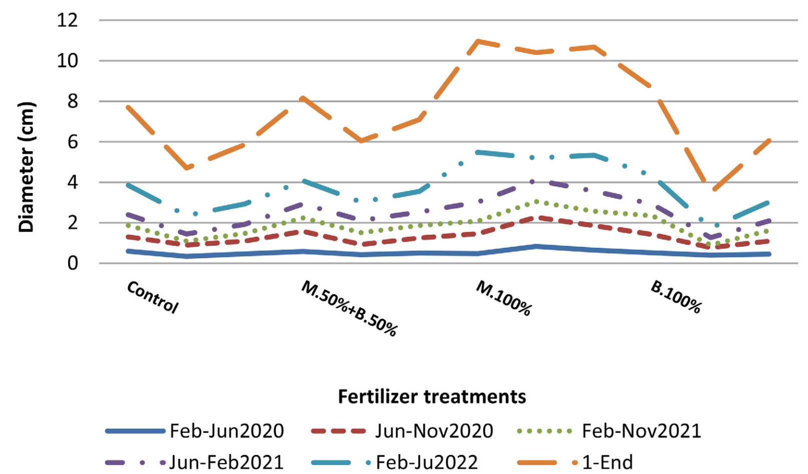

Figure 5. Yearly diameter increment (cm) of *Swietenia mahagoni*.

100% NPK followed by 50% NPK and 50% bio-fertilizer treatment. The role of bio-fertilizer was obvious in increasing the height and diameter of tree species due to its ability to decompose complex compounds into simple compounds with easy uptake by tree roots. It also confirmed the importance of reducing the use of mineral fertilizers and replacing them with microorganisms that can be more available components that benefit plants without affecting the environment.

Fertilization has been increasing both the quantity and quality of the tree species. This may be a result of ideal doses of NPK that can affect the regular functioning of body organs and the growth parameters. On the other side, bio-fertilizers more gradually release available nutrients over a long time, unlike mineral fertilizer which releases nutrients within a shorter period to trees. Many investigators studied the effect of NPK fertilization on the vegetative growth characteristics of the seedlings and young trees of various woody tree species, such as [27] who found that stem length and diameter were stimulated due to NPK fertilization treatments compared with untreated plant. Nitrogen and phosphorus application improved growth in coarse soil [28].

On the other side, Sayed *et al.* (2010) [29] showed that the mixture of N 45-P 20-K 40 g/tree produced the longest and thickest stems of *Azadirachta indica, Khaya ivorensis* and *K. senegalensis* (6-year-old) grown in loamy sand soil.

Studies on *Azadirachta indica* [30], *Taxodium distichum* [31], and *Melia azedarach* and *Albizzia lebbek* [32], found that NPK fertilization increased growth parameters. Nitrogen treatments increased aboveground net primary production (ANPP) by 33% and 25% above controls, [33]. Bio-fertilizers led to an increase in quality and plant growth as compared with control [34].

Application of fertilization resulting in an increase in height and dbh annual increment, compared with unfertilized trees. Large growth responses resulting from applied 100% NPK and 50% NPK + 50% bio fertilizer could be sustained by further fertilizer additions. The results of this study indicated that species of the tested trees may respond differentially to fertilizer treatment, *K. senegalensis* was more responsive to all treatments as compared with *S. mahagoni*. These results suggest that research into the possible use of nutrient manipulation as a means of influencing the growth of wood in sandy soil is needed.

These results are in harmony with those of Chen *et al.* (1997) [35] who declared that P not only significantly improved the increment of button diameter, height, and crown diameter but also caused earlier canopy closure of the stand. Results also, agree with Afa *et al.* (2011) [36], who found no toxic effect on using NPK 15:15:15 fertilizer application, at the same time result was incompatible with [37] [38] who found that organic fertilizer had faster growth rate than plants treated with NPK fertilizer.

3.2. Leaf Area

Statistical analysis presented in (**Table 2**), showed highly significant differences among fertilizer treatments, species, and (sp. and fertilizer treat.). *Khaya senegalensis* excelled over *Swietenia mahagoni* in leaf area 33.67 and 10.58 cm^2, respectively. When, (M. 100%) treatment gave the highest leaf area 31.31 cm^2, followed by (M.50% + B.50% treatment) 22.59 cm^2. Moreover, in the interaction between treatments and tree species, *Khaya senegalensis* recorded the highest leaf area values with all treatments, especially with (M.100%) treatment (48.60 cm^2) and then (M.50% + B.50%) treatment 33.49 cm^2. Although, *Swietenia mahagoni* showed the same behavior with fertilizer treatments the highest leaf area was recorded with (M.100%) treatment 14.01 cm^2 then, (M.50% + B.50%) treatment 11.69 cm^2, but in general it gave the lowest values of leaf area compared with *Khaya senegalensis* as showed in Table 2. It is logical to find that the mean value of *Khaya senegalensis* leaf area is higher than that of *Swietenia mahagoni*, this is due to the morphological differences in the two species, as *Khaya senegalensis* leaves are larger than *Swietenia mahagoni* leaves. These results are in harmony with [39] on loblolly pine and sweet gum. Contrary to the result of [1], who found that the highest leave area of *Khaya senegalensis* seedlings was found with organic fertilizer then, NPK 15:15:15 fertilizer, This could be due to the effect of organic manures to enhance the seedlings growth performance compared to inorganic fertilizer (NPK 15:15:15) more over the significantly on the result is depending on the seeds source zone.

3.3. Tree Biomass

The growth of tree species was improved as a result of different treatments under new sandy soil, especially of *K. senegalensis*. Table 2 and Table 3 indicate the analysis of variance of total fresh, shoot, root, and total dry biomass with differences ($P < 0.05$) among fertilizer treatments, species, and the interaction between them.

Table 3. Means of shoot, root and total tree dry biomass (kg) for studied species treatments and their interaction.

Species Treatments	Shoot dry biomass (kg)			Root dry biomass (kg)			Total tree dry biomass (kg)		
	Khaya senegalensis	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means
Control	4.40 cd	1.18 d	2.79 B	1.55cd	0.40d	0.98 C	5.96cde	1.57e	3.77 D
M.50% + B.50%	17.52a	6.52bc	12.02 A	5.20b	1.46cd	3.33 B	22.72b	7.98cde	15.35 B
M. 100%	21.9a	8.47bc	15.19 A	8.76a	2.54c	5.65 A	30.67a	11.01cd	20.84 A
B.100%	9.44b	3.72 cd	6.58 B	2.72c	1.12cd	1.92 C	12.16c	4.84de	8.5 C
Means	13.32A	4.97A		4.56 A	1.38 B		17.88A	6.35A	
LSD.0.05 Treatment	3.55			1.34			4.67		
LSD.0.05 Species	16.19			3.03			19.22		
LSD.0.05 Interaction	5.015			1.90			6.60		

Means with the same Letters are not significant, Capital Letters for species and treatments.

As indicated in the statistical analysis (Table 2 and Table 3), fertilizer treatments showed a highly significant effect. While, the interaction between species and fertilizer (sp. and fertilizer interaction) varied between highly significant and significant effects, at the same time species had no significant effect on these parameters except for root biomass was significant. Table 2 and Table 3 showed that the highest fresh weight, shoot, root, and total dry biomass observed in (M.100%) treatment (45.82, 15.19, 5.65, and 20.84 kg), then (M.50% + B.50%) treatment (28.77, 12.02, 3.33 and 15.35 kg, respectively).

It was clear that there was no significant between (M.100%) and (M.50% + B.50%) treatments of shoot dry biomass (15.19 and 12.02 kg, respectively). while, in the interaction between sp. and fertilizer, *Khaya senegalensis* had the highest fresh weight, shoot, root, and total dry biomass (68.88, 21.9, 8.76, and 30.67 kg, respectively) with (M.100%) treatment. When species showed no significance of different characters except for root biomass was significant, as shown in Table 3.

The results indicated that application of NPK fertilizer levels stimulates growth by increasing the availability of nutrients generally, thereby enhancing crown development and the size of photosynthesizing surfaces. The most obvious effect of fertilizer addition on nutrient-limited sites is an increase in growth rates and productivity. In this concern, Bumatay (1990) [40] reported that N and P fertilization treatments increased seedling's dry weight and biomass of *Casuarina equisetifolia.* Nitrogen deficiency reduced leaf area, while P deficiency caused a great reduction in dry matter of *K. senegalensis*, on the same tree species [41].

On the other side, the use of excessive chemical fertilizers has decreased soil microbial life and upset the balance between soil microbes and plants, negatively impacting plant nutrition, production, and soil health. Bio-fertilizers hold the potential to revive soil biology and increase farmers' current agricultural productivity, while at the same time contributing to the soil's ability to produce more in the future [42]. Fertigation had increased height, diameter, and production of foliage, stem, and branch mass of Sweet gum trees [39].

3.4. Stored Carbon

Stored carbon by Metric Tonne (MT) for Aboveground, belowground, and total stored carbon were calculated and statistically analyzed as presented in (Table 4). By all the odds fertilizer treatments had a highly significant effect, followed by (sp. and fertilizer treat.) treatments that recorded highly significant differences in below-ground stored carbon, and had a significant difference in stored carbon for both above-ground and total. On the other hand (Table 4) presented the mean values of above, below and total stored carbon and as expected the highest means were observed with (M.100%) than with (M.50% + B.50%) treatments (0.28, 0.11 and 3.82 MT, respectively), (0.22, 0.06 and 2.82 MT, respectively). However, there was no significant between (M.100%) and (M.50% + B.50%) treatments (0.28 and 0.22 Mt, respectively). Noticeable, for the interaction between (sp. and fertilizer treat.). *Khaya senegalensis* with (M.100%) treatment had the highest values for stored carbon on above, below ground, and total stored carbon (0.40, 0.16, and 5.63 MT, respectively), **Table 4**.

This result is matched by the fact that the higher the biomass content the higher carbon stored, according to [43]. Tree biomass is the main component of the carbon stock of vegetation, for that, tree species are the best and simplest ways to store carbon again, while, tree species as forests have the majority of the global vegetation biomass [44]. Moreover, according to [45] woody vegetation stock is estimated at 422 billion tons of dry matter above-ground biomass of stems, branches, tops, and foliage. Also, good soil biology builds organic matter in the soil to store carbon and breaks organic matter down to release carbon back into the atmosphere [46].

3.5. Basal Area and Tree Volume

Doubtless, the previous fertilizer treatments affected significantly on trees growth which is reflected in feddan productivity of growing basal area and volume as shown in **Figure 6** and **Figure 7**. Noticeable, from the figures that (M.100%) treatment had the major effect on feddan productivity of the basal area and volume for both species and overtop with *Khaya senegalensis* (2.74 m^2 and 9 m^3)/feddan, respectively). These results are in line with those of [47] who revealed that nitrogen significantly increased the diameter, height, basal area, and volume growth of black spruce. The average annual change of height, diameter at breast height (DBH), and basal area (BA) of *K. senegalensis* were significantly increased as affected by the third interaction among N, P, and K fertilization within the period of the experiment [5]. Moreover, the tree volume and total biomass must be determined to measure the carbon pool accurately [48] [49]. Tree volume and dbh are the most time-consuming and accurate approaches that can be used to predict wood biomass using a regression model [25] [50].

Table 4. Means of above stored Carbon (MT), below stored Carbon (MT) and total stored Carbon (MT) for studied species, treatments and their interaction.

Species Treatments	Above stored Carbon (Mt)			Below stored Carbon (Mt)			Total stored Carbon(Mt)		
	Khaya senegalensis	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means	*Khaya senegalensis*	*Swietenia mahagoni*	Means
Control	0.08 cd	0.022 d	0.05 C	0.03 cd	0.01 d	0.02 C	1.09 cde	0.29 e	0.69 D
M.50% + B.50%	0.32 a	0.12 bc	0.22 A	0.10 b	0.03 cd	0.06 B	4.17 b	1.46 cde	2.82 B
M. 100%	0.40 a	0.16 bc	0.28 A	0.16 a	0.05 c	0.11 A	5.63 a	2.02 cd	3.82 A
B.100%	0.17 b	0.07 cd	0.12 B	0.05 c	0.02 cd	0.04 C	2.23 c	0.89d e	1.56 C
Means	0.24 A	0.09 A		0.08 A	0.03 B		3.28 A	1.17 A	
LSD.0.05 Treatment		0.066			0.025			0.857	
LSD.0.05 Species		0.301			0.059			3.52	
LSD.0.05 Interaction		0.092			0.035			1.211	

Means with the same Letters are not significant, Capital Letters for species and treatments.

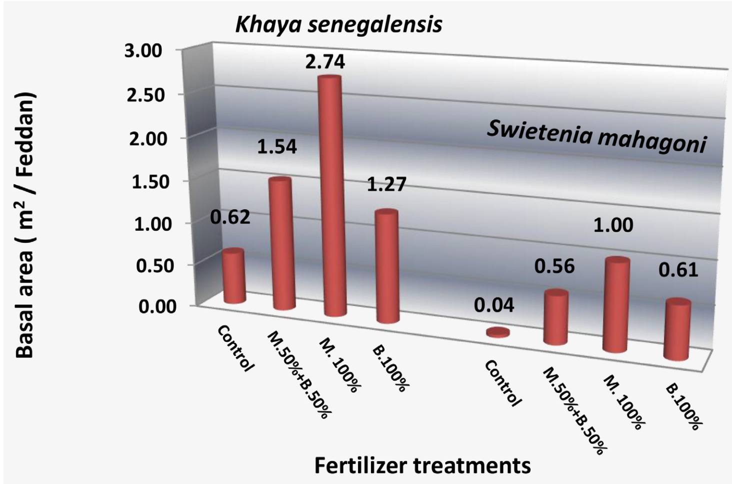

Figure 6. Basal area (m^2/Feddan) for studied species under different fertilizer treatments.

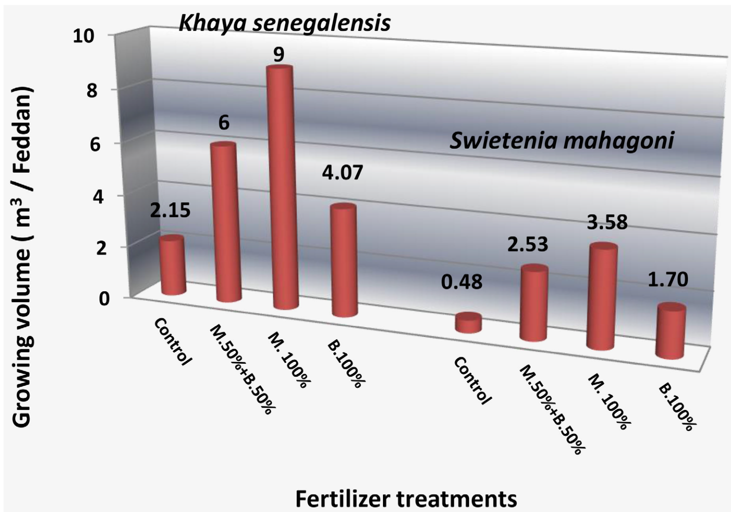

Figure 7. Total growing volume (m^3/Feddan) for studied species under different fertilizer treatments.

3.6. Microbial Account

The presence of viable and physiologically active microorganisms could be indicated by microbial account; therefore, it is considered an important parameter of soil quality. In this study, the microbial account was taken before and after the experiment.

The total microbial counts in the soil before planting (uncultivated) were few about (33×10^6) ($3.6E+08 \times 10^6$) of bacteria compared to soil subjected to different fertilizer treatments and species. The microbial total counts were developed in the soil samples collected from the mineral and bio-fertilizer treatments compared to the control soil treatment (Table 5). This was obvious from the counts of bacteria ($70 - 33 \times 10^6$) ($7.6E+08 - 5.4E+08 \times 10^6$), while the bacterial count was the highest with bio-fertilizer as compared with others.

Table 5. Soil analysis of two tree species affected by different treatments.

Treatments	pH	EC $dS \cdot m^{-1}$	Cations ($meq \cdot L^{-1}$)				Anions ($meq \cdot L^{-1}$)				Aval. ppm		no. of colonies (10^6)	Avg. CFU/ml (10^6)
			Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	SO_4^{-2}	N	P		
K. senegalensis Cont.	8.2	0.75	3.03	2.16	2.58	0.14	--	3.30	2.54	2.07	478.40	11.00	33	5.0 E+08
K. senegalensis M.50% + B.50%	8.2	0.92	4.55	1.94	3.39	0.21	--	3.30	2.54	2.33	500.48	11.20	70	7.2E+08
K. senegalensis M.100%	8.2	0.78	3.03	2.16	2.79	0.19	--	3.30	2.54	4.25	588.04	11.00	60	5.5E+08
K. senegalensis B.100%	8.2	0.67	3.03	2.16	2.44	0.21	--	3.30	2.54	2.00	426.88	11.00	64	5.0E+08
S. mahagoni Cont.	8.0	1.01	6.06	1.73	3.83	0.14	--	3.30	2.54	5.94	447.68	11.22	51	5.6E+08
S. mahagoni M.50% + B.50%	8.2	1.17	4.55	3.25	4.00	1.35	--	2.83	4.24	6.07	750.72	13.72	64	7.0E+08
S. mahagoni M.100%	8.0	0.67	3.03	1.52	2.72	0.21	--	2.83	2.54	2.84	463.68	11.50	56	7.6E+08
S. mahagoni B.100%	8.2	0.72	3.03	2.16	2.72	0.30	--	2.83	4.24	6.07	750.72	13.72	54	5.4E+08

These results explain that, free-living microbes can colonize the plant endosphere as a means of enhancing trees productivity. Endophytic microbes play an important role in tree growth promotion, as they employ direct or indirect mechanisms to facilitate tree growth by producing phytohormones and various secondary metabolites. The roles of endophytic microbes in sustaining tree growth under biotic and abiotic stresses through these mechanisms can provide functions in establishing host plant interactions for maximum use in the agricultural sector as an eco-friendly alternative tool to improve growth and yield. The positive effect of bio-fertilizer related to fix nitrogen, phosphorus and potassium to the soil by forming symbioses with the plant root, *Azotobacter* and *Bacillus* bacteria enhancing symbiotic efficiency in shaping plant-bacteria interactions [15]. These were proved by [51] on *Azadirachta indica.*

3.7. Mineral Content in Soil

NPK was determined in soil samples collected from the control, mineral, and bio-fertilizer treatments. Overall, treatment includes soil fertilized by each of 50% of the recommended dose of NPK plus 50% of bio-fertilizer was the most effective compared to control soil treatment. Results in Table 5 showed that the NPK was raised up, as the part per million of available soil-nitrogen among the two species ranged, from 426.88 to 750.72, available phosphorus ranged from 11.00 to 13.72 ppm, and potassium ranged from 0.14 to 1.35 $meq \cdot L^{-1}$compared to blank soil sample (control) of *Khaya senegalensis* and *Swietenia mahagoni*

(447.68 - 478.40 ppm), (11.00 - 11.22 ppm) and (0.14 meq·L^{-1}), respectively. The result is in agreement with that reported by [52] [53]. Also, the experimental results are in harmony with those indicated by Arif *et al.*, (2017) [54], which showed that low and declining soil organic matter contents pose a significant threat to soil fertility, crop productivity, and economic returns in arid and semi-arid agro-ecosystems. General approaches are required to build and sustain soil organic matter and bio-fertilizers in such soils to enhance nutrient use efficiencies.

Generally, the soil type on which the experiment was established has been defined as sandy soil, and growth increases have been obtained on this soil type from applications of fertilization. Sandy soils are generally low in soil nutrition elements and organic matter. Due to fast organic matter decomposition rates resulting from generally higher temperatures. Then, fertilizer application improved nutrient availability in the soil. NPK application not only improved nutrient availability to the tree species, especially in poor soil, as explained by the results but also, preserved the mineral content of the soil from deterioration by adding biofertilizer. That was matched with [36] who mentioned that *K. senegalensis* seedlings to grow efficiently and healthily, they have to be supplied with adequate and balanced nutrient stock. Furthermore, tree species are varied in their nutrient requirement, and varied sites with different site chemical and physical conditions [6].

4. Conclusions

This study revealed that all treatments applied were valuable sources of fertilizer for the growth of *Khaya senegalensis* and *Swietenia mahagoni*; they greatly improved the growth performance of treated trees over the controls. 100% mineral fertilizer demonstrated better growth attributes such as greater height, collar diameter, and total biomass than other treatments, followed by 50% mineral and 50% bio-fertilizer. These concluded that biofertilizers improve soil fertility by providing essential elements like nitrogen, Phosphorus, and Potassium by directly supplying them or transforming them into soluble forms. In addition, they also help trees to uptake several micronutrients. These results also indicate that *K. senegalensis* and *S. mahagoni* can be successfully established in sandy soils with the application of 80 g NPK per tree followed by 40 g NPK + 40 g bio-fertilizer per tree, there by establishing successful plantations.

NPK and bio-fertilizer application to *K. senegalensis* and *S. mahagoni* plantations resulted in increases in their growth that depend on NPK level and bio-fertilizer.

5. Recommendations

To improve the growth of *Khaya senegalensis* and *Swietenia mahagoni* trees (3 - 4 years old) prefer adding 40 g NPK and 40 g bio-fertilizer per tree (44 kg NPK and 44 kg biofertilizer/hectare, approximately) twice a year at March and September in sandy soil, for reducing the impact of excess chemical fertilizers, support soil fertility and sustainability.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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