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EFFECT OF *Leucaena leucocephala* LEAFY BIOMASS AND NPK FERTILISER ON THE GROWTH AND YIELD OF OKRA, *Abelmoschus esculentus* (L.) MOENCH

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ABSTRACT. Okra, *Abelmoschus esculentus* (L.) Moench, is a multipurpose vegetable crop grown in tropical and subtropical regions of the world for its immature seed pods and leaves. The crop seldom reaches its yield potential in most of these areas, primarily due to a decline in soil fertility. As a result, a field experiment was carried out at the Faculty of Renewable Natural Resources Demonstration Farm, KNUST-Kumasi to assess the effect of NPK (15:15:15) fertiliser and *Leucaena leucocephala* leafy biomass application on the growth and yield of okra. The treatment combinations were laid out in a 3 × 3 factorial randomised complete block design with 9 treatments replicated 4 times for a total of 36 experimental units. *Leucaena* leafy biomass and NPK were evaluated solely and in combinations at a rate of 75 kgN/ha on a weight basis. The treatment combinations were applied as follows: T1 = Control; T2 = 0.14 kg NPK (15:15:15); T3 = 0.07 kg NPK (15:15:15); T4 = 0.5 kg *L. leucocephala* leafy biomass; T5 = 0.25 kg *L. leucocephala* leafy biomass; T6 = T2 + T4; T7 = T3 + T5; T8 = T2 + T5; T9 = T3 + T4. The number of days from planting to the first anthesis of okra differed significantly ($p < 0.05$). T3 showed the least number of days to the first anthesis observation (47 days), while T9 had the highest number of days to the first anthesis (49.3 days). On a weekly basis (starting with 5 weeks after planting, WAP), height was not significantly different among the various treatments. Stem diameter followed a sequence similar to plant height, starting from 5 to 10 WAP, where no significant differences occurred between treatment means. However, mean values revealed that okra plants varied significantly in height; T9 had the tallest plants (27.2 cm), while T2 and T8 had the shortest plants (21.2 and 21.2 cm, respectively). There was a significant difference between the treatment means and stem diameter. In the same advanced line, T9 had the highest stem diameter (9.9 mm), with T5 having the lowest stem diameter

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(6.9 mm). Fruit yield was also significantly different, with T4 having the most fruit (39,259 fruits per ha) and T8 having the least (19,259 fruits per ha). The fruit dry weight was significantly different, as the highest weight was recorded in T7 (12.5 tonnes/ha) and the lowest was recorded in T9 (5.3 tonnes/ha). The combination treatment T9 [0.07 kg NPK (15:15:15) fertiliser + 0.5 kg *L. leucocephala* leafy biomass per plot] had a significantly improved height and diameter compared to the other treatments. The highest fruit yield of okra was recorded in T4 (0.5 *kg L. leucocephala* leafy biomass per plot), and the highest dry weight of okra was registered in T7 (0.07 kg NPK (15:15:15) fertiliser + 0.25 kg *L. leucocephala* leafy biomass per plot). Therefore, it is recommended that sole *L. leucocephala* leafy biomass (T4) and its combination with NPK (15:15:15) fertiliser (T9) be adopted by smallholder farmers to cultivate okra in the tropics.

Keywords: effect; organic fertiliser; inorganic fertiliser; okra production.

INTRODUCTION

The foundation of African economies mainly depends on agriculture and its associated activities, which employ over 60% of indigenous people in the tropics (Msangi, 2014). In addition to the major food staples in the tropics, vegetable crops constitute important agricultural produce in developing countries, including Ghana, of which okra cannot be overlooked (Dittoh *et al.*, 2013).

Okra, *Abelmoschus esculentus* (L.) Moench (F: Malvaceae), is commonly cultivated throughout all ecological zones in the tropics for its immature seed pods, which are consumed as vegetables (Muhammed *et al.*, 2013; Kishor *et al.*, 2016). In the tropics, okra can be cultivated alone or as an intercrop and is normally consumed with starchy foods to improve palatability (Ojiewo *et al.*, 2013). After green chili pepper, okra is the second-most exported vegetable in Ghana (Saavedra-Gonzalez *et al.*, 2014). Therefore, improving okra production could generate greater economic revenues and returns in the country.

However, the decline in soil fertility reduces nutrient uptake, whichy contributes extensively to a drastic fall in okra yields in sub-Saharan Africa (Olowoake *et al.*, 2015). According to Emran *et al.* (2021), declining crop productivity leads to low farmers' incomes and increases rural poverty among smallholder farmers in the tropics. Galloway *et al.* (2008) and Davidson *et al.* (2012) reported that most tropical farmers adopted the intensive use of inorganic fertilisers solely to increase okra yields, but this has not been supportive and sustainable enough due to the associated expensive nature and environmental hazards that cause low crop production, especially during application without recommended doses that may harm plants and human consumers.

According to Partey and Thevathasan (2013), using leafy biomass from leguminous agroforestry tree species, such as *Leucaena leucocephala*, as a source of plant nutrients can increase crop yields comparable to, and in some cases greater than, the effects of sole inorganic fertiliser application on soil fertility, crop growth, and yield. Agroforestry systems help improve the fertility status of the soil through litter fall, nutrient cycling, nutrient pumps, safety nets, and nitrogen fixation from leguminous agroforestry trees (Fahad *et* *al.*, 2022). Studies have been conducted on *Gliricidia sepium* leafy biomass as an organic material for soil fertility improvement; less research has focused on other potential agroforestry species, such as *L. leucocephala*, on various smallholder farms for okra production, eventually having a negative impact on okra production in the tropics (Amodu *et al.*, 2019). The present study hypothesised that the incorporation of *L. leucocephala* leafy biomass into the soil of okra plants would improve its organic matter content and increase yield production for smallholder farms to meet the high demand for okra in tropical markets. *Leucaena leucocephala* leafy biomass could serve as an alternative and cheap source for the improvement of soil fertility, reducing the total inputs of farm costs. The specific objectives of this study were to determine the effects of applied *L. leucocephala* leafy biomass and NPK (15:15:15) alone and in combination on the height, stem diameter, number of days to first flowering, fruit yield, and fruit dry weight of okra.

MATERIALS AND METHODS

Description of the study area

The research was carried out at the Faculty of Renewable Natural Resources (FRNR) research and demonstration farm of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana (*Figure 1*). The farm is situated at latitude 6.40°N and longitude 1.37°W in the moist semi-deciduous forest zone of Ghana (annual rainfall ranges from 1250–1500 mm), and the major wet season from May to July, accompanied by a minor wet season from September until the end of November. The farm location is characterised by prolonged dry spells from December to March and a short one in August. The daily mean temperature is 25.6°C, with the lowest average temperature of 20°C from December to February and the average warmest temperature of 33°C in March. The mean annual temperature and humidity are 26.61°C and 67.6%, respectively (Adu and Asiamah, 1992). The soil belongs to the Asuansi series of the Bomso and Nta Association, which is classified as Ferric Acrisol in the taxonomy of soil (FAO, 1976), with a texture in the sandy-loam class. The Ferric Acrisols are well drained and moderately deep but strongly acidic (Neina and Agyarko-Mintah, 2022).

Experimental Approach and Procedure

Land preparation

The study site was cleared manually from other foreign vegetation and materials before planting, and bed preparation was carried out before planting, using a pickaxe, shovel, cutlass, rake, and hoe.

Sources of fertiliser

The first was an organic fertiliser, the leafy biomass of *L. leucocephala* (between 5 and 10 years old), which was collected from trees at the FRNR demonstration and research farm, KNUST. The chemical composition of *L. leucocephala* includes 22–30% fibre, minerals, vitamins, flavonoids, and tannins (Gupta *et al.*, 2014). The chemical composition of *Leucaena* in this study included nitrogen (2.5% N).

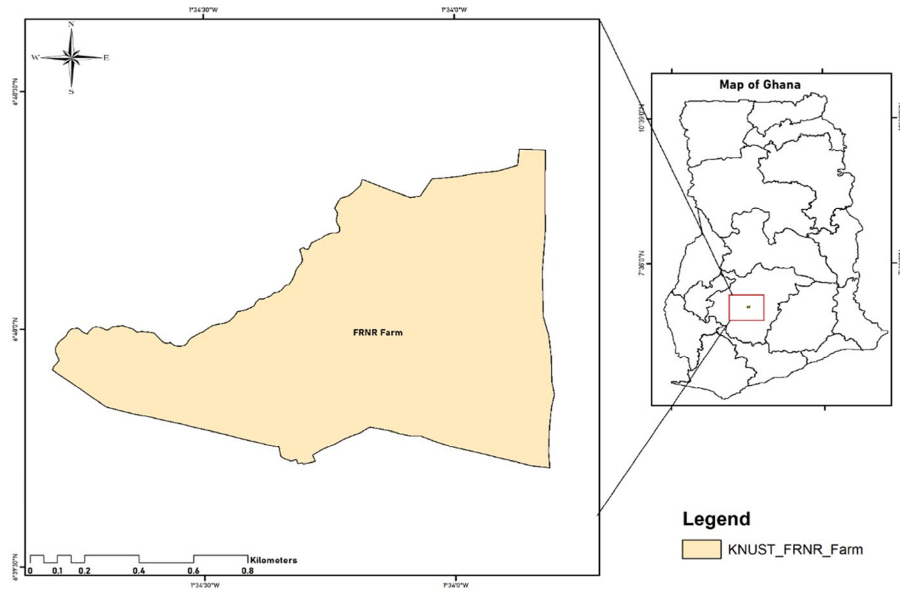

Figure 1 – Map of the Kwame Nkrumah University of Science and Technology (KNUST)

The second was inorganic fertiliser; NPK (15:15:15) inorganic fertiliser was purchased from a licenced agrochemical shop. Different proportions of *L. leucocephala* leafy biomass and NPK (15:15:15) were weighed using an electronic balance, and each was applied alone or in combination at different doses.

Source of okra seeds and viability testing

Seeds were obtained from the Council for Scientific and Industrial Research of Ghana (CSIR), Fumesua-Kumasi, and tested for viability using the floating method to ascertain germination potential, as viable seeds settled at the bottom (used in the experiment), while the non-viable ones floated (were discarded). To ensure efficient germination, the viable seeds were soaked in water for 24 h to soften the seed coat.

Leucaena leococephala leafy biomass application

Leafy biomass of *L. leococephala* was incorporated into the soil two weeks before planting (WBP) in various treatments during the field experiment (0, 0.5, and 0.25 kg per plot).

Fertiliser application

NPK fertiliser was applied two weeks after germination (2 WAG) according to the associated dose determined for each treatment (0, 0.14, and 0.07 kg per plot).

Sowing of seeds

Pre- and post-sowing irrigation was conducted throughout the experimental period during the dry season. Four seeds were sown at a depth of 1.5 cm per hill at a planting distance of 0.6–0.5 m one week after the biomass was incorporated, and one week after germination, the NPK (15:15:15) fertiliser was applied. Okra seedlings were thinned out to one seedling per hill one week after germination. Thinning was performed to ensure that plants left in the field had uniform growth and minimised competition for nutrients and water. Watering was performed as needed with a watering can.

Weed control

Weeds were manually controlled using a hoe, cutlass, and by hand.

Pest and disease control

Cyber force was applied at a rate of 0.5 litres per hectare (Okee, 2020) to control caterpillars and beetles. Spraying was done from two weeks after germination (2 WAG) until fruiting.

Harvesting

The fresh pods were harvested by hand and using a knife.

Experimental Design and Treatment Allocation

The experiment was laid out in a 3 × 3 factorial randomised complete block design (RCBD) with nine treatments randomly allocated and replicated four times. The size of the experimental site was 20.2 m × 7.55 m (152.5 m^2) with a total of 36 plots.

Each unit plot size was 1.8 m × 1.5 m (2.7 m^2) with 16 hills per plot, and an alley of 0.5 m between plots and blocks was maintained to ensure a true reflection of each treatment per plot.

FACTOR 1
(*L. leucocephala* leafy biomass)

- Level 1 = 0 kg
- Level 2 = 0.5 kg *L. leucocephala* leafy biomass
- Level 3 = 0.25 kg *L. leucocephala* leafy biomass

FACTOR 2
(NPK 15:15:15 fertiliser)

- Level 1 = 0 kg
- Level 3 = 0.14 kg of NPK (15:15:15) fertiliser
- Level 3 = 0.07 kg NPK (15:15:15) fertiliser
- The N demand for okra is 75 kg/ha (Adoasi-Ahyiah, 2017).

The fertiliser treatments were as follows:

- T1 (control) = without *L. leucocephala* or NPK;
- T2 = 0.14 kg of NPK per plot (518.5 kg NPK/ha);
- T3 = 0.07 kg NPK per plot (257.3 kg NPK/ha);
- T4 = 0.5 kg *L. leucocephala* per plot (1851.9 kg biomass/ha);
- T5 = 0.25 kg *L. leucocephala* per plot (925.93 kg biomass/ha);
- T6 = T2 + T4;
- T7 = T3 + T5;
- T8 = T2 + T5;
- T9 = T3 + T4.

The treatments were designed to provide 75 kg N/ha.

Data Collection and Analysis

Data on okra growth and yield parameters were collected weekly from 2 weeks after planting (WAP) to 12 WAP. Plant height, stem diameter, and number of days to the first anthesis were considered growth parameters. Plant height was measured from the soil surface to the tip of the highest leaf using a metre ruler. Stem diameter was measured with a digital calliper 5 cm from the ground. The numbers of days to first anthesis were calculated for the first flowering time by visual observations. Data on yield parameters were collected on the number of fruits and the dry fruit weight at harvest. The number of pods/fruit was obtained by visual counting, and the dry weight of pods/fruit was measured using an electronic balance after oven drying at 105°C in the laboratory. The data were analysed for differences using the analysis of variance (ANOVA) technique based on STATISTIX 7 software at a 5% level of significance. The least significant difference (LSD) was employed to compare the means, which were significantly different, and the results were presented in tables and graphs using Microsoft Excel.

RESULTS

Height (cm) of okra on a weekly basis from 5 to 10 WAP

The effects of various fertiliser treatments on okra height growth over a 12-week study period are illustrated in *Table 1*. On a weekly basis (starting from 5 WAP), differences in height for the various treatments did not differ significantly, with p-values ranging from 0.1265 to 0.9598.

All treatments showed steady increments in height throughout the experimental period. T9 had the highest plant height (27.2 cm), followed by T4 and T7 (25.5 and 25.8 cm, respectively), T3 and T6 (24.1 and 24.9 cm, respectively), T1 and T5 (22.8 and 22.8 cm, respectively), and T2 and T8 (21.2 and 21.2 cm, respectively). The ANOVA at a 5% significance level showed that the treatments were significant ($p < 0.05$). However, there were no significant differences between treatment groups T1, T3, T4, T5, T6, and T7. T2 and T8 were not significantly different from each other, but they both differed significantly from T9 in relation to plant height (*Figure 2*).

Main and interaction effects on plant height

Main effect

The main effects of NPK and *L. leucocephala* biomass were significant, with respective p-values of 0.000.

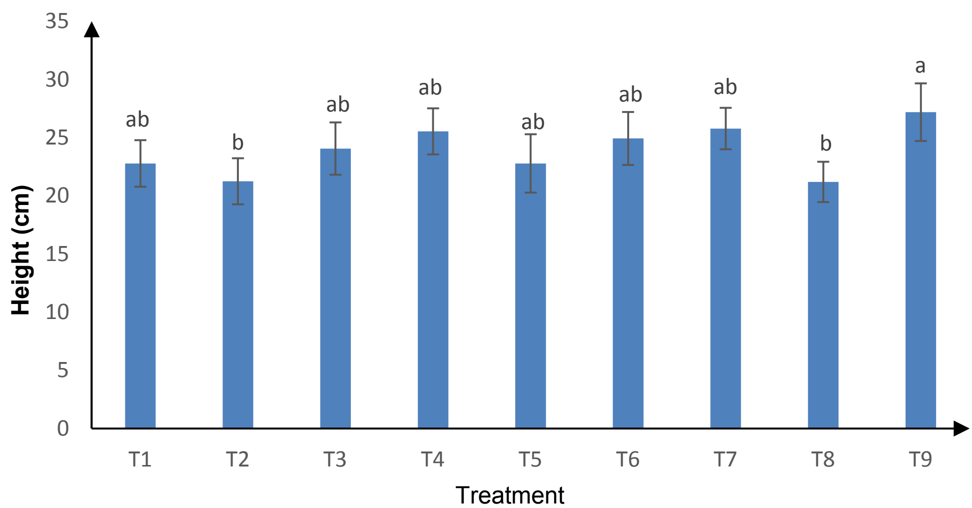

Figure 2 – Effect of *Leucaena leucocephala* leafy biomass, NPK (15:15:15) fertiliser, and their combination on okra plant height (cm)

The main effect of NPK was significant (F (1, 2) = 621.9, p = 0.000).

The main effect of *L. leucocephala* leafy biomass was also significant (F (1, 2) = 595.6, p = 0.000).

Interaction

The interaction of NPK and *L. leucocephala* leafy biomass with plant height was significant (F (1, 5) = 1520.820, p = 0.000) (*Table 2*).

Stem diameter (mm) of okra on a weekly basis from 5 to 10 WAP

Similar to plant height, the stem diameter was affected by *L. leucocephala* leafy biomass and NPK from 5 to 10 WAP. There were no significant differences between the treatment means, with p-values ranging from 0.3729 to 0.4995 (*Table 3*).

The mean stem diameter showed different responses to the treatments at the end of the experiment (*Figure 3*). The okra stem diameter followed the same pattern as the plant height. There was a significant difference between the treatment means throughout the experiment. T9 had the highest diameter (9.9 mm), followed by T8, T7, and T1 (8.5, 8.4, and 8.3 mm, respectively); T3, T6, and T4 (7.9, 7.9, and 7.8 mm, respectively); T2 (7.3 mm); and T5 (6.9 mm). The ANOVA at a 5% significance level showed that the treatments were significantly different (p < 0.05).

Main and interaction effects on diameter

Main effect

The main effect of NPK was significant (F (1, 2) = 702.964, p = 0.000).

The main effect of *L. leucocephala* leafy biomass was also significant (F (1, 2) = 1361.953, p = 0.000).

Interaction

The interaction of NPK and *L. leucocephala* leafy biomass on the diameter of okra was significant (F (1, 5) = 2310.658, p = 0.000) (*Table 4*).

Table 1 – Effects of different doses of *Leucaena leucocephala* leafy biomass and NPK (15:15:15), separately and in combination, on okra height (cm) from 5–10 WAP

Treatments		5 WAP (±SeM)	6 WAP (±SeM)	7 WAP (±SeM)	8 WAP (±SeM)	9 WAP (±SeM)	10 WAP (±SeM)
T1	Control	11.7±0.7^{abc}	17.5±2.5^{abc}	21.6±3.4^{a}	25.8±4.4^{a}	30.1±5.4^{a}	30.0±5.4^{a}
T2	NPK	8.6±1.0^{c}	14.3±1.9^{c}	19.1±2.5^{a}	24.7±3.1^{a}	30.4±3.9^{a}	30.4±3.9^{a}
T3	NPK	12.2±1.4^{ab}	18.1±2.1^{abc}	22.9±3.7^{a}	27.2±4.0^{a}	31.9±6.5^{a}	40.0±6.5^{a}
T4	*Leucaena*	13.8±1.2^{a}	21.1±2.4^{a}	24.8±2.9^{a}	28.6±3.8^{a}	32.5±4.9^{a}	32.5±4.9^{a}
T5	*Leucaena*	11.4±1.8^{abc}	15.1±2.5^{bc}	20.5±4.1^{a}	26.1±5.7^{a}	31.7±7.4^{a}	31.7±7.4^{a}
T6	Combinations	11.5±1.6^{abc}	19.8±1.7^{abc}	23.9±3.6^{a}	28.4±5.0^{a}	33.0±6.3^{a}	32.9±6.3^{a}
T7	Combinations	11.5±0.9^{abc}	20.3±1.5^{ab}	25.7±1.7^{a}	29.7±1.7^{a}	33.7±2.5^{a}	33.7±2.5^{a}
T8	Combinations	9.2±1.2^{bc}	16.1±1.8^{abc}	20.2±2.2^{a}	24.3±2.8^{a}	28.6±3.5^{a}	28.6±3.5^{a}
T9	Combinations	9.9±0.3^{bc}	18.7±1.1^{abc}	25.2±2.1^{a}	31.9±3.4^{a}	38.7±4.8^{a}	38.6±4.8^{a}
P-Value		0.1265	0.2452	0.7434	0.9239	0.9598	0.9598
LSD		3.48	5.80	8.76	11.78	15.21	15.19
CV		21.55	22.32	26.65	29.62	32.58	32.45

Means followed by the same letter (s) are not significantly different at (p ≤ 0.05%) using the least significant difference (LSD); SeM = Standard Error of the Mean; LSD = Least Significant Differences; CV = Coefficient of Variation; WAP = Weeks After Planting

Table 2 – Means of different levels of *Leucaena* biomass and NPK (15:15:15) fertiliser

Combination	0 kg	0.5 kg *Leucaena* biomass	0.25 kg *Leucaena* biomass
0 kg	22.8	25.5	22.8
0.14 kg NPK	21.2	24.9	21.2
0.07 kg NPK	24.1	27.2	25.8

Table 3 – Effect of *Leucaena leucocephala* leafy biomass and NPK on stem diameter (mm) of the okra from 5 to 10 WAP

Treatments		5 WAP (±SeM)	6 WAP (±SeM)	7 WAP (±SeM)	8 WAP (±SeM)	9 WAP (±SeM)	10 WAP (±SeM)
T1	Control	5.7±0.4[ab]	6.8±0.9[ab]	7.7±1.2[ab]	8.8±1.4[ab]	10.5±1.8[ab]	10.6±1.8[ab]
T2	NPK	4.6±0.5[b]	5.5±0.6[b]	6.7±1.1[b]	8.0±1.5[b]	9.4±1.9[ab]	9.4±1.9[ab]
T3	NPK	5.0±0.6[ab]	6.8±0.6[ab]	7.7±1.0[ab]	8.6±0.5[ab]	9.8±1.0[ab]	9.8±1.0[ab]
T4	*Leucaena*	5.8±0.2[ab]	6.8±0.4[ab]	7.4±0.4[ab]	8.3±0.6[ab]	9.3±1.0[ab]	9.3±1.0[ab]
T5	*Leucaena*	4.8±0.9[ab]	5.7±0.9[b]	6.4±1.2[b]	7.4±1.2[b]	8.5±1.1[b]	8.6±1.1[ab]
T6	Combinations	6.1±0.4[a]	6.6±0.4[ab]	7.5±1.0[ab]	8.2±0.8[ab]	9.5±1.0[ab]	9.4±1.0[ab]
T7	Combinations	5.6±0.2[ab]	7.2±0.1[ab]	8.1±0.3[ab]	9.1±0.6[ab]	10.2±1.0[ab]	10.0±1.0[ab]
T8	Combinations	5.3±0.4[ab]	6.7±0.9[ab]	8.0±1.0[ab]	9.3±0.8[ab]	10.7±1.0[ab]	10.7±1.0[ab]
T9	Combinations	6.0±0.3[a]	7.8±0.3[a]	9.3±1.0[a]	10.9±1.0[a]	12.6±1.3[a]	12.6±1.3[a]
P-Value		0.2770	0.3729	0.4268	0.4227	0.4985	0.4995
LSD		1.39	1.87	2.37	2.81	3.47	3.47
CV		17.67	19.42	21.38	22.19	23.77	23.76

Means followed by the same letter (s) are not significantly different at (p ≤ 0.05%) using the least significant difference (LSD); SeM = Standard Error of the Mean; CV = Coefficient of Variation; WAP = Weeks After Planting

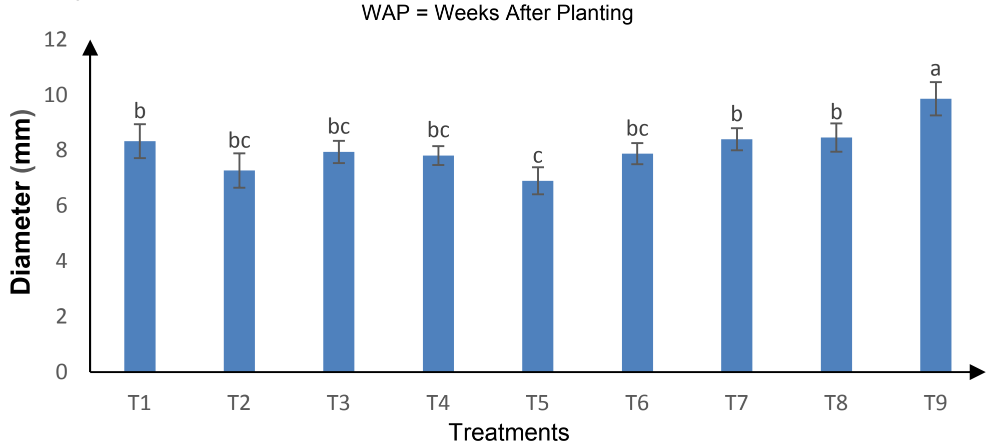

Figure 3 – Effect of *Leucaena leucocephala* leafy biomass, NPK (15:15:15) fertilizer and their combination on okra stem diameter (mm)

Number of days to first anthesis

There was a significant difference between the applied treatment means in the number of days to the first anthesis with $p < 0.05$ (*Table 5*).

Main and interaction effects on the number of days to the first anthesis

Main effect

The main effect of NPK was significant (F (1, 2) = 17723.077, p = 0.000).

The main effect of *L. leucocephala* leafy biomass was also significant (F (1, 2) = 6171.429, p = 0.000).

Interaction

The interaction of NPK and *L. leucocephala* leafy biomass on the number of days to first anthesis of okra was significant (F (1, 5) = 22887.417, p = 0.000) (*Table 6*).

The mean values of okra fruit yield during the period of experimentation indicated that the treatments were significantly different ($p < 0.05$). T4 had the highest number of fruits per hectare (39,259 fruits/ha), followed by T7 (33,704 fruits/ha), T6 (26,667 fruits/ha), T2 (25,556 fruits/ha), T5 (24,444 fruits/ha), T3 (24,444 fruits/ha), T1 (24,074 fruits/ha), T9 (24,074 fruits/ha), and T8 (19,259 fruits/ha). There was no significant difference between the treatment regimes of T1, T2, T3, T5, T6, T7, and T9, but they differed significantly from T8, which was also different from T4 (*Figure 4*).

Main and interaction effects on fruit yield

Main effect

The main effect of NPK was significant (F (1, 2) = 224.976, p = 0.000).

The main effect of *L. leucocephala* leafy biomass was also significant (F (1, 2) = 275.455, p = 0.000).

Interaction

The interaction of NPK and *L. leucocephala* leafy biomass with the fruit yield of okra was significant (F (1, 5) = 594.684, p = 0.000) (*Table 7*).

The highest dry weight of fruit at the end of the growth cycle was recorded in T7 (12.5 tonnes/ha), followed by T6 (11.8 tonnes/ha), T4 (10.6 tonnes/ha), T1 (8.6 tonnes/ha), T3 (8.1 tonnes/ha), T8 (7.8 tonnes/ha), and T2 and T5 (7.1 and 6.7 tonnes/ha, respectively). The lowest dry weight was recorded in T9 (5.3 tonnes/ha). An ANOVA at a significance level of 5% indicated significant differences between the treatments ($p < 0.05$).

There was no significant difference between treatment groups T1, T2, T3, and T8, but they differed from treatment groups T6 and T7, which were not significantly different from each other. These groups were significantly different from T4, T5, and T9, which were also significantly different from each other (*Figure 5*).

Main and interaction effects on fruit dry weight

Fruit dry weight

Main effect

The main effect of NPK was not significant (F (1, 2) = 7569.000, p = 0.319).

Table 4 – Mean stem diameter of okra (mm) at different levels of *Leucaena* biomass and NPK (15:15:15) fertiliser

Combination	0 kg	0.5 kg Leucaena biomass	0.25 kg Leucaena biomass
0 kg	8.3	7.8	6.9
0.14 kg NPK	7.3	7.9	8.5
0.07 kg NPK	7.9	9.9	8.4

Table 5 – Effect of *Leucaena leucocephala* leafy biomass and NPK on the number of days to first anthesis of okra

Treatments	T1	T2	T3	T4	T5	T6	T7	T8	T9
Days to 1st anthesis (±SeM)	48.0± 0.4^{ab}	48.5± 0.6^{a}	47.0± 0.4^{b}	48.0± 0.4^{ab}	48.5± 0.6^{a}	48.0± 0.0^{ab}	49.0± 0.0^{a}	49.0± 0.4^{a}	49.3± 0.5a
P-value	0.0339								
LSD	1.27								
CV	1.81								

Means followed by the same letter (s) are not significantly different at ($p \leq 0.05\%$) using the least significant difference (LSD); SeM = Standard Error of the Mean; CV = Coefficient of Variation

Table 6 – Means of fruit yield of okra/ha at different levels of *Leucaena* biomass and NPK (15:15:15) fertiliser

Combination	0 kg	0.5 kg *Leucaena* biomass	0.25 kg *Leucaena* biomass
0 kg	48	48	48.5
0.14 kg NPK	45	48	49
0.07 kg NPK	47.3	49.3	49

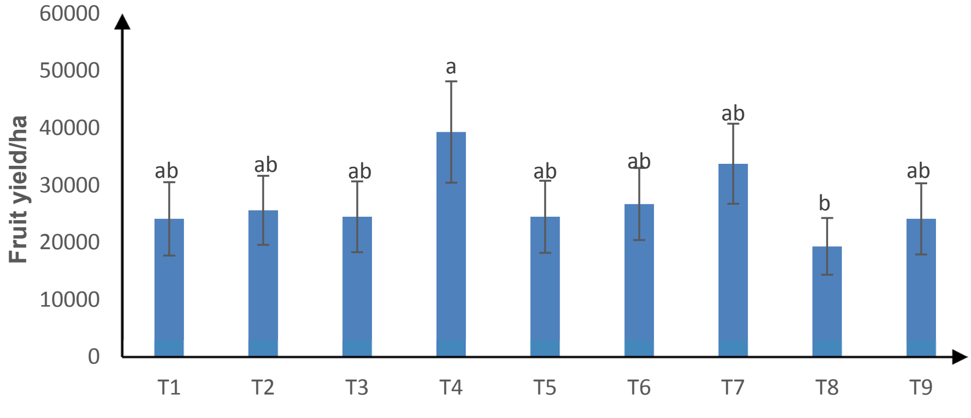

Figure 4 – Effect of *Leucaena leucocephala* leafy biomass, NPK (15:15:15) fertiliser and their combination on the number of okra fruits (yield/ha) at harvest

Table 7 – Mean dry weight (tonnes/ha) of okra at different levels of *Leucaena* biomass and NPK (15:15:15) fertiliser

Combination	0 kg	0.5 kg Leucaena biomass	0.25 kg Leucaena biomass
0 kg	24,074	39,259	24,444
0.14 kg NPK	25,556	26,667	19,259
0.07 kg NPK	24,444	24,074	33,704

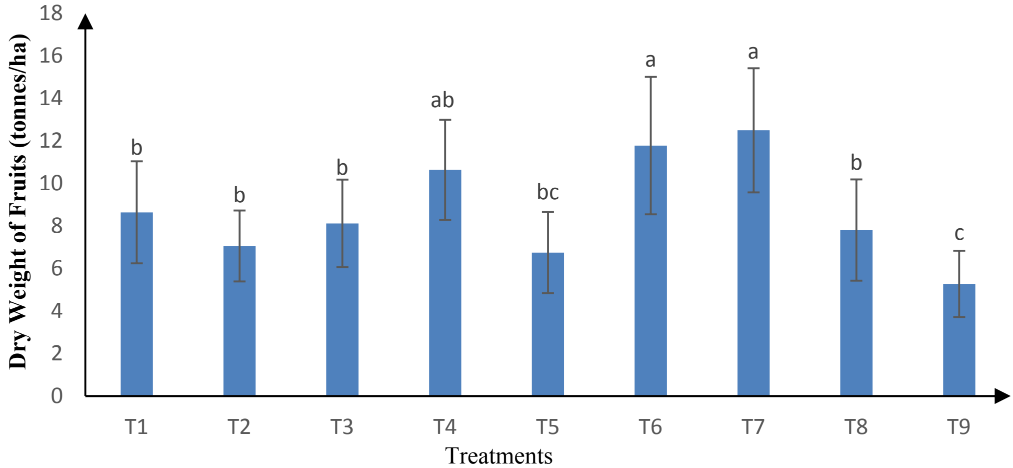

Figure 5 – Effect of *Leucaena leucocephala* leafy biomass, NPK (15:15:15) fertilizer and their combination on the dry weight (tonnes/ha) of okra plants

The main effect of *L. leucocephala* leafy biomass was significant (F (1, 2) = 463.408, p = 0.000).

Interaction

The interaction of NPK and *L. leucocephala* leafy biomass on the fruit dry weight of okra was significant (F (1, 5) = 2183.365, p = 0.000).

Interpretation of main and interactive effects

Main effects of NPK and *L. leucocephala* leafy biomass on growth and yield parameters

The main effects of the different levels of NPK showed a significant effect on the height, diameter, and fruit yield of okra, except for dry fruit weight. The level of NPK at 0.07 kg significantly improved the growth parameters better than the other levels of NPK. In contrast, the level of NPK at 0 k improved the fruit yield of okra, with significantly higher levels than others that were not significant for dry fruit weight of okra (*Table 9* and *Table 10*).

The main effects of the different levels of *L. leucocephala* leafy biomass had a significant effect on the height, diameter, fruit yield, and dry fruit weight of okra. The level of *L. leucocephala* leafy biomass at 0.5 kg had a significant effect on the height, diameter, fruit yield, and dry fruit weight of okra. However, 0.25 kg *L. leucocephala* leafy biomass significantly improved the diameter of the okra. This means that either the sole application of NPK or *L. leucocephala* leafy biomass could provide adequate amounts of nutrients required for the growth and yield of okra (*Table 9* and *Table 10*).

Interaction of NPK and *L. leucocephala* leafy biomass with growth and yield parameters

The interaction between the two dependent variables on the growth and yield of okra was statistically significant ($p < 0.05$).

Height (cm)

The highest response in okra plant height occurred at 0.07 kg NPK + 0.5 kg

L. leucocephala biomass and 0.07 kg NPK + 0.25 kg *L. leucocephala* leafy biomass, and the lowest response was recorded at 0.14 kg NPK + 0.25 kg *L. leucocephala* leafy biomass (*Table 9*).

Diameter (mm)

The highest diameter occurred at 0.07 kg NPK + 0.25 kg *L. leucocephala* leafy biomass, and the lowest diameter resulted from 0 kg NPK + 0 kg *L. leucocephala* leafy biomass (*Table 9*).

Number of days to First Anthesis

The longest period to the first anthesis was observed at levels of 0.07 kg NPK + 0.25 kg *L. leucocephala* leafy biomass, and the shortest period was recorded at 0.14 kg NPK + 0.25 kg *L. leucocephala* leafy biomass (*Table 9*).

Fruit yield/ha

The highest fruit yield was observed at 0.07 kg NPK + 0.5 kg *L. leucocephala* leafy biomass, and the lowest was observed at 0.14 kg NPK + 0.25 kg *L. leucocephala* leafy biomass (*Table 10*).

Dry fruit weight (tonnes/ha)

The greatest dry fruit weight occurred at levels of 0.07 kg NPK + 0.5 kg *L. leucocephala* leafy biomass and 0.07 kg NPK + 0.25 kg *L. leucocephala* leafy biomass, and the lowest interaction was recorded at 0.07 kg NPK + 0 kg *L. leucocephala* leafy biomass (*Table 10*).

Table 8 – Mean fruit dry weight of okra at different levels of *Leucaena* biomass and NPK (15:15:15) fertiliser

Combination	0 kg	0.5 kg Leucaena biomass	0.25 kg Leucaena biomass
0 kg	8.6	10.6	6.7
0.14 kg NPK	7.1	11.8	7.8
0.07 kg NPK	8.1	5.3	12.5

Table 9 – Height, diameter, and number of days to the first flowering of okra in response to different rates of NPK (15:15:15) fertiliser and *Leucaena leucocephala* leafy biomass application

Treatments	Height (cm)	Diameter (mm)	Number of days to the first anthesis
NPK (kg)			
0	23.7±0.06^{b}	7.7±0.06^{b}	48.2±0.12^{a}
0.14	22.4±0.06^{c}	7.9±0.12^{b}	47.3±0.12^{b}
0.07	25.7±0.48^{a}	8.7±0.06^{a}	48.5±0.12^{a}
Significance			
Level	0.000	0.000	0.000
***Leucaena* biomass (kg)**			
0	22.7±0.06^{c}	7.8±0.06^{b}	46.8±0.06^{c}
0.5	25.9±0.03^{a}	8.5±0.06^{a}	48.4±0.06^{b}
0.25	23.3±0.12^{b}	7.9±0.06^{b}	48.8±0.06^{a}
Significance			
Level	0.000	0.000	0.000
Interaction			
NPK × *Leucaena*	0.000	0.000	0.000

Means followed by the same letter (s) are not significantly different at ($p \leq 0.05\%$) using the least significant difference (LSD)

Table 10 – Fruit yield/ha and dry fruit weight (tonnes/ha) of okra in response to the different rates of NPK fertiliser and *Leucaena leucocephala* leafy biomass application

Treatments	Fruit yield/ha	Dry fruit yield (tonnes/ha)
NPK (kg)		
0	29,259±0.33[a]	8.6±0.12[a]
0.14	23,827±1.15[b]	8.9±0.12[a]
0.07	24,407±0.58[a]	8.6±0.17[a]
Significance		
Level	0	0.319
***Leucaena* biomass (kg)**		
0	24,691±0.58[c]	7.9±0.03[b]
0.5	30,000±0.00[a]	9.2±0.12[a]
0.25	25,802±1.15[b]	9.0±0.00[a]
Significance		
Level	0	0
Interaction		
NPK × *Leucaena*	0	0

Means followed by the same letter (s) are not significantly different at (P≤ 0.05%) using the least significant difference (LSD)

This demonstrates that the effects of NPK and *L. leucocephala* leafy biomass were great enough to enhance the growth and yield performance of okra.

DISCUSSION

Growth parameters (height and diameter) of okra on a weekly basis from 5 to 10 WAP

The results from the experiment (*Table 1* and *Table 3*) suggest that soils amended with only *L. leucocephala* leafy biomass or NPK or their combination applied at the rate of 75 kg N/ha showed no effect on okra growth parameters from 5 to 10 WAP. This might be attributed to the fact that most essential nutrient elements, such as N, P, K, Ca, and Mg, released from the applied fertilisers were absorbed and used up by the okra plants at the initial phase, and the residual nutrients were not sufficient for subsequent crop growth support. These nutrient elements are important for plant growth and play a crucial role in soil fertility improvement and crop yields (Ahmad *et al.*, 2020; Iqbal *et al.*, 2021; Kumar *et al.*, 2020). Adequate levels of these nutrients in the soil can increase plant growth, yield, and quality (Zilio *et al.*, 2023). This agrees with Janzen *et al.* (1990), Janzen *et al.* (2019), Hao *et al.* (2020), and Akkal-Corfini *et al.* (2021), who reported that the contribution of nitrogen from fertilisers applied to crops was 1–4% of the nitrogen content of the applied fertilisers. Additionally, although soil analysis was not done, the soil at the study site was acidic and poor in nutrients, which significantly affected crop growth (Minden *et al.*, 2021; Rengasamy, 2010; Rahman *et al.*, 2018).

Mean height (cm) of okra

Soil amended with *L. leucocephala* leafy biomass and NPK (15:15:15) fertiliser applied separately and in combinations at a rate of 75 kg N/ha had a significant effect on okra plant height. The significant rise in okra plant height when amended with fertiliser regimes of T6, T7, T8, and T9 might have resulted in the efficient use of NPK with *Leucaena* leafy biomass, which prevents their nutrients from run-off and leaching in places of application and releases them into the soils of okra plants, as evidenced by faster growth. This finding is congruous with previous research conducted by Young (1997) and Senarathne and Udumann (2021), in which an increase in the growth and yield of maize responded to *Leucaena* leafy mulch, but the results were more effective when combined with mineral fertiliser. Furthermore, the height of okra differed significantly between the *L. leucocephala* leafy biomass amended plots and the NPK-fertilised plots. This could explain how *Leucaena* leafy biomass improves the soil's organic matter, humus, and nutrient conditions. Higher organic matter in the soil might have contributed to enhancing soil particles, thereby preventing them from leaching and erosion, which made nutrients available for use by okra plants for growth and development. This agrees with Zhang *et al.* (2019) and Lal (2020), who reported the positive impacts of soil organic matter on other properties, such as soil aggregation, water, and nutrient holding capacity of soils. The study also agrees with Akinmutimi *et al.* (2021), who observed an increase in the height of okra in organic manure-amended plots. In contrast, the decrease in okra height under NPK-amended plots could be extensively attributed to nutrient decline and unavailability due to losses, such as erosion/run-off, leaching, and volatilisation (Lan *et al.*, 2022). This made nitrogen and other essential nutrients, such as P and K, which are required for plant growth, unavailable for okra plants. This finding agrees with Adekiya *et al.* (2020) and Okee (2020), who reported the depletion of nutrients and the reduction of okra yields in NPK-amended plots. Additionally, *L. leucocephala* leafy biomass resulted in a significant increase in soil nutrients, such as organic matter, nitrogen, phosphorus, and potassium, compared to NPK fertiliser. This was because the NPK fertiliser in the treated plots might have been lost through leaching and erosion. However, the decrease in calcium and magnesium in NPK fertiliser-treated plots compared to those amended with *L. leucocephala* leafy biomass could be due to the absence of calcium and magnesium in NPK fertiliser, as reported by Adekiya *et al.* (2020).

Mean stem diameter (mm) of okra

Both fertiliser-amended plots had larger okra diameters than the control plots. This might have made the contribution of nutrients by *Leucaena* leafy biomass and NPK fertiliser possible, improving soil fertility better than in those plots not amended. This indicates that both organic and inorganic fertilisers have the potential to enrich the nutrients and fertility status of soil, which is vital to ensuring better crop productivity. This result is in concordance with previous research by Shirin *et al.* (2019) and Mishra *et al.* (2020), who reported significant differences in the growth parameters of okra treated with organic and inorganic fertilisers. However, the findings of this study contradict those of Okee (2020), who did not find a significant difference in okra stem diameter in organic and inorganic fertiliser-amended plots. Greater diameters were recorded in okra stems after T9 application, which could be attributed to the integrated application of *Leucaena* leafy biomass and NPK, which might have contributed to the effectiveness and efficiency of nitrogen use by the okra plants for optimal growth and development. This agrees with previous research by Adeoye *et al.* (2008), Makinde *et al*. (2010), Oke *et al.* (2012) and Olowoake *et al.* (2015), who reported that the advantageous mineralisation of nutrients in organomineral fertiliser because of the effect of inorganic constituents on organic constituents could potentially result in an upsurge in plant growth parameters.

Number of days to the first anthesis of okra

The results regarding the first anthesis were significant in the various treatments during the growth period of the plant. This could have occurred because P, which is an important element for flowering due to the amounts released into the soil by the applied fertilisers, was sufficient to significantly enhance flowering in the respective treatments. This agrees with findings by Akande *et al.* (2010), Singh *et al.* (2020), and Ahirwar *et al.* (2021), who stated that P and K fertilisers have the potential to improve earlier flower initiation. Differences in flowering periods among okra plants did not greatly occur in the current study, which implies that the maturity periods of okra in the various fertiliser regimes did not vary since okra plants are of the same cultivar. This is in line with previous studies by Eshiet and Brisibe (2015), who indicated that the maturity levels of okra varied among cultivars since the number of days to first anthesis in four varieties of okra varied considerably between varieties but not within the same variety.

Yield and Yield Components of Okra Fruit Yield/ha

The significant difference in the fruit yield of okra between the applied soil amendments, particularly the maximum yield of okra fruit recorded in T4, could be attributed to the sole application of *Leucaena* leafy biomass. The application of *Leucaena* leafy biomass as an organic manure played an important role in improving the soil organic matter content and, through decomposition and mineralisation, made nutrients available for use by the okra plants, thereby increasing pod yields. Several studies have investigated the effects of *L. leucocephala* leafy biomass on crop yield, with many finding positive results. Kumar *et al.* (2013) found that the application of *L. leucocephala* leafy biomass to maize resulted in a significantly higher yield compared to control treatments. Similarly, Ijoyah *et al.* (2019) found that the application of *L. leucocephala* leafy biomass to cassava resulted in a significantly higher yield compared to control treatments. Partey and Thevathasan (2013) and Kugedera (2022) found that using leafy biomass of leguminous agroforestry tree species, such as *L. leucocephala*, as a source of plant nutrients increased crop yields comparable to, and in some cases greater than, the effect of sole inorganic fertiliser application on soil fertility, crop growth, and yield. This study disagrees with the results observed by Agyemang *et al.* (2012), who reported higher grain yields of maize under combinations of *Gliricidia* mulch and inorganic fertiliser, *Senna siamea* leafy biomass and inorganic fertiliser, and *L. leucocephala* biomass and an inorganic source of nitrogen. In contrast, the yield reduction due to the sole application of NPK (T2 and T3) and the control might be attributed to volatilisation, erosion, and leaching of nutrients from the soil and the unavailability of essential nutrients in the control (T1) with significant influence on fruiting in okra. This agrees with Okee (2020) and Akinmutimi *et al.* (2021), who attributed lower pod yields in okra to the control and inorganic fertiliser-amended plots due to inadequate and unavailability of sufficient amounts of nutrients, as okra plants could only depend on the inherent fertility of the soil. The use of NPK fertiliser has been shown to have mixed effects on crop yield. Some studies have found that NPK fertilisers can increase crop yield (Singh *et al.*, 2018), while others have found no significant effect or negative effects on yield (Imtiaz *et al.*, 2019).

Dry weight (tonnes/ha) of okra pods

The significant increase in dry okra pod weight indicated the possibility that the combined application of *Leucaena* leafy biomass with NPK fertiliser (T6 and T7) might have provided adequate amounts of both major and minor nutrient elements in the soil. The presence of these nutrients contributed to improving the physicochemical properties of the soil during the period of growth and development of the okra plants. This agrees with Gayathri and Thayamini (2020), who recorded an increase in the growth and yield characteristics of okra due to an adequate amount and release of micro- and macronutrient elements from the integrated use of organic and inorganic fertilisers. Similar results were observed in sorghum by Kugedera *et al.* (2020) and Agyemang *et al.* (2012), who stated that the higher cob weight of maize in the combination of *G. sepium* mulch and inorganic fertiliser, the combination of *S. siamea* leafy biomass and inorganic fertiliser, and the combination of *L. leucocephala* leafy biomass and an inorganic source of N resulted in a higher cob weight than the sole applications and the control. Njukwe *et al.* (2021) found that the combination of *L. leucocephala* leafy biomass and NPK fertiliser resulted in a higher maize yield compared to control treatments but did not result in a significantly higher yield compared to the use of *L. leucocephala* leafy biomass alone. In contrast, our findings contradict the previous study by Okee (2020), who observed the maximum weight of okra observed in NPK-fertilised plots.

CONCLUSIONS

The research was carried out to assess the potential of leafy biomass from agroforestry tree species, such as *L. leucocephala*, and NPK (15:15:15) fertiliser for okra production in the tropics. The results demonstrated that the use of Leucaena leafy biomass and NPK (15:15:15) as soil amendments positively affected okra growth and yield performance but to varying degrees.

Growth parameters (height, diameter, and number of days to first anthesis)

T9 (T9 = T3 + T4) significantly improved okra plant height and stem diameter compared to the other treatments. The number of days to first anthesis was significantly reduced by T2, T5, T7, T8, and T9.

Yield parameters (fruit yield and dry fruit weight)

Fruit yield/ha

The highest okra fruit yield (39,259 fruits/ha) was recorded in T4 (0.5 kg *L. leucocephala* leafy biomass per plot), while the lowest yield (19,259 fruits/ha) was recorded in T8 (T2 + T5).

Dry fruit weight (tonnes/ha)

The highest dry weight of okra (12.5 tonnes/ha) was registered in T7 (T3 + T5), while the lowest dry weight (5.3 tonnes/ha) was recorded in T9 (T3 + T4).

Recommendations

To tackle the deleterious effects associated with the sole application of inorganic fertiliser, including NPK (15:15:15), in the long term, the use of leafy biomass from agroforestry tree species, such as *L. leucocephala*, in T4 could be adopted by smallholder farmers in the tropics. Moreover, the use of *L. leucocephala* leafy biomass and its integration with NPK (15:15:15) in T9 can be adopted by poor-resourced farmers as a substitute for the sole use of NPK fertiliser for okra and other crop production in sub-Saharan Africa. Further investigations with other levels of Leucaena mulch and NPK should also be carried out to determine the optimum rate for optimum growth and yield of okra in the tropics. In addition, further studies can be done on the soil chemical profile of each treatment at the start and end of the experiment to assess the contribution of treatments to soil fertility.

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