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AGRONOMIC PERFORMANCE OF MAIZE (*Zea mays* L.) FERTILIZED WITH SIAM WEED (*Chromolaena odorata* L.) LEAF RESIDUES IN RAINFOREST ZONE OF NIGERIA

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ABSTRACT

Maize (Zea mays L.) is a staple crop in Nigeria, yet yields remain low due to declining soil fertility and dependence on inorganic fertilizers that are costly and environmentally unsustainable. This study investigated the use of Siam weed (Chromolaena odorata L) residues as an organic amendment under rainforest agro-ecological conditions in Benin City, Nigeria. Field trials were conducted at the Teaching and Research Farm, University of Benin, Benin City, across two seasons with leaf residues rates of 0, 10, 30, and 50 kg ha^{-1}. Experimental design was Randomised Complete Block with four replications. Soil properties, plant growth, phenological traits, and yield components were measured. Results showed that Chromolaena leaf residues significantly improved soil nutrient status, reduced acidity, enhanced nitrogen uptake, and improved maize growth and yield. Application rates of 30 and 50 kg m^{-2} increased plant height (155.9 and 160.3 cm, respectively), shortened anthesis-silking intervals (2.4, 1.5 days) and enhanced nitrogen uptake (3.37, 4.35 g plant^{-1}). These application rates also boosted grain yield (3.0, 3.8 t ha^{-1}) by up to 192 and 268% compared to control plots and enhanced stover yield (2.7, 3.3 t ha^{-1}), offering added value for livestock feeding. Grain yield showed strong negative and positive correlations with phenological traits and growth/yield attributes, respectively. Findings highlight Chromolaena leaf residues as a cost-effective, eco-friendly organic fertilizers, capable of improving maize productivity and supporting sustainable crop-livestock systems in Nigeria.

Key words: maize yield, *Chromolaena odorata*, organic fertilizer, soil fertility, rainforest

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop in sub-Saharan Africa (SSA) and the third most important cereal crop in the world after wheat and rice (Erenstein *et al.*, 2022). Its production stands at 1.24 billion metric tonnes globally, 85 metric tonnes in Africa and 11.05 metric tonnes in Nigeria in the year 2023 (FAO, 2025). Globally, the average maize yield is approximately 5.1-5.7 t ha^{-1}, reflecting the widespread adoption of improved hybrids, mechanisation, and high input use in major producing countries (FAO, 2023; OECD/FAO, 2025). In contrast, the average maize yield in sub-Saharan Africa is about 2 t ha^{-1}, largely due to limited access to improved seeds, fertilizers, irrigation, and modern agronomic practices. Nigeria, despite being one of the largest maize producers in Africa, records national average yields ranging between 1.6 and 2.1 t ha^{-1}, which is far below the global average (IITA, 2022; FAO, 2023). This substantial yield gap highlights the persistent constraints affecting maize production in Nigeria, such as declining soil fertility, erratic rainfall, pest and disease pressure, and limited adoption of improved production technologies. Addressing these constraints is essential to improve maize productivity and enhance food security in the country.

Maize plant requires high amounts of nutrients for its proper growth and development (Amissah *et al.*, 2023). Among the various nutrients required, nitrogen (N) is the most critical because it promotes proper growth, development and high yield of the crop. Nitrogen is also imperative for chlorophyll synthesis, protein production, and proper grain development (Sharma *et al.*, 2019). Although the use of chemical fertilizers has been proven to be convenient and impactful on maize yields, the resulting adverse effects, such as rapid N decline in soils, low N recovery efficiency and reduced grain quality, are impediments to improved food and nutrition security (Kakar *et al*., 2020, Udvardi *et al.*, 2021). Furthermore, these chemical fertilizers are expensive in SSA, a reason for its low utilisation of well below the 50 kg ha^{-1} target set by the African Fertilizer Summit of 2006 (Njoroge *et al.*, 2018). Even though chemical fertilizers can help achieve high yields, these have been found to be environmentally unfriendly in the long run and detrimental to soil health (Pahalvi *et al*., 2021; Krasilnikov, 2022). Concomitantly, organic fertilizer resources, such as plant residues, have the potential to mitigate these issues. These fertilizers are cheaper and also capable of improving the soil physical and chemical properties, causing optimal nutrient availability and

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high yield of maize (Iqbal *et al*., 2020). Organic mulch materials abound in many communities in the rainforest zone of Nigeria which can serve as organic amendment. These include tree leaves, grasses, and crop residues. For example, *Azadiracta indica* (neem) is widely distributed across agroecological zones in Nigeria and provides readily available mulch material that can suppress weed growth and enhance soil fertility through gradual nutrient release (Alamu *et al*., 2011; Onunwa *et al*., 2025). *Moringa oleifera* leaves are also valued for their rapid decomposition and high nutrient content, improving crop performance and reducing weed pressure (Fadeyi *et al*., 2023; Adeleye and Nwangburuka, 2025). Among others, *Terminalia catappa*, *Mangifera indica* and *Gliciridia sepium* also provide leaf litter suitable as mulch to enhance soil organic matter and cycle nutrients (Okoh and Edu, 2019).

Furthermore, for fallow species, Siam weed (*Chromolaena odorata* L.) appears to improve nutrient levels in the soil, enhancing its physical and chemical properties (Aboyeji, 2019). *Chromolaena odorata* is an excellent fallow species and soil fertility indicator, having high biomass production, fast decomposition rate and high N content (Agustina *et al.*, 2019). *Chromolaena odorata* if used as an organic amendment, possesses the capacity to increase the nutrient level of the soil, as do inorganic fertilizers; thus, furnishing maize crops with essential nutrients needed, consequently leading to an increase in crop yield (Kone *et al*, 2012). The leaves and tender stems decompose rapidly when applied as mulch because of low lignin content and moderate C:N ratio with slow nutrient release. Its fast growth rate can be harnessed for green manure. For example, some workers (Ojeniyi *et al*., 2012; Agbede and Afolabi, 2014) in south-western Nigeria have shown that Chromolaena leaves can substantially improve soil OM and nutrient availability when used as green manure or surface mulch. When used as a soil amendment, it increased soil pH, enhanced cation exchange capacity and boosted microbial activity that contributed to better root development and nutrient uptake (Adekiya *et al*., 2020). For maize grown with Chromolaena leaf residues, yield improvements have been linked to enhanced N release from decomposing Chromolaena residues (Agbede and Afolabi, 2014). Chromolaena is also reported to be rich in N (2.0-3.5%), P (0.2-0.5%), K (1.0-2.5%), Ca (1.0-2.0%) and Mg (0.3-0.8%), making it comparable to most leguminous green manures in nutrient supply (Ojeniyi *et al*., 2012; Agbede and Afolabi, 2014;). Therefore, the plant can be considered as a viable organic component of integrated soil fertility management systems. Although well distributed across agroecological zones of Nigeria and occurs as an abundant fallow plant, these desirable attributes have however, not been exhaustively researched in the rainforest agro-ecological conditions in south-south Nigeria. The objective of this study was to evaluate the potential of *Chromolaena odorata* residues as an organic amendment when applied on the soil surface for maize production in the Rainforest zone of Nigeria.

MATERIALS AND METHODS

Experimental Site

The field experiment was carried out in two seasons, early (April-July) and late (August-November), 2024, at the Faculty of Agriculture Training and Research Farm, University of Benin, Benin City, in Nigeria. Benin City is situated in the tropical rainforest of Nigeria at 06° 20′ N and 5° 37′ E, at an altitude of 78 m asl. The soil at the research site is classified as Ultisols (Umweni *et al*. 2014). Rainfall is of high intensity and bimodal, beginning in March/April and ending in October/November with a short dry spell in August. Annual precipitation ranges from 1900-2050 mm in Benin City, with an average annual temperature of 26.2 °C (Okonofua *et al*., 2023). Before the establishment of the trial, the land was under fallow for about 2 years with heavy vegetation consisting mainly of Guinea grass (*Panicum maximum* Jacq). Prior to trial establishment, a composite soil sample was made from 18 cores taken across the trial field at a depth of 15 cm using precision auger for analysis of routine soil physical and chemical properties. At harvest of the crop, soil samples were again taken for each treatment over replications and bulked. A composite sample was taken for each treatment, labelled as appropriate. All soil samples were taken to the International Institute of Tropical Agriculture (IITA) analytical services laboratory, Ibadan, (ASLAB) for routine soil physical and chemical analysis. Sand, clay and silt properties of the soil were determined using the Hydrometer method of mechanical analysis (Bouyoucous, 1951). Soil pH of the experimental site was determined using H_2O method (Clark, 1922; Bates, 1954). Regular macro-Kjeldahl method was used to determine Total N (Jackson 1958). Bray No. 1 method was used to determine Available P (Bray and Kurtz, 1945; Jackson, 1958). The Flame photometer and atomic absorption spectrophotometer methods were used to determine K, Ca, Mg, Na (Jackson, 1958). Rainfall and minimum and maximum temperatures for the period of the trial are given in Figure 1.

Maize Cultivar Used

Open-pollinated maize, variety SAMMAZ 52 (matures in 110-120 days, consists of intermediate levels of pro-vitamin A content (9.8 µg g^{-1}), tolerant to maize streak virus, rust, leaf blight and curvularia leaf spot, yield potential 6 t ha^{-1} in Northern Guinea savannah) obtained from Premier Seed Company Ltd, Zaria, Nigeria was used for the study.

Treatments and Experimental Design

Treatments consisted of four rates of fresh green siam (*Chromolaena odorata*) leaf residues (0, 10, 30, 50 kg ha^{-1}). Treatments were laid out in a randomised complete block design replicated four times. Each plot measured 2.25 m × 2.0 m. The distance between plots was 0.50 m and replications 0.75 m. The Chromolaena leaves were obtained from nearby bush regrowth of the plant. The rate of a given treatment was divided into three equal fresh weights. Thus, the freshly cut *Chromolaena* leaves, accurately weighed, were applied at sowing and at 2 and 4 weeks after sowing (WAS). Moisture content of the fresh material was not determined. The Chromolaena leaf residues were applied evenly on the entire surface of each treatment plot. No other organic or inorganic fertilizers were applied to the soil apart from the Chromolaena leaf residues.

Cultural Practices

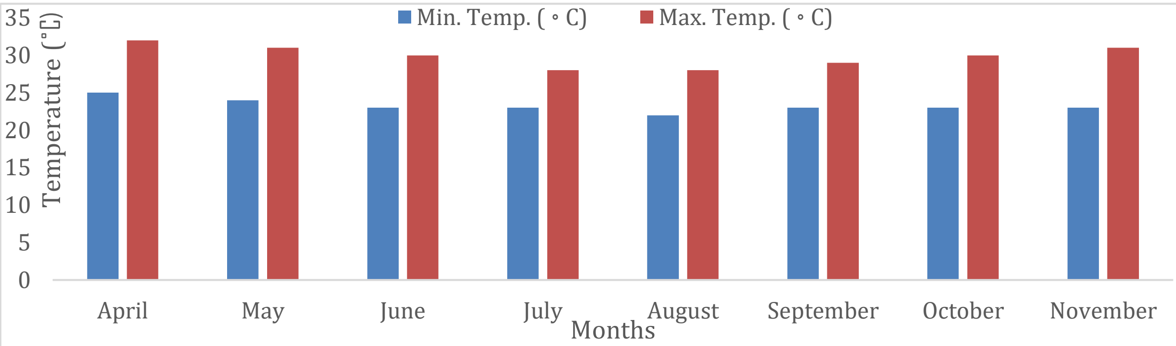
Land preparation involved manual clearing with cutlasses, followed by debris removal without burning. The soil was not tilled. Seeds were sown on the flat at the rate of two seeds per hole, 4-5 cm deep in moist soil in April (early season) and August (late season) of 2024, at a spacing of 75 cm × 25 cm. August sowing was repeated on the same site as April sowing. Seedlings were thinned to one plant per stand two weeks after sowing to achieve a plant population of 53,333 plants ha^{-1}. Hand weeding was done at 3 and 5 WAS; with limited use of hoe. A wire mesh was put around the experimental plot to discourage the infestation of Hares (*Lepus europaeus*) and Grasscutter (*Thryonomys swinderianus*). Army-worm (*Spodoptera frugiperda*) infestation was controlled with the use of organic pesticide; a solution of neem leaves and garlic after boiling in water for 15 min. and allowed to cool down, applied to the whorl of the plant weekly till when plants tasseled. Red-billed quelea (*Quela quela*) infestation was controlled by covering the cobs with transparent polythene bags to prevent feeding on the cobs.

Siam Weed (*Chromolaena odorata*) Leaf Analysis

At each time of treatment application, fresh Chromolaena leaves were harvested, labelled and taken to ASLAB for determination of total N, phosphorus and potassium contents. These primary nutrients are basic to maize growth, development and yield. Total N was determined using the Micro-Kjeldhal Method (Black, 1965; Sprince and Rowley, 1957; Jackson, 1958; AOAC International., 2023). The P and K were determined using the dry ashing method for determinations of Ca, Mg, K and P in plant tissue (AOAC International., 2023).

Measurement

Maize plant height in cm was measured from the base of the plant to where tassel branching began, on 5 consecutive plants, along the middle row (net plot), using calibrated tape at harvest. Number of days to 50% anthesis was determined when half of the number of plants in the net plot had tassels with pollen extrusions (counting from the day of sowing). Number of days to 50% silking was determined when half of the plants in the net plot had silks. Plants were determined mature when 95% of the cobs had their husk turned brown. Anthesis-silking interval (ASI) was measured as the difference between number of days to 50% silking and number of days to 50% anthesis (Equation 1). The number of ears per plant was determined by harvesting all the plants in the net plot and dividing by the number of plants in that row. Harvested cobs were airdried for two weeks, threshed and grains were weighed, computed as grain yield ha^{-1} adjusted to 15% moisture content (Equation 2). Moisture content of grains was determined by using Farmex MT-16 grain moisture tester. Also, 1000-seed weight was



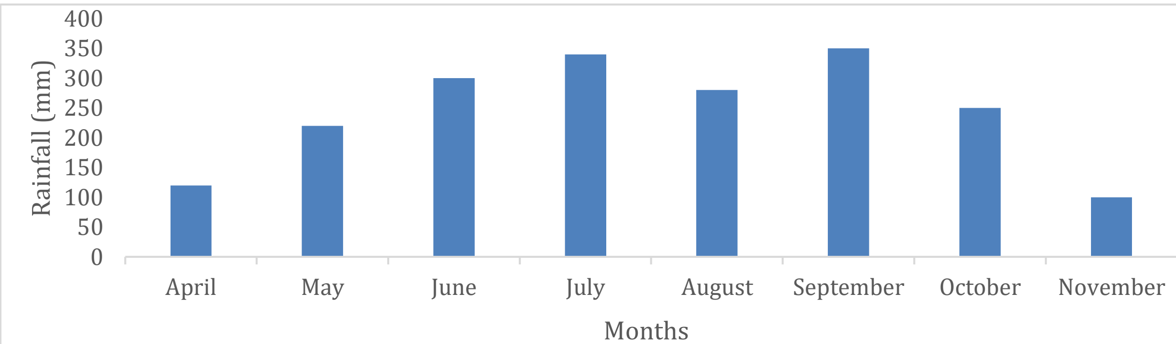


Figure 1: Rainfall and minimum and maximum temperature in during the period of the trial in Benin City

determined by counting and weighing 1000 seeds per net plot. At harvest, all the plants in the middle row that formed the net plot were cut and separated into leaves, husks and stems. They were dried to a constant weight, weighed and expressed as leaf dry matter, husk dry matter and stem dry matter per plant, respectively. The leaf, husk and stem dry matter were added to calculate stover yield ha^{-1}. To determine plant nutrient uptake, the N concentration of leaf, husk, stem and grain was determined. The weighed leaves, husks, stems and grains were expressed in g $plant^{-1}$. The dried plant samples were ground to pass through a fine mesh sieve and analysed for N concentration (%) using Kjedahl digestion method (AOAC International, 2023). Nitrogen uptake was calculated as given in Equation 3. The three equations mentioned here are as follows:

$$S - A = \text{ASI} \qquad (1);$$

where *S* is number of days from maize sowing to 50% silking, *A* is the corresponding number of days to 50% anthesis, and ASI is anthesis-silking interval.

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{net plot yield (g)}}{\text{net plot area}} \times \frac{100-\text{MC}}{85} \times 10 \qquad (2);$$

where net plot yield is grain yield from the net plot (g), net plot area is the area of the net plot from where harvesting was carried out, 100 is constant, MC is grain moisture at the time of weighing, 85 is based on the percentage moisture content allowed (e.g., 15% MC will have a residual of 85% for correction), and 10 is another constant.

$$\text{N uptake (g plant}^{-1}) = \frac{\text{N concentration (\%)}}{100} \times \text{dry matter yield (g plant}^{-1}) \qquad (3);$$

where N uptake is nitrogen accumulated in plant biomass (g $plant^{-1}$), N concentration is nitrogen content of plant tissue (%), and dry matter yield is dried biomass per plant (g $plant^{-1}$).

Because the biomass was partitioned into grain, leaf, husk and stem components, N uptake was calculated separately for each component and summed up to obtain total plant N uptake per plant:

Total N uptake = N grain + N leaf + N husk + N stem.

Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of SAS (SAS for Windows Release 9.4, SAS Institute, 2022). In the Model, replication was treated as a random effect; and Chromolaena leaf residues rate as fixed effect in determining expected mean square and appropriate F-tests in the ANOVA. Because season × leaf residues rate was not significant for most of the variables, particularly grain yield, the data for the early and late seasons were pooled. Differences between two significant treatments means were compared with Students' t-test, based on the standard error of the difference (SED) at 5% level of probability. The Pearson's correlation coefficient was used to test for relationship between grain yield and other variables using PROC CORR of SAS.

RESULTS AND DISCUSSION

The present study had focused on assessing the potential of *Chromolaena odorata* leaf residues as an organic fertilizer source for maize production through soil fertility improvement as manifest in plant growth and grain yield when applied on the soil surface. Mineral composition of the Chromolaena leaves at the different times of application is presented in Table 1. The leaves of Chromolaena had high N content (2.37%) and good levels of P (0.29%) and K (1.85%). With this nutrient profile, Chromolaena can be utilised as a valuable organic fertilizer source (Ogundare *et al*., 2015; Numas *et al*., 2023; Win, 2025).

Soil Properties Before Cropping

Mineral composition of the soil before field experimentation is shown in Table 2. The soil is classified sandy with a pH of 5.25. The soil had total N of 0.72 g kg^{-1} which is considered relatively low in N (Chude *et al*., 2012). This N level may limit the yield potential of maize. Typical N requirements for maize are around 60-150 kg N ha^{-1}, depending on the variety and target yield (Chude *et al*., 2012; Abebe and Feyisa, 2017; Golla *et al*., 2018; Golla, 2021; Bekele, 2022; Aigbe *et al*. 2023; Rawal *et al*., 2024). The soil had total organic carbon (TOC) of 13.6 g kg^{-1} which is considered to be relatively low (Chude *et al*., 2012). Low TOC can impact soil fertility, structure and water-holding capacity. Also, the soil had medium to low phosphorus (P). While the available P may be sufficient for maize production, response to phosphorus fertilizer is likely. The soil nutrient status for potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), and the hydrogen and aluminum status of the soil, suggest the soil to be acidic with low levels of essential nutrients. This may impact soil fertility and plant growth. Growing maize with *C. odorata* leaf residues without inorganic fertilizers could be an appropriate way to manage this soil.

Soil Properties After Cropping

Mineral composition of the soil after field experimentation is presented in Table 2. After the first season of growing maize, the pH of the soil reduced below its initial levels. In the second season, however, the pH of the soil improved with increasing rates of Chromolaena leaf residue application, surpassing its initial levels. At the end of the early season, total N decreased in plots with leaf residue rates of 0 and 10 kg ha^{-1} whereas total N status was maintained as the initial at Chromolaena leaf residue rate of 30 kg ha^{-1} or improved at 50 kg ha^{-1}. At the end of the late season, total N decreased further in plots that did not receive Chromolaena leaf residues. But there was a rise in total N above the initial level in plots that received Chromolaena leaf residues. Similar trend was recorded for TOC and available P. Potassium level decreased at all Chromolaena leaf residues rates in the early season. This decline continued in the late season except for

Table 1: Mineral composition of *C. odorata* leaves

% Mineral nutrient	First application	Second application	Third application	Mean
N	1.85	2.5	2.77	2.37
P	0.23	0.38	0.25	0.29
K	2.00	2.04	1.54	1.85

Chromolaena leaf residue rates of 30 and 50 kg ha^{-1} where there was a slight improvement in K level. There was a gradual increase in Ca, Mg and Na levels in the soil in proportion to the application rates of Chromolaena leaf residues, beyond their initial level over the course of the two seasons.

These findings, suggest that the applied Chromolaena leaf residues improved the soil nutrient status for the maize crop. There was a decrease in exchangeable H^+ and Al^{3+} with increasing leaf residues rate. However, the recorded decrease in exchangeable H^+ and Al^{3+} with increasing Chromolaena leaf residues coincides with the rise in pH levels. This relationship is significant because, H^+ and Al^{3+} contribute to soil acidity. Their reduction suggests a buffering effect by the Chromolaena leaf residues, counteracting the inherent acidity and creating a more conducive environment for plant growth. A higher pH generally improves the availability of nutrients like P that can become locked up in acidic soils. This explains the recorded increase in available P (AvP) with rising pH levels due to Chromolaena leaf residues over the course of the two seasons. Based on these findings, essentially, Chromolaena leaf residues appears to promote soil nutrient dynamics. As it decomposes, it neutralises acidity (lowers H^+ and Al^{3+}) and enriches the soil with organic matter (increases TOC). This, in turn, improves soil pH and the availability of essential nutrients (N, P, K) for plant uptake.

Plant Nitrogen Uptake

Results of N uptake in maize plants are summarised in Table 3. Total N uptake in maize plants was influenced by Chromolaena leaf residues application rate ($p < 0.0001$). Nitrogen uptake increased progressively from 1.78 g $plant^{-1}$ in the control to 2.46, 3.37, and 4.35 g $plant^{-1}$ at 10, 30, and 50 kg ha^{-1}, representing increases of 38.2%, 89.3%, and 144.4%, respectively, relative to the control. The increases at 10, 30 and 50 kg ha^{-1} were significant compared to the control ($p = 0.0249$, < 0.0001 and < 0.0001, respectively). At 10 kg ha^{-1}, N uptake was lower than at 30 kg ha^{-1} ($p = 0.0040$) and 50 kg ha^{-1} ($p < 0.0001$). There was also a significant difference between the 30 and 50 kg ha^{-1} rates ($p = 0.0023$).

These findings clearly show that fertilizing maize with Chromolaena leaf residues enhances N uptake in a rate-dependent manner. The progressive increase in N uptake from 1.78 at 0 kg ha^{-1} to 4.35 g $plant^{-1}$ at 50 kg ha^{-1} suggest that the residues serve as a valuable source of organic N. The increase in N uptake can be attributed to improved soil N availability resulting from the decomposition and mineralisation of Chromolaena biomass. Organic residues enhance soil fertility by supplying nutrients and stimulating microbial activity, thereby facilitating nutrient cycling and plant uptake. The results are consistent with Palm *et al*. (2001) that high-quality organic inputs promote N mineralisation and ensure synchronisation between N release and crop demand. Furthermore, mulch-mediated increases in soil moisture retention and temperature regulation likely contributed to enhanced N use efficiency by reducing volatilisation losses and leaching, as reported in conservation agriculture systems (Giller *et al*., 2009).

Considering soil fertility management, the results underscore the potential of Chromolaena residues to reduce dependence on synthetic fertilizers. The use of these residues not only improves N nutrition but also contribute to long-term soil health by enhancing organic matter content and microbial diversity. For small-scale farmers, particularly those with limited access to chemical fertilizers or where it is costly, use of such residues could be a practical strategy to boost maize productivity. Nonetheless, while the highest rate (50 kg ha^{-1}) produced the greatest N uptake, considerations of residue availability, labour requirements, and potential allelopathic effects should guide recommendations for field application.

Plant Phenology

Maize phenological development was influenced ($p < 0.0001$) by applied Chromolaena leaf residues (Table 4). At rates of 10, 30, and 50 kg ha^{-1}, number of days to anthesis was significantly higher than for control plots ($p = 0.01$). Chromolaena leaf residues rates of 30 and 50 kg ha^{-1} had similar effects on anthesis ($p = 0.9816$). Number of days to silking varied among the leaf residues rates ($p < 0.0001$). It decreased with increase in Chromolaena leaf residues rate. However, the number of days to silking was similar at Chromolaena leaf residues rates of 30 and 50 kg ha^{-1} (p=0.1659). Anthesis–silking interval (ASI) differed among the treatments ($p < 0.0001$).

Table 2: Physical and chemical properties of the experimental soil before cropping and after cropping

Leaf residues rate (kg ha^{-1})	Sand (g kg^{-1})	Silt	Clay	Soil pH	Total N (g kg^{-1})	Total OC	AvP (mg kg^{-1})	K^+ (cmol kg^{-1})	Ca^{2+}	Mg^{2+}	Na^+	H^+	Al^{3+}
Initial	885	65	50	5.25	0.72	13.6	10.5	0.16	0.58	0.18	0.08	0.38	0.2
April sowing after cropping													
0	888	58	56	5.15	0.5	6.0	5.77	0.10	0.58	0.16	0.08	0.35	0.18
10	886	61	53	4.98	0.55	11.7	6.58	0.13	0.60	0.13	0.1	0.38	0.18
30	886	64	50	5.04	0.72	14.4	9.33	0.13	0.61	0.15	0.1	0.36	0.17
50	889	64	47	5.11	0.79	15.8	9.75	0.14	0.62	0.16	0.1	0.36	0.16
August sowing after cropping													
0	892	52	56	5.2	0.65	20.1	5.32	0.12	0.62	0.13	0.11	0.21	0.1
10	890	58	52	5.15	0.88	21.5	8.1	0.14	0.62	0.16	0.1	0.23	0.12
30	888	60	52	5.27	0.8	22.7	9.88	0.17	0.65	0.18	0.12	0.2	0.09
50	894	60	46	5.33	0.85	21.2	10.6	0.18	0.67	0.2	0.12	0.2	0.07

Note: Data are bulked values of soil samples for each treatment taken over replications.

Chromolaena leaf residues narrowed the ASI achieved at Chromolaena leaf residues rates of 30 and 50 kg ha^{-1} compared with that in the control ($p < 0.0001$). However, differences between rates of 0 and 10 kg ha^{-1} were not significant ($p = 0.6646$). Differences were also not recorded between rates of 30 and 50 kg ha^{-1} ($p = 0.2443$). Results for number days to maturity followed the same trend as with ASI.

Chromolaena leaf residues application shortened the time to anthesis, silking, and maturity, while reducing ASI. At 0 kg ha^{-1}, maize reached anthesis at 66.7 days, silking at 73.6 days, and maturity at 93.7 days, with an ASI of 6.9 days. At the rate of 10 kg ha^{-1} residues reduced these values slightly, with anthesis at 63.3 days, silking at 69.9 days, maturity at 92.6 days, and an ASI of 6.5 days. More pronounced effects were observed at higher residue rates; at 30 kg ha^{-1}, anthesis occurred at 54.1 days, silking at 56.8 days, maturity at 82.6 days, and the ASI narrowed to 2.4 days. Similarly, at 50 kg ha^{-1}, anthesis and silking occurred at 54.1 and 55.7 days respectively, with maturity at 81.7 days and the shortest ASI of 1.5 days.

The reduced number of days to anthesis, reduced number of days to silking, reduced number of days to maturity and narrowed ASI, all indicate that the Chromolaena leaf residues accelerated maize development. With higher rates of 30-50 kg ha^{-1}, maize reached anthesis and silking more than 10 days earlier than the control, while maturity was shortened by ca. 12 days. Such acceleration in phenology suggests improved soil conditions, likely due to enhanced mineralisation of organic matter and nutrients release (Tables 2 and 3; Ogundare *et al*., 2015). Organic mulch, besides conserving soil moisture and reducing soil temperature (Obalum *et al*., 2012; Bu *et al*., 2013; Okorie *et al*., 2024), improves soil microbial activities and hence soil fertility and soil structure, suppresses weeds, and ultimately enhances crop yields (Iqbal *et al*., 2020; Osakwe *et al*., 2023; Obi *et al*., 2024).

Table 3: Total N uptake by maize fertilized with *Chromolaena odorata* leaf residues

Chromolaena leaf residues rate (kg ha^{-1})	Total N uptake (g $plant^{-1}$)
0	1.78
10	2.46
30	3.37
50	4.35
Mean	2.99
Standard error of the difference	0.2764
p value	< 0.0001

Table 4: Phenology of maize fertilized with *Chromolaena odorata* leaf residues

Chromolaena leaf residues rate (kg ha^{-1})	Days to anthesis	Days to silking	Anthesis-silking interval (ASI)	Days to maturity
0	66.7	73.6	6.9	93.7
10	63.3	69.9	6.5	92.6
30	54.1	56.8	2.4	82.6
50	54.1	55.7	1.5	81.7
Mean	59.6	64	4.3	87.7
SED	1.07	0.72	0.74	1.27
p value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

SED - standard error of the difference

The narrow ASI indicates that the system had no stress and that the plant had some adequacy in growth conditions. The ASI is a critical determinant of reproductive success in maize, as prolonged intervals often signal stress conditions that reduce kernel set and yield (Bolaños and Edmeades, 1996; Borrás and Vitantonio-Mazzini, 2018). The shortened ASI here implies improved synchrony between male and female flowering, bettering pollination efficiency and grain formation. This finding aligns with the reports that organic amendments, including crop residues, improve crop vigour and reproductive performance by alleviating nutrient stress and enhancing soil fertility (Uzoh *et al*., 2017; Onah *et al*., 2023).

Plant Height, Number of Ears and 1000-Seed Weight

Growth and yield components of maize were influenced ($p < 0.0001$) by applied Chromolaena leaf residues (Table 5). Plant height, number of ears per plant, and 1000-seed weight, all increased with higher residue application rates. Plants grew taller when leaf residues were applied relative to control ($p < 0.0001$). Plant height increased with increase in leaf residues rate. At 0 kg ha^{-1}, maize plants attained a height of 114.6 cm, at 10 kg ha^{-1} residues increased plant height to 131.4 cm, at 30 kg ha^{-1}, plant height further increased to 155.9 cm and 50 kg ha^{-1} produced the tallest plants (160.3 cm). Application of leaf residues at all rates increased number of ears relative to the control ($p < 0.0001$). At 0 kg ha^{-1}, maize plants produced 0.8 ears per plant (4.3 plants m^{-2}), at 10 kg ha^{-1} residues increased number of ears to 1 ear $plant^{-1}$ (5.3 ears m^{-2}). At 30 kg ha^{-1}, number of ears remained at 1 ear $plant^{-1}$ (5.3 ears m^{-2}), and 50 kg ha^{-1} maintained number of ears at 1 ear $plant^{-1}$ (5.3 ears m^{-2}). Seed weight was heavier when leaf residues were applied compared to control ($p < 0.0001$). At 0 kg ha^{-1}, maize plants recorded a 1000-seed weight of 160.2 g. At 10 kg ha^{-1}, residues raised seed weight to 208.7 g. At 30 kg ha^{-1}, seed weight rose to 215.9 g. The highest residue rate (50 kg ha^{-1}) achieved the greatest seed weight of 230.9 g.

The positive response of growth and yield components of maize to applied Chromolaena leaf residues reflects the role of the residues in improving soil fertility and nutrient availability. The improvement in plant height is consistent with earlier findings that Chromolaena residues supply readily mineralisable organic matter, which boosts N availability and crop growth (Ogundare *et al*., 2015). Seed development also benefited from residue application. The rise in seed weight with applied residues indicates that residue application improved grain filling and kernel quality. Similar results were reported by Uzoh *et al*. (2017) who found that incorporation of crop residues significantly improved maize yield. The stability of number of ears among residues' rates suggests that yield gains at higher residue levels were driven primarily by improvements in seed size and weight rather than ear production.

For management purposes, these results highlight the potential of *Chromolaena* residues to improve both vegetative growth and reproductive output in maize. Increase in plant height and seed weight contribute directly to higher yields, while the stabilisation of ear number indicates that residue application promotes the quality rather than quantity of reproductive structures. Therefore, for smallholder farmers in Nigeria and elsewhere, where access to mineral fertilizers is limited, the use of locally available Chromolaena residues offers a cost-effective strategy to boost productivity.

Grain and Stover Yields

The results summarising the effects of Chromolaena leaf residues on grain and stover yields are presented in Table 6. Plants had higher grain yield when Chromolaena leaf residues were applied relative to control (p < 0.0001). Performance improved with each rise in the rate of leaf residues. The significant increments in grain yield from rate of 0-50 kg ha^{-1} ranged from 94% to 266%. The use of Chromolaena leaf residues clearly contributed to high grain yields. This is because Chromolaena leaf is rich in plant nutrients (Table 1) which are released to the soil for plant growth and development during the decomposition of the organic material. The higher leaf residues rate led to increased grain yield due to increased availability of nutrients essential for greater growth leading to greater photosynthesis and greater grain filling (Tables 2 and 3). Agustina *et al*. (2019), reported that Chromolaena leaf residues contribute to higher yields essentially through improved soil fertility, nutrient management, water management and weed suppression derived from the soil being covered and the fast decomposition rate of the Chromolaena leaf residue, which in turn promote narrow ASI. Kone *et al*. (2012), reported increased plant performance when Chromolaena leaf residue was used as an organic mulch and attributed the effect to the high nutrient composition of the organic material and the release of the nutrients during decomposition. Agbede *et al.* (2014), Awopegba *et al.* (2016) and Aigbedion-Atalor *et al.* (2019), reported high yields in yam and maize when Chromolaena residues were used as mulching material. Mugwedi (2020) also reported that the use of Chromolaena leaves as mulch increased crop yields by improving the soil physical and chemical properties.

Stover yield of maize was significantly influenced by fertilizing with Chromolaena leaf residues (p < 0.0001). Stover yield increased progressively with higher residue application rates. At 0 kg ha^{-1}, stover yield was 1359.8 kg ha^{-1}. When applied at 10 kg ha^{-1}, residues increased stover yield to 2041.7 kg ha^{-1}. At 30 kg ha^{-1}, stover yield rose further to 2668.8 kg ha^{-1}. The highest residue rate (50 kg ha^{-1}) produced the maximum stover yield of 3260.0 kg ha^{-1}, representing more than a twofold increase in stover yield compared to the control. The dose-dependent increase in stover yield suggests that nutrient availability was the key driver, supporting efficient partitioning of assimilates into both reproductive and vegetative components. This increase in stover yields has implication for livestock production. This is because maize stover is an important feed resource in livestock production. Ewansiha and Osaigbovo (2016) reported that greater attention is being given to livestock production in the South-South of Nigeria due to climate change. More herds in the region means heightened need for livestock feed. The increasing human and livestock population in the region will elicit crop-livestock interactions. Success in crop-livestock production system will rely heavily on the use of crop residues. Maize is the cereal mainly grown in the region. The grain will not only provide feed; the plant residue will also provide feed as fodder. And use of Chromolaena plant residues to grow maize will mean sustainable production without harming the environment.

Meanwhile, the shorter plants, longer days to reach anthesis and silking, the longer days to reach maturity, wider ASI and lower seed weight, together with lower grain yield and lower stover yield, obtained with zero application of Chromolaena leaf residues were likely due to the sole dependence on the intrinsic soil fertility which was not sufficient for optimal agronomic performance. This demonstrates the implications of the poor nutrient status of the soil before the commencement of the experiment; it could not support plant growth. It was rather heightened by nutrient mining by the maize plants growing on it (Table 2). Plots without applied Chromolaena residues produced 1.0 t ha^{-1}. Whereas global maize yields average approximately 5.1-5.7 t ha^{-1} due to intensive mechanisation, widespread use of improved hybrids, irrigation, and high external inputs (FAO, 2023; OECD/FAO, 2025), the yields in SSA, including Nigeria, remain relatively low at about 2 t ha^{-1} because of declining soil fertility, erratic rainfall, low fertilizer use, and limited access

Table 5: Plant height, number of ears and seed weight of maize fertilized with *C. odorata* leaf residues

Chromolaena leaf residues rate (kg ha^{-1})	Plant height (cm)	Number of ears (No. plant^{-1})	1000-seed (g)
0	114.6	0.8	160.2
10	131.4	1.0	208.7
30	155.9	1.0	215.9
50	160.3	1.0	230.9
Mean	140.5	0.9	203.9
SED	4.01	0.03	10.87
P value	< 0.0001	< 0.0001	< 0.0001

SED - standard error of the difference

Table 6: Grain and stover yield of maize fertilized with *C. odorata* leaf residues

Chromolaena leaf residues rate (kg ha^{-1})	Grain yield	Stover yield
	(kg ha^{-1})	
0	1027.0	1359.8
10	1994.5	2041.7
30	3002.1	2668.8
50	3783.8	3260.0
Mean	2451.8	2332.6
SED	285.19	162.30
P value	< 0.0001	< 0.0001

SED - standard error of the difference

to improved production technologies (FAO, 2023; IITA, 2022). In the present study, grain yields of 3.0-3.8 t ha^{-1} obtained with Chromolaena odorata residues obtained at moderate to high application rates were considerably higher than the average yield commonly reported for SSA. This indicates that the use of Chromolaena residues improved soil nutrient availability and enhanced maize productivity under rainfed tropical conditions. This is consistent with earlier reports that the use of plant-based materials as mulch or fertilizer has shown the potential to improve soil fertility, soil health and yield of crops as inorganic fertilizers with little or no environmental consequences (Iqbal *et al*, 2020). More so, plant-based fertilizer sources are cost-effective, environmentally friendly and biodegradable and of no harm to human health (Gaitanis *et al.*, 2023).

Therefore, the yield advantage recorded in this study may be interpreted as a contribution toward narrowing the maize yield gap that exists between African production systems and global maize-producing regions. Analyses of yield gap have shown that poor soil fertility management remains one of the major constraints limiting maize productivity across SSA (Tittonell and Giller, 2013; van Ittersum *et al*., 2016). The relatively higher yields recorded in the present study suggest that the use of locally available organic biomass resources such as Chromolaena odorata can partially alleviate nutrient limitations and improve crop performance in low-input farming systems. Notwithstanding that the yields obtained were still below the global average, they represent a substantial agronomic improvement within the context of Nigerian smallholder agriculture where maize yields are often constrained by inadequate fertilizer application and declining soil organic matter.

Correlations between Plant Attributes

Results of correlation analysis are shown in Table 7. Grain yield was negatively and markedly correlated with number of days to 50% anthesis (r = –0.759; p < 0.0001), number of days to 50% silking (r = –0.796; p < 0.0001), anthesis-silking interval (r = –0.668; p < 0.0001), and number of days to maize maturity (r = –0.700; p < 0.0001). These findings imply that as number of days to attainment of anthesis, silking and maturity shortens with narrower ASI, grain yield of maize improved. These findings are consistent with reports that shortened anthesis-silking intervals improve pollination efficiency and kernel set in maize (Ogundare *et al*., 2015). This may be so in the absence of stress in the cropping system. It meant that there was adequacy of nutrient availability and supply, adequacy of soil moisture, absence of pests and presence of other favourable environmental conditions. This is consistent with the report that Chromolaena leaf residues improve growth conditions for higher yielding (Iqbal *et al*., 2020). Nutrient availability was as caused by the use of Chromolaena leaf residues. With favourable conditions for maize to grow and produce, the only critical factor of growth was nutrient that control plots could not enjoy. Hence, the observed poor performance at zero application of leaf residues. The results further indicate that delayed flowering and maturity, as well as prolonged reproductive intervals, are detrimental to yield.

Table 7: Relationships between some maize agronomic traits and maize grain yield

Attributes	Correlation coefficient	Significance (p)
Days to anthesis	–0.759	< 0.0001
Days to silking	–0.796	< 0.0001
Anthesis-silking interval	–0.668	< 0.0001
Days to maturity	–0.700	< 0.0001
Plant height	0.849	< 0.0001
Number of ears	0.436	< 0.0126
1000-seed weight	0.700	< 0.0001
Stover yield	0.857	< 0.0001
Plant nitrogen uptake	0.865	< 0.0001

Grain yield, however, correlated positively and markedly with plant height (r = 0.849; p < 0.0001), number of ears (r = 0.436; p = 0.0126), 1000-seed weight (r = 0.700; p < 0.0001) and stover yield (r = 0.857; p < 0.0001). Higher yielding was associated with taller plants, higher seed weight and higher stover yield. These were in turn associated with higher rate of Chromolaena leaf residues. The positive correlations further underscore the importance of vigorous vegetative growth, efficient ear production, and robust seed development in driving yield outcomes. Uzoh *et al*. (2015) reported similar patterns of variations in maize grain and dry matter yields in response to animal manures in acid Ultisols, buttressing the link between vigorous vegetative growth and grain filling.

Moreover, grain yield had a very strong positive correlation with N uptake (r = 0.865; p < 0.0001), indicating that N acquisition is a key determinant of maize productivity in the study area. This relationship suggests that increases in plant N uptake are closely associated with corresponding increases in grain yield, confirming the central role of N as a limiting nutrient in maize production. The positive association reflects the fundamental physiological role of N in crop growth and yield formation (Ebido *et al*., 2024). Nitrogen is an essential component of chlorophyll, proteins and enzymes involved in photosynthesis and biomass accumulation. Accentuated N uptake improves photosynthetic efficiency and assimilates production, which are critical for grain filling and final yield (Sinclair and Horie, 1989). Similarly, Sanchez (2019) emphasised that the availability of N is often the most important constraint to cereal productivity in tropical soils, where inherent soil fertility is typically low.

Number of ears had positive but weaker correlation (r = 0.436; p = 0.0126) with grain yield, suggesting that though reproductive structure formation contributes to yield, it is less influential than plant height, seed weight and N uptake. The study demonstrates that yield gains under Chromolaena leaf residues are primarily driven by physiological efficiency—early flowering, reduced reproductive stress, and improved nutrient uptake, meaning that residue application enhances both the quantity and quality of grain, while also boosting stover yield, which provides additional benefits such as livestock feed and organic matter for soil improvement. The corresponding increase in yield with increase in N uptake buttress the importance of organic residue management in sustainable intensification. Therefore, by recycling locally available biomass such as Chromolaena leaves, farmers can improve soil fertility, and reduce reliance on synthetic fertilizers. This aligns with climate-smart agriculture principles that promote resource-efficient and low-emission farming systems (FAO, 2013) and supports Nigeria's Agricultural Transformation Agenda (FMARD, 2012), which prioritises farmer-led innovations to enhance staple crop productivity.

Overall, the use of Chromolaena residues agrees with sustainable soil fertility management strategies by improving soil organic matter, enhancing nutrient cycling, and reducing dependence on inorganic fertilizers. The application of *Chromolaena odorata* biomass has been shown to significantly improve soil N availability and maize performance in Nigeria. Studies have demonstrated that Chromolaena residues increase plant-available N and enhance maize growth and yield, particularly when integrated with inorganic fertilizers (Ogundare *et al.*, 2015). Similarly, Chromolaena mulch and fallow systems have been reported to improve soil organic matter and nutrient status, leading to increased maize yield and nutrient uptake (Ojeniyi *et al*., 2012). The rapid decomposition and nutrient release characteristics of Chromolaena biomass make it an effective organic amendment capable of partially substituting mineral N fertilizers (Aboyeji, 2019). The steady rise in N uptake, plant growth and grain and stover yields, recorded at 10, 30, and 50 kg ha^{-1} of *Chromolaena odorata* residues suggests a strong potential for this biomass to serve as an alternative nutrient source in maize production systems in Nigeria. While the highest response was achieved at 50 kg ha^{-1}, the associated labour and biomass requirements may limit its practical adoption. On the contrary, 30 kg ha^{-1} appears to offer an optimal balance between agronomic benefits and feasibility, making it a suitable recommendation for smallholder farmers. For sustainable use, farmers should source 30 kg ha^{-1} of *Chromolaena odorata* residues through rotational harvesting of regrowth, applied at or shortly before planting, and placed on the entire soil surface. This rate can be integrated with small quantities of mineral N fertilizer to improve nutrient use efficiency while reducing input costs. Proper management of biomass and prevention of seed spread are essential to ensure long-term sustainability and avoid ecological risks. Fortunately, in Nigeria, it is common to see Chromolaena shrubs growing in the neighbourhoods as they grow abundantly, with the leaves readily available. Chromolaena fallows abounds and apart from growing freely, farmers may commence planting the shrub in the neighbourhoods of their farms and utilise the leaves as a means of fertilizers to improve their maize crop yield.

CONCLUSION

This study shows that *Chromolaena odorata* residues, when applied on soil surface significantly improve soil fertility, nutrient dynamics, maize growth and yield in tropical rainforest conditions. Leaf residues rates of ≥ 30 kg ha^{-1} were most effective, enhancing N uptake, grain yield, and stover production. Beyond crop productivity, the increased stover yield provides added value for livestock feeding, strengthening crop-livestock integration. Given its abundance, rapid decomposition, and high nutrient content, low-cost and environmental benefits, *C. odorata* represents a sustainable, low-cost, eco-friendly and accessible organic fertilizer alternative for smallholder farmers. Adoption of this practice can help close maize yield gap, improve food security, and promote resilient agricultural systems in sub-Saharan Africa. Further research across diverse agroecological zones and over longer timeframes would strengthen understanding of its long-term agronomic and ecological impacts.

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