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Short-term effects of *Chormolaena odorata* on soil organic matter evolution and maize production in the central-western Côte d'Ivoire

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ABSTRACT

Low soil fertility and the high cost of mineral fertilizers constrain maize production in Côte d'Ivoire. This study evaluated the short-term effects of *Chromolaena odorata* mulch on soil organic matter and maize grain yield over three consecutive cropping seasons. A randomized complete block experiment with three replicates compared four treatments on soil following a five-year *C. odorata* fallow: mulch alone (Co), mulch plus mineral fertilizer (Co_NPK), mineral fertilizer alone (NPK), and an unfertilized control (To). Initial soil organic matter and total nitrogen ranged from 2.39% to 2.98% and from 0.14% to 0.16%, respectively. After the first crop, total soil nitrogen declined to 0.05% in all treatments. Soil organic matter remained below baseline after the second crop. By the end of the third season, it had increased significantly above baseline in Co, Co_NPK, and To, with increases of approximately 166%, 72%, and 61%, respectively. In the first season, Co yielded 10.74 t/ha, significantly more than the other treatments (7.63–8.75 t/ha, overall p = 0.017). In the second season, Co and Co_NPK each yielded 2.50 t/ha, significantly less than To and NPK (3.01–3.02 t/ha, overall p = 0.014). In the third season, yields ranged from 2.04 to 2.50 t/ha, with no significant differences among treatments (p = 0.328). The grain yield advantage of mulch alone was confined to the first season after fallow.

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INTRODUCTION

Maize is the second most important cereal crop in Côte d'Ivoire after rice, with national production of approximately 1.6 million tons per year grown on about 640,000 hectares (FAOSTAT, 2026). It is a staple cereal for both human and animal consumption. It is essential to the agro-industry in this West African country. However, rain-fed maize cultivation is subject to climatic uncertainties. Furthermore, the general decline in soil fertility constitutes a major constraint on the country's agricultural production (Koné *et al.*, 2022 ; Konan *et al.*, 2025). Depending on the region, maize is grown as a stand-alone crop or in combination or rotation with legumes. The high domestic demand for grain maize leads many producers to use mineral fertilizers to improve yields, often at the expense of crops such as cotton, for which fertilizers pre-financed by extension agencies are diverted to maize cultivation (Ouattara and Kouakou, 2021). The high cost of fertilizers further compounds the production constraints of food crops, including maize (Theriault *et al.*, 2018), especially in areas where access to pre-financed fertilizers is limited. In this context, it becomes difficult to meet the nutrient requirements of maize cultivation, which is known to be highly demanding in nitrogen, potassium, and phosphorus (Setiyono *et al.*, 2010 ; Csaba *et al.*, 2021 ; Li *et al.*, 2023), and to improve maize production. It is therefore important to find cost-effective and efficient soil management alternatives that are resilient to increasing soil depletion.

Cultivation practices that promote organic matter management, such as the incorporation of crop residues, cover crops, the application of organic amendments, and crop rotations, significantly improve soil organic matter content, which increases soil fertility and supports high agricultural yields (Liu *et al.*, 2006 ; FAO, 2011 ; Salisu *et al.*, 2025). Organic matter improves soil nutrient and water storage as well as soil biodiversity. The use of plant biomass as a fertilizer is increasingly recommended for improving soil fertility in Africa (Mureva *et al.*, 2021 ; Laub *et al.*, 2023). The biomass of *Chromolaena odorata*, used during fallow periods has proven effective in increasing soil organic matter, carbon stocks, total nitrogen, and phosphorus, thereby improving soil fertility under African agro-ecological conditions (Tondoh *et al.*, 2013; Mbalila, 2021; Molongo *et al.*, 2023). The management of this plant, generally considered a weed, after fallow is not highly valued in the traditional agricultural system. It is typically burned or cut and removed from the fields before crops establishment (Hauser and Mekoa, 2009; Shackleton *et al.*, 2017). The substantial biomass of this shrub, which is readily accessible to soil microorganisms, constitutes a source of organic matter beneficial to crops (Gonnety *et al.*, 2012; Koné *et al.*, 2021). However, few studies have been conducted on the integration of *C. odorata* into the cropping system for maize cultivation. Such a study could provide an ecological solution for managing soil fertility in maize cropping systems and improving cereal production in Côte d'Ivoire. The objective of this study is to evaluate the influence of incorporating *C. odorata* into maize cropping system with straw return on the evolution of soil organic matter and maize production on soil cultivated regularly over three consecutive growing seasons.

MATERIALS AND METHODS

Study area characteristics

The experiment was located at Sika N'guessankro (6.9176781N ; 6.3281935W) in the mesophilic forest zone of central-western Côte d'Ivoire, specifically in the Haut-Sassandra region under a hot and humid tropical climate characterized by two dry seasons alternating with two wet seasons. The average temperatures range from 24.78°C to 28.17°C (Kouassi *et al.*, 2022). The cumulative annual rainfall from 1991 to 2020 is estimated at 1,200 mm (SODEXAM, 2024). In the region, rainfall is nearly zero in January and increases gradually reaching its peak in September, with an average of 220 mm. Rainfall measurements were taken at the experimental site using a rain gauge during the second and the third maize growing seasons. The cumulative rainfall for the second cropping season is estimated at 205.6 mm (Fig. 1). The rain distribution was over the first two

months following maize sowing, from August to September 2024, corresponding to the maize vegetative growth stage.

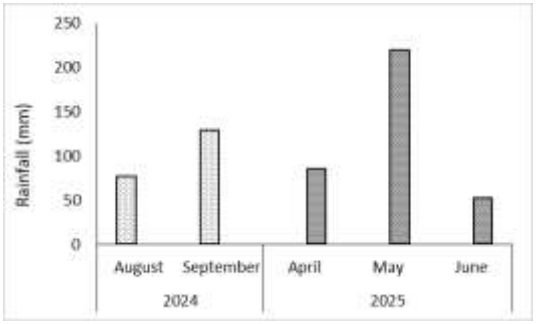


Fig. 1. Rainfall values over the second (2024) and third (2025) maize cropping season

During the third cropping season, cumulative rainfall was 356.2 mm. Rainfall occurred over the first three months after sowing, specifically in April, May, and June 2025. These months correspond to maize vegetative growth and flowering stages.

The soils are predominantly Ferrallitic, developed on a granitic substrate (DGATDR, 2015). The soil used for the survey is a plateau Ferralsol derived from a five-year-old *Chromolaena odorata* fallow.

Experimental design and set up

The experiment was set up in a randomized complete block design with four treatments repeated three times. The individual plots measured 5 m × 4 m and were spaced 1 m apart.

Four treatments were investigated : (i) organic fertilization, (ii) organo-mineral fertilization, (iii) mineral fertilization and the control. The organic fertilization consisted of applying *Chromolaena odorata* fresh above-ground biomass as mulch on soil before and during crop establishment. At the beginning of each season, the above-ground biomass of *C. odorata* resulting from land clearing on the organic and organo-mineral fertilization plots was added as mulch at the rate of 9 t/ha in the first season and 5 t/ha in the subsequent seasons. On the organo-mineral fertilization plots, in addition to the mulch, mineral fertilizer was applied.

Thus, 45 N + 45 P + 45 K kg/ha were applied at 15 days after sowing, followed by the application of 138 N kg/ha at 30 days after sowing on these plots. During manual weeding, the above-ground biomass of *C. odorata* was mowed and spread on the soil, in the organic and organo-mineral fertilization plots. In the control and mineral fertilization plots, *C. odorata* was uprooted and all biomass was removed from the plots before establishing the maize crop. At the time of weeding, the *C. odorata* biomass from these treatments was also removed from the plots. The mineral fertilization treatment consisted of applying 45 N + 45 P + 45 K kg/ha at 15 days after sowing followed by 138 N kg/ha at 30 days after sowing, for a total of 183 N + 45 P + 45 K kg/ha. The control did not receive any fertilizer. The trials were conducted under rain-fed conditions. At harvest, the maize ears were removed from the plots.

The dried stalks and leaves remained as mulch and the regrowth of grasses and *C. odorata* was left as cover crops between two maize cropping seasons in all treatments. Plot preparation was carried out as previously mentioned for the subsequent maize cropping season. The first cropping season was established in March 2024 and sowing occurred on 28 March 2024. The second cropping season was established in August 2024 and the last in March 2025. The maize seed variety used in the first growing season was the LG 501 hybrid (Seed Co West and Central Africa), with a potential yield of 6 t/ha to 8 t/ha and a growth period of 105 to 110 days. The last two cropping seasons were conducted using the DK 818 maize seed variety (Bayer WCA), which has average and potential yields of 5.6 t/ha and 10 t/ha, respectively, with a growth period of 140 days.

Soil sampling and analysis

Soil samples were collected from each treatment at 20 cm depth, both before and after crop establishment. A composite soil sample was prepared for each treatment. The samples were sent to the laboratory for analysis. There, soil samples were dried and sieved using a 2-mm mesh sieve. They were then

ground, then the total nitrogen and total organic carbon contents were analyzed using a Bruker Alpha II Fourier transform mid-infrared (MIR-FT) spectrometer. The pH was measured with an electrode pH-meter.

Data analyses

Data were analyzed using SAS 9.1 software. The Shapiro-Wilk test and Batlett test were respectively performed to assess the normality and the homogeniety of data. When the data distribution was not normal, the Kruskal-Wallis and Friedman tests were used to compare means at the 5 % significance level. When the data distribution was normal, an analysis of variance was performed and the Tukey test was used to compare the means at the 5 % significance level.

RESULTS

Initial soil chemical characteristics

The soil was conditioned from five years old *Chromolaena odorata* fallow. The C/N ratios ranging from 9.98 to 11.17 indicate good soil capacity for decomposing organic matter. The soils under organic fertilization (pH = 5.63) and organo-mineral fertilization (pH = 5.53) are more acidic (p = 0.000). The soil organic carbon (C), C/N ratio, total N, and organique matter (OM) are similar across all treatments. The soil characteristics before crop establishment is shown in Table 1.

Table 1. Initial soil chemical characteristics

Fertilizer treatments	pH	C (%)	C/N	nt (%)	OM (%)
Co	5.63 ± 0.09^{c}	1.54 ± 0.02^{a}	10.90 ± 0.94^{a}	0.14 ± 0.01^{a}	2.65 ± 0.03^{a}
To	6.50 ± 0.10^{a}	1.54 ± 0.17^{a}	11.17 ± 0.45^{a}	0.14 ± 0.01^{a}	2.65 ± 0.30^{a}
Co_NPK	5.53 ± 0.07^{c}	1.39 ± 0.17^{a}	9.98 ± 0.65^{a}	0.14 ± 0.02^{a}	2.39 ± 0.28^{a}
NPK	6.10 ± 0.10^{b}	1.73 ± 0.42^{a}	10.27 ± 0.82^{a}	0.16 ± 0.03^{a}	2.98 ± 0.73^{a}
p_value	0.000	0.801	0.653	0.750	0.801

Co: organic fertilization; To: control; Co_NPK: organo-mineral fertilization; NPK: mineral fertilization

Table 2. Soils chemical characterics evolution over maize cropping seasons

Growing season	Fertilizer treatments	pH	C (%)	C/N	nt (%)	OM (%)
Co	Initial statement	5.63 ± 0.09^{c}	1.54 ± 0.02^{b}	10.90 ± 0.94^{b}	0.14 ± 0.01^{a}	2.65 ± 0.03^{b}
	1^{rst} season	6.66 ± 0.03^{b}	1.11 ± 0.08^{b}	21.65 ± 0.62^{b}	0.05 ± 0.00^{b}	1.92 ± 0.15^{b}
	2nd season	6.81 ± 0.07^{b}	1.34 ± 0.11^{b}	26.00 ± 2.37^{b}	0.05 ± 0.00^{b}	2.31 ± 0.19^{b}
	3rd season	7.42 ± 0.29^{a}	4.10 ± 1.00^{a}	63.87 ± 13.8^{a}	0.06 ± 0.00^{b}	7.06 ± 1.72^{a}
	p_value	0.000	0.009	0.003	0.000	0.009
To	Initial statement	6.50 ± 0.10^{b}	1.54 ± 0.17^{b}	11.17 ± 0.45^{c}	0.14 ± 0.01^{a}	2.65 ± 0.30^{b}
	1^{rst} season	6.77 ± 0.08^{b}	1.29 ± 0.15^{b}	24.38 ± 1.33^{b}	0.05 ± 0.00^{b}	2.22 ± 0.26^{b}
	2nd season	6.60 ± 0.14^{b}	1.20 ± 0.28^{b}	22.73 ± 2.99^{b}	0.05 ±0.01^{b}	2.07 ± 0.48^{b}
	3rd season	7.21 ± 0.06^{a}	2.48 ± 0.09^{a}	38.53 ± 0.88^{a}	0.06 ± 0.00^{b}	4.27 ± 0.16^{a}
	p_value	0.004	0.004	0.000	0.000	0.004
Co_NPK	Initial statement	5.53 ± 0.07^{b}	1.39 ± 0.17^{b}	9.98 ± 0.65^{b}	0.14 ± 0.02^{a}	2.39 ± 0.28^{b}
	1^{rst} season	6.67 ± 0.06^{a}	1.17 ± 0.07^{b}	22.71 ± 0.89^{b}	0.05 ± 0.00^{b}	2.01 ± 0.12^{b}
	2nd season	6.94 ± 0.22^{a}	1.17 ± 0.02^{b}	24.19 ± 1.20^{b}	0.05 ± 0.00^{b}	2.02 ± 0.04^{b}
	3rd season	7.25 ± 0.08^{a}	2.40 ±0.46^{a}	43.88 ± 5.57^{a}	0.05 ± 0.00^{b}	4.12 ± 0.80^{a}
	p_value	0.000	0.024	0.009	0.000	0.024
NPK	Initial statement	6.10 ± 0.10^{c}	1.73 ± 0.42^{a}	10.27 ± 0.82^{c}	0.16 ± 0.03^{a}	2.98 ± 0.73^{a}
	1^{rst} season	6.68 ± 0.04^{b}	1.28 ± 0.11^{a}	23.43 ± 1.53^{b}	0.05 ± 0.00^{b}	2.20 ± 0.18^{a}
	2nd season	6.86 ± 0.09^{b}	1.48 ± 0.17^{a}	27.25 ± 2.80^{b}	0.05 ± 0.00^{b}	2.54 ± 0.28^{a}
	3rd season	7.38 ± 0.30^{a}	3.79 ± 1.07^{a}	56.35 ± 14.0^{a}	0.07 ± 0.00^{b}	6.51 ± 1.85^{a}
	p_value	0.000	0.168	0.000	0.001	0.168

Co: organic fertilization; To: control; Co_NPK: organo-mineral fertilization; NPK: mineral fertilization

Changes in the soil following cropping seasons

The incorporation of the biomass of *C. odorata* into cropping practices promoted changes in the soil chemical characteristics after each maize cropping season. Soil organic carbon and organic matter contents, slighly decrease after the first maize cropping on the organic fertilization plot. The

decrease in C content are estimated at 27.8% compared to the initial state of this plot. Furthermore, across all treatments, nitrogen levels decrease significantly ($p = 0.001$) while the pH values increase ($p = 0.000$), except for the pH of the control plot (Table 2), shifting toward neutrality. Soil nitrogen levels significantly decrease ($p = 0.000$) by approximately 60%, dropping to 0.05%.

After two successive maize cropping, the C/N ratio increase on the organic fertilization (C/N = 26) and the mineral fertilization (C/N = 27.5) plots. But after the third maize cropping, soil organic matter and carbon contents significantly increase under the organic fertilization ($p = 0.009$), the organo-mineral fertilization ($p = 0.024$), and the control ($p = 0.004$). Soil organic matter values increase by 165.9 % on the organic fertilization plots, 118.29 % on the organo-mineral fertilization plots and 60.8 % on the control, relative to the initial soil values. All C/N values are very high ($38.53 \leq C/N \leq 63.87$) and the soil pH becomes alkaline in all treatments ($7.21 \leq pH \leq 7.42$). The variation in pH values between the second and third cropping season is statistically significant on the organic fertilization, mineral fertilization, and the control plots.

Table 3. Grain maize yields (t/ha) over cropping seasons

Treatments	1rst cropping season	2nd cropping season	3rd cropping season
Co	10.74[a]	2.5[b]	2.5[a]
To	7.63[b]	3.01[a]	2.09[a]
Co_NPK	8.75[b]	2.5[b]	2.2[a]
NPK	7.84[b]	3.02[a]	2.04[a]
p_value	0.017	0.014	0.328

Co: organic fertilization; To: control; Co_NPK: organo-mineral fertilization; NPK: mineral fertilization

Impact on maize yield

The large amount of nutrients contributed to meet maize yield potential, even when *C. odorata* residues were removed from the plot without burning. Grain maize yields were high across all treatments. Indeed, yields were closed to the potential grain maize yield on the mineral fertilization (7.84 t/ha), the organo-mineral fertilization (8.75 t/ha) and the control (7.63 t/ha) plots (Table 3). The organic fertilization treatment resulted in higher maize grain yields (10.74 t/ha, $p = 0.017$). In the second maize cycle, significant variations were observed in grain maize yield. Indeed yields dropped sharply, with the lowest values ($p = 0.014$) recorded on the organic and the organo-mineral fertilization plots (2.5 t/ha). The decrease in yields compared to the first cropping season is estimated at 76.7%, 71.4%, 61.5%, and 60.6% respectively on the organic fertilization treatment, the organo-mineral fertilization treatment, the mineral fertilization treatment and the control. Finaly, in the third consecutive cropping season, maize yields remained stable on the organic fertilization treatment (2.5 t/ha) while they decline on the mineral fertilization treatment (2.04 t/ha, a 32.5% decrease), the control (2.09 t/ha, a 30.6% decrease), and the organo-mineral treatment (2.2 t/ha, a 12% decrease) compared to the second cropping season.

DISCUSSION

Soils initial chemical characteristics and maize production

After five years of fallow with *C. odorata*, soil nutrient levels were high, particularly nitrogen, and the C/N ratio indicated good mineralization of organic matter. Grain maize yields were consequently high, particularly in the Co treatment. *Chromolaena odorata* cover crops are well known for their ability to improve soil fertility. The large amount of standing biomass produced by *C. odorata* is a key factor in improving soil quality (Tondoh *et al.*, 2013). Kassi *et al.* (2017) showed that the average time required to restore adequate mineral and organic soil reserves under *C. odorata* fallow is estimated at 5 years. These nutrients reserves are critical for successful crop production. They were necessary to produce maize at its yield potential, even when *C. odorata* residues were removed from the plot in the control treatment, without burning during soil preparation. Since the

crop was grown using a system of reduced tillage, soil disturbance was minimal. In these conditions, 50 % of the *C. odorata* mulch took about 18 days to decompose (Tetteh *et al.*, 2008). The high quality of the products derived from *C. odorata* litter would make them readily accessible to microorganisms, as suggested by Gonnety *et al.* (2012) and Koné (2009). The addition of the above-ground biomass of *C. odorata* is thought to have stimulated biological activity and increased the mineralization of organic matter on the plots receiving organic fertilizer. Under these conditions, the maize crop benefits more from the nutrient reserves of the *C. odorata* fallow and yields significantly higher.

Changes in soils chemical characteristics and maize production over cropping seasons

After the first maize cropping, soil nitrogen levels dropped sharply across all treatments, while soil organic matter content, C/N ratio, and pH gradually increased. The soil N depletion may be due to the former maize crop nutrients absorption. Indeed, maize is a highly nitrogen-demanding crop (Yin *et al.*, 2014), therefore meeting its needs led to a significant decrease in soil nitrogen. The maximum N uptake by plants results in the production of maximum biomass (Csaba *et al.*, 2021), which ensures a good yield. Nitrogen uptake increases dry matter production, grain yield, and its components. According to the model for predicting grain maize yields based on nutrient uptake, provided by Setiyono *et al.* (2010), N exports per hectare during the first cropping could be estimated at 176.1 kg, 143.5 kg, 128.6 kg, and 125.1 kg, respectively, for the organic, organo-mineral, mineral, and control treatments. These high N exports influenced the course of subsequent maize crop, particularly the rate of organic matter mineralization as reflected by the C/N ratio.

The very high C/N ratios suggest a significant slowdown in mineralization, particularly on organic and mineral fertilization plots. On these plots particularly, the quantities of crop residues applied as mulch were high as there is a relationship between final maize yield and biomass at harvest (Guérif and Seguin, 1991). The *C. odorata* above-ground biomass added to the maize stover earlier applied at the harvest contributed to increase soil organic matter content during the subsequent maize crop. The decomposition rate of maize stover is known to be lower compared to that of *C. odorata*. Indeed, according to Tetteh *et al.* (2008) the maize stover mulch can take 45 days to lose 50 % of biomass on wet season and about 18 months to decompose 40 % on dry season. In this condition, N immobilization can occur, especially when the soil's moisture content is low. In addition, during the second cropping season, the amount of rainfall (205.6 mm) was less than what the maize crop needed, for which the required amount varies between 222 mm and 515 mm (Jangre *et al.*, 2022; Navatha *et al.*, 2020; Sanjay and Mukesh, 2020; Santosh *et al.*, 2022). The water deficit is believed to have contributed to reduce the intensity of biological activity in soils that received large amounts of plant residues. After three maize cropping, the continued practice of returning crop residues to the soil in a reduced-tillage system promoted significant accumulation of soil organic matter as recorded by many authors (Liu *et al.*, 2006; FAO, 2011; Irintsoa, 2017).

The impacts on grain maize yields differed. Indeed, the grain maize yields were lower than the potential yields during le second and third cropping seasons. Maize yields were higher on the plots treated with mineral fertilizer and on the control plot during the second growing season, whereas in the third season, yields were lower on those plots. In the second cropping season, the low rainfall during the second month after sowing did not allow maize to complete properly its growing cycle, as rain stopped just at the flowering stage. Maize crop is more sensitive to nitrogen and water limitations (Lemaire *et al.*, 1996), especially when these limitations occur during the period ranging from two weeks before flowering to 2–3 weeks afterward, which is considered the most critical because it corresponds to grain pollination. A lack of water can reduce the final yield by up to 50 %, and in the event of water stress during the grain-filling stage, the yield can be reduced by 21 %

(Ameline, 2019). Therefore, the decrease in yields was estimated at 50 % on the organic and organo-mineral fertilization plots, and 40 % on the control and the mineral fertilization compared to the average maize variety yield. Furthermore, the decline in soil biological activity in plots that received large amounts of plant residues has contributed to slow the availability of nutrients to the crop at a decisive stage of yield elaboration. Since the transition between the first two cropping season was short-lived-approximately two months-the *C. odorata* litter, rich in soluble carbon, decomposed more rapidly than the maize residues, as suggested by Koné (2009). The accumulated nutrient pool was likely gradually utilized during the early growth stages of the plant. Unlike the mineral-fertilized plots, where an external N supply was applied to support maize nutrition and compensate for potential nutritional deficiencies, the organic fertilization treatment were unable to make sufficient nitrogen available to the maize during the critical yield-building stage. Furthermore, the above-ground biomass of *C. odorata* applied during plot maintenance likely could not be decomposed in time to allow for sufficient nutrient availability for the maize in the organic fertilization treatment. In this regard, Mbalila (2021), who studied the mineralization of *C. odorata* biomass, suggested a 12-week interval between the incorporation of *C. odorata* biomass into the soil and the plants' uptake of nutrients resulting from the mineralization of this herbaceous plant. Under organo-mineral fertilization conditions, a high C/N ratio does not promote the availability of nitrogen contained in organic residues. Furthermore, the nitrogen supplied by fertilization can be immobilized by soil microorganisms, thereby reducing its effectiveness and the crop's nitrogen uptake (Angus, 2001; Nasrollahi *et al.*, 2021).

During the third maize growing season, the rainfall amount was sufficient (356.7 mm) to meet maize crop needs and was spread out over the first three months of cropping. Under these conditions, soil mulching with *C. odorata* biomass on the organic fertilization treatment supported maize nutrition. The results obtained under organic fertilization suggest that maize benefited from the residual effect of soil mulching, carried out during previous cropping seasons as reported by Molongo *et al.* (2023). Yields decreased on the mineral fertilization treatment (2.04 t/ha), on the control (2.09 t/ha), and on the organo-mineral fertilization treatment (2.2 t/ha), the drop was approximately 32.5 %, 30.6 % and 12 % of the yield achieved in the second cropping season respectively. On the control, the maintenance of the mineral reserves built up during fallow does not expand the two formers maize cropping (N'Dri *et al.*, 2019).

CONCLUSION

Applying *Chromolaena odorata* mulch alone produced a grain yield advantage in the first maize cropping season after a five-year fallow. The mulch-only treatment yielded 10.74 t/ha, significantly more than the other treatments. In the second season, its yield was lower than those of the unfertilized control and mineral fertilizer treatments. Its mean yield was 2.50 t/ha in both the second and third seasons, and no significant yield differences among treatments were detected in the third season.

Soil organic matter initially declined and, by the end of the third season, exceeded baseline levels in the mulch-only, mulch-plus-mineral-fertilizer, and unfertilized control treatments. Because maize residues were returned under reduced tillage in all treatments, the experiment could not isolate the effects of those practices. Overall, the results support a first-season yield benefit from *C. odorata* mulch alone. Longer trials using the same maize cultivar across seasons would help determine whether that benefit persists under varying rainfall conditions.

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