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Optimizing Sunflower Productivity Through Combined Organic Amendments: A Sustainable Alternative to Mineral Fertilization in Tropical Soil

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ABSTRACT

Tropical soils often suffer from rapid organic matter depletion and declining fertility, leading many farmers to rely heavily on mineral fertilizers. While effective in the short term, these inputs are costly, environmentally damaging, and increasingly unsustainable. This study evaluated whether combining two locally available organic amendments, cow dung compost and plantain peel biochar, could offer a more sustainable pathway to improve sunflower (Helianthus annuus) productivity in a tropical savanna soil in Dang locality, (Ngaoundere, Cameroon). A randomized complete block design with nine treatments, including unfertilized plots and varying combinations of compost and biochar, was established under field conditions. Soil, compost, and biochar were chemically characterized prior to application. Germination rate, Plant growth parameters (leaf number, and leaf area), phenological traits (days to flowering), and yield components (seed weight and yield per hectare) were monitored. Both biochar and the local soil were alkaline, while the compost was slightly acidic and exceptionally rich in organic matter. The combined application of compost and biochar significantly enhanced vegetative growth, stimulated flowering, and improved overall productivity. Amended plant with 500 g of compost combined with 20 g of biochar per plant (the most promising fertilizer) produced the highest seed yield (2.74 t/ha), markedly outperforming the control (1.90t/ha) and chemical fertilizer (2.10t/ha). These results demonstrate that combining cow dung compost and plantain peel biochar may improves sunflower yield by 44% and 30% respectively in comparison with control and NPK chemical fertilizer application, and also soil health, offering a sustainable alternative to mineral fertilizers for tropical smallholder farming systems.

Keywords: *Biochar, Compost, Sunflower, Tropical soils, Yield optimization.*

1. Introduction

Sunflower (*Helianthus annuus* L.) is the fourth most important oilseed crop globally, valued for its edible oil and for its by-products used in animal feed and various industries [19,9]. In Sub-Saharan Africa, particularly in Cameroon, sunflower cultivation is gaining ground as a strategic crop to meet the growing demand for vegetable oils and improve the livelihoods of rural populations [11,17]. However, its productivity in tropical regions remains severely limited by inherently low soil fertility, rapid mineralization of organic matter, and the high cost of mineral fertilizers for smallholder farmers [26,3]. Tropical ferralitic soils, such as those of the Adamawa Cameroon Region, are characterized by low cation exchange capacity (CEC), strong phosphorus fixation, and an acidic to neutral pH that can restrict nutrient availability [20,14]. To maintain yields, farmers frequently resort to synthetic NPK fertilizers, which, although effective in the short term, contribute to soil acidification, loss of microbial biodiversity, nitrate leaching, and greenhouse gas emissions [23,12]. In addition, their increasing cost often makes them unaffordable for the poorest farmers, highlighting the urgent need for affordable, locally available, and environmentally friendly alternatives. Organic amendments such as compost and biochar have emerged as promising tools for sustainable soil fertility management [1]. Produced compost with organic residues, provides a balanced mixture of nitrogen, phosphorus, potassium, and stabilized organic matter that stimulates microbial activity and the gradual release of nutrients [7,21]. Biochar, a carbon-rich solid material derived from biomass pyrolysis under limited oxygen, is characterized by high porosity, a large specific surface area, abundant negative surface charges, and an often-alkaline pH, which improve soil water retention, CEC, and nutrient retention while sequestering carbon [13,10]. Although each amendment has been studied separately, their combination remains insufficiently explored in Sudanian agroecological systems.

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This study aimed to evaluate their individual and synergistic impacts on sunflower growth and yield.

2. Materials and Methods

2.1 Study area

The study was conducted during two cropping year 2025 in the experimental field of the Faculty of Science of the University of Ngaoundere (Cameroon). The geographical parameters of the field are : 7°24'61'' North latitude, 13°34'24'' East longitude, and 1155.80 m altitude. The area belongs to the agro-ecological zone II of Cameroon and is characterized by a High Guinean Savannah with a six-month rainy season (May to October) and six-month dry season (November to April).

2.2 Plant material

The plant material consisted of a local, non-certified sunflower variety (Figure 1a). The seeds (Figure 1b) used for sowing were striped (grey and cream).

1a: Flower **1b:** Seeds

Figure 1: flower (1a) and Seeds (1b) of Helianthus annuus

2.3. Fertilizers

Fertilizers used include compost, biochar and chemical fertilizer. Composting was carried out using cow dung for three months by the heap method: alternating layers of cow dung, straw, and a microbial inoculum were arranged, moistened, covered with white plastic to maintain temperature and humidity, and turned every two weeks to ensure aeration. The mature compost was sieved and stored. Biochar was produced from mature plantain banana peels. These peels were sun-dried for one week and then pyrolyzed in a double-barrel reactor at very high temperatures between 300 and 900°C under limited oxygen supply for approximately 2 hours. The resulting biochar was ground, sieved, and stored. NPK chemical fertilizer was purchased on the local market in Ngaoundere Cameroon.

2.4 Experimental design and Chemical analysis of growth substrate (growing soil and compost)

The experimental design was a randomized complete block with nine (9) treatments (unfertilized plot as negative control), NPK chemical fertilizer (20-10-10) as positive control), compost (500 g/hole), three levels of biochar (10g/hole; 20 g/hole and 30 g/hole)), the combination of compost with 10 g, 20 g or 30 g of biochar/hole). All treatment were replicated three times.

Soil samples were collected from the study site using a fifteen-point randomization system (1 kg per point). All these samples were mixed to form a composite sample representative of the study site (15 kg of soil). Soil samples were taken at 30 cm depth. The chemical analyses of soil, produced biochar and compost were carried out according to standard methods. Analysis parameters include moisture content, pH, electrical conductivity, organic matter content, carbon content, Nitrogen content and potassium content.

2.5 Data collection and statistical analyzes

Germination rate was assessed from 3 to 8 DAS (days after sowing). Growth parameters (plant height and foliar production) were determined during the vegetative phase. The dates of the first floral bud, 50% flowering, and 100% flowering were recorded. After harvest, the number of seeds per capitulum was determined. The 1000 seeds weight was also determined and grain yield per net plot were measured using top loading MP10001 electronic balance (Shanghai Scientific instrument Co. Ltd) [22]. Yield per hectare was estimated based on 70 000 plants/ha.

All the data were statistically analysed using the Statgraphics Plus Program version 5.0. The significance of differences was determined using Duncan test.

3. Results

3.1 Chemical characteristics of soil, compost, and biochar

The soil, compost and Biochar's chemical properties before the experiment are presented in Table 1. The local soil was alkaline (pH 7.74 ± 0.02) with a moderate organic matter content (15.80 ± 0.51%) and a low total nitrogen content (4.01 ± 0.04%). The compost was slightly acidic (pH 6.26 ± 0.08) and exceptionally rich in organic matter (85.58 ± 1.86%), total nitrogen (41.08 ± 2.55%), and potassium (21.16 ± 4.33%). The biochar was strongly alkaline (pH 9.52 ± 0.06) with a high ash content (65.44 ± 0.83%), very high potassium (159.12 ± 12.24%) and a moderate organic matter content (36.33 ± 3.9%).

Table 1: Soil, Compost and Biochar chemical properties

Paramters	Soil	Compost	Biochar
WC (%)	90.61±0.17	63.25±0.50	34.56±0.83
DMC (%)	9.38±0.17	36.75±0.50	65.44±0.83
TC (%)	86.60±0.14	14.42±1.86	63.67±3.90
pH	7.74±0.026	6.26±0.08	9.52±0.06
EC(µS/cm)	53.70±0.61	6.64±0.06	6.41±0.60
MO (%)	15.80±0.51	5.58±1.86	36.33±3.90
C (%)	8.60±0,36	32.52±0.71	13.8±1.48
N (%)	4.01±0.04	41.08±2.55	26.73±0.70
K (%)	0.80±0.05	21.16±4.33	159.12±12.24

__Legend : MO__ : Organic Matter; __pH__: Hydrogen potential; __WC__ : Water content, __EC__ : Electrical conductivity; __C:__ Carbon; __N:__ Nitrogen; __K:__ Potassium; __TE__ : Teneur en Eau ; __DMC__ : Dry Matter Content, __TC:__ Ash Content

3.2 Germination rate

A total of 290 out of 314 seeds germinated, corresponding to an overall germination rate of 89%. Germination began at 3 DAS (12%), reached 75% at 5 DAS, and stabilized at 89% at 8 DAS. No significant differences were observed among treatments.

3.3 Vegetative growth parameters

Vegetative parameters were recorded in Table 2. Plant height varied significantly among treatments ($p < 0.001$). At 70 DAS, the tallest plants were recorded in T_7 : (243 ± 38.36 cm), followed by T_6 : (234.5 ± 27.8 cm) and T_5 : (228.7 ± 31.2 cm), while T_4 : (189.3 ± 42.5 cm) and T_2 : (195.6 ± 39.7 cm) showed the lowest heights. T_7 was 1.17 times taller than the control (C) (207.8 ± 40.1 cm).

The number of leaves peaked at 70 DAS and then declined. The highest leaf number at 70 DAS was observed in T_6 : (34.25 ± 5.18), 1.33 times higher than the control C : (25.56 ± 5.01). The lowest leaf count was recorded in T_4 : (23.94 ± 5.6).

Leaf length and width measured at 84 DAS showed that T_7 produced the longest leaves (27.32 ± 7.03 cm) and T_1 the widest leaves (20.32 ± 4.98 cm), while T_2 had the smallest leaves (21.01 ± 6.26 cm in length and 14.76 ± 5.61 cm in width).

Stem diameter at the collar increased progressively until 84 DAS. At 84 DAS, T_6 exhibited the largest mean diameter (2.61 ± 0.71 cm), significantly greater than C (2.09 ± 0.82 cm). T_2 displayed the smallest diameter (1.52 ± 0.71 cm).

Table 2: Summary of agronomic parameters by treatment

Treatment	Plant height (cm)	50% flowering	Yield (t/ha)
C (Control)	Low	73	Low
C^+ (NPK)	Moderate	68	Moderate
T_1 (Compost)	High	67	High
T_2–T_4 (Biochar)	Moderate	69–71	Moderate
T_6 (Compost + 20 g biochar)	High	66	2.74 (best treatment)
T_7 (Compost + 30 g biochar)	Very high (243 cm)	66	Slightly lower

*Legend : **C** : Control ; **C+** : Positive Control ; **T1** : Compost (500 g) ; **T2** : Biochar 10 g ; **T3** : Biochar 20 g ; **T4** : Biochar 30 g ; **T5** : Compost (500 g) + 10 g Biochar ; **T6** : Compost (500 g) + 20 g Biochar ; **T7** : Compost (500 g) + 30 g Biochar.*

3.4 Phenology and yield components

The first floral bud appeared earliest in T_7 : (57 DAS) and T_5 : (58 DAS), and latest in C^+ and T_4 : (64 DAS). The 50% flowering stage (Table 3) was reached earliest in T_1 : (66 DAS) and T_7 (67 DAS), compared to 73 DAS for T_2. Full flowering (100%) occurred between 74 and 79 DAS for all treatments (Table 3). The number of seeds per capitulum was highest in T_6 : (759.47 ± 248.25), compared to only 443.11 ± 197.09 in T_2.

Table 3: Effect of fertilizers on flowering

Treatments	1st Floral	50% flowering	100% flowering
C	60 DAS	72 DAS	79 DAS
C+	64 DAS	71 DAS	79 DAS
T1	59 DAS	66 DAS	76 DAS
T2	62 DAS	73 DAS	78 DAS
T3	62 DAS	71 DAS	79 DAS
T4	64 DAS	73 DAS	78 DAS
T5	58 DAS	69 DAS	74 DAS
T6	61 DAS	70 DAS	75 DAS
T7	57 DAS	67 DAS	76 DAS

*Legend : **C** : Control ; **C+** : Positive Control ; **T1** : Compost (500 g) ; **T2** : Biochar 10 g ; **T3** : Biochar 20 g ; **T4** : Biochar 30 g ; **T5** : Compost (500 g) + 10 g Biochar ; **T6** : Compost (500 g) + 20 g Biochar ; **T7** : Compost (500 g) + 30 g Biochar, **DAS** : Day After Sowing.*

3.5 Seed yield

The 1000 seeds weight was highest in T_6 : (51.5 ± 0.5 g) and T_1 : (50 ± 10 g), and lowest in T_4 : (36.5 ± 0.5 g) and T_3 : (37 ± 6 g). Estimated seed yield per hectare followed the same trend (Figure 2): T_6 achieved the highest yield (2.74 ± 0.02 t/ha), followed by T_7 : (2.52 ± 0.18 t/ha), T_1 : (2.37 ± 0.05 t/ha) and C^+ : (2.10 ± 0.05 t/ha). The lowest yields were recorded in T_2 : (1.34 t/ha) and T_4 : (1.45 t/ha). T_6 outperformed the unfertilized control (C) (1.90 t/ha) by 44% and the NPK control C^+ by 30% (Figure 3).

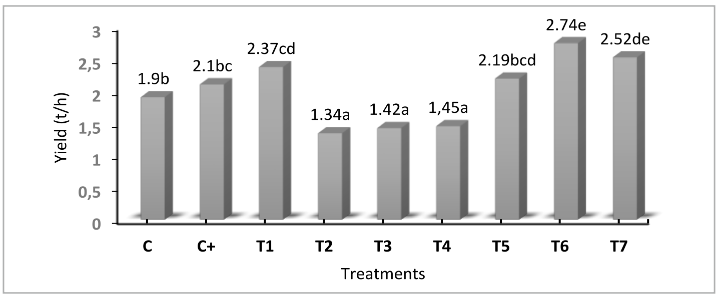

Figure 2: Hectare yield across nine treatement groups
Values of bands affected by the same letter are not significant differents

4. Discussion

The superior performance of the compost–biochar combination, particularly at the moderate biochar rate (T_6), compared to the control and single-input treatments, highlights a clear synergistic interaction between organic nutrient supply and soil conditioning.

The chemical properties of the amendments partly explain these results. The soil, although near neutral, is inherently poor in available nitrogen and phosphorus, which limits sunflower productivity without external inputs. The compost, rich in organic matter and total nitrogen, provided a substantial pool of mineralizable nitrogen, explaining why compost alone (T_1) performed well and was competitive with NPK. These results corroborate those of previous studies on organic amendments and crop productivity [3,21].

Biochar alone, especially at a high dose (T_4: 30 g), did not improve growth and even depressed some yield components, probably due to its strong alkalinity (pH 9.52). Sunflower performs optimally in a pH range of 6.0–7.5 [18]; excessive alkalinity can reduce the availability of phosphorus and micronutrients and inhibit root development [5]. The low fertility of the T_2–T_4 treatments also indicates that biochar is not a primary source of nutrients but rather a soil conditioner that requires a nutrient-rich co-amendment to be effective [1,13].

The compost–biochar combination mitigated these limitations. Biochar improved soil physical properties, water retention, and likely adsorbed ammonium and nitrate, reducing nitrogen leaching [16,4]. Compost provided a balanced supply of nutrients and stimulated microbial activity. The synergy was maximized at the intermediate biochar dose of 20 g (T_6), where the positive conditioning effects occurred without excessive alkalinization. At the highest combined dose (T_7: 30 g), plant height was maximal, but yield slightly decreased compared to T_6, indicating that excessive vegetative growth can occur at the expense of reproductive sink strength, as reported by [15, 25]. This suggests the existence of an optimal biochar threshold beyond which yield is no longer improved. The combination of biochar and Rhizobium strongly stimulates nitrogen-fixing symbiosis and increases biomass, protein, and chlorophyll levels.

Phenologically, the combined treatments accelerated flowering, with T_7 reaching the first floral bud 7 days earlier than T_0 and T_4. Such earliness can be advantageous in regions with irregular rainfall, shortening the cropping cycle and reducing exposure to end-of-season water stress, as observed in previous studies [26,6].

The yield of 2.74 t/ha achieved with T_6 clearly exceeds the regional average of 1.2–1.5 t/ha in Cameroon [17], and also surpasses the NPK treatment. This demonstrates that a well-designed organic strategy can not only match but also exceed conventional mineral fertilization. From a sustainability perspective, the combined application supports long-term soil health: compost restores organic matter, while biochar contributes to carbon sequestration and nutrient retention [16,24]. This approach aligns with the principles of climate-smart agriculture and the circular economy, as both amendments are produced from locally available waste.

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5. Conclusions

This study demonstrates that the integrated application of cow dung compost and plantain peel biochar, particularly at the dose of 500 g compost + 20 g biochar (T_6), significantly improves sunflower growth, accelerates flowering, and increases seed yield to 2.74 t/ha, surpassing the unfertilized control by 44% and NPK by 30%. The results reveal a strong synergistic effect, but one that is dose-dependent: moderate biochar rates optimize productivity, while an excess of biochar can induce high alkalinity and promote vegetative growth at the expense of grain yield. This approach represents a local and environmentally friendly alternative to mineral fertilizers, supporting both crop productivity and long-term soil health. Long-term field studies and economic evaluations are needed to promote large-scale adoption by smallholder farmers.

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