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Compost as an Alternative to Inorganic Fertilizers in Cowpea [*Vigna unguiculata* (L.) Walp.] Production

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ABSTRACT

Soil fertility management is essential to sustain agricultural production in smallholder farming systems. An experiment was carried out to assess the viability of the combined use of compost and inorganic fertilizers as an alternative to conventional inorganic fertilization under greenhouse conditions. The 10 treatments, arranged in a randomized complete block design (RCBD) with six replications, consisted of a control, conventional mineral fertilization (150 kg NPK ha^{-1}), composts added to the soil alone (2.5, 5, 7.5, and 10 t ha^{-1}), and their combination with 50% of recommended rate of inorganic fertilizers (75 kg NPK ha^{-1}). Application of 7.5 t ha^{-1} of compost and 50% of the recommended dose of inorganic fertilizer (75 kg NPK ha^{-1}) gave the significantly highest seed yield, corresponding to a 30% increase over NPK-fertilized plants. The combined application of 2.5 or 10 t ha^{-1} compost with 75 kg NPK ha^{-1} increased plant height by 38% compared with the NPK treatment. Additionally, stem diameter increased by 53% when 5 t ha^{-1} of compost and 75 kg NPK ha^{-1} were mixed. As expected, control plants produced the most nodules (108), 85% more than inorganic fertilization. Plants fertilized with 7.5 or 10 t ha^{-1} of compost and 75 kg NPK ha^{-1} produced 17% more pods, seeds per pod, and seeds per plant than NPK treatments. However, fertilization treatments had no significant effects on cowpea fresh and dry biomass or SPAD values. The results reveal that combining compost with inorganic fertilizer reduced synthetic fertilization by 50%, while producing growth and yields comparable to, or even higher than, recommended inorganic fertilization. This experiment demonstrated that integrated soil fertility management can be used as an alternative to the use of inorganic fertilizers in cowpea cultivation.

1 | Introduction

Low soil fertility poses a significant threat to food security and agricultural productivity in sub-Saharan Africa's smallholder farming systems (Bationo and Waswa 2011; Digrado et al. 2022; Vanlauwe and Giller 2006). Soil degradation is primarily due to soil disturbance, unsustainable erosion rates (Schillaci et al. 2023), soil compaction and secondary salinization, nutrient run-off, and depletion of stable soil organic matter (Babur et al. 2021; Mafongoya et al. 2006). Developing approaches to improve soil health and productivity is crucial to addressing the steady decline in soil fertility in sub-Saharan Africa (Bationo and Waswa 2011; Diatta et al. 2020b; Masso et al. 2017). This can be achieved by managing and recycling organic waste, which can be converted into nutrient-rich soil amendments. Inorganic fertilizers provide nutrients, but they do not replenish organic matter lost during cultivation or enhance soil health. Most smallholder farmers in Africa rarely apply inorganic fertilizers due to their high cost and irregular yields (Diatta et al. 2020a; Mbow et al. 2021; Vieira Junior et al. 2024).

Organic matter inputs are increasingly used to restore the fertility of agricultural soils (Tadiello et al. 2023). These amendments increase organic matter (Bulluck Iii et al. 2002; Diacono and Montemurro 2011), stimulate soil microbial activity (Bulluck Iii et al. 2002; Diacono and Montemurro 2011), improve soil physical properties, promote healthy soil structure, and improve aeration and water holding capacity (Larney and Angers 2012). The addition of organic matter promotes the introduction of micro-organisms which support soil biological activity and extract nutrients for plant uptake (Tejada, Hernandez, and Garcia 2006). When properly handled, organic amendments prevent soil-borne diseases without the need for chemicals (Bailey and Lazarovits 2003). Organic amendments also provide nutrients for plants, which are released slowly and help boost crop yields (Diacono and Montemurro 2011; Diatta et al. 2023a), hence enriching the soil after cultivation (Zhang et al. 2016). Furthermore, organic amendments have a greater impact on soil quality when applied repeatedly (Zhang et al. 2016) and require less fossil fuel than inorganic fertilizers, reducing greenhouse gas emissions (Hernández et al. 2016). Therefore, organic amendments can improve soil fertility by adding organic matter and increasing water holding capacity. The complete removal of residues for fuel and fodder production, coupled with intense and excessive plowing, has depleted soil organic carbon pools, leading to a decline in soil fertility and water holding capacity and an increasing recurrence of crop failure (Baruth et al. 2022; Giller et al. 2011). Because of their low responsiveness to external inputs such as mineral fertilizers, degraded soils often result in lower returns on agricultural investments due to the reduced efficiency of fertilizer use.

It is now recognized that soil fertility must be restored if smallholder agricultural production is to be improved and food security ensured (Badiane et al. 2001; Diatta et al. 2020a; Mbow et al. 2021; Vieira Junior et al. 2024). In addition, the use of unique strategies such as organic soil amendments is common and has positive effects on a variety of physical, chemical, and biological characteristics (Edwards, Medina, and Asker 2023). Nevertheless, it can have detrimental side effects, including nutrient imbalances, such as excess nutrients (e.g., phosphorus). Because of their ability to better target multifunctionality, integrated techniques such as the combined use of compost and inorganic fertilizers offer several advantages over business-as-usual management options and could be a viable substitute for inorganic fertilization because of their beneficial interactions and complementarities. Research has shown that implementing this technique increases crop yields, improves soil carbon storage, and reduces emissions from the use of N fertilizers, helping to meet future food supply demands (Babur et al. 2021; Bulluck Iii et al. 2002; Diacono and Montemurro 2011; Diatta et al. 2023a).

Inorganic fertilizers are essential for plant growth and crop yields. It has been shown that combining compost or organic amendments with inorganic fertilizers can increase the yields of various crops, such as maize (*Zea mays* L.) (Zhang et al. 2016), mungbean (*Vigna radiata* (L.) Wilczek) (Diatta et al. 2023a), peanut (*Arachis hypogea* L.) (Argaw 2017), soybean (*Glycine max* (L.) Merr.) (Ruth et al. 2017), tomato (*Solanum lycopersicum* L.) (Hernández et al. 2014), and wheat (*Triticum aestivum* L.) (Demelash et al. 2014). This approach also improves soil physical properties, such as stable aggregate percentage and water holding capacity (Hernández et al. 2016). A greater microbial community and activity than those treated with synthetic fertilizers alone were also observed with soil amended with compost and inorganic fertilizers (Hernandez et al. 2019). Thus, the combined use of organic and inorganic inputs may be a beneficial nutrient management strategy to reduce reliance on mineral fertilizers and increase crop yields, such as cowpea.

Cowpea [*V. unguiculata* (L.) Walp.] is one of the crops that is most intensively grown in Africa (Tivana et al. 2021). According to FAOSTAT (2023), Africa produced 8,703,523 tonnes of cowpea in 2021, mainly in sub-Saharan Africa (Nigeria 3,628,613 t, Niger 2,661,883 t, Burkina Faso 705,768, Kenya 250,260 t, and Senegal 239,194 t) (FAOSTAT 2023). In Senegal, climatic variability, the shortening or disappearance of fallow periods, and the intrinsically poor organic matter content of soils limit crop yields, threatening the food security of smallholders (Diatta et al. 2020a; Junior et al. 2023). It is therefore essential to propose solutions that will increase the sustainability of agricultural ecosystems without compromising productivity (Masso et al. 2017; Nath et al. 2023; Uebersax et al. 2023; Vanlauwe and Giller 2006).

Combining compost with inorganic fertilizers can be a good strategy to lower the demand for traditional mineral fertilizers and make the economy more circular (Razza et al. 2018). By using this method, the rate at which inorganic fertilizers are applied to the soil can be reduced, bringing financial benefits for smallholders, reducing the risk of soil deterioration and nutrient leaching while preserving soil quality. The aim of this study was to optimize the ratio between compost and inorganic fertilizer to maximize crop yield while reducing the amount of inorganic fertilizer used.

2 | Materials and Methods

2.1 | Soil Characterization

A greenhouse experiment with cowpea plants was conducted at Gaston Berger University experimental farm, Saint-Louis, Senegal (16°03′19.0″N 16°25′39.0″W). The soils used in this study are classed as Eutric regosols, which are poorly developed and frequently dry soils (Herrick et al. 2013). They have been under permanent fallow for over 25 years and consist of mainly of sandy loam soils (Table 1). They are highly vulnerable to drought and have a high base saturation in the subsoil and a limited water retention capacity and high permeability; on the other hand, their drainage allows for an optimal suitability for horticultural crops (Diatta et al. 2023b). The study site has a Sudano–Sahelian climate with two distinct seasons: a longer dry season (November to June) and a shorter rainy season (July to October). The research region is characterized by an average annual rainfall of 450 mm, average maximum temperatures of 37°C, and average minimum temperatures of 16°C.

TABLE 1 | Physical and chemical properties of soil and compost.

Parameters	Soil	Compost[a]
Clay (%)	8.25	—
Sand (%)	75.00	—
Silt (%)	16.75	—
Bulk density	1.526	—
Field capacity (cm^3 water/cm^3 soil)	0.156	—
pH (1:2.5)	8.23	7.03
Electrical conductivity (1:2.5) (mS cm^{-1})	0.269	5.920
Total carbon (%)	0.793	16.113
Total nitrogen (%)	0.124	5.755
C:N	6.395	2.800
Organic matter (%)	1.364	—
Available phosphorus (mg kg^{-1})	34.740	—
Exchangeable calcium (cmol kg^{-1})	2.625	1500.00
Exchangeable magnesium (cmol kg^{-1})	0.75	180.00
Exchangeable sodium (cmol kg^{-1})	0.155	29.90
Exchangeable potassium (cmol kg^{-1})	0.0728	46.41

[a]pH and EC cattle, sheep manure (1:5) materials: deionized water mixture on a volumetric basis.

2.2 | Compost

The compost used in this experiment was prepared at the National Center for Agronomic Research-Senegalese Institute of Agricultural Research (CNRA-ISRA) in Bambey (Senegal) using peanut shells, domestic waste, animal dung, crop residues (millet [*Pennisetum glaucum* L.] and maize straw). The crop residues and animal manure were collected from farms near the CNRA. The composting system, known as an improved composting system, compared to the traditional pile composting, comprises three boxes separated by 20 cm partitions and pits connected to the boxes to collect the leachate. Composting was carried out in open-air piles with periodic turning. The advantages of this system include continuous compost production, reduced labor involved in turning, control of the composting process, efficient water use and good leachate management, and the production of quality compost. Prior to employing the compost in the field trials, samples were taken from six different locations within the pile, combined, and analyzed.

2.3 | Soil and Compost Analysis

Randomly selected soil samples were taken from fields at a depth of 20 cm, and composite soil samples were air-dried in a dust-free glasshouse before being sieved to pass a 5-mm particle size diameter. The soil samples' physical and chemical characteristics (Table 1) were examined at the National Center for Agronomic Research-Senegalese Institute of Agricultural Research (CNRA-ISRA) in Bambey (Senegal). Soil texture was determined by measuring the fine fractions (clays and silts) by sedimentation and the coarse fractions (coarse, medium, and fine sands) by sieving on standardized screens. Field capacity and soil bulk density were determined as described by Gupta and Larson (1979) and Chopart (1980), respectively. Soil pH and electrical conductivity (EC) were determined as described by Mathieu, Pieltain, and Jeanroy (2003) while soil total C, total N, and available P were determined using Walkley and Black (1934), Olsen (1982), and Kjeldahl (1883) modified methods, respectively. The SOM was calculated using the formula SOM = carbon content × 1.72 (with 1.72 being the adapted van Bemmelen coefficient of cultivated soils) (Nelson and Sommers 1996).

2.4 | Experimental Design and Treatments

A randomized complete block design (RCBD) was used to arrange the experimental pots, with six replicates for each treatment. The analysis of variance (ANOVA) model (McIntosh 2015) for a RCBD with 10 treatment levels and 6 replications can be represented as:

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the observation for the k^{th} plot in the j^{th} block receiving the i^{th} treatment, μ is the overall population mean, τ_i is the effect of the i^{th} treatment group (i = 1, 2, ..., 10), β_j is the effect of the j^{th} block (j = 1, 2, ..., 6), $(\tau\beta)_{ij}$ is the interaction effect between the i^{th} treatment and the j^{th} block, and ε_{ijk} is the random error term for the k^{th} plot in the j^{th} block receiving the i^{th} treatment

The treatments were as follows:

1. Control
2. Recommended rate of inorganic fertilizer (150 kg NPK ha^{-1})
3. Compost 2.5 t ha^{-1} (one-half-fold of recommended dose)
4. Compost 5 t ha^{-1} (recommended dose)
5. Compost 7.5 t ha^{-1} (three-halves-fold of recommended dose)
6. Compost 10 t ha^{-1} (twofold of recommended dose)
7. One-half-fold of recommended dose of compost + one-half-fold of recommended dose of NPK
8. Recommended dose of compost + one-half-fold of recommended dose of NPK
9. Three-halves-fold of recommended dose of compost + one-half-fold of recommended dose of NPK
10. Twofold of recommended dose of compost + one-half-fold of recommended dose of NPK

The cowpea seeds (var. Yacine) used in this experiment were supplied by the Faculty of Agronomy, Aquaculture, and Food

TABLE 2 | Experimental treatments.

No.	Treatment	Application rate
Control	Control	$0.0\,t\,ha^{-1}$
CP2.5	Compost	$2.5\,t\,ha^{-1}$
CP5.0	Compost	$5.0\,t\,ha^{-1}$
CP7.5	Compost	$7.5\,t\,ha^{-1}$
CP10	Compost	$10\,t\,ha^{-1}$
NPK150	NPK: 6–20-10	$150\,kg\,ha^{-1}$
CP2.5 + NPK75	Compost + NPK	$2.5\,t\,ha^{-1} + 75\,kg\,ha^{-1}$
CP5.0 + NPK75	Compost + NPK	$5.0\,t\,ha^{-1} + 75\,kg\,ha^{-1}$
CP7.5 + NPK75	Compost + NPK	$7.5\,t\,ha^{-1} + 75\,kg\,ha^{-1}$
CP10 + NPK75	Compost + NPK	$10\,t\,ha^{-1} + 75\,kg\,ha^{-1}$

Technology at Gaston Berger University. The fertilization treatments included the control treatment with no fertilizer, inorganic fertilizer ($150\,kg\,ha^{-1}$ of NPK 6-20-10), four rates of compost (2.5, 5, 7.5, and $10\,t\,ha^{-1}$), and a mixture of organic amendments and inorganic fertilizers (Table 2). The rate of NPK (6-20-10) was supplied at the recommended rate of $150\,kg\,ha^{-1}$. As for compost, the rate of $5\,t\,ha^{-1}$ was used as the recommended dosage based on earlier Senegalese research on soil enhancement, yield growth, and farmer acceptance (Badiane et al. 2001; Coly et al. 2021; Diatta et al. 2023a; Faye et al. 2021). Prior to seeding, the compost was allowed to equilibrate for 7 days in the pots, watered with river water, and kept at 80% of field capacity. The river water is characterized by pH (1:2.5) of 6.35, CE (1:2.5) ($\mu s\,cm^{-1}$) of 8.41, exchangeable Ca ($mg\,kg^{-1}$) of 105.00, exchangeable Mg ($mg\,kg^{-1}$) of 18.00, exchangeable Na ($mg\,kg^{-1}$) of 24.15, and exchangeable K ($mg\,kg^{-1}$) of 3.82. The experimental pots were filled with 2.750 kg of soil on which the corresponding nutrient source was uniformly applied and incorporated at approximately 15 cm in each pot as per fertilization treatment. To avoid loss of soil, a polythene bag was used at the bottom of each plastic pot. Two seeds were sown in each pot, and during the experiment, a standardized gravimetric technique of daily pot weighing (twice daily) was used to regulate watering regimes and progressively reach 80% of field capacity. The cowpea plants were thinned to one plant per pot after 1 week of seedling emergence. All treatments, except for those using compost and fertilizer, used comparable crop cultural methods throughout the growth cycle.

2.5 | Data Collection

To compare foliar chlorophyll concentrations between fertilization methods, readings from a Soil Plant Analysis Development (SPAD)-502 chlorophyll meter (Konica Minolta Sensing Americas, Inc.) were taken on the third leaf from the top at various stages, including sowing, vegetative growth, flowering, pod development, and maturity. Spectral reflectance, especially between the red and infrared wavelengths, is a rapid and nondestructive way to measure leaf chlorophyll concentration and N content since they are closely connected (Gitelson, Gritz, and Merzlyak 2003). The SPAD values correlate positively with grain production, growth, and chlorophyll content and are used as a vegetative index in cowpea. At maturity, the plant's height, stem diameter, and number of branches were measured. Following these evaluations, cowpea pods were manually harvested every week until all fully developed pods were removed from the plants. At harvest, the pod length, number of pods, number of seed pod^{-1}, and number of seed $plant^{-1}$ were collected. The dry matter of the seeds from each plant during harvest was used to determine seed yield, and seed yield per plant was also calculated.

2.6 | Statistical Analyses

The growth, yield, and components of the yield of cowpea plants were statistically examined using the 2022 JMP Statistical Discovery LLC SAS JMP Pro version 15.0.0 statistical software (SAS Institute Inc., Carey, North Carolina, United States). The effects of the fertilization treatments were examined using the ANOVA model presented in Section 2.4 (Gomez and Gomez 1984) on plant height, stem diameter, root length, number of nodules, SPAD values, number of pods $plant^{-1}$, length of pods, number of seed pod^{-1}, number of seed $plant^{-1}$, and seed yield. Fisher's protected Least Significant Difference (LSD) was employed for mean separation when treatment differences were noted at the = 0.05 significance level.

3 | Results

3.1 | Plant Growth

The growth obtained in compost-treated soils, either alone or in combination with inorganic fertilization, was significantly different ($p \leq 0.05$) from soils treated with the recommended dose of mineral fertilizer (Figures 1–3). Plant height significantly ($p \leq 0.05$) varied in response to organic and synthetic fertilizer addition (Figure 1). The tallest plants were observed in the treatments CP2.5 + NPK75 and CP10 + NPK75, both of which recorded 26.88 cm, corresponding to a 38% increase over plants treated with inorganic fertilizers (Figure 1). They are followed by CP5.0 and CP5.0 + NPK75 treatments with plants recording 26.75 and 26.38 cm, respectively.

Stem diameter followed a similar pattern to that of plant height (Figure 2). The highest stem diameter (9 cm) was obtained when 50% of the recommended rate of inorganic fertilization was combined with the addition of $5\,t\,ha^{-1}$ compost, while fertilized plants with NPK recorded only 5.88 cm (Figure 2). Regardless the type of combination used, stem diameter was always greater than values obtained with mineral fertilization, although the differences were not always statistically significant ($p > 0.05$).

In terms of root growth, plants receiving CP10 alone showed the lowest length (16.50 cm) (Figure 3), but this was not statistically different from CP5.0 + NPK75 and CP10 + NPK75 ($p > 0.05$). Few differences in root length were observed between the other treatments, although plants in the CP7.5 + NPK75 treatment showed the greatest length with 31.00 cm (Figure 3). They were followed by plants fertilized with NPK with 26.50 cm.

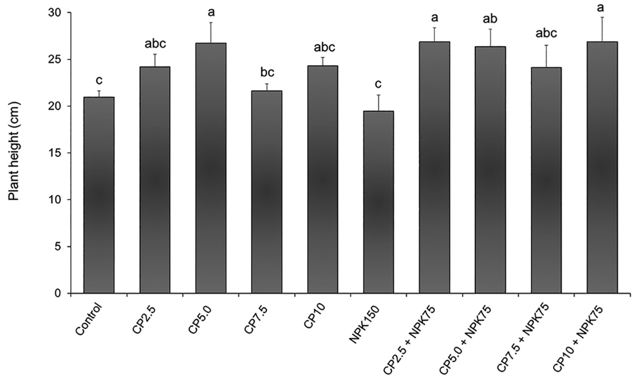

FIGURE 1 | Effects of compost, inorganic fertilizers, and compost-NPK combination on plant height of cowpea. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent standard error of the mean (n = 60).

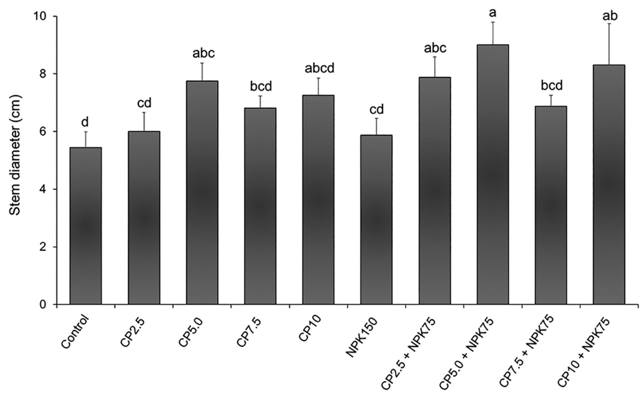

FIGURE 2 | Effects of compost, inorganic fertilizers, and compost-NPK combination on stem diameter of cowpea. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent standard error of the mean (n = 60).

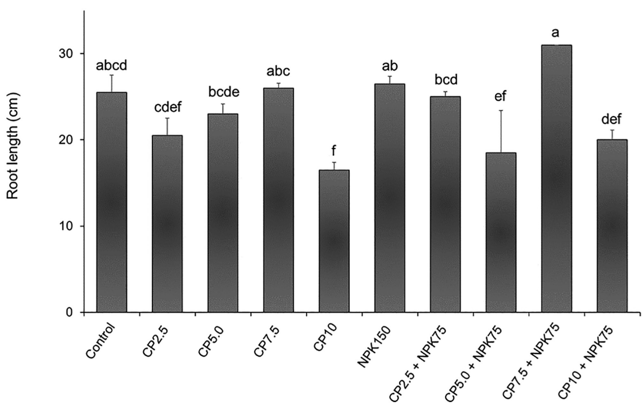

FIGURE 3 | Effects of compost, inorganic fertilizers, and compost-NPK combination on root length of cowpea. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent standard error of the mean (n = 60).

As expected, unfertilized plants produced the significantly highest number of nodules with 106.50 per plant, while the application of inorganic fertilizer alone produced 57.50 nodules

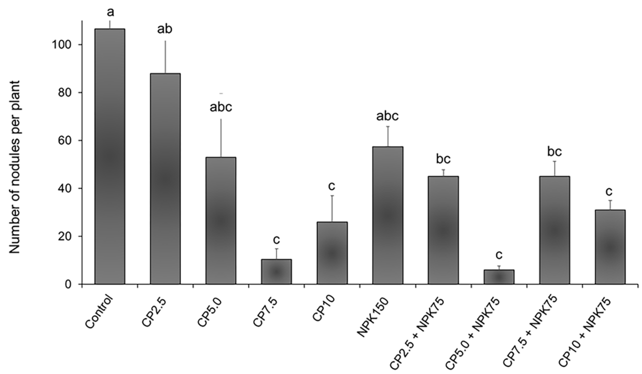

FIGURE 4 | Effects of compost, inorganic fertilizers, and compost-NPK combination on nodule number of cowpea. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent standard error of the mean (n = 60).

(Figure 4). The results showed that the number of nodules decreased when the compost rate was increased and used alone, reaching 10.50 (Figure 4). When mineral fertilization was combined with compost, the number of nodules averaged 31.75 and was significantly different from that of NPK-fertilized plants.

3.2 | Yield Components

The effect of compost, inorganic fertilization, and their combination on cowpea yield components was assessed at harvest by measuring pod length (centimeter), number of pods per plant, number of seeds per pods, and number of seeds per plant. The pod length of plants amended only with compost at 10 t ha^{-1} was significantly higher than that of the other treatments (Table 3). This corresponds to an increase of 23% compared with plants fertilized only with NPK. The CP10 treatment was followed by CP7.5 + NPK75 and CP10 + NPK75 with 14.5 and 13.8 cm, respectively.

As shown in Table 3, NPK fertilization and its combination with compost at 7.5 and 10 t ha^{-1} significantly promoted pod production per plant, with eight pods per plant, on average. However, these treatments were not significantly different from NPK-fertilized plants, which produced the same number of pods per plant. Control plants exhibited the significantly lowest values of number of pods per plant at harvest compared with other treatments. In general, the combined use of compost and mineral fertilizer produced a greater number of pods than use of compost alone (Table 3).

The number of seeds per pod and number of seeds per plant followed a similar pattern to the number of pods per plant. Plants fertilized with 50% of the recommended dose of synthetic fertilizer and 7.5 and 10 t ha^{-1} of compost always recorded significantly higher values than other treatments for number of seeds per pod and number of seeds per plant, with 7 and 56, respectively (Table 3). They were always followed by NPK-fertilized plants, which produced 6 seeds per pod and 48 seeds per plant. The absence of organic and mineral fertilizers (control) reduced these parameters and gave the significantly lowest values in this study (Table 3).

TABLE 3 | Effects of compost, inorganic fertilizers, and compost-NPK combination on pod length number of pods/plant, number of seeds/pod, and number of seeds/plant of cowpea.

Treatments	Pod length (cm)	Number of pods/plant	Number of seeds/pod	Number of seeds/plant
Control	12.3[a]e	3f	5c	15g
CP2.5	11.6g	5d	6b	30d
CP5.0	12.2f	4e	4d	16f
CP7.5	11.5h	5d	4d	20e
CP10	15.0a	7b	6b	42c
NPK150	12.2f	8a	6b	48b
CP2.5 + NPK75	13.3d	6c	5c	30d
CP5.0 + NPK75	11.1i	5d	4d	20e
CP7.5 + NPK75	14.5b	8a	7a	56a
CP10 + NPK75	13.8c	8a	7a	56a

Note: Means within column, followed by different letters, are significantly different (Fisher's protected LSD, $p = 0.05$).
[a]Each value is the mean of six replicates.

TABLE 4 | Effects of compost, inorganic fertilizers, and compost-NPK combination on fresh and dry biomass of cowpea.

Treatments	Root fresh weight (g)	Stem fresh weight (g)	Leaf fresh weight (g)	Root dry weight (g)	Stem dry weight (g)	Leaf dry weight (g)
Control	5.685[a]abcd	11.16a	34.20a	1.19bc	1.97a	4.40a
CP2.5	6.05abc	8.46a	29.91a	1.10bcd	1.36a	5.16a
CP5.0	3.35cd	5.01a	23.91a	0.65d	0.94a	3.22a
CP7.5	3.595cd	11.56a	40.09a	0.86cd	1.74a	6.42a
CP10	3.98cd	6.82a	23.64a	0.85cd	1.29a	3.28a
NPK150	6.97ab	11.88a	33.95a	1.43ab	2.41a	4.62a
CP2.5 + NPK75	4.82bcd	9.31a	36.26a	1.035bcd	1.73a	5.20a
CP5.0 + NPK75	2.94d	7.37a	34.42a	0.715cd	1.13a	5.93a
CP7.5 + NPK75	8.23a	12.08a	48.32a	1.935a	2.30a	5.97a
CP10 + NPK75	4.475bcd	8.43a	32.76a	0.905bcd	1.59a	4.17a

Note: Means within column, followed by different letters, are significantly different (Fisher's protected LSD, $p = 0.05$).
[a]Each value is the mean of six replicates.

Comparing the effects of the combined compost and inorganic fertilizer treatments on cowpea yield components, Table 3 shows that the highest values were obtained with CP7.5 + NPK75 and CP10 + NPK75 for pod length (14.15 cm, on average), number of pods per plant (8), number of seeds per pod (7), and number of seeds per plant (56), followed by CP2.5 + NPK75. The combined application of compost at 5 t ha^{-1} and 75 kg ha^{-1} NPK recorded the lowest values among the combined treatments. Although CP5.0 + NPK75 recorded the lowest values among the combined treatments, it recorded higher values than the recommended rate of inorganic fertilizers, except for cowpea pod length.

3.3 | Fresh and Dry Biomass

The effects of the combined use of compost and inorganic fertilizers on cowpea biomass were determined at harvest by measuring fresh and dry root, stem, leaf, and total biomass. Table 4 and Figure 5 show that plants in the CP7.5 + NPK75 treatment recorded the highest fresh and dry biomass values with 68.625 g and 10.205 g, respectively, although they were not statistically different from plants receiving inorganic fertilizers. As for root biomass, CP7.5 + NPK75 (8.23 and 1.935 g) exhibited the highest dry and fresh biomass than other treatments, although significant differences with the NPK (6.97 and 1.43) treatments were not found ($p > 0.05$) (Table 4).

The total fresh and dry biomass of cowpea is shown in Figure 5. The biomass of plants amended with compost or inorganic fertilizer alone was similar to that of plants grown with a combination of compost and inorganic fertilization. However, the biomass harvested from CP7.5 + NPK75 and NPK treatments was greater than biomass from other treatments. For compost alone or inorganic fertilizer treatments, the total fresh and dry biomass was

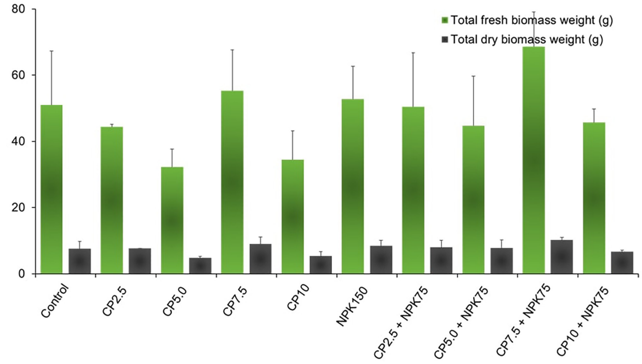

FIGURE 5 | Effects of compost, inorganic fertilizers, and compost-NPK combination on fresh and dry biomass of cowpea. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected LSD, and error bars represent standard error of the mean ($n = 60$).

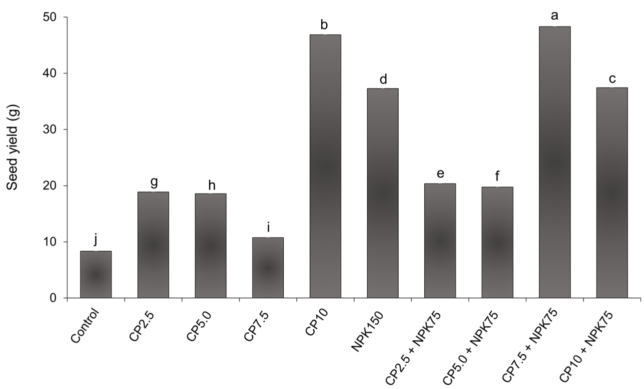

FIGURE 6 | Effects of compost, inorganic fertilizers, and compost-NPK combination on seed yield of cowpea. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected LSD, and error bars represent standard error of the mean ($n = 60$).

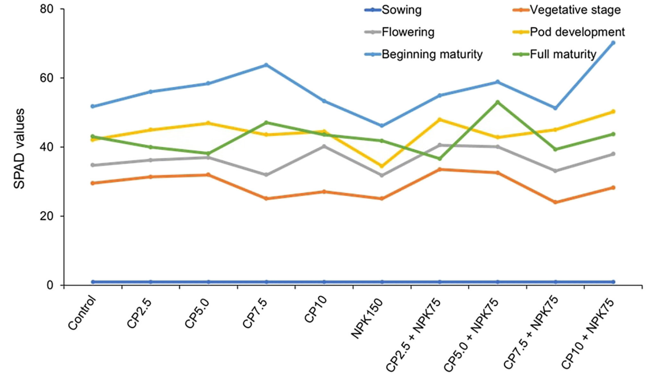

FIGURE 7 | Effects of compost, inorganic fertilizers, and compost-NPK combination on mean SPAD values of cowpea at sowing, vegetative stage, flowering, pod development, beginning maturity, and full maturity. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected LSD, and error bars represent standard error of the mean ($n = 60$).

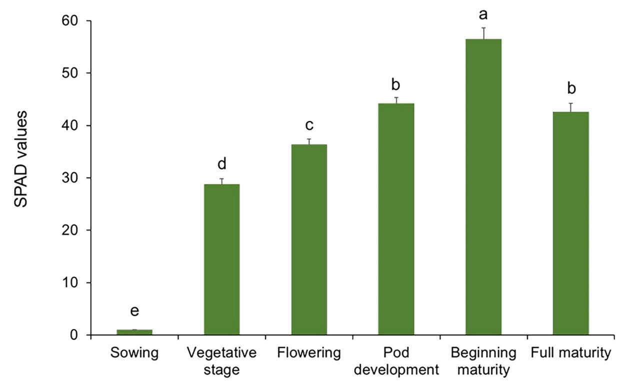

FIGURE 8 | Variations of mean SPAD values of cowpea at sowing, vegetative stage, flowering, pod development, beginning maturity, and full maturity. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected LSD, and error bars represent standard error of the mean ($n = 60$).

similar to that of plants grown in soils treated with combined organic and inorganic fertilization (Figure 5). Although no significant differences were found between treatments, analysis of the figure shows that combined use of organic and mineral fertilization improved biomass production compared with the use of compost alone.

3.4 | Yield

Cowpea seed yield differed significantly between fertilization treatments (Figure 6). As shown in Figure 6, the seed yield of plants grown in soils amended with compost at 7.5 t ha^{-1} and 50% of the recommended rate of inorganic fertilizer (CP5.0 + NPK75) increased significantly compared to other treatments. They recorded a 30% increase compared with plants fertilized with the recommended dose of NPK. Figure 6 shows that CP7.5 + NPK75 treatment is followed by CP10 and CP10 + NPK75, which recorded 46.85 and 37.45 g, respectively. Analysis of the figure also revealed that plants fertilized with the combination of compost and inorganic fertilizer produced the highest yield compared with the single application of compost. The average seed yield of plants amended with compost is 23.76 g while the combined use of organic and mineral fertilization yielded 31.47 g. The lowest seed yield was observed for control plants which had 8.33 g.

3.5 | SPAD Values

The SPAD-502 chlorophyll meter readings were collected on cowpea plants at sowing, during vegetative growth, at flowering, during fruit formation, and at maturity stages. No differences were observed among fertilization treatments: Cowpea showed similar SPAD values throughout the growing cycle (Figure 7). Although no differences were observed, CP2.5 + NPK75 treatment recorded the highest values at vegetative (34) and flowering (41) stages (Figure 7). At pod development and beginning maturity, plants in the CP10 + NPK75 treatment gave the highest values with 50 and 70, respectively, while CP5.0 + NPK75 treatment produced the highest values with 53 (Figure 7). Compared with sole addition of compost, the combined application of compost and mineral fertilization appeared to increase SPAD values.

With regard to variations in SPAD values according to growth stages, the figure shows that the mean values were significantly different ($p < 0.05$) (Figure 8). From the vegetative development stage (28.83) until the beginning of maturity, SPAD values grew steadily, reaching 56.47, before declining to 42.62 at full maturity. Values recorded at beginning of maturity correspond to an increase of 55% and 28% compared with the flowering and pod development stages.

4 | Discussion

The substantial use of synthetic fertilizers in modern agriculture has significantly enhanced crop yields but has led to the disruption and contamination of the natural agroecosystem. Therefore, combining inorganic fertilizers with organic amendments such as compost may be a viable and sustainable strategy for increasing crop yields while protecting the environment. We evaluated the effects of NPK fertilizers and compost alone and in combination on cowpea growth parameters such as plant height (Figure 1), stem diameter (Figure 2), and root length (Figure 3) to optimize the ratio between organic and inorganic fertilizers. Our results showed that cowpea plants amended with compost alone or in combination with 50% of the recommended rate of mineral fertilizers had higher plant height and stem diameter but not a greater root length than the addition of inorganic fertilization alone. Application of CP2.5 + NPK75, CP10 + NPK75, CP5.0, and CP5.0 + NPK75 resulted in significantly higher plant height (39% increase, on average) compared to inorganic fertilization, while plants amended with CP5.0 + NPK75 and CP10 + NPK75 resulted in 47% increase in stem diameter. These results show that sustained plant growth can be obtained when organic amendments are combined with the reduced rate of inorganic fertilizers compared to standard mineral fertilization.

They are also consistent with those reported for maize (Situmeang et al. 2015), millet (Coly et al. 2021), mungbean (Diatta et al. 2023a), sorghum (*Sorghum bicolor* L.) (Sher et al. 2022), soybean (Almaz, Halim, and Martini 2017), and rice (*Oryza* sp.) (Kavitha and Subramanian 2007).

The observed increase in plant growth under the combined application of compost and inorganic fertilizer can be attributed to the readily available nutrients from inorganic fertilizers during the early stages of plant development and the continued availability of nutrients in forms available for plant uptake from compost in the later stages (Ripoche et al. 2015).

Enhanced plant growth after compost application has been associated with improved soil physical properties, such as reduced bulk density, improved infiltration and hydraulic conductivity, and increased water content and plant-available water (Kranz et al. 2020; Nath et al. 2023). Therefore, the combination of compost and a lower concentration of 50% mineral fertilizer can be a viable optimization ratio.

It is well documented that nodule number is positively correlated with N fixation (Mohammadi et al. 2012), and that legume crops that fix the most N_2 tend to derive less N from the soil (Diatta et al. 2020c; Peoples et al. 2009; Unkovich et al. 2008). It is therefore not surprising that unfertilized plants have the highest number of nodules compared to other treatments. It is worth noting that treatments that promoted plant growth, such as CP2.5 + NPK75, CP10 + NPK75, and CP5.0 + NPK75, had the lowest number of nodules (Figure 4). Heath, Stock, and Stinchcombe (2010) also reported that the presence of available N inhibits the number of associations (nodules) with rhizobia for legume plants. Therefore, the low number of nodules for the combined use of compost and synthetic fertilizer can be attributed to the greater availability of nutrients, particularly N. Based on these results, it can be concluded that combined application of organic and inorganic amendments can potentially increase nutrient availability, particularly N, compared to the sole addition of inorganic fertilizer.

The combination of compost and synthetic fertilizer increased cowpea growth and produced greater pod length, number of pods per plant, number of seeds per pod, and number of seeds per plant than synthetic fertilizers (Table 3).

Similarly, Olusegun (2014) combined pig manure ($8\,t\,ha^{-1}$) with NPK (60 kg NPK) and found significant increase in the number of pods per plant and number of seeds per cowpea pod compared with inorganic fertilizer application alone. Almaz, Halim, and Martini (2017) noted similar values in soybean for number of pods per plant and number of seeds per pod when comparing 50% NPK + 100% poultry manure and 100% NPK treatments. The greater effect of the integrated use of an organic amendment and an inorganic fertilizer compared to the sole application of mineral fertilizer is due to the improved physical and chemical properties as well as the balanced and extended supply of nutrients (Ripoche et al. 2015). Research has shown that the combined use of fertilizers and organic manure can improve several key aspects of crop development, including nitrogen use efficiency (NUE), macro- and micronutrient recovery, and P and K availability, all of which contribute to improved soil fertility (Eichler-Löbermann, Köhne, and Köppen 2007; Zhang et al. 2016). In addition, Siddiqui et al. (2011) found that compost added beneficial microorganisms, essential micronutrients, and other bioactive compounds, while inorganic fertilizers provided the major nutrients in the combined use of compost and organic fertilizer.

Although the combined application of organic and inorganic amendment has been reported to increase plant growth and biomass production, no significant differences were found for fresh and dry stem, leaf, and total biomass of cowpea, except for root biomass in the present study (Table 4). In contrast with our results, Mohammadi et al. (2012) noted that the combined application of organic amendments and inorganic fertilizers increased biomass production and improved water quality. Several authors reported that the combined application of organic and inorganic fertilizers improved soil microbial population, soil organic matter, and structural stability, all of which promote plant growth and subsequent biomass production (Hernández et al. 2014). The increase in biomass because of organic and inorganic fertilizer applications has been attributed to the availability and release of plant nutrients, thus contributing to soil quality. It has also been shown that the enhanced biomass production can be attributed to the increase in soil–water holding capacity, porosity, soil aeration, SOM, and aggregate stability, as well as to the reduction of bulk density. These results suggest that the combined use of organic and inorganic fertilizers is a better alternative for increasing crop biomass compared to the sole application NPK fertilizer.

The increase in cowpea yield under combined application of compost and NPK was due to the increase in the number of pods per plant, number of seeds per pod, and number of seeds per plant. According to Almaz, Halim, and Martini (2017), the increase in yield components can be attributed to a balanced supply of nutrients to crops throughout the crop growth period, as organic amendments undergo decomposition, during which a series of nutrient transformation phases take place. Enhanced nutrient supply and greater mineralization of nutrients from organic amendments will ultimately lead to improved crop growth, biomass production, and seed yield. Soil improvement following organic amendment can be attributed to the organic matter that compost added to the soil, increasing its organic matter load as well a higher concentration of certain water-soluble nutrients (K, P, Ca, Mg, and S) (Almaz, Halim, and Martini 2017; Olusegun 2014). Clarholm, Skyllberg, and Rosling (2015) and Ros et al. (2011) explained that the mineralization process of soil organic matter gradually releases nutrients.

Consequently, long-term applications of organic matter increase the chemical fertility of the soil by increasing the amount of C_{org} and N content, as well as the amount of K and P that can be extracted from the soil. Other benefits include reduced leaching of N into groundwater, as N from organic amendment can be sequestered for mineralization in subsequent cropping seasons.

In comparison with similar studies carried out in Africa, the combined application of compost with the reduced rate of the recommended rate (mainly 50%) of inorganic fertilizers improved the productivity of legume crops compared with the recommended rate of inorganic fertilizers. The study conducted by Issoufa, Ibrahim, and Abaidoo (2020) showed that the combined use of compost applied at 8 t ha^{-1} and 50% of the recommended rate of synthetic fertilizer increased cowpea yield by 51% compared to the application of 100% of the recommended rate of synthetic fertilizer, probably due to increase in rainwater use efficiency. In Niger, the highest cowpea yields of 360.5 and 389 kg ha^{-1} resulted from the application of 2.5/5 t ha^{-1} compost + 75 kg ha^{-1} DAP, representing 78% and 257% compared to the recommended rate which is 200 kg ha^{-1} for NPK (15-15-15) and 100 kg ha^{-1} for DAP (18-46-0) (Abdou et al. 2016). Some et al. (2016) added phosphate (2 t ha^{-1}) to compost (3 t ha^{-1}) and manure (3 t ha^{-1}) in Burkina Faso and reported increase in the yields of cowpea by 70%–80% compared to sole compost and manure applications, attributable to the positive influence of organo-mineral intakes on soil biological activity. These results underline the potential for improving cowpea productivity by incorporating locally sourced organic compost with half the recommended dose of synthetic fertilizer. These results also imply that smallholder farmers can adopt this integrated approach to counter declining soil fertility, improve nutrient availability, and increase cowpea grain yield.

Compost application has been reported to increase leaf N concentration through enhanced uptake of macro- and micronutrients. However, differences were not found between the recommended rate of inorganic fertilizer, the sole application of compost, and the combination of compost with 50% of conventional inorganic fertilizer rates (Figure 7). It is worth noting that all the combination treatments had a numerically higher SPAD value than the recommended rate of NPK, demonstrating the potential of combined use to increase chlorophyll concentration in plants. Several studies have reported that the application of organic matter increases the amount of chlorophyll, thus improving the efficiency of plant photosynthesis (Badar et al. 2015; Diatta et al. 2023a; Du et al. 2020; Ginting et al. 2003).

The absence of any significant difference between NPK alone and the combined use of compost and 50% of NPK suggest that compost-NPK combination leads to the same effects when used as a replacement for mineral fertilizers. We can therefore conclude that the amount of N released from the composts through mineralization of the organic matter and readily available N from inorganic fertilizer could be sufficient to meet plant N requirements, since all treatments produced SPAD values comparable to or higher than those obtained with inorganic fertilization. Regarding variations in mean SPAD values for cowpea at different growth stages (Figure 8), our results showed that there was a gradual increase from sowing to beginning maturity, followed by a decrease at full maturity. This is consistent with previous research, as illustrated by Kandel (2020) who observed significant differences in SPAD value for maize at different ages, with a reported increase in age and decrease at the time of maturity.

5 | Conclusion

Declining soil organic matter and decline in soil fertility in Senegal underscore the critical need for strategies to replenish soil organic carbon for field crop production. The evolution of soil fertility in the Senegal agricultural system shows that soil organic matter management could be an essential component in preventing soil deterioration. To this purpose, Senegal's national agricultural research systems have focused on composting as a method of increasing soil quality and crop productivity. This study provides evidence for the optimal ratio of inorganic and organic fertilizers for cowpea. We found that combining compost (7.5 t ha^{-1}) with inorganic fertilizers (75 kg NPK ha^{-1}) can potentially increase long-term soil quality and crop production when compared to using inorganic fertilizers alone. According to our results, applying 5 or 7.5 t of compost and 75 kg of NPK ha^{-1} enhanced most of growth and yield parameters, as well as the seed yield. This suggests that farmers might reduce the amount of inorganic fertilizer required by 50% while still producing a yield comparable to or greater than the recommended rate of inorganic fertilizer. To understand the long-term consequences of their use, more study is needed to investigate the impacts of compost and inorganic fertilizers on agricultural production over a greater region and over multiple growing seasons. Furthermore, there is a need for broad and ongoing agricultural extension to encourage farmers to make and utilize compost. Overall, compost application can reduce the amount of inorganic fertilizers required for crop production while also reducing environmental pollution.

Author Contributions

Andre A. Diatta: conceptualization, data curation, formal analysis, methodology, supervision, validation, visualization, writing–original draft. **Ghislain Kanfany:** investigation, validation, writing–review and editing. **Boubacar Camara:** investigation, validation, writing–review and editing. **César Bassène:** conceptualization, methodology, supervision, writing–review and editing. **Anicet G. B. Manga:** conceptualization, methodology, supervision, writing–review and editing. **Mahmoud Seleiman:** validation, writing–review and editing. **Cheikh Mbow:** validation, writing–review and editing. **Calogero Schillaci:** data curation, investigation, validation, visualization, writing–review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

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