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Use of Eco-friendly fertilizers in sandy soils and its effect on productivity and quality of cowpea crop in Egypt

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LOW ORGANIC matter is one of the main challenges facing successful agricultural production in Egyptian sandy soils. Therefore, adding eco-friendly fertilizers can help to increase fertility in the sandy soil, increase the growth and productivity of crops. This research looked at the effects of biochar, vermicompost, and mix on productivity, quality, and economic profitability of cowpea in sandy soils during two growing seasons (2023 and 2024). The Mixture treatment had the best productivity, with grain yields of 1.06 tons/fed and straw yields of 4.58 tons/fed in 2024, as well as the highest harvest index (20.05%). Nutritional composition assessments revealed considerable gains in macronutrient concentrations, with the Mixture having the highest nitrogen (4.07%), phosphorus (0.65%), and potassium (2.37%) levels in grains. Furthermore, grain quality was significantly improved; the Mixture (50:50) had the highest protein content (25.44%), total carbohydrates (55.79%), and oil content (3.36%) in 2024, outperforming all other treatments. Economic research revealed that the mixture had a higher net income of 20,200 L.E. than vermicompost (17,600 L.E.) and Biochar (18,440 L.E.). These enhancements are related to the complementing actions of biochar and vermicompost. Biochar improves soil physical qualities such as water retention and aeration, whilst vermicompost offers a rich supply of nutrients and promotes microbial activity. The results highlight the potential for organic amendments to increase crop yield, quality, and economic returns in nutrient-deficient sandy soils. This strategy is consistent with sustainable agricultural principles. So, more studies are needed to investigate long-term impacts in various agro ecosystems.

Keywords: Biochar; Cowpea; Mixture; Quality; Sandy soil; Vermicompost.

Introduction

Cowpea (*Vigna unguiculata* L.) is a big protein-rich food legume utilized by humans and animals. Cowpea is a significant legume, particularly in hot, dry, and subtropical climates. It is notably rich in protein (25%) and fat (1.9%), fiber (6.3%), and carbohydrates (63.6%). It also produces a versatile crop that may be utilized as both a leafy and grain legume. It is a high-quality crop for fattening sheep and cattle, and it is also recommended for milking cows (Chatterjee and Bandyopadhyay 2017 and El-Kassas *et al*., 2017).

Cowpea is well-suited to the Egyptian summer climate. In 2018, the total planted area of this crop in Egypt was projected to be 9155 for dry seed production, with an average yield of 980 kg/fed., (fed =2400 m^2). Providing fodder for animals is one of the world's most difficult tasks, especially when demand rises in tandem with global population growth. Furthermore, one of the criteria of sustainable agriculture is to improve soil productivity and preserve its fertility, which is a significant issue, particularly given the considerable human activity on soil (Abdel Aziz *et al*., 2024 and Essa *et al*., 2021).

The eco-friendly fertilizers allow for long-term soil carbon storage, which has potential benefits for agricultural sustainability such as increased productivity, reduced environmental impacts, water retention, and improved soil fertility through their effects on soil physicochemical and biological properties (Aynehband, *et al*., 2017 and Ammar *et al*., 2023). In a study by Liang *et al*., (2024), they found that the co-application of biochar and manure is a long-term viable strategy to improve productivity of acid soil due to its soil pH improvements, organic carbon, nutrient retention, and availability. Biochar promotes soil moisture retention and aeration, and it also attracts soil microbes.

Organic materials contribute to reducing waste volume and producing an end product enriched with nutrients. This process is called composting. This source of energy is used in agricultural activities due to its positive impact on the soil's physical and chemical properties, such as its ability to store carbon, thus reducing global warming, and improving porosity, structure of the soil, thereby increasing its ability to retain water (Mohammed *et al*., 2024).

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The addition of biochar to agricultural fields increases crop output to a reasonable level. Biochar decreases soil acidity and improves nutrient retention. Mixing biochar with diverse soils, manure, or compost improves crop soil efficiency, decreases manure application, and prevents nutrient loss (El-Naggar *et al*., 2019 and Tian *et al*., 2021).

Biochar is a relatively new idea with potential applications in bioenergy generation, soil fertility, and agricultural yield. Other possible advantages include reduced nitrate leaching, adsorption of pollutants like arsenic and copper from soils, and a decrease in trace gas emissions from soil. Biochar has gained popularity in recent years due to its unique property of high water adsorption, which makes it an effective soil supplement. Biochar fertilizers enhance the adsorption sites, which will retain supplied inorganic nutrients. (Saletnik *et al*., 2019; Sayed *et al*., 2020 and Noreldin *et al*., 2024).

Biochar is a fine-grained, carbon-rich charcoal created by the pyrolysis of biomass in a low-oxygen environment, which improves soil fertility. It is known for having a high cation exchange capacity and being naturally alkaline. Overall, it has various good impacts on soil characteristics, including promoting microbial growth, reproduction, and minimizing soil nutrient loss (Liu *et al*., 2016 and Soud *et al*., 2023).

Fazal *et al*., (2023) found that applying biochar boosted mungbean production and quality while also increasing soil organic matter. Biochar has a high water-holding capacity in soil, with biochar outperforming biochar-free soil. Vermicompost, for example, is a well-known biological process that converts organic waste into nutrient-rich fertilizer. Vermicomposting is an organic waste breakdown technique that utilizes earthworms to help in waste stabilization. This method comprises a symbiotic interaction between earthworms and microorganisms that results in a stable, homogeneous, humus-like product known as vermicompost (Singh and sukul 2019 and Cirka *et al*. , 2022).

Vermicompost may improve soil fertility in many ways, including physical, chemical, and biological. Physically, vermicompost-treated soil has improved aeration, porosity, and moisture retention. Chemical qualities such as pH, electrical conductivity, and organic matter content are also enhanced to increase crop output (Lim *et al*., 2014 and Dey Chowdhury *et al*., 2023).

Vermicompost is gaining popularity as a combination with biochar fertilizers to maintain and increase soil quality. As a result, the current research aims to offer evidence that adding biochar and vermicompost fertilizers improves cowpea crop productivity under sandy soil conditions Ding *et al*., 2021). In a study by Essa *et al*., (2023) they found that adding a mixture of biochar and vermicompost fertilizers could be an alternative for improving wheat productivity and quality metrics in sandy soil environments.

Therefore, against this backdrop, this study was conducted to study the effect of adding biochar, vermicompost, eco-friendly fertilizers, and their mixture on the yield and quality of cowpea crops in sandy soil.

Material and Methods

Experimental Site

In Wadi El-Natroun (30.58°N; 30.33°E), El-Behaira, Egypt, two field experiments were carried out in the summers of 2023 and 2024 to investigate the impact of applying fertilizers made of vermicompost and biochar on cowpea quality and productivity on sandy soils.

Soil Sample and Analysis

To ascertain the physical and chemical properties, a representative soil sample (0–30) was collected from the experimental field before to each season's planting. The physical and chemical characteristics of the soil and the chemical analysis of irrigation water are shown in Tables 1 and 2 using the Carter and Gregorich technique (2008).

Table 1. Physical and chemical properties of the experimental site before sowing.

Particle size distribution (%)		Chemical analysis		NPK (mg/kg)	
Clay	3.60	pH (1:2.5)	7.80	N	23.00
Silt	6.10	EC dSm^{-1} (1:5)	0.56	P	3.90
Fine sand	21.70	$CaCO_3$ (%)	2.58	K	55.00
Coarse sand	68.60	O.M (%)	0.06		
Texture class	Sandy				

Table (2): Chemical analysis of irrigation water used**.**

pH	EC dSm^{-1}	Soluble cations (mg/L)				Soluble anions (mg/L)			
		K^+	Na^+	Mg^{2+}	Ca^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
7.82	0.80	2.20	4.12	5.40	7.20	0.00	4.90	0.60	13.42

Preparation of biochar and vermicompost

Biochar was produced from olive wood obtained from olive pruning. Physical contaminants were eliminated, and the material was milled to a consistent size before undergoing oven drying. Pyrolysis was conducted in an automated furnace at a temperature range of 350–400 °C, with residence duration of 1 hour and a continuous heating rate. For vermicomposting, an effective technique for transforming various organic wastes into nutrient-dense vermicompost depends on the meticulous management of source materials.

Organic wastes, typically safe for earthworms, may be used directly as fuel in vermicomposting beds, yielding high-quality vermicompost. However, certain feedstocks may include volatile gases that may be harmful to earthworms and have excessive moisture, necessitating comprehensive pre-treatment to assure earthworm safety and quality. Pre-treatment strategies in the vermicomposting process include drying organic materials to reduce volatile gases toxic to earthworms, reducing excessive moisture, commencing microbial breakdown, and softening waste. Subsequently, pre-composting makes the feedstock more appetizing for earthworms and aids in odor reduction. Furthermore, pre-treatment is crucial in transforming the grain into a more biodegradable and extractable substrate..

These grains, containing biopolymers like lignin and cellulose, require pre-treatment to break down these complex chemicals for simpler digestion by microorganisms. Various pre-treatment procedures, including alkali, acid, hydrothermal, or enzymatic treatments, enhance nutrient availability by hydrolyzing the grain biopolymers. Both biochar and vermicompost are submitted for analysis as illustrated in Table 3

Table 3. Chemical analysis of biochar and vermicompost.

Parameters	Biochar	Vermicompost
Moisture (%)	3.60	22.68
pH	9.15	6.8
EC (dSm^{-1})	8.87	1.13
Carbon (%)	٢0٢.1	17.55
Nitrogen (%)	0.55	1.23
Phosphorus (%)	0.22	0.32
Potassium (%)	1.41	1.33
Calcium (%)	4.40	5.80
Magnesium (%)	2.60	3.70

Experimental design

The experiments were arranged in completely randomized design (CBD) with 3 replicate. Fertilizers made of biochar and vermicompost were spread out in the main plot, while sub-plots received different rates of treatment.

Experimental Site

The research was performed in an experimental field situated in a semi-arid area characterized by sandy soils with little organic matter (<1%) and limited water retention ability. The region has an average annual precipitation of 400 mm, with temperatures fluctuating between 25°C and 40°C.

Cultural practices

Cowpea (Dokki-331) grains were seeded in mid-May at a rate of 30 kg/fed (fed =4200 m^2) in both seasons. Plots were 15 m^2 in size, with 5 ridges (5 m long and 0.6 m width), and grains were seeded in hills 25 cm apart, with two plants per hill when thinned. Cowpea varieties were received from the Feed Research Department, Feed Research Institute, and Agricultural Research Centre in Egypt. Following thinning, half the quantity of nitrogen was supplied once 30 days after planting at a rate of 30 kg N/fed in the form of ammonium nitrate (33.5% N). Phosphorus was provided at a rate of 30 kg P_2O_5/fed as Calcium super phosphate fertilizer (15.5% P_2O_5) before to planting. In both seasons, a drip irrigation system was used at a rate of 2 L/hour at intervals of 2-4 days.

Treatments

Biochar or vermicompost treatments were blended with calcium superphosphate and administered to the examined soil by the homogeneous mixing with the surface layer of soil before crop planting. The full randomized block design and the following treatments of biochar and vermicompost were applied.

1. Control (**R_0**) = without biochar or vermicompost fertilizer.
2. Biochar (**R_1**) =250 kg/fed
3. Biochar (**R_2**) =500 kg/fed
4. Biochar (**R_3**) =1000 kg/fed
5. Vermicompost (**R_4**) =250 kg/fed
6. Vermicompost (**R_5**) =500 kg/fed
7. Vermicompost (**R_6**) =1000 kg/fed
8. Mixture (50%) (**R_7**) = (125 Bio+ 125 Vermi.) kg/fed
9. Mixture (50%) (**R_8**) = (250 Bio+ 250 Vermi.) kg/fed
10. Mixture (50%) (**R_9**) = (500 Bio+ 500 Vermi.) kg/fed

Yield and its components

At harvest time, 10 random guarded plants representing each treatment were chosen to assess of plant height (cm), number of pod/plant, grain weight/plant (g) and 100-grain weight (g). All plants in each plot were harvested to assess the grain yield (ton/fed), straw yield (ton/fed), biological yield (ton/fed) and biological yield (ton/fed) were determined as well as harvest index.

Biological yield (ton/fed) = Grain yield + Straw yield

Harvest Index (%) = Grain yield/Biological yield *100

Chemical analysis

Total nitrogen and soluble carbohydrate content in grains was evaluated using A.O.A.C (2000), and crude protein was calculated by multiplying N% by 6.25 factors (Magomya *et al.*, 2014). Carter &

Gregorich (2008) method for estimating phosphorus levels using a spectrophotometer1720 UV (using a spectrophotometer at 470 nm). According to Motsara & Roy (2008), K+ concentrations were measured using Jenway PFP7 and PFP7/C emission flame light meter.

Statistical analyses

To identify differences between means, statistical analyses were done in accordance with Snedecor and Cochran (1990), using CoStat version 6.3 and the least significant differences (LSD) at a 5% level.

Results

Yield components

This table includes data on the impacts of several fertilizer treatments (biochar, vermicompost, and a mix of both) and their application rates (R_0 to R_9) on plant growth and production characteristics for 2023 and 2024. The criteria assessed are plant height, number of pods per plant, grain weight per plant, and 100-grain weight. Here's a thorough interpretation as in Table 4 and Figs. (1a and 1b):

Key Observations

The control consistently exhibited the lowest values for all tested parameters over both years, showing the favorable influence of fertilizer treatment

Effect of Biochar

Gradual increases in fertilizer rates (R_1 to R_3) enhanced all metrics, exhibiting a clear dose-response connection. For example, in 2024, plant height increased from 1.34 m (R_1) to 1.58 m (R_3), and the number of pods per plant climbed from 14.68m (R_1) to 17.14m (R_3).

Effect of Vermicompost

Similar tendencies are found, with higher rates (R_4 to R_6) yielding continuous gains in plant height, pod number, and grain weight. Vermicompost typically beats biochar at equal rates.

Effect of Mix

The blend of biochar and vermicompost (50% each) exhibited improved outcomes compared to either fertilizer applied alone, particularly at higher rates. For instance, in 2024, R_9 reported the maximum plant height (1.74 m), number of pods per plant (20.11), and grain weight (15.02 g).

Year-to-year comparisons (2023 vs. 2024)

Across all treatments and rates, performance increased marginally in 2024 compared to 2023, perhaps owing to better environmental conditions or cumulative soil health advantages.

Table 4. Effect of eco-friendly fertilizers and mixture application on yield components of cowpea under drip irrigation in sandy soil.

Fertilizers	Rates (Kg/fed)	2023				2024			
		Plant height (m)	No. of pod /plant	Grain weight /plant(g)	100-grain weight (g)	Plant height (m)	No. of pod /plant	Grain weight /plant(g)	100-grain weight (g)
Control	R_0	1.10	11.22	9.69	11.72	1.15	13.59	9.77	12.37
Biochar	R_1	1.26	12.12	10.40	12.56	1.34	14.68	10.55	13.25
	R_2	1.37	13.18	12.35	12.78	1.43	15.96	12.53	13.48
	R_3	1.49	14.15	13.15	13.12	1.58	17.14	13.34	13.83
Mean		**1.37**	**13.15**	**11.97**	**12.82**	**1.45**	**15.93**	**12.14**	**13.52**
Vermi-compost	R_4	1.29	13.22	11.93	13.04	1.38	16.01	12.11	13.75
	R_5	1.42	14. 34	12.63	13.09	1.51	17.37	12.81	13.80
	R_6	1.58	15.40	13.97	13.27	1.69	18.65	14.17	13.99
Mean		**1.43**	**14.31**	**12.84**	**13.13**	**1.53**	**17.34**	**13.03**	**13.85**
Mix (50%) (Bio+Vermi)	R_7	1.32	13.36	13.66	13.54	1.41	16.18	13.25	14.28
	R_8	1.47	15.45	13.75	13.62	1.54	18.71	14.71	14.39
	R_9	1.67	16.60	13.80	13.99	1.74	20.11	15.02	14.46
Mean		**1.49**	**15.14**	**13.74**	**13.72**	**1.56**	**18.33**	**14.33**	**14.38**
$LSD_{0.05}$	Sources	0.05	0.22	0.26	0.14	0.03	0.25	0.27	0.15
	Rates	0.03	0.30	0.32	0.08	0.02	0.30	0.33	0.09

R_0= Control (without fertilizer) *R_1= Biochar (250 kg/fed)* *R_2= Biochar (500 kg/fed)*
R_3= Biochar (1000kg/fed) *R_4= Vermicompost (250 kg/fed).* *R_5= Vermicompost (500 kg/fed)*
R_6= Vermicompost (1000 kg/fed) *R_7= Mix 50% (125 +125 kg/fed)* *R_8= Mix 50% (250+250 kg/fed)*
R_9= Mix 50% (500+500 kg/fed). *S = Sources* *R=Rates*

Mean and LSD interpretation

1-Mean effects

The mean values for all traits confirm that overall performance improved with fertilizer application compared to the control. For example, the mean plant height increased from 1.40 m in 2023 to 1.48 m in 2024.

2. LSD (Least Significant Difference)

- **Sources:** The LSD values for sources (e.g., biochar, vermicompost, and mix) indicate that even small differences in treatments are statistically significant.
- **Rates:** LSD values for rates confirm that increasing fertilizer rates lead to statistically significant improvements.
- **Best treatment:** The Mix (50% biochar + 50% vermicompost) at the highest rate (R_9) is the most effective; it provided the best results in all studied characteristics.

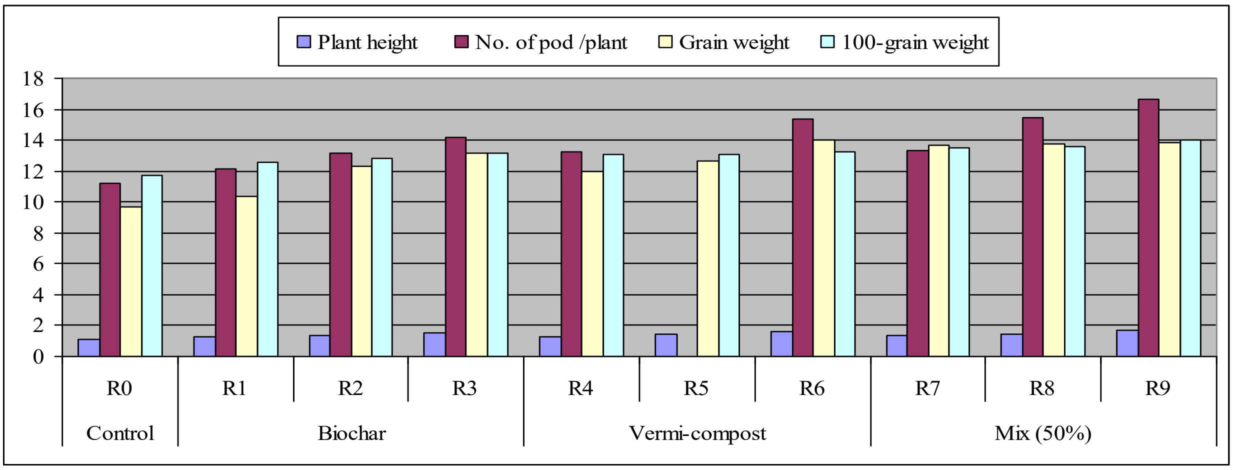

Fig. 1a. Effect of eco-friendly fertilizers and mixture application on yield components of cowpea under drip irrigation in sandy soil season 2023.

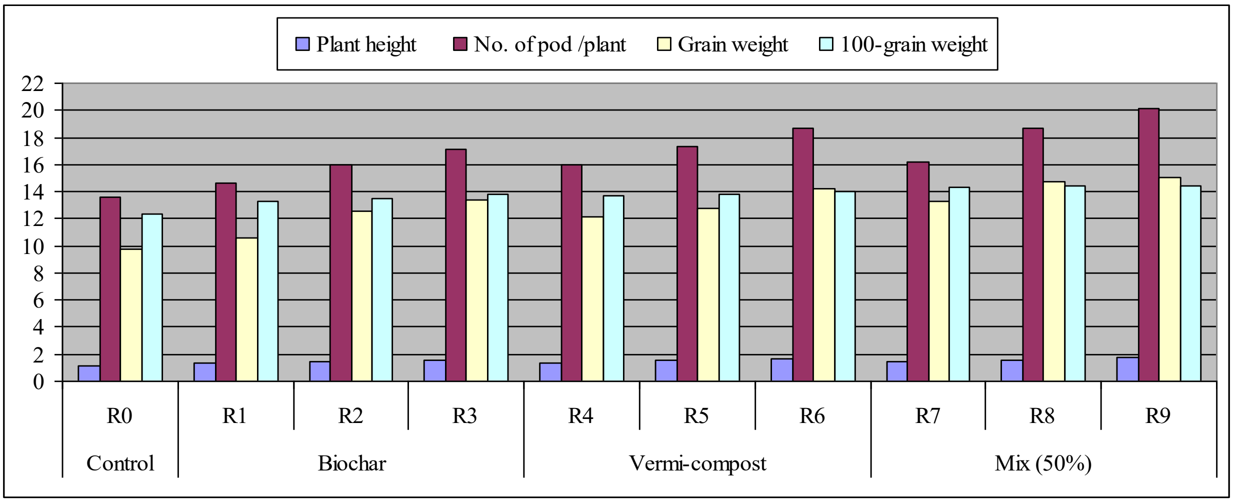

Fig. 1b. Effect of eco-friendly fertilizers and mixture application on yield components of cowpea under drip irrigation in sandy soil season 2024.

Grain and straw yield

Table 5 and figures (2a and 2b) compare the effects of different fertilizers (control, biochar, vermicompost, and a 50% mix of both) applied at different rates (R_0 to R_9) on various crop yield parameters, such as grain yield, straw yield, biological yield, and harvest index, over two years (2023 and 2024). The following is a thorough interpretation:

Control treatment: The Control treatment has the lowest values across all yield metrics in both years. This illustrates the influence of fertilization on enhancing yield.

Grain yield: 0.65 tons/fed and 0.73 tons/fed in both 2023 and 2024 years.

Straw yield: 2.71 tons/fed and 2.80 tons/fed in 2023 2024, respectively.

Biological yield: 3.39 tons/fed and 3.53 tons/fed in both 2023 and 2024, respectively.

Harvest index: Slight rise from 19.96% in 2023 to 20.72% in 2024, showing a small gain in grain production compared to the total biomass.

Biochar treatment: Biochar applications demonstrate a dose-dependent improvement in yield with greater rates resulting to better performance.

Grain yield: In 2024, R_3 (highest rate) produced 0.92 tons/fed, much greater than the control and lesser biochar rates.

Straw yield: Increased from 3.65 tons/fed at control to 4.16 tons/fed at R_3 in 2024.

Biological yield: A comparable rise was found in biological yield with increasing Biochar rates, reaching 5.08 tons/fed at R_3 in 2024.

Harvest index: Showed minor improvements with increasing rates, from 15.23% (control) to 18.07% (R_3) in 2024, showing a better allocation of biomass to grains at higher rates.

Vermicompost treatment: Vermicompost treatment also had a favorable influence on yield, with larger application rates yielding the greatest outcomes.

Grain yield: At R_6, vermicompost led to 0.99 tons/fed in 2024, the highest among the different fertilizer treatments.

Straw yield: Straw yield grew from 3.66 tons/fed at R_4 to 4.32 tons/fed at R_6 in 2024, suggesting an improvement with rising rates.

Biological yield: Similarly, biological yield rose, reaching 5.31 tons/fed at R_6.

Harvest index: Remained very steady, with a tiny increase in 2024, to 17.71% at R6 to 18.61% at R_6.

Mix treatment: The mix treatment exhibited the highest overall effectiveness across most metrics.

Grain yield: At R_9 in 2024, the grain yield was 1.06 tons/fed, which was the highest seen across all treatments.

Straw yield: The combined treatment also generated the greatest straw yield at R_9, 4.58 tons/fed in 2024. Biological output: Biological output peaked at 5.64 tons/fed at R_9.

Harvest index: The harvest index exhibited fluctuation, with the maximum value (20.05%) at R_8, but nevertheless remained significant for R_9 (18.83%). This shows that the combination of fertilizers may enhance both grain and straw production while keeping a healthy balance. From 2023 to 2024, except for the mix treatments, where the numbers were more varied.

Table 5. Effect of eco-friendly fertilizers and mixture application on grains and straw yield of cowpea under drip irrigation in sandy soil.

Fertilizers	Rates (Kg/fed)	2023 Grains yield (ton/fed)	2023 Straw yield (ton/fed)	2023 Biol. Yield (ton/fed)	2023 Harvest Index (%)	2024 Grains yield (ton/fed)	2024 Straw yield (ton/fed)	2024 Biol. Yield (ton/fed)	2024 Harvest Index (%)
Control	**R_0**	0.65	2.71	3.39	19.96	0.73	2.80	3.53	20.72
Biochar	**R_1**	0.70	3.65	4.31	15.23	0.72	3.77	4.49	16.02
	R_2	0.76	3.84	4.60	16.54	0.83	3.96	4.79	17.39
	R_3	0.84	4.04	4.87	17.19	0.92	4.16	5.08	18.07
Mean		**0.77**	**3.84**	**4.59**	**16.32**	**0.82**	**3.96**	**4.79**	**17.16**
Vermi-compost	**R_4**	0.75	3.66	4.41	16.93	0.82	3.78	4.60	17.81
	R_5	0.81	3.88	4.69	17.34	0.89	4.00	4.89	18.27
	R_6	0.90	4.18	5.08	17.71	0.99	4.32	5.31	18.61
Mean		**0.82**	**3.91**	**4.73**	**17.33**	**0.90**	**4.03**	**4.93**	**18.23**
Mix (50%) (Bio+Vermi)	**R_7**	0.81	3.66	4.47	18.19	0.87	3.78	4.65	18.72
	R_8	0.92	3.91	4.83	19.06	1.01	4.03	5.04	20.05
	R_9	0.97	4.44	5.41	17.92	1.06	4.58	5.64	18.83
Mean		**0.90**	**4.00**	**4.90**	**18.39**	**0.98**	**4.13**	**5.11**	**19.20**
$LSD_{0.05}$	Sources	0.02	0.10	0.09	0.68	0.03	0.11	0.10	0.70
	Rates	0.02	0.06	0.06	0.40	0.02	0.07	0.07	0.46

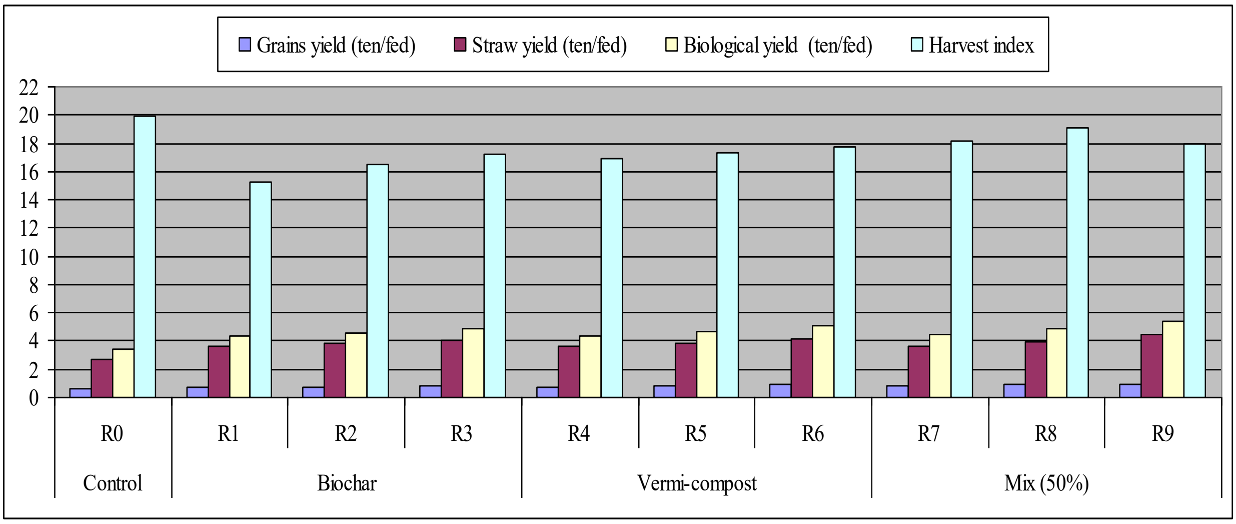

Fig. 2a. Effect of eco-friendly fertilizers and mixture application on grains and straw yield of cowpea under drip irrigation in sandy soil season 2023.

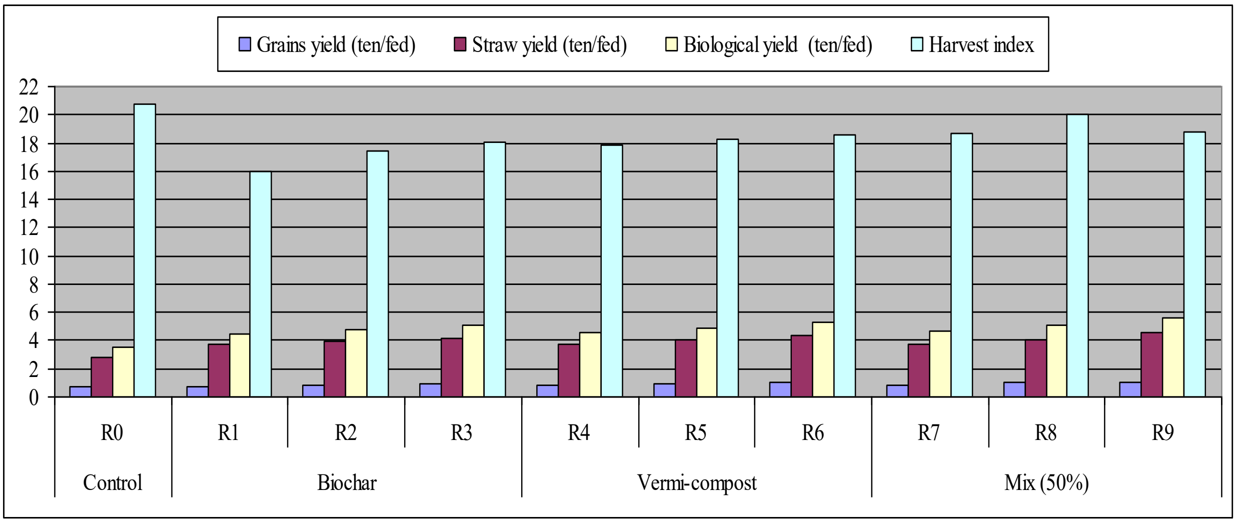

Fig. 2b. Effect of eco-friendly fertilizers and mixture application on grains and straw yield of cowpea under drip irrigation in sandy soil season 2024.

Year-to-year comparison (2023 vs. 2024)

Grain yield: There was an overall rise in grain yield across all treatments in 2024 compared to 2023, suggesting improved growing conditions, nutrient availability, or cumulative impacts from fertilizer use over time.

Straw yield: A similar pattern was found with straw yield, where 2024 values were consistently greater than those in 2023.

Biological yield: Biological yield also rose across all treatments, indicating the overall improvement in biomass output.

Harvest index: The harvest index grew modestly for most treatments

3.3. Macro elements

Table 6 and Figures 3, illustrate the nutrient content of nitrogen (N), phosphorous (P), and potassium (K) in the crops, under several fertilization treatments (control, biochar, vermicompost, and a 50% mix of biochar and vermicompost) applied at varying rates (R_0 to R_9) throughout two years (2023 and 2024). Here is the interpretation and analysis of the data:

Control treatment: The Control (R_0) treatment provides constant values over the two years (2023 and 2024) for nitrogen, phosphorus, and potassium.

Nitrogen content: 2.86% in both years.

Phosphorus content: 0.40% in 2023, rising slightly to 0.41% in 2024.

Potassium content: 1.83% in 2023, rising little to 1.85% in 2024. This data demonstrates that the control treatment, with no extra fertilizer, leads in relatively modest and steady nutrient content over the two years.

Biochar treatment: Biochar application leads to an increase in the nitrogen, phosphate, and potassium content, particularly at greater application rates.

Nitrogen: nitrogen content rose from 2.82% in R_1 (2023) to 3.35% at R_3 (2024). The highest rate (R_3) in 2024 resulted in a nitrogen concentration of 3.35%, more than the control treatment.

Phosphorus: the phosphorus concentration also rose from 0.49% at R_1 to 0.56% at R_3 in 2024, showing biochar's good influence on phosphorus availability.

Potassium: Potassium concentration exhibited an increased trend, rising from 1.77% at R_1 to 2.15% at R_3 in 2024, suggesting the impact of biochar in boosting potassium absorption by plants. Biochar treatment considerably enhances nutrient content, especially at higher application rates (R_3), proving the efficiency of biochar as a fertilizer in boosting nutrient absorption.

Vermicompost treatment: Vermicompost also leads to an increase in nitrogen, phosphate, and potassium content with greater rates demonstrating better effects.

Nitrogen: The nitrogen level varied from 3.21% at R_4 in 2023 to 3.81% at R_6 in 2024. Vermicompost considerably increased nitrogen availability, with the greatest value found at R_6 in 2024.

Phosphorus: Phosphorus level rose from 0.52% in R_4 to 0.59% at R_6 in 2024.

Potassium: Potassium also rose from 1.90% at R_4 to 2.18% at R_6 in 2024, further proving the favorable impacts of vermicompost on nutritional levels.

The vermicompost treatment, particularly at higher rates (R_6), enhances the total nutritional content, comparable to biochar, although with a minor variation in magnitude.

Mix treatment: The Mix treatment (50% biochar and 50% vermicompost) generated the greatest values for nitrogen, phosphorus, and potassium across the varied rates.

Nitrogen: Nitrogen concentration varied from 3.30% at R_7 to 4.07% at R_9 in 2024, demonstrating that the joint application of biochar and vermicompost is more successful than the individual treatments of either.

Phosphorus: Phosphorus concentration exhibited a continuous rise, from 0.59% at R_7 to 0.65% at R_9 in 2024, demonstrating that the combination promotes phosphorus availability more efficiently than biochar or vermicompost alone.

Potassium: Potassium concentration rose from 1.99% at R_7 to 2.37% at R_9 in 2024, with the greatest levels recorded in the mix treatments, further confirming the synergistic impact of mixing biochar and vermicompost. The combined treatment (R_9) provided the maximum nitrogen, phosphate, and potassium content in both years, indicating the greater advantages of mixing biochar and vermicompost for increased nutrient absorption.

Year-by-year comparison (2023 vs. 2024)

Nitrogen: Overall, nitrogen content increased across all treatments in 2024 compared to 2023. This implies that the fertilizers supplied sufficient nitrogen for plant growth and development, with higher rates resulting in higher nitrogen content.

Phosphorus: Phosphorus levels rose across all treatments in 2024, while the increases were often less than nitrogen. This shows that phosphorus availability remained generally steady, with small enhancements from fertilizers.

Potassium: Similarly, potassium content increased in 2024, indicating that fertilizers improve potassium absorption.

Table 6. Effect of eco-friendly fertilizers and mixture application on macro elements of cowpea under drip irrigation in sandy soil.

Fertilizers	Rates (Kg/fed)	2023 Nitrogen	2023 Phosphorus (%)	2023 Potassium	2024 Nitrogen	2024 Phosphorus (%)	2024 Potassium
Control	**R_0**	2.86	0.40	1.83	2.86	0.41	1.85
Biochar	**R_1**	2.82	0.49	1.77	2.90	0.53	1.87
	R_2	3.06	0.51	1.92	3.15	0.55	2.03
	R_3	3.25	0.53	2.03	3.35	0.56	2.15
Mean		**2.91**	**0.47**	**1.84**	**2.97**	**0.50**	**1.92**
Vermi-compost	**R_4**	3.21	0.52	1.90	3.31	0.56	2.01
	R_5	3.59	0.54	1.99	3.70	0.58	2.11
	R_6	3.75	0.55	2.06	3.81	0.59	2.18
Mean		**3.52**	**0.54**	**1.98**	**3.61**	**0.58**	**2.10**
Mix (50%) (Bio+Vermi)	**R_7**	3.30	0.59	1.99	3.46	0.61	2.10
	R_8	3.63	0.58	2.12	3.74	0.63	2.24
	R_9	3.99	0.57	2.24	4.07	0.65	2.37
Mean		**3.64**	**0.58**	**2.12**	**3.76**	**0.63**	**2.24**
$LSD_{0.05}$	Sources	0.15	0.07	0.05	0.11	0.08	0.04
	Rates	0.11	0.05	0.04	0.10	0.05	0.03

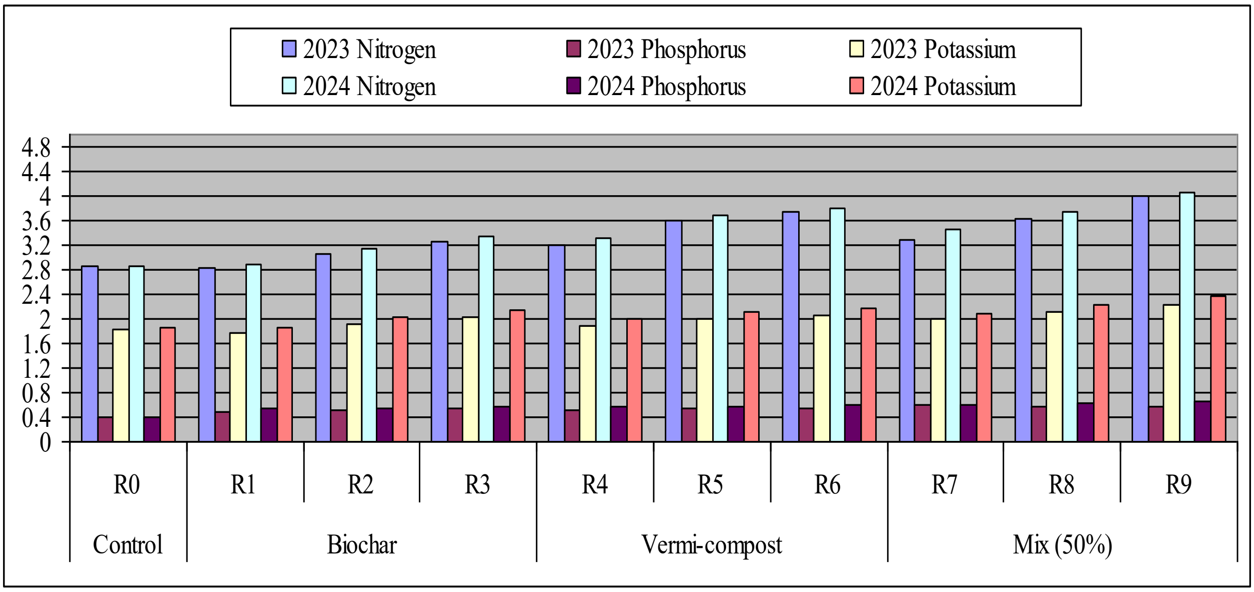

Fig. 3. Effect of eco-friendly fertilizers and mixture application on macro elements of cowpea under drip irrigation in sandy soil seasons 2023 and 2024.

Prices: The application rate also significantly affects the nutritious content for all three elements (N, P, and K), according to the $LSD_{0.05}$ values for rates. Increased fertilizer application seems to enhance nutrient absorption, since greater rates result in larger nutrient concentrations in the plants.

Grain quality
Table 7 and Figure 4, compare the impact of various fertilizers and application rates on protein, total carbohydrate, and oil content in crops across two years (2023 and 2024). It compares the effects of control, biochar, vermicompost, and a 50% mix of biochar and vermicompost applied at different rates (R_0 to R_9).

Control treatment: In both years, the control treatment had the lowest protein, total carbohydrate, and oil content values. Protein content was 17.88% in both years, showing little improvement without fertilization.

Total carbohydrate content: 40.72% in 2023 and 41.13% in 2024, with just a little rise. **Oil content**: Slightly higher in 2024 (2.21%) than in 2023 (1.95%), most likely owing to natural environmental changes rather than fertilizer impacts. This emphasizes the need of fertilizer application to improve crop quality.

Biochar treatment: Protein Content: Improved gradually at increasing rates, from 17.63% at R_1 in 2023 to 20.94% at R_3 in 2024. This shows that using biochar increases nitrogen availability, which is necessary for protein synthesis.

Total Carbohydrates: increased considerably from 39.75% in R_1 in 2023 to 46.24% at R_3 by 2024.

Oil content: Gradually rose from 2.05% at R_1 in 2023 to 2.96% at R_3 in 2024, demonstrating biochar's ability to boost oil accumulation. Biochar improves crop quality, although only somewhat compared to vermicompost and mix treatments.

Vermicompost treatment: Protein content: Significant improvement at increasing rates, from 20.06% at R_4 in 2023 to 23.81% at R_6 by 2024. Vermicomposting enhances nitrogen availability, considerably increasing protein content.

Total Carbohydrates: Significantly increased, from 45.23% in R_4 in 2023 to 53.39% at R_6 in 2024.

Oil Content: Increased from 2.24% at R_4 in 2023 to 3.08% at R_6 in 2024, demonstrating that vermicompost is more successful than charcoal in promoting oil biosynthesis. Vermicompost improves all three metrics significantly, particularly at greater rates (R_6).

Table 7. Effect of eco-friendly fertilizers and mixture application on quality of cowpea yield under drip irrigation in sandy soil.

Fertilizers	Rates (Kg/fed)	2023			2024		
		Protein	T. Carb. (%)	Oil	Protein	T. Carb. (%)	Oil
Control	**R_0**	17.88	40.72	1.95	17.88	41.13	2.21
	R_1	17.63	39.75	2.05	18.13	40.13	2.31
Biochar	**R_2**	19.13	43.08	2.42	19.69	43.50	2.73
	R_3	20.31	45.79	2.62	20.94	46.24	2.96
Mean		**19.02**	**42.87**	**2.36**	**19.59**	**43.29**	**2.67**
	R_4	20.06	45.23	2.24	20.69	45.68	2.53
Vermi-compost	**R_5**	22.44	50.65	2.43	23.13	51.15	2.74
	R_6	23.44	52.88	2.75	23.81	53.39	3.08
Mean		**21.98**	**49.59**	**2.47**	**22.54**	**50.07**	**2.78**
	R_7	20.63	46.56	2.28	21.63	47.01	2.57
Mix (50%)	**R_8**	22.69	51.21	2.49	23.38	51.71	2.81
(Bio+Vermi)	**R_9**	24.94	55.76	2.90	25.44	55.79	3.36
Mean		**22.75**	**51.18**	**2.56**	**23.48**	**51.50**	**2.91**
	Sources	0.94	2.14	0.06	0.67	2.18	0.07
$LSD_{0.05}$	Rates	0.65	1.46	0.03	0.65	1.48	0.04

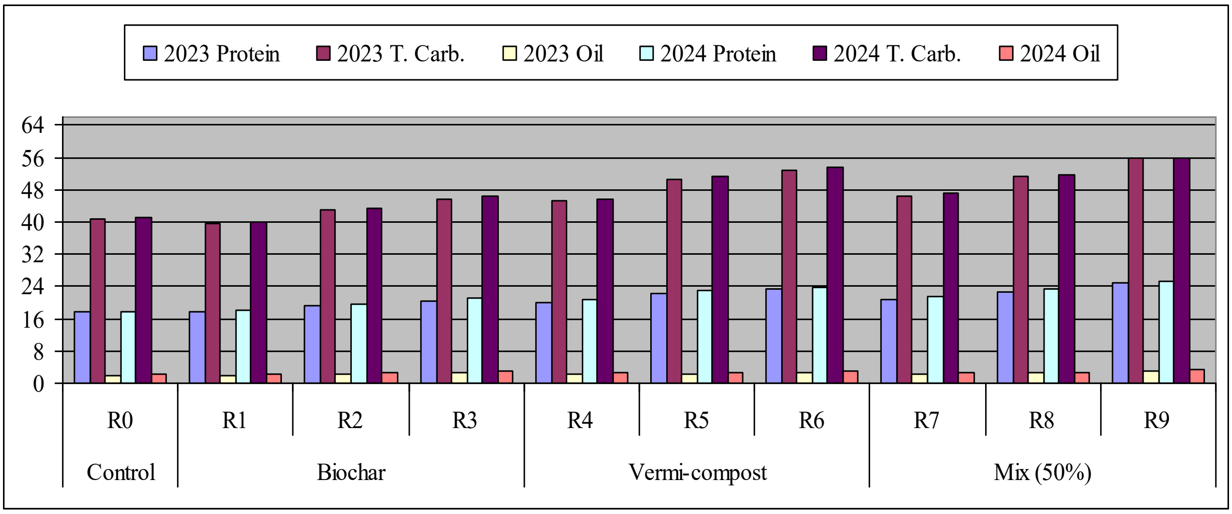

Fig. 4. Effect of eco-friendly fertilizers and mixture application on quality of cowpea yield under drip irrigation in sandy soil seasons 2023 and 2024.

Mix treatment

Protein content: The mix treatments had the highest values, ranging from 20.63% at R_7 to 25.44% at R9 in 2024. Total carbohydrate content increased dramatically, peaking at 55.79% in R_9 in 2024. This suggests a synergistic impact of biochar and vermicompost on glucose buildup. Oil content reached at R_9 in 2024 (3.36%), topping both biochar and vermicompost. The mix treatment consistently outperformed the individual fertilizers, particularly at the highest application rate (R_9), suggesting the added benefit of mixing biochar and vermicompost.

Year-to-year comparison (2023 vs. 2024)

All metrics (protein, carbohydrates and oil content) increased in 2024 compared to 2023, most likely owing to fertilizer applications or better environmental conditions. The Mix treatment (R_9) demonstrated the largest increase over time, demonstrating its efficacy in boosting crop quality.

Statistical analysis: The $LSD_{0.05}$ results show significant variations in protein, total carbohydrate, and oil content among fertilizer types (control, biochar, vermicompost, and mix). This supports the relevance of fertilizer selection in impacting crop quality measures.

Rates: The $LSD_{0.05}$ results show substantial variations in application rates, with higher rates leading to better crop quality. This emphasizes the significance of tailoring fertilizer rates for optimal outcomes.

Economic feasibility

The table (8) assesses the economic viability of employing various fertilizer kinds and quantities in crop production, including grain and straw yields, related earnings, and net income after accounting for fertilizer expenses. The fertilizers tested were control (no fertilizer), biochar, vermicompost, and a 50/50 mix of biochar and vermicompost.

Important observations

Control treatment

Fertilizer cost: The control treatment has no fertilizer cost, resulting in the greatest net income among the treatments when expenditures are considered alone (15525L.E.). The grain yield is 0.69 tons/fed, whereas straw yield is 2.55 ton/fed, resulting in the lowest total revenue of 15525 L.E. Despite the lack of fertilizer input, the reduced yield highlights the necessity of fertilizer usage in increasing productivity and profitability.

Biochar treatment: Fertilizer costs 5000 L.E., grain yield grew to 0.88 tons/fed, while straw output climbed to 4.10 tons/fed. The grain income is 30800 L.E., while straw income is 10025 L.E., for total revenue of 40825 L.E. and a net income of 20825 L.E. Biochar greatly enhances yield and profitability compared to the control, resulting in a net income gain of 15525 L.E.

Vermicompost treatment: Fertilizer costs 7000 L.E. (the most among treatments). The grain yield increased to 0.95 ton/fed, while straw output reached 4.25 ton/fed. The grain income is 33250 L.E., while straw income is 10625 L.E., for a total income of 43875 L.E. and a net income of 21875 L.E. Although vermicompost enhances yield and total revenue, the greater cost affects net income when compared to biochar

Table 8. Economic feasibility of eco-friendly fertilizers and mixture on the yield of cowpea in sandy soil average of two years.

Fertilizers Types	Costs Planting (L.E./fed)	Fert. Applied (kg/fed)	Costs Fert. (L.E.)	Grain yield (ton/fed)	Grain Price (L.E)	Straw yield (ton/fed)	Straw Price (L.E)	Total yield income	Net (L.E.)
Control	15000	0.00	0.00	0.69	24150	2.55	6375	30525	15525
Biochar	15000	1000	5000	0.88	30800	4.10	10025	40825	20825
Vermicompost	15000	1000	7000	0.95	33250	4.25	10625	43875	21875
Mixture (50 %)	15000	1000	6000	1.02	35070	4.51	11275	46345	25345

Biochar*=5.00 L.E/kg* ***Vermicompost*** *=7.00 L.E/kg* ***Grain****= 35.00 L.E/kg* ***Straw****= 2.5.00 L.E/kg*

Net (L.E.) *= Total yield incomee (L.E)- (Costs Planting + Costs Fertilizers) (L.E)*

This implies that vermicompost may be less cost-effective unless used in conjunction. Mixture (50% biochar, 50% vermicompost) costs 6000 L.E. The blend has the greatest yields, with a grain yield of 1.02 tons/fed and straw yield of 4.51 tons/fed. The grain income is 35070 L. E, straw income is 11275 L.E., giving the greatest total income of 46345L.E. and net income of 25345 L.E. The combination beats the other treatments in terms of total and net income. The combination of biochar and vermicompost increases production and economic returns, making it the most lucrative treatment.

Economic insights

Profitability Rankings: Mixture (50% biochar) > Vermicompost > Control. The blend offers the highest return on investment because to its balanced cost and much greater yield.

Cost-effectiveness: Biochar had a larger net income than Vermicompost despite having higher yields, demonstrating the relevance of fertilizer cost in determining profitability.

Yield vs investment: Increased fertilizer investment leads to higher yields and revenues. However, additional net income increases decline as expenses rise, emphasizing the necessity for cost-effective alternatives such as mixes.

Best fertilizer strategy: The most successful technique is the mixture (50% biochar + 50% vermicompost), which produces the best grain and straw yields, total revenue, and net income. This strategy makes use of the complementing advantages of both fertilizers. Economic viability: While biochar is a cost-effective alternative on its own, the mixture's enhanced output makes the somewhat higher expenditure worthwhile.

Discussion

The research assesses the impact of several fertilizer treatments (biochar, vermicompost, and their combination) on crop yield, nutritional quality, and economic performance. The findings from the two seasons (2023 and 2024) show considerable improvements in yield metrics, nutritional content, and profitability compared to the control, highlighting the treatments potential in sustainable agriculture. Fertilizer treatment resulted in substantial gains in grain, straw, and biological yields compared to the control in both seasons. Among the treatments, the 50:50 mixture of biochar and vermicompost produced the best yields, with grain yield reaching 1.06 ton/fed and straw yield 4.58 tons/fed in 2024, demonstrating a synergistic impact of the combined amendments. Vermicompost also worked well, resulting in significant production improvements due to its high organic matter content. Biochar, despite increasing yields, was less successful as a solo treatment than vermicompost or the mixture. The harvest index (HI) was less varied across treatments, indicating effective biomass partitioning into economic yield.

The mixture has the highest HI (20.05 % in 2024), indicating its potential to increase agricultural output efficiency. The results indicate that the mixture optimizes both nutrient supply and soil structure, enhancing water and nutrient retention. These effects are particularly beneficial for sandy soils, which typically suffer from low fertility and poor moisture retention. The findings show that the mixture improves both fertilizer availability and soil structure, hence increasing water and nutrient retention, as confirmed by (Ali *et al*., 2019). These benefits are especially advantageous to sandy soils, which often have low fertility and poor moisture retention. This trend was also seen in the biochar treatment, which provided little plant-available N and P throughout both growth stages. Higher soil organic carbon content improves sorption of micronutrients, trace metals, and pesticides (Lair *et al*., 2006). Biochar-amended soils may have improved plant development during the second growth phase, perhaps due to the sorption of allopathic chemicals. While vermicompost is non-toxic to plants and provides vital nutrients, as well as growth-promoting chemicals such as cytokinins, auxins, and gibberellins. These chemicals promote plant development and have desirable properties like as permeability, aeration, drainage, water storage capacity, and microbiological activity (Singh, *et al*., 2019). Nutritional quality: macronutrients (nitrogen, phosphorus, potassium). The nutritional analysis demonstrated considerable increases in nitrogen (N), phosphorus (P), and potassium (K) content in grains under all fertilizer treatments.

Notably: In 2024, the mixture had the greatest macronutrient concentration, with nitrogen at 4.07% and potassium at 2.37%. Vermicompost produced significant nitrogen enrichment, most likely owing to its organic nitrogen concentration and microbial activity, while biochar increased phosphorus and potassium absorption. Protein, carbohydrates, and fat content In 2024, the mixture considerably increased protein content (25.44%), total carbohydrates (55.79%), and oil content (3.36%), exceeding other treatments. Vermicompost alone shows significant benefits, notably in protein content, highlighting its nutrient-dense character. Improvements in grain quality metrics demonstrate the effectiveness of organic additions in meeting both nutritional and market criteria. The complimentary impacts of biochar and vermicompost in the mixture highlight their potential to improve crop nutrition; this was in agreement with (Urmi, *et al*., 2022 and Rashad, *et al*., 2022).

Practical and environmental implications

The results highlight the agronomic and environmental advantages of organic additions.

Soil health improvement: Biochar improves soil physical qualities including porosity and water retention, while vermicompost increases nutrient availability and microbial activity.

Sustainability: Using organic fertilizers decreases reliance on synthetic inputs, lowers carbon emissions, and increases soil organic matter.

Scalability: The mixture's consistent performance across yield, quality, and economic metrics indicates that it is a scalable technique for increasing productivity on marginal soils, such as sandy soils.

Conclusion

This research shows that applying biochar, vermicompost, and a 50:50 mixture improves crop production, grain quality, and economic profitability in sandy soils during two growing seasons (2023 and 2024). Among the treatments, the mixture consistently outperformed biochar and vermicompost used separately. The mixture achieved the best grain and straw yields, nutritional concentrations, and grain quality, as well as the largest net economic return. The results demonstrate the synergistic benefits of mixing biochar, which enhances soil structure and water retention, with vermicompost, which supplies vital nutrients and encourages microbial activity.

This integrated strategy was successful in tackling sandy soils' intrinsic difficulties, such as low fertility, poor nutrient retention, and limited water-holding capacity. From an economic standpoint, the mixture was also the most cost-effective, resulting in the greatest net revenue owing to enhanced yield and quality improvements. This conclusion shows that the mixture not only improves agricultural output but also assures farmers' financial viability, making it a long-term alternative to conventional fertilization approaches. The increase in grain protein, carbohydrate, and oil content highlights the importance of these organic amendments in improving food quality, which aligns with global food security objectives.

Future prospects

To expand upon these results, the following research paths are suggested:

Long-term field studies: Examine the cumulative impacts of biochar, vermicompost, and their Mixture throughout numerous cropping cycles to assess soil health, nutrient dynamics, and crop yield.

Optimizing application rates: Experiment with various Biochar and Vermicompost ratios and application rates to find the most efficient combination for your crops and soil type.

Climate resilience: Evaluate these adjustments' effectiveness in reducing the effects of climate change, such as drought stress and temperature changes, on crop growth and production.

Microbial interactions: Investigate the microbial community dynamics under various treatments to get a better understanding of the processes governing nutrient availability and soil fertility.

Broader applicability: Test these organic amendments on diverse crops and agro to establish their scalability and adaptability to other agricultural contexts. Future studies that address these research gaps will provide a more thorough knowledge of the potential of biochar, vermicompost, and their mixtures in supporting sustainable farming practices. This information will help policymakers, researchers, and farmers implement environmentally benign and economically feasible methods for increasing agricultural output and resilience in degraded and resource-constrained soils.

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Conflict of interest

The authors declares there are no actual or potential competing interests, including any financial, personal, or other relationships with other people or organizations.

References

AOAC. 2000. Official methods of analysis of 15th edition, the association: Official Agricultural Chemists. Washington. D.C. https://law.resource.org/pub/us/cfr/ibr/002/ aoac.methods.1.1990.pdf

Abdel Aziz TB, Hossam MS, Sayed A. Abo-M, Khalil MS, Asmaa MS. 2024. Cowpea (*Vigna unguiculata* L. Walp) morpho-physiological and yield responses to chemical, organic, and bio-fertilizers at various watering levels utilizing drip irrigation system. Plant Production Science, 27 (2):110–124 https://doi.org/10.1080/134 3943X .2024.2340833

Ali K, Wang X, Riaz M, Islam B, Khan ZH, Shah F, Munsif F, Haq S. 2019. Biochar: an eco-friendly approach to improve wheat yield and associated soil properties on sustainable basis. Pakistan J. of Botany, 51(4) https:// doi.org/10.30848/ PJB2019-4(7)

Ammar EE, Rady HA, Khattab AM, Amer MH, Mohamed SA, Elodamy NI, AL-Farga A, Aioub AAA. 2023. A comprehensive overview of eco-friendly bio-fertilizers extracted from living organisms. Environ. Sci. Pollut. Res. Int., 30(53):113119–113137. https://doi.org/10. 1007/s11356-023-30260-x

Aynehband A, Gorooei A, Moezzi AA 2017. Vermicompost: an eco-friendly technology for crop residue management in organic agriculture. Energy Procedia 141:667–671. https://doi.org/10.1016/j.egypro.2017.11. 090

Carter MR, Gregorich EG. 2008. Soil sampling and methods of analysis, second edition, Canadian Society of Soil Science by Taylor & Francis Group, LLC. https://www. routledge.com/Soil-Sampling-and-Methods-of-Analysis/CarterGregorich/ p/book/97808 49335860

Chatterjee R, Bandyopadhyay S. 2017. Effect of boron, molybdenum and bio-fertilizers on growth and yield of cowpea (*Vigna unguiculata* L. Walp.) in acid soil of eastern Himalayan region. J. Saudi Soc. Agric. Sci. 16:332-6. https://doi.org/10.1016/j.jssas. 2015.11.001

Cirka M, Altuner F, Eryigit T, Bildirici N. 2022. Effects of vermicompost applications on some yield and yield properties of wheat. J. of Applied Sci., 7(1): 146–156 http://dx. doi.org/10.52520/ masjaps.213

Dey Chowdhury S, Suhaib KH, Bhunia P, Surampalli RY. 2023. A critical review on the vermicomposting of organic wastes as a strategy in circular bioeconomy: mechanism, performance, and future perspectives. Environ Technol., 30:1-38 https://doi.10.1080/09593330.2023.2215 458

Ding Z, Kheir AMS, Ali OAM, Hafez EM, El-Shamey EA, Zhou Z, Wang B, Lin X, Ge Y, Fahmy AE, Seleiman MF. 2021. A vermicompost and deep tillage system to improve saline-sodic soil quality and wheat productivity. J. Environ. Manag., 2020 :111388. https://doi.org/10.1016/jjenvman. 2020.111388

El-kassas MSA, El-hamahmy MAM, El-Beik AK. 2017. Organic fertilizers improved growth and productivity of cowpea (*Vigna unguiculata* (L.) Walp) under water stress condition in El-Arish Region. Hortscience J. of Suez Canal University, 6(1):1-13 https://www.researchgate.net/publication /324699374

El-Naggar A, Lee SS, Rinklebe J, Farooq M, Song H, Sarmah AK, Zimmerman AR, Ahmad M, Shaheen SM, Ok YS. 2019. Biochar application to low fertility soils: A review of current status, and future prospects. Geoderma, 337:536-554. https://doi.org/ 10.1016/j.geoderma.2018. 09.034

Essa RE, Afifi AA, El-Ashry SM, Mohamed MF. 2023. Productivity of some winter wheat (*Triticum aestivum* L.) varieties through integrated application of vermicompost and biochar in sandy soil. Egypt. J. Agron., 45(2):201-212 https://doi.org/10.21608/ AGRO.2023.2286 25.1385

Essa RE, Thalooth AT, El-Ashry SM, Mohamed MF. 2021. Impact of potassium silicate application and pattern on yield and quality of cowpea under fertigation. Middle East J. of Applied Sci., 11(04):832-838 https://doi. org/10.36632/mejas/2021.11.4.63

Fazal J, Zafar HK, Muhammad I, Muhammad AK, Fazal S, Sayed H, Farooq S, Muhammad A. 2023. Biochar for improving crop productivity and soil fertility Sustainable Agriculture Reviews, 61: 76-98 https://doi. org/10.1007/978-3-031-26983-7

Lair GJ, Gerzabek MH, Haberhauer G, Jakusch M, Kirchmann H. 2006. Response of the sorption behavior of Cu, Cd, and Zn to different soil management. J. Plant Nutr. Soil Sci., 169:60–68. https://doi.org/10. 1002/jpln. 200521752

Liang D, Ning Y, Ji C, Zhang Y, Wu H, Ma H, Zhang J, Wang J. 2024. Biochar and manure Co-Application increases rice yield in low productive acid soil by increasing soil pH, organic carbon, and nutrient retention and availability. Plants, 13(7):973. https://doi. org/10.3390/plants 13070973.

Lim SL, Wu TY, Lim PN, Katrina Shak KPY. 2014. The use of vermicompost in organic farming: overview, effects on soil and economics. J. Sci. Food Agric., 95:1143-1156 https://doi.org/10.1002/jsfa .6849

Liu C, Wang H, Tang X, Guan Z, Reid BJ, Rajapaksha AU, Ok YS, Sun H. 2016. Biochar increased water-holding capacity but accelerated organic carbon leaching from a sloping farmland soil in China. Environ. Sci. Pollut. Res. 23:995-1006. https://doi.org/10.1007/ s11356-015-4885-9.

Magomya AM, Kubmarawa D, Ndahi JA, Yebpella GG. 2014. Determination of plant proteins via the Kjeldahl method and amino acid analysis: A comparative study. Intern. J. of Sci. and Techn. Res., 3(4):68-72. http://www.ijstr.org

Mohammed AA, Younis SM, Ghaly AE, Ibrahim MM. 2024. Influence of carbon source on composting process. Egypt. J. Agron., 46(2): 315-327 https://doi.org/10.21608/ AGRO. 2024.309549.1482

Motsara MR, Roy RN. 2008. Guide to laboratory establishment for plant nutrient analysis, Fertilizers and plant nutrition bulletin 19, FAO Food and Agriculture organization of the United Nations, Rome, http://www.fao. org/3/i0131e/i0131e.pdf

Noreldin T, Abd-El Hameed SM, Amer MA, Ahmed, MAA, Amer A. 2024. The Potential influence of biochar and/or compost on spearmint yield and water productivity in newly reclaimed soil. Egypt. J. Agron., 46(1):191-212 https://doi.org/10. 21608/agro. 2024.297026.1444

Rashad M, Hafez M, Popov AI, Gaber H. 2022. Toward sustainable agriculture using extracts of natural materials for transferring organic wastes to environmental-friendly ameliorants in Egypt. Int. J. Environ. Sci. Technol., 20:7417–7432 https://doi.org/10. 1007/s137 62-022-04438-8

Saletnik B, Zaguła G, Bajcar M, Tarapatskyy M, Bobula G, Puchalski C. 2019. Biochar as a multifunctional component of the environment - A Review. Appl. Sci., 9(6):1139. https://doi.org/10.3390/app906 1139

Sayed AM, Ali RS, Shahram L, Mani M, Mojtaba A. 2020. Integrated application of biochar and bio-fertilizer improves yield and yield components of cowpea under water-deficient stress. Italian J. of Agron., 15(2):94-101. https://doi.org/10.4081/ija. 2020.1581

Singh L, Sukul P. 2019. Impact of vermicompost, farm yard manure, fly ash and inorganic fertilizers on growth and yield attributing characters of maize (*Zea mays* L.). Plant Arch., 19:2193–2200. http://www.plantar chives.org/19-2/2193-2200%20 (5198).pdf

Snedecor GW, Cochran WG. 1990. Statistical Methods: The Iowa State Univ. 8th Ed. Iowa State. Univ., Press, Ames Iowa, U.S.A. https://doi.org/10.3102/107699860190033 04

Soud AA, Tohamy SE, Kholi MME, Wahab BG, Mekhemar GAFA, Ahmed AM, Mohamed SH. 2023. Berseem clover productivity in the presence of a combination of bio-fertilizers, organic fertilizers and biochar under sandy soil conditions. Pakistan J. of Biotech., 20(1):10–20. https://doi.org/10. 34016/pjbt.2023.20.01 .583

Tian X, Li Z, Liu Z, Wang Y, Li B, Zhang K, *et al*., 2021. Combined effect of biochar and nitrogen fertilizer reduction on rapeseed productivity and nitrogen use efficiency. Arch. Agron. Soil Sci., 68:1159-1174. https://doi.org/10.1080/03650340.2021.18 72782

Urmi TA, Rahman MM, Islam MM, Islam MA, Jahan NA, Mia MAB, Akhter S, Siddiqui MH, Kalaji HM. 2022. Integrated nutrient management for rice yield, soil fertility, and carbon sequestration. Plants, 11(1):138. https://doi.org/10.3390/ plants 11010138