Nepal Journal of Botany, (2025), *2*, 65-75
https://doi.org/10.3126/njob.v2i01.78189

Effect of Biochar-amended organic and inorganic manures on growth and yield of Okra (*Abelmoschus esculentus* (L.) Moench)

Anuja Dahal[1], Ajay Jaishi[2*], Subash Babu Ghimire[3], Pushpa Chaulagain[1], Soma Koirala[1], Sristi Karki[1] and Salon Kharal[1]

[1]Agriculture Faculty, Jibika College of Agriculture Sciences, Agriculture and Forestry University, Itahari Nepal
[2]Department of Agriculture, School of Sciences, Kathmandu University, Kavre, Nepal
[3]Agriculture Faculty, DD Institute of Advance Studies, Hemawati Nandan Bahuguna Garwal University, Dehradun India
[*]Corresponding author: ajay.jaishi@ku.edu.np

Abstract

The cultivation of okra in the Terai region primarily relies on chemical fertilizers, which degrade microbial activity and causes nutrient imbalances, ultimately affecting the growth and yield of okra. Replacing synthetic chemical inputs with biochar (BC) and organic manures can enhance soil microbiota and crop productivity. The field experiment was conducted in Ramdhuni, Sunsari, Nepal during April –July, 2023 to evaluate the effects of BC combined with various organic and inorganic manures on growth and yield of okra. The experiment was conducted using a randomized complete block design (RCBD) with seven treatments: (200 kg Nha^{-1})-BC + farmyard manure (FYM), BC + vermicompost (VC), BC + poultry manure (PM), BC + goat manure (GM), BC + pig manure (PiM), BC + chemical fertilizer (NPK), and control—with each treatment replicated thrice. The yield and yield attributing characters significantly improved with biochar amended organic manures. BC+PM yielded the highest plant height (78.72 cm), number of branches (4.4), number of leaves (71.53), average fruit weight (16.42 g), and yield (19.89 Mtha^{-1}). Compared to BC+NPK, BC+PM showed a greater increase in plant height (12.1%), number of branches (19.9%), fruit weight (21.0%) and yield (47.7%). Hence, integrating BC with PM could be an ideal treatment to reduce the effect of chemical fertilizer and maximize the productivity of okra in Nepal.

Keywords: Biochar, Chemical fertilizer, Organic Manure, Productivity

1. Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is a warm-season vegetable belonging to the Malvaceae family. It is one of the oldest cultivated crops, valued for its edible green pods (Acharya et al., 2022). Okra thrives in warm temperatures, with an optimal range between 21°C and 35°C. The plant prefers well-drained, sandy soils rich in organic matter and requires sun light for optimal growth. In Nepal, imbalanced nutrient management, particularly excessive use of chemical fertilizers combined with insufficient organic inputs has reduced soil fertility and lowered vegetable productivity (Dahal & Manandhar, 2021). The average yield of okra in Nepal is significantly lower (11.53 Mt ha^{-1}) than the crop's actual productivity (18-22 Mt ha^{-1}) (Adhikari & Piya, 2020; Adhikari & Gyawali, 2024; Agriculture Information and Communication Center (AITC), 2023).

Biochar (BC), a porous carbon material derived from pyrolyzed biomass, enhances soil structure, water retention, and nutrient availability. Its application in combination with poultry manure (PM) or cattle waste amplifies these benefits, driving significant yield improvements in crops by optimizing soil-plant interactions (Dahal et al., 2021). The combination of BC with PM has been found to increase okra fruit yield by 170% compared to control and by 53.26%

over inorganic fertilizers alone, demonstrating significant yield-boosting potential of BC when used with organic amendments (Shrestha et al., 2024). While the immediate effects of BC on okra growth and yield may not always be significant, its long-term benefits, such as increased soil organic carbon and higher cation exchange capacity (CEC), can improve soil health and enhance crop performance over time (Sangotoye et al., 2024). Incorporating BC with organic manures offers a sustainable approach to improving soil fertility and boosting okra production, providing both immediate and long-term agricultural benefits.

Integration of biochar with organic manures like cattle urine, farmyard manure (FYM), poultry manure (PM), vermicompost (VM) and goat manure (GM) offers significant potential to enhance soil fertility, improve agricultural productivity, and reduce reliance on chemical fertilizers (Schmidt et al., 2017; Yadav et al., 2023). Field trials in Nepal have demonstrated that BC enriched with cattle manure resulted in a 320% increase in marketable radish yield compared to control plots (Dahal et al., 2021). Similarly, the application of urine-enriched BC has been observed to double yields in various crops, outperforming conventional chemical fertilizers (Schmidt et al., 2017). The objective of the study was to assess okra (Arka Anamika) production and agricultural sustainability by evaluating the efficacy of biochar combined

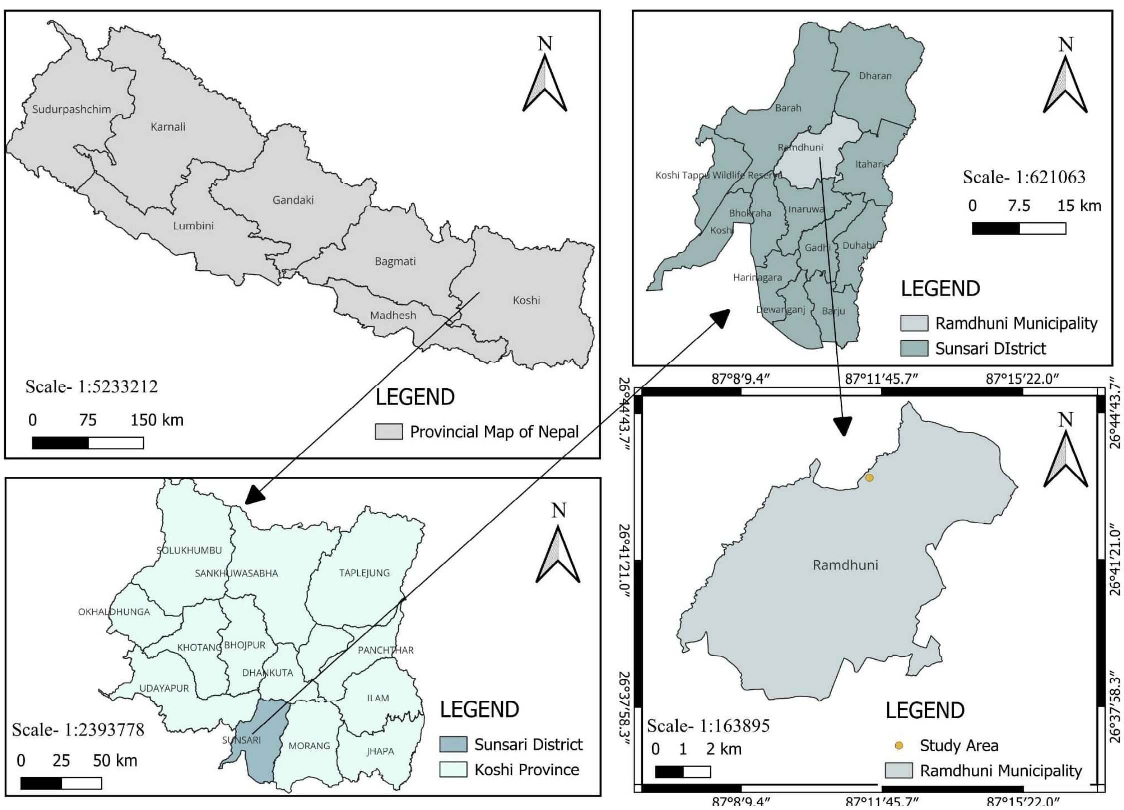

Fig 1. Map of Nepal showing experimental site at Jibika College, Ramdhuni Municipality, Sunsari, Koshi Province, Nepal

with various organic manures and studying their effects on crop growth and yield performance.

2. Materials and Methods

2.1 Experimental site

The study was conducted at Jibika College of Agricultural Science, Ramdhuni, Sunsari, Nepal (26.720681°N, 87.190744°E; 100 m altitude) from April to July 2023. The study site is located in a tropical region, characterized by distinct wet and dry seasons, with temperatures ranging from 15°C to 35°C (Fig. 1).

2.2 Experimental design and treatments

This experiment was followed a single factor RCBD with seven treatments and replicated three times The gross field area measured 251.075 m² (20.75 m × 12.1 m), including a 1 m border, while the net area of production was 127.575 m². Each plot (6.075 m²; 2.25 m × 2.7 m) was spaced 50 cm apart, with 1 m between blocks. The test crop used was okra cv. Arka Anamika, a high-yielding hybrid variety, planted at a spacing of 45 cm × 45 cm. The treatment combination, the rate of Nitrogen applied and the amount of manure are mentioned in Table 1.

2.3 Soil and manure analysis

Soil and manure samples (FYM, PM, GM, and PiM) were collected from the research field (0-30 cm depth), and Jibika Agricultural Farm, respectively. For each manure type, 10-15

Table 1. Seven different treatments involved in experiment and their description

S. N.	Treatment	Rate of N applied through organic manure (kgha^{-1})	Amount of manure equivalent to N (kg plot^{-1})
1	BC + FYM	200	12.66
2	BC + VC	200	10.63
3	BC + PM	200	8.51
4	BC + PiM	200	11.90
5	BC + GM	200	9.72
6	BC + NPK	200:100:80	0.25:0.68:0.08
7	Control	0	-

BC was applied at the rate of 2 Mtha^{-1} (Acharya et al., 2022; Dahal et al., 2021) in the treatment plots along with organic manures and $NP_2O_5K_2O$. The amount of BC allotted for each plot was 1.76kg.

Table 2. Nutrient status of various organic manures for the study of okra at Ramdhuni, Sunsari, 2023

Source of nutrient	Available amount (%) of elements				
	FYM	VC	Poultry	Pig	Goat
Available Nitrogen, %	1.74	2.0	2.5	1.6	1.6
Available Phosphorous, %	2.03	3.3	2.4	4.5	2.05
Available Potassium, %	1.7	4.5	2.06	1.5	4.2
Available Organic Carbon, %	15.0	14.7	13.4	14.5	15.8
Moisture content, %	81.0	75	75.0	57.1	28.0
pH Value	7.7	8.8	7.0	7.3	9.1

random samples were collected from multiple locations within their respective piles and composite samples were prepared. All nutrient analyses were performed at the Regional Soil and Fertilizer Testing Laboratory in Jhumka, Sunsari. The experimental site is characterized by sandy loam soil with strongly acidic pH (5.3), containing 2.01% organic matter and nutrient levels of 0.1% nitrogen, 110.2 kgha^{-1} available phosphorus, and 272 kgha^{-1} available potassium, along with a bulk density of 1.41 gcm^{-3}. The nutrient status of different manures is presented in Table 2.

2.4 Cultural operations

BC, at the rate of 2 Mt ha^{-1}, and organic manures (FYM, GM, PM, PiM, VC) at the rate of 200 kg ha^{-1} (recommended dose) were applied two days before sowing. Chemical fertilizer (200:180:60 kg ha^{-1} NPK) was applied during sowing (Agriculture Information and Communication Center (AITC), 2023) with half N + full P/K as basal dose and remaining N top-dressed at 45 days after sowing (DAS). Okra seeds (pre-soaked and shade-dried) were sown on 8th April, 2023 and thinned to 30 plants/plot. Irrigation was applied daily until 50% germination, and then as needed. Manual weeding was done at 20 and 40 DAS. Harvesting was commenced at 45 DAS and involved multiple pickings of tender fruits at 3–4-day intervals post-flowering, with individual fruit measurements were recorded.

2.5 Data collection and analysis

Date on phenological stages such as days to first germination and flowering were also recorded. Growth parameters (plant height, leaf number, and branch number per plant) were recorded at 20, 35, 50, 65, and 80 DAS from five randomly selected and tagged plants per plot, excluding border plants. Yield parameters (number of fruits per plant, fruit length (cm), weight of fruit(g) and yield (Mt ha{ ¹)) were measured during harvest. All data were analyzed using one-way ANOVA, followed by Duncan's Multiple Range Test (DMRT) at a 95% confidence level (Gomez & Gomez, 1984) in Microsoft Excel and R studio v. 1.3.1056.

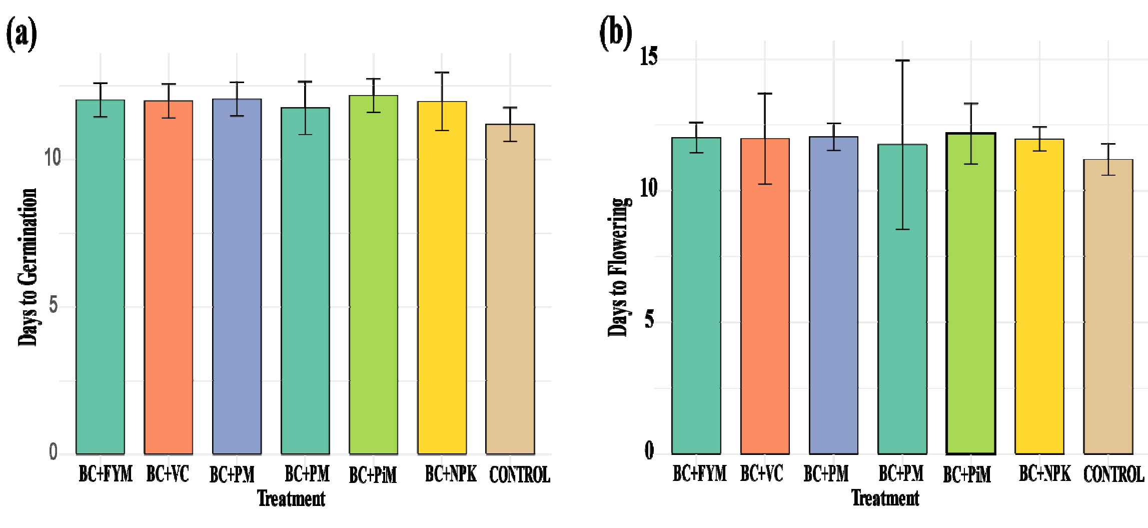

Fig 2. Effect of biochar and its combination with organic and inorganic manures on days to the germination and days to germination; (a) Days to germination (b) Days to flowering. Bar indicates ±SD (n = 3)

3. Results

3.1 Days to first germination and flowering

Statistical comparisons showed no significant differences ($p > 0.05$) in days to germination and days to flowering among the treatments. However, the control showed the earliest germination and flowering (11.18 days). Among the BC based combinations, BC+PiM poultry manure had the fastest germination (11.74 days) and flowering (11.74 days), while BC+GM took the longest time (12.16 days for both stages). The other treatments: BC+FYM, BC+VC, BC+PM, and BC+NPK were very close, ranging between 11.96 to 12.04 days for both germination and flowering, with no major differences between them (Fig. 2).

3.2 Plant height

The treatments showed distinct effects on plant height across growth stages. At 20 DAS, no significant differences were observed among treatments (Fig. 3). By 35 DAS, BC+PiM produced significantly taller plants than BC+GM and the control, while BC+FYM and BC+PM showed intermediate performance. At 50 DAS, BC+PM resulted in the tallest plants, significantly overtaking BC+PiM, BC+GM, BC+NPK, and the control. The advantage of BC+PM became more pronounced at 65 DAS, where it maintained significantly greater plant height compared to all other treatments except BC+FYM. By 80 DAS, while BC+PM and BC+VC showed numerically higher values,

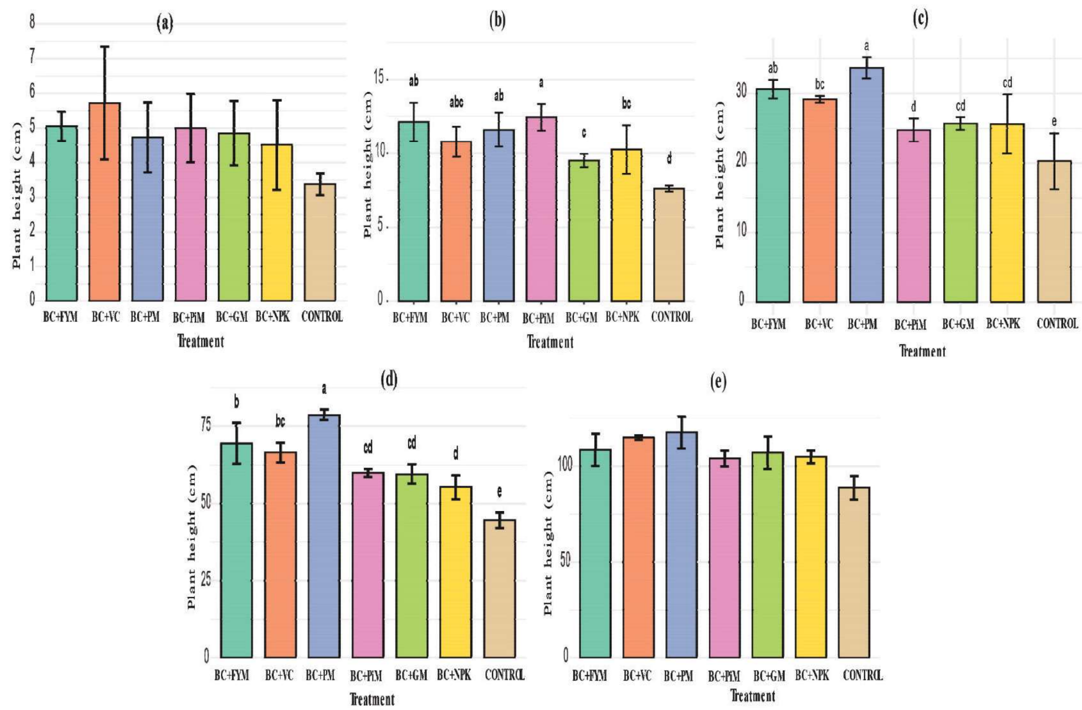

Fig 3. Effect of biochar and its combination with organic and inorganic manures on plant height of okra (a) Plant height at 20 DAS (b) Plant height at 35 DAS (c) Plant height at 50 DAS (d) Plant height at 65 DAS (e) Plant height at 80 DAS. Bar indicates ±SD ($n = 3$); Different letters indicate significant differences ($p < 0.05$)

no statistically significant differences were detected among treatments. The organic amendments (particularly BC+PM and BC+FYM) generally promoted better growth than inorganic amendment (BC+NPK) (Fig. 3).

3.3 Number of branches

The number of branches varied significantly among treatments at different growth stages. At 35 DAS, BC+PM produced significantly more branches than all other treatments (Table 3). By 50 DAS, BC+PM again resulted in the highest branch count, significantly outperforming the treatments (BC+NPK and control), however most treatments (BC+VC, BC+PiM, BC+GM) were statistically similar. At 65 DAS, no significant differences were observed among treatments, but BC+VC and BC+PM had numerically higher number of branches. By 80 DAS, while differences were non-significant, BC+PM and BC+PiM trended higher, whereas the control remained the lowest. Overall, BC+PM consistently demonstrated superior branching, particularly in early stages, while the control and BC+NPK often yielded fewer branches (Table 3).

3.4 Number of leaves

At 20 and 35 DAS, no significant differences were observed among treatments for leaf number per plant. By 50 DAS, BC+VC and BC+PM produced significantly more leaves than the control and BC+NPK, with BC+FYM and BC+PiM showing intermediate values. At 65 DAS, BC+PM significantly outperformed BC+GM, BC+NPK, and the control, while other treatments (BC+VC, BC+FYM, BC+PiM) were statistically similar. By 80 DAS, though no significant differences were detected, BC+PM (71.53) and BC+VC (53.13) recorded the highest leaf counts, whereas the control (45.33) and BC+FYM (47.13) had the lowest values. At 80 DAS, the number of leaves showed non-significant, differences among the treatments (Table 4)

Table 3. Effect of biochar and its combination with organic and inorganic manures on number of branches (plant^{-1})

Treatments	No. of branches			
	35 DAS	**50DAS**	**65DAS**	**80DAS**
BC + FYM	0.33^{c}	2.73^{ab}	3.47	3.20
BC + VC	1.47^{b}	3.00^{ab}	3.80	3.93
BC + PM	2.27^{a}	3.60^{a}	3.53	4.40
BC + PiM	1.07^{b}	2.80^{ab}	3.40	4.07
BC + GM	0.47^{c}	2.80^{ab}	3.13	3.47
BC + NPK	0.60^{c}	2.20^{bc}	2.60	3.67
Control	0.27^{c}	1.80^{c}	2.47	3.13
SEm(±)	0.0004	0.002	0.002	0.003
$LSD_{0.05}$	0.41	0.85	ns	ns
CV (%)	24.93	17.71	16.18	17.18

SEm: Standard Error of the mean, LSD: Least Significant Difference (p>0.05), CV: Coefficient of Variation, Means followed by same letter(s) do not differ significantly at 5% DMRT, ns: non-significant (At 50 DAS, except control, all treatment are not significantly different)

Table 4. Effect of biochar and its combination with organic and inorganic manures on number of leaves (plant^{-1})

Treatments	No. of leaves (plant^{-1})				
	20 DAS	35 DAS	50DAS	65DAS	80DAS
BC + FYM	2.73	8.93	18.07^{ab}	44.33^{ab}	47.13
BC + VC	2.87	11.00	20.07^{a}	48.20^{ab}	53.13
BC + PM	2.73	9.00	20.00^{a}	55.07^{a}	71.53
BC + PiM	2.73	9.00	18.20^{ab}	46.73^{ab}	57.60
BC + GM	2.27	7.13	14.60^{ab}	38.27^{b}	55.20
BC + NPK	2.33	7.27	14.27^{b}	39.27^{b}	60.80
Control	2.00	5.47	12.80^{b}	37.67^{b}	45.33
SEm(±)	0.002	0.023	0.054	0.237	1.60
$LSD_{0.05}$	ns	ns	5.03	10.50	ns
CV (%)	21.17	22.32	16.78	13.34	27.48

SEm: Standard Error of the mean, LSD: Least Significant Difference ($p<0.05$), CV: Coefficient of Variation, Means followed by same letter(s) do not differ significantly at 5% DMRT, ns: non-significant

3.5 Yield and yield parameters

3.5.1 Number of fruits per plant

The number of fruits per plant was not significantly affected by different treatments. However, higher fruit numbers were observed in VC with BC-treated plants, followed by PM with BC. The lowest number of fruits per plant was recorded in BC+NPK treatment (Fig. 4a).

3.5.2 Fruit weight

Significant differences ($p < 0.05$) were observed in fruit weight among different treatments. BC+PM produced the heaviest fruits (16.42 g), which was significantly higher than BC+NPK and control, but it was statistically similar to BC+FYM, BC+VC, BC+PiM, and BC+GM. The lowest fruit weight was found in BC+NPK treatment (13.57 g) (Fig. 4b).

3.5.3 Fruit length

The length of okra fruits was not significantly affected by treatments, but BC+PM resulted in longer fruits, while the shortest fruits were recorded in control plots (Fig. 4c).

3.5.4 Yield of okra

The results showed significant differences in yield among treatments ($p < 0.05$). BC+PM produced the highest yield (19.89 Mtha^{-1}), which was significantly greater than all other treatments. BC+VC (16.09 Mtha^{-1}) and BC+FYM (15.42 Mtha^{-1}) performed moderately, with BC+VC being statistically superior to BC+FYM. The lowest yields were observed in BC+GM (13.66 Mtha^{-1}), BC + NPK (13.47 Mtha^{-1}), and the control (11.46 Mtha^{-1}), with the control being significantly inferior to all biochar-amended treatments. Among the low-performing treatments, BC+NPK did not differ significantly from BC+GM but was superior to the control (Fig. 4d).

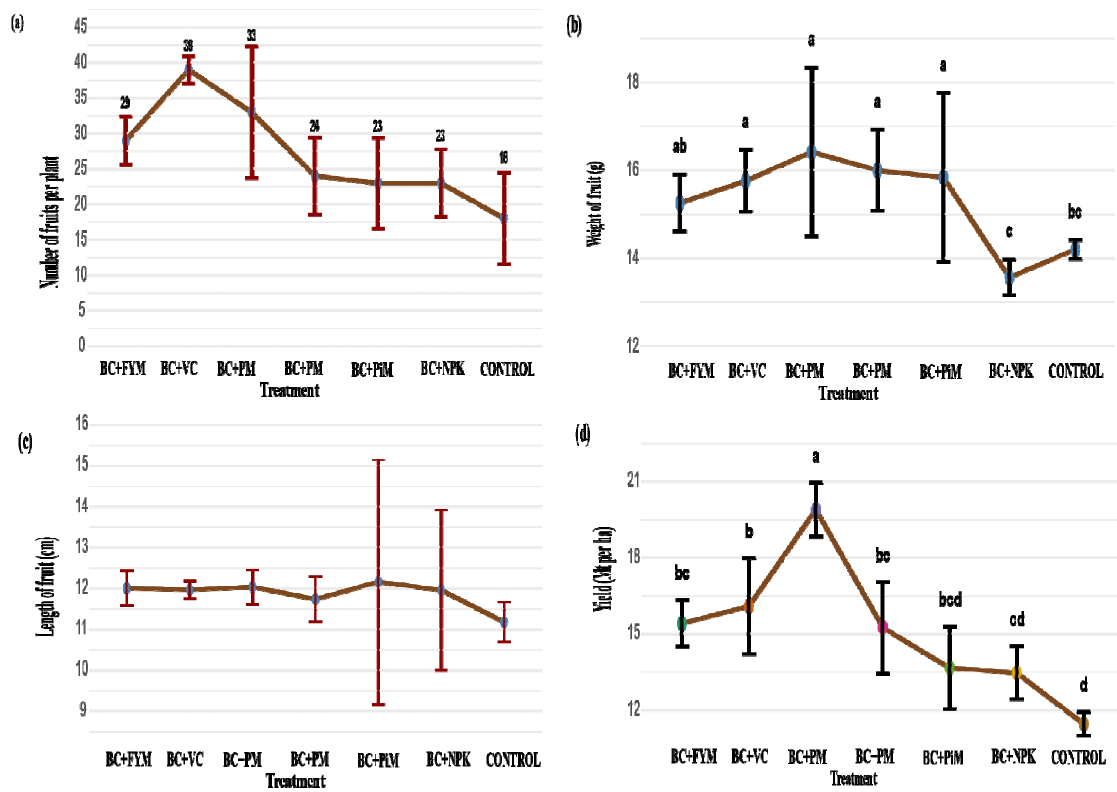

Fig 4. Effect of biochar and its combination with organic and inorganic manures yield and yield parameters (a) Number of fruits per plant (b) Fruit weight (c) Fruit length (d) Yield of okra; Bar indicates ±SD (n = 3); Letters indicate significant differences ($p < 0.05$).

4. Discussions

Our findings demonstrate that the biochar amended poultry manure (BC+PM) enhanced plant height, leaf number and number of branches during peak vegetative growth (35-65 DAS) and improved yield compared to other BC amended organic and inorganic manure. Although statistical analysis showed no significant differences ($p > 0.05$) among the treatments, the combined application of BC+PM consistently produced numerically higher values across multiple growth and yield parameters. The high NPK content in poultry manure, when amended with biochar, likely enhanced nutrient retention and use efficiency, leading to improved growth and yield parameters in okra. This is highly related with the findings of Aboyeji et al. (2021) and Acharya et al. (2022) which showed improved okra yield and nutrient uptake due to rich nutrient profile of PM. In our study, the BC+PM treatment yielded the highest okra production (19.89 Mtha^{-1}), while BC+NPK had significantly lower yield and fruit weight. Improved plant growth parameters such as plant height and number of branches under BC+PM treatment supports the findings of Abdul Reeza & Azman (2022), while the highest number of fruits per plant under VC treatment supports the findings by Arancon et al. (2003) who noted the role of VC in enhancing phosphorus and potassium availability. However, because soil residual potassium and phosphorus levels were not assessed in this study, this interpretation should be approached with caution, and additional research is required to directly confirm the nutrient dynamics associated with VC application.

The role of BC as a soil amendment is discussed by Lehmann et al. (2006) and Steiner et al. (2007), who highlighted the ability of BC to improve soil structure, enhance nutrient retention, and reduce leaching. The combination of biochar with NPK fertilizer resulted in poor plant growth and low fruit yield likely because the nutrients from chemical fertilizer were rapidly adsorbed onto the biochar surface, reducing their availability to plants. Jeffery et al. (2011) reported that biochar with fertilizers can improve soil properties. In our study, combining biochar with NPK showed low yield, likely because nutrients were trapped by biochar and not easily available to plants. According to Glaser et al. (2002), BC plays a notable role in carbon sequestration and long-term fertility, relating with our recommendation for sustainable okra cultivation using organic amendments like PM and VC in combination with BC.

Recent studies from Gairhe et al. (2024) and Acharya et al. (2022) confirm the potential of BC-based amendments in sustainable agriculture. Biochar-based organic fertilizers improve crop growth by enhancing water and nutrient retention capacity of soil (Brtnicky et al., 2019). However, some studies show that mixing manure with biochar may not always boost plant growth and could even have no effect or reduced benefits in some cases (Hagemann et al., 2017). BC enriched with cattle urine and blended with goat manure significantly improved soil pH, organic carbon, total nitrogen, and available phosphorus and potassium, enhancing okra fruit yield in sandy loam soils of Nepal (Acharya et al., 2022). These findings align with the findings of Dahal et al. (2021) confirming that BC – particularly when combined with nutrient-rich organic inputs like PM or VC – serves as a transformative solution for enhancing okra yield, improving soil health, and promoting environmentally sustainable production in tropical farming systems.

5. Conclusion

The study shows that using BC with organic manure improves certain growth and yield traits in okra, though not all parameters were affected. Poultry manure with BC application showed superior performance in major growth and yield traits in comparison to BC amended inorganic source. These findings recommend the adoption of poultry manure-biochar amendments in sandy loam soils to optimize okra productivity while promoting sustainable soil health through organic farming practices. However, it is important to note that these results are based on observations from a single growing season; therefore, further multi-season and multi-site studies are necessary to validate and generalize these findings across different environmental conditions.

6. Acknowledgements

The authors are highly thankful to Jibika College of Agricultural Sciences and Jibika Agriculture Farm for creating a favorable environment for the research work. Our heartfelt appreciation also goes to our mentors, and friends for their constant support, insightful discussions, and motivation during the course of research.

7. References

Abdul Reeza, A., & Azman, U. H. (2022). Effect of Organic Waste Fertilizers on Growth and Development of Okra (*Abelmoschus esculentus* (L.) Moench). *Pertanika Journal of Tropical Agricultural Science*, *45*(4), 1021–1034. https://doi.org/10.47836/pjtas.45.4.10

Aboyeji, C. M., Olaniyan, D. O., Dunsin, O., Adekiya, A. O., Okunlola, F. O., Ejue, S. W., Adebiyi, O. T., Olofintoye, T. A., Aremu, C. O., Afolayan, J. O., & Adeniyi, H. A. (2021). Physiological growth, yield and quality responses of okra to sole and combined soil application of green biomass, poultry manure and inorganic fertilizers. *Plant Physiology Reports*, *26*, 709-721. https://doi.org/10.1007/s40502-021-00628-7

Acharya, N., Vista, S. P., Shrestha, S., Neupane, N., & Pandit, N. R. (2022). Potential of biochar-based organic fertilizers on increasing soil fertility, available nutrients, and okra productivity in slightly acidic sandy loam soil. *Nitrogen*, *4*(1), 1-15. https://doi.org/10.3390/nitrogen4010001

Adhikari, A., & Piya, A. (2020). Effect of different sources of nutrient on growth and yield of okra (*Abelmoschus esculentus* (L.) Moench). *International Journal of Environmental & Agriculture Research*, *6*(1), 45-50.

Adhikari, S. P., & Gyawali, C. (2024). Comparative analysis of manures and fertilizer on okra growth, yield and its economics in Baitadi, Nepal. *Archives of Agriculture and Environmental Science*, *9*(3), 422-430. https://doi.org/10.26832/24566632.2024.090303

Agriculture Information and Communication Center (AITC). (2023). *Agriculture diary*. Ministry of Agriculture and Livestock Development, Government of Nepal.

Arancon, N. Q., Edwards, C. A., Bierman, P., Metzger, J. D., Lee, S., & Welch, C. (2003). Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries. *Pedobiologia*, *47*(5–6), 731–735. https://doi.org/10.1078/0031-4056-00251

Brtnicky, M., Dokulilova, T., Holatko, J., Pecina, V., Kintl, A., Latal, O., Vyhnanek, T., Prichystalova, J., & Datta, R. (2019). Long-term effects of biochar-based organic amendments on soil microbial parameters. *Agronomy*, *9*(11), 747. https://doi.org/10.3390/agronomy9110747

Dahal, S., & Manandhar, B. (2021). Soil management practices in commercial vegetable farming in changing socioeconomic context in Makawanpur, Nepal. *Environmental Challenges*, *4*, 100188. https://doi.org/10.1016/j.envc.2021.100188

Dahal, S., Vista, S. P., Khatri, M., & Pandit, N. R. (2021). Effect of biochar blended organic fertilizers on soil fertility, radish productivity and farm income in Nepal. *Archives of Agriculture and Environmental Science*, *6*(4), 416-425. https://doi.org/10.26832/24566632.2021.060402

Gairhe, J. J., Bhattarai, P., Gyanwali, P., Khanal, R., Mainali, R., Poudel, S., Pokhrel, M., & Sharma, P. K. (2024). Effect of various biochar on selected soil properties and agronomical parameters of okra (*Abelmoschus esculentus* (L.) Moench) at Rupandehi, Nepal. *Archives of Agriculture and Environmental Science*, *9*(1), 134-142. https://doi.org/10.26832/24566632.2024.0901019

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—A review. *Biology and Fertility of Soils*, *35*(4), 219–230. https://doi.org/10.1007/s00374-002-0466-4

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research. 2nd ed.* John Wiley & Sons Ltd.

Hagemann, N., Joseph, S., Schmidt, H.-P., Kammann, C. I., Harter, J., Borch, T., Young, R. B., Varga, K., Taherymoosavi, S., Elliott, K. W., McKenna, A., Albu, M., Mayrhofer, C., Obst, M., Conte, P., Dieguez-Alonso, A., Orsetti, S., Subdiaga, E., Behrens, S., & Kappler, A. (2017). Organic coating on biochar explains its nutrient retention and stimulation of soil fertility. *Nature Communications*, *8*(1), 1089. https://doi.org/10.1038/s41467-017-01123-0

Jeffery, S., Verheijen, F. G. A., Van Der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment*, *144*(1), 175–187. https://doi.org/10.1016/j.agee.2011.08.015

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems – A review. *Mitigation and Adaptation Strategies for Global Change*, *11*(2), 403–427. https://doi.org/10.1007/s11027-005-9006-5

Sangotoye, S. E., Atere, C. T., Taiwo, L. B., & Olayinka, A. (2024). Improving soil chemical properties and okra (*Abelmoschus esculentus*) yield through complementary applications of biochar, and organic and inorganic fertilizers. *Journal of Plant Nutrition*, *47*(15), 2530–2542. https://doi.org/10.1080/01904167.2024.2354193

Schmidt, H., Pandit, B. H., Cornelissen, G., & Kammann, C. I. (2017). Biochar based fertilization with liquid nutrient enrichment: 21 field trials covering 13 crop species in Nepal. *Land Degradation & Development*, *28*(8), 2324–2342. https://doi.org/10.1002/ldr.2761

Shrestha, A., Sai, R., & Devkota, M. (2024). Potential of biochar-based fertilizers for increasing the productivity of okra in Gajuri, Dhading. *Turkish Journal of Agriculture - Food Science and Technology*, *12*(s1), 2021–2031. https://doi.org/10.24925/turjaf.v12is1.2021-2031.6946

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., De Macêdo, J. L. V., Blum, W. E. H., & Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, *291*(1–2), Article 1–2. https://doi.org/10.1007/s11104-007-9193-9

Yadav, S. P., Bhandari, S., Bhatta, D., Poudel, A., Bhattarai, S., Yadav, P., Ghimire, N., Paudel, P., Paudel, P., Shrestha, J., & Oli, B. (2023). Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research*, *11*, 100498. https://doi.org/10.1016/j.jafr.2023.100498