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Potential of Biochar-Based Fertilizers for Increasing the Productivity of Okra in Gajuri, Dhading

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ABSTRACT

Sustainable agricultural production depends on increasing crop productivity while preserving soil health and reducing environmental risk. The purpose of this study was to evaluate the potential of biochar (10 t ha^{-1}) based organic and inorganic fertilizer for increasing okra productivity through a field experiment conducted in Gajuri, Dhading. A 130 m^2 area was divided into six treatment groups, each with four replications, using a Randomized Complete Block Design. The following were the treatments: i) inorganic fertilizer (RF); ii) biochar plus inorganic fertilizer (BF); iii) biochar plus vermicompost (BVC); iv) biochar plus poultry manure (BPM); v) biochar (BC); vi) control; neither biochar nor fertilizer (CK). The recommended rates of urea, di-ammonium phosphate (DAP), and muriate of potash (MOP) were applied to the mineral NPK fertilizers in RF and BF. The rate whereby organic fertilizers were applied was 200 kg N ha^{-1}. Plots treated with biochar and various fertilizer groups were compared in terms of growth and yield efficiency. The BVC treatment was found to exhibit poorer growth performance in terms of plant height, number of leaves, primary branches, and nodes compared to the combination of biochar and poultry manure. Fruit output rose by 170% over CK (7.13 mt ha^{-1}) and by 53.26% over RF (12.58 mt ha^{-1}) after BPM treatment (19.28 mt ha^{-1}). While BF and RF did not significantly differ in terms of growth characteristics, BF outproduced RF by 29% and CK by 126.79% in terms of pod yield. BF and BPM offered greater financial rewards than alternative treatments.

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Introduction

Okra (*Abelmoscus esculentus* L.) is one of the known and utilized species of the family Malvaceae. It is a chief summer vegetable widely grown from the tropics to sub-tropics and warmer parts of the temperate zone for its nutritious, tender pods. Okra can be grown in a wide variety of soil types, ranging from sandy loam to clay soil, and at temperatures ranging from 20°C to 30°C (Dada & Fayinminnu, 2010). It contains carbohydrates, proteins, and vitamin C in large quantities, as well as essential and non-essential amino acids that are comparable to those of soybeans (Adeboye and Oputa, 1996).

Okra is grown on 9584 ha of land nationwide, with production and productivity of 112260 metric tons and 11.95 metric tons ha^{-1}, respectively. In the Dhading district, the total area under okra production is 168 ha, while production and productivity are 1399 metric tons and 8.39 metric tons per ha, respectively (MoALD 2022). In the last three years, the productivity of okra in Nepal has been on the rise while it has been decreasing in Dhading (MoALD 2022). Poor soil fertility (low pH, organic matter (OM), cation exchange capacity (CEC), base saturation, and available nutrients), inadequate use of chemical and organic fertilizers, and a lack of effective crop management practices by farmers are the main causes of decreased productivity (Acharya et al., 2022). Similarly, the degradation of land and poor soil health (acidic soil pH, low OM%, low N, and low K) is one of the major problems faced by farmers in Dhading with lowland and upland areas (Kharal et al., 2018). So, poor soil health and inadequate use of chemical and organic fertilizers have resulted in a decreased yield of okra in Dhading.

Research and application of various fertilizer and plant management techniques are being done in order to improve production and address the responsible causes. The positive effects of the simultaneous utilization of organic and inorganic fertilizer on okra yield and quality have been substantiated by several studies (Adekiya et al., 2020a; Akhter et al., 2019; Bharthy et al., 2017; Miah et al., 2020).

The highest quality and quantity of okra were recorded by Sachan et al. (2017) when a combination of NPK, Farm Yard Manure (FYM), poultry, and vermicompost was used concurrently. Other management practices include the use of mulching material to reduce weed density, conserve moisture, and increase yield (Ojiako et al., 2019; Puri et al., 2022; Shamim et al., 2018). One such nutrient management strategy could be the addition of biochar to the soil. Biochar is a carbon-rich, fine-grained product produced by the pyrolysis of organic matter such as wood, tree branches, agricultural waste, cow manure (Pandit et al., 2021). The addition of biochar significantly improves soil health and crop yield in poor to medium fertile soil and in acidic soil (El-Naggar et al., 2019; Van Zwieten et al., 2010).

Multiple studies have demonstrated the efficacy of biochar as a soil amendment, capable of enhancing degraded soil, improving soil fertility, and even boosting crop growth and yield (Murtaza et al., 2021). As the accumulation of soil organic C is vital for improving soil properties, biochar with a high carbon content (60–80%) can have a positive impact on soil properties (Blanco-Canqui, 2017). Blanco-Canqui (2017) reported that the application of biochar decreases soil bulk density by 3 to 31%, increases porosity by 14 to 64%, increases the availability of water by 4 to 130%, increases the stability of wet aggregates by 3 to 226%, and has variable effects on dry aggregate stability. Many studies have demonstrated the ability of biochar to increase the pH of the soil, particularly in acidic soil (Martinsen et al., 2015; Song et al., 2018; Van Zwieten et al., 2010). Liang et al (2014) suggested that the presence of a high amount of alkaline earth metals such as Mg^{+2}, Ca^{2+}, etc. in biochar is responsible for the increase in soil pH following biochar application. Therefore, biochar can act as a liming agent, neutralizing soil acidity and improving the availability of essential soil nutrients (El-Naggar et al., 2019). Many studies have provided strong evidence that the addition of biochar influences the NPK content of the soil. The incorporation of biochar increases N availability by reducing leaching, increasing retention (absorption of ammonium and nitrate ions), and reducing volatilization of ammonia (Major et al., 2012; Rondon et al., 2007). Joseph et al. (2021) found that the addition of biochar increased available P by a factor of 4.6, and an increase in plant yield was significantly high in low-nutrient P-sorbing acidic soil.

An increase in crop yield with the combined application of biochar and fertilizer has been demonstrated by numerous researchers. Acharya et al. (2022) investigated the effect of biochar-based fertilizers on soil fertility and productivity of okra and observed that biochar-blended goat manure resulted in the highest fruit yield, 88% more than the control. Rondon et al. (2007) reported a positive impact of biochar addition on Biological Nitrogen Fixation (BNF) in common beans and their pod yield. In a greenhouse experiment conducted by Uzoma et al. (2011) on the effect of cow manure biochar on maize productivity in sandy soil, they observed maximum yield and Water Use Efficiency (WUE) with cow manure biochar applied at a rate of 15 t/ha, with 150% more yield and 139% more WUE than the control.

These studies illustrate the positive impacts of adding biochar to soil health, productivity, and crop yield in addition to other organic or chemical fertilizers. The agronomic and financial consequences of co-applying biochar with organic or chemical fertilizers to okra plants in Nepal, however, have not been extensively studied. One such study, conducted in a controlled greenhouse, examines the effects of biochar on okra plants. The purpose of this study was to examine the effects of biochar-based inorganic and organic fertilizers on the vegetative and reproductive performance of okra, as well as to evaluate the impacts of biochar-based fertilizer on okra yield under open field conditions. This experiment's specific goal was to determine whether blended fertilizer containing biochar could increase okra production. Additionally, to evaluate the impact of adding biochar on okra productivity and identify the most efficient and economical method of raising okra yields.

Materials and Methodology

Location, Site Weather and Soil Properties

A field experiment was conducted in Gajuri-1, Dhading, Nepal, which falls under the PMAMP vegetable zone, Dhading from March to July 2023. The location of the experiment is situated at an altitude of 347 meters above sea level. Figure 1 and Figure 2 present information on the climatic conditions during the study's duration and the location of the experimental area, respectively. Table 1 illustrates the characteristic of soil from the research field.

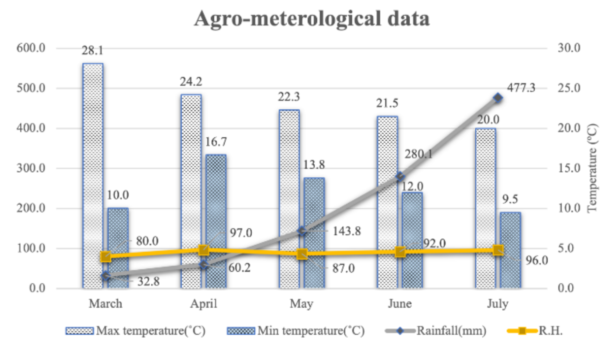

Figure 1. Agrometeorological information during the experimental period at Gajuri-1, Nepal from March 2023 to July 2023

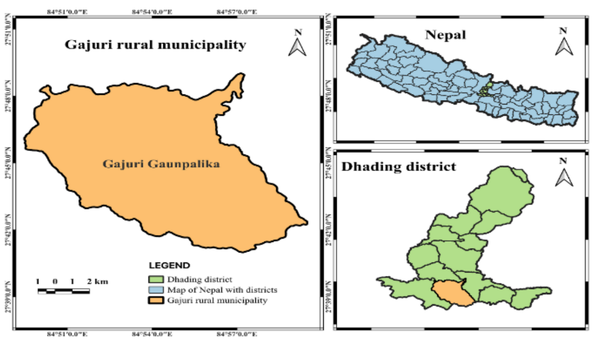

Figure 2. Location of the experiment field

Table 1. Characteristics of soil and biochar

Parameters	Soil	Biochar
pH	7.1	9.3
Texture	Sandy-loam	-
Organic matter (%)	0.23	-
Organic carbon (%)	-	13.6
Total Nitrogen (%)	0.23	0.81
Available Phosphorous (kg ha^{-1})	23.84	-
Available Potassium (kg ha^{-1})	244.8	-

Table 2. Description and Dosage of Different Treatment Used in the Experiment.

Treatment number	Description	Abbreviation	Dosage (per ha)
Treatment 1 (T_1)	Control (no biochar and no NPK)	CK	n/a
Treatment 2 (T_2)	Inorganic fertilizer	RF	MOP: 133 kg DAP: 391.2 kg Urea: 260.8 kg
Treatment 3 (T_3)	Inorganic fertilizer + Biochar	BF	MOP: 133 kg DAP: 391.2 kg Urea: 260.8 kg Biochar: 10 ton
Treatment 4 (T_4)	Vermicompost + biochar	BVC	8.89 ton + 10 ton
Treatment 5 (T_5)	Poultry Manure + biochar	BPM	8.50 ton + 10 ton
Treatment 6 (T_6)	Biochar	BC	10 ton

Biochar Production

The biochar used in the experiment was produced by "Kon-tiki" method, a simple and effective method, especially for small farm holders (Dahal et al., 2021). The ideal temperature to produce biochar is 400-550^{0}C (Baidoo et al., 2016; Naeem et al., 2014). Biomass materials such as wood, agricultural residues, and other organic waste were collected from nearby area around the research field and sun-dried for one day. A cone shaped pit with a diameter and depth of 1 m was made. A small fire was started at the bottom of the pit using dry kindling, and after the fire was established, the collected biomass material was added layer after layer, gradually and in small amounts, to maintain a controlled burn. This process was repeated until the pit was filled with biochar. Once the charcoal was fully charred, water was poured over the pit to stop the combustion process, and it was allowed to cool down for 24 hours. Then, the resulting biochar was ground into fine particles and used for the experiment.

Experimental Setup and Cultivation Practices

The experiment investigated the effects of six treatments replicated three times in a Completely Randomized Block Design (RCBD). Three treatments consisted of a mixed biochar formulation: (i) biochar + mineral NPK fertilizer; (ii) biochar + poultry manure; (iii) biochar + vermicompost; the other two treatments consisted of the sole application of (iv) mineral NPK fertilizer; (v) biochar; and the remaining treatment was a non-fertilized control (neither biochar nor any fertilizer). Urea (46% nitrogen), di-ammonium phosphate (DAP - 46% P_2O_5 and 18% nitrogen), and muriate of potash (60% K_2O) were used as mineral fertilizers. Poultry manure and vermicompost were acquired from poultry farm and local agrovet respectively. Biochar was applied at a rate of 10 ton ha^{-1} (Acharya et al., 2022; Dahal et al., 2021). The characteristics of biochar is represented in Table 1. NPK content of poultry manure and vermicompost was determined by nutrient analysis. Poultry manure contained 2.35% nitrogen (N), 0.08% phosphorus (P), and 2.65% potassium (K), while vermicompost contained 2.25% nitrogen (N), 1.2% phosphorus (P), and 2.2% potassium (K). The fertilizers were mixed with biochar for 24 hours, two days prior to sowing, and then mixed with the soil one day prior to sowing. The other two treatments, involving sole applications of biochar and mineral fertilizer, were mixed with the soil one day before sowing took place. The application rate of various fertilizers was based on the recommended rate of fertilizer application for okra as 200:180:80 NPK ha^{-1} (Bhattarai et al., 2020). Each treatment plot measured 1.5 * 2.4 m^2 with a plant-to-plant spacing of 30 cm and row-to-row spacing of 50 cm.

The field was deeply tilled to break the soil, followed by cultivation and planking to achieve proper soil tilth. The treatment material was applied in line at a depth of 7-8 cm one day prior to sowing. The seeds of Rizwan Gorkha (Abelmoschus esculentus), a F1 hybrid plant, were used in this experiment. Seeds to be sown were soaked overnight and sown at a depth of 3–4 cm. The full dose of DAP and MOP and the half dose of urea were applied at the time of sowing. The remaining dose of urea was top dressed in two equal splits at 30 and 40 days after sowing (DAS). Intercultural operations, including weeding, irrigation, and thinning, were carried out at regular intervals. Practices of pest and disease management were carried out as and when needed uniformly across the treatment plots. The okra pods were harvested after reaching maturity and at regular intervals of 2–3 days.

Analysis Method Used

Soil samples were collected from a depth of 10-15 cm at 20 different locations in a "W" shaped pattern to create one composite sample for soil parameter analysis. The collected soil sample was analyzed for pH, texture, organic matter content (%), total nitrogen (%), available phosphorus (kg ha⁻¹), and available potassium (kg ha⁻¹). The biochar used in the experiment was analyzed for pH, organic carbon content (%), and total nitrogen (%). Similarly, poultry manure and vermicompost were analyzed for total nitrogen (%), available phosphorus (kg ha⁻¹), and available potassium (kg ha⁻¹).

The pH of the soil was measured with a digital pH meter using a soil-to-distilled water ratio of 1:2.5. Soil texture was assessed using the hydrometer method (Soil Management Directorate, 2017). Organic matter and organic carbon content were analyzed using the Walkley-Black method (Walkely & Black, 1934). The total nitrogen content was determined through the Kjeldahl method, involving digestion with concentrated sulfuric acid (H_2SO_4) and subsequent distillation with 40% sodium hydroxide (NaOH) followed by acid titration (Soil Management Directorate, 2017). Available phosphorus was measured using the modified Olsen method (Olsen et al., 1954), while available potassium was determined using a flame photometer after treating the soil samples with normal ammonium acetate (Soil Management Directorate, 2017).

Agronomic and Yield Parameters

Five plants in each plot were tagged for data collection. Vegetative parameters, namely plant height, number of leaves per plant, number of branches per plant, number of nodes in the main stem and stem diameter, were measured from 30 to 75 DAS at a 15-day interval. Reproductive parameters, namely pod length (cm), pod diameter (cm), fresh weight (gm), number of fruits per plot, days to 50% flowering, and days to 1st harvest, were also measured. Plant height and pod length were measured with a measuring scale; stem diameter and pod diameter were measured using a Vernier caliper; and fresh weight was measured using a weighing machine. Days to the first harvest were noted for each plant in the plot, and an arithmetic mean was calculated. Days to 50% flowering were documented as the days when more than 50% of the plants in the plot reaching flowering stage.

Economic Analysis

The costs incurred during the production of okra were both fixed (land lease) and variable (biochar, seed, fertilizers, field preparation, irrigation, intercultural activities, etc.). Based on data obtained from field trials, the gross return (GR), net return (NR), and benefit-cost (BC) ratios were computed. The selling price of okra was set as per the market price during the harvesting period. Gross return (Eq. 1) was calculated as the total return generated before deducting cultivation-related costs, whereas net return (Eq. 2) was calculated as the total return generated after deducting all cultivation-related costs from the gross return. Net return was divided by total production costs to determine the benefit-cost ratio (Eq .3).

Gross returns = Total marketable yield × Selling price of okra (Eq. 1)

Net returns = Gross returns – Total cost of production (Eq. 2)

Benefit: Cost Ratio (B: C) = Net returns/Total cost of production (Eq. 3)

Data Analysis

Data collected from the sample plant was entered systemically in MS Excel (Office package 2019). Data was analyzed using R-studio version 4.2.2. Packages such as ggfortify, gvlma and agricolae were used for checking ANOVA assumptions and carrying out ANOVA and Least Significant Difference (LSD) analysis. One way ANOVA was performed to access the effect of various biochar-based fertilizer on the vegetative, reproductive, and phenological parameters of okra. Significant differences among the mean were analyzed by using Least Significant Difference (LSD) at 5% level of significance.

Results

Vegetative Parameters

The effect of fertilizer on the plant height of okra was found to be statistically significant at all stages of observation (Table 3). At 30 DAS, the highest plant height was observed in BVC treatment (10.74 cm), which was statistically similar to BPM treatment (10.54 cm). However, at other stages (45, 60, and 75 DAS), BPM treatment had the highest plant height, being statistically similar to BVC treatment at 45 DAS (26.175 cm) and 75 DAS (131.77 cm). Similarly, the lowest plant height was observed in the control treatment, followed closely by the BC treatment. Although BF and RF exhibited no statistical difference across all DAS, BF consistently showed higher plant height compared to RF.

Table 3. Plant Height of Okra Influenced by Different Fertilizers.

Treatment	Plant height (cm)			
	30DAS	45DAS	60DAS	75DAS
CK	8.75^{d}	22.60^{c}	66.40^{b}	82.60^{d}
RF	9.93^{bc}	26.18^{b}	75.86^{a}	121.77^{bc}
BF	9.86^{bc}	27.25^{b}	77.76^{a}	127.13^{bc}
BVC	10.74^{a}	26.18^{b}	77.50^{a}	131.77^{ab}
BPM	10.54^{ab}	29.92^{a}	81.38^{a}	137.26^{a}
BC	8.64^{cd}	25.53^{b}	68.30^{b}	89.54^{d}
LSD (0.05)	0.767	2.645	6.023	9.097
SEM (±)	0.106	0.362	0.825	1.245
F-probability	***	***	**	**
CV (%)	5.22	6.73	5.41	5.31

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

Table 4. Number of Leaves per Plant of Okra Influenced by Different Fertilizers.

Treatment	Number of leaves per plant			
	30DAS	45DAS	60DAS	75DAS
CK	2.74	8.40[d]	15.33[d]	22.36[d]
RF	3.05	11.75[bc]	20.97[c]	29.68[c]
BF	3.20	11.70[bc]	24.50[ab]	32.01[bc]
BVC	2.80	12.95[ab]	22.69[bc]	34.72[b]
BPM	3.05	1399[a]	26.85[a]	39.54[a]
BC	2.90	10.55[c]	17.80[d]	24.13[d]
LSD (0.05)	0.43	1.793	3.061	2.86
SEM (±)	0.045	0.246	0.419	0.392
F-probability	NS	**	**	**
CV (%)	7.32	10.4	9.61	6.30

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

Table 5. Stem Diameter of Okra Plant Influenced by Different Fertilizer.

Treatment	Stem diameter (cm)			
	30DAS	45DAS	60DAS	75DAS
CK	0.308	0.498[d]	0.804[d]	0.941[c]
RF	0.331	0.552[bc]	0.949[bc]	1.135[b]
BF	0.34	0.578[b]	1.011[ab]	1.233[a]
BVC	0.355	0.656[a]	1.07[a]	1.246[a]
BPM	0.349	0.546[bc]	0.968[bc]	1.122[b]
BC	0.307	0.529[cd]	0.91[c]	1.073[b]
LSD (0.05)	0.054	0.037	0.07	0.094
SEM (±)	0.037	0.032	0.06	0.081
F-probability	NS	***	***	***
CV (%)	8.61	4.40	4.91	5.56

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

Table 6. Number of Nodes per Plant of Okra Influenced by Fertilizer.

Treatment	Number of nodes on main stem per plant			
	30DAS	45DAS	60DAS	75DAS
CK	1.88	7.50	10.10[d]	11.91[d]
RF	2.19	8.60	12.37[bc]	16.50[b]
BF	2.13	8.10	12.70[bc]	17.02[b]
BVC	1.92	9.63	13.95[b]	17.47[b]
BPM	2.24	11.28	15.75[a]	19.42[a]
BC	2.02	7.45	11.60[cd]	13.80[c]
LSD (0.05)	1.08	3.91	1.701	1.28
SEM (±)	0.5330	0.459	0.233	0.176
F-probability	NS	NS	**	***
CV (%)	35.32	25.88	8.94	5.35

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

The number of okra leaves per plant exhibited significant variation ($p<0.01$) except at 30 DAS (Table 4). Across all days of observation, the maximum number of leaves per plant was found in response to BPM treatment, followed by BVC and BF treatments. In contrast, the lowest value was observed in response to control, closely followed by BC treatment. BF showed a higher number of leaves in comparison to RF in all cases, with RF being statistically similar to BF at 45 and 75 DAS.

Similarly, stem diameter varied significantly ($p<0.01$) except at 30 DAS (Table 5). Maximum stem diameter was found in response to BVC treatment, which was followed by BF and BPM treatments. The lowest values were observed in the case of control, followed by BC treatment, with control being at par with BC at 45 DAS. Moreover, the number of nodes on the main stem per plant in okra exhibited significant variation in response to fertilizers at 60 DAS and 75 DAS ($p<0.001$) but was non-significant at 30 DAS and 45 DAS (Table 6).

At 60 DAS and 75 DAS, BPM treatment exhibited superior performance, followed by BVC, RF, and BF treatments, with the latter three treatments showing no statistical difference between them. The lowest number of nodes was observed in control, followed closely by BF treatment. Additionally, the number of primary branches per plant significantly varied ($p<0.01$) except at 45 DAS (Table 7). The highest number was obtained under BPM, followed by BVC and BF, which were both statistically similar to each other. The lowest number was obtained under CK, which was statistically similar to RF and BC.

Reproductive and Phenological Parameters

Application of different fertilizers had a significant effect on reproductive and phenological parameters except for pod diameter (Table 8). The lowest number of days to the first harvest was observed in response to BF treatment (51.25), which was statistically similar to all other treatments except for the control (59). Similarly, the lowest number of days to 50% flowering was observed in the case of BVC treatment (48.50), which was statistically similar to other treatments except control (54.50). In addition, the highest productivity was observed in response to BPM treatment (19.28 mt/ha), which was statistically similar to BVC treatment (17.46 mt/ha). Conversely, the lowest productivity was reported in the control (7.13 mt/ha), which was on par with the BC treatment (9.23 mt/ha). The highest number of pods per plant was observed in the BPM treatment (18.70), which was statistically similar to BVC treatment (17.75). In contrast, the lowest number was observed in the case of the control (9.10), followed by the BC treatment (10.85). The highest average fruit weight was observed in the case of BVC treatment (17.85 g), which was statistically similar to BPM treatment (17.32 g). Conversely, the lowest fruit weight was observed in response to the control (13.80 g) being statistically similar to BC treatment (14.44 g). The highest fruit length was observed in response to BPM treatment (13.97 cm), which was statistically at par with BVC treatment (14.41 cm). The lowest number was observed in control (12.23 cm), followed by BC treatment (13.02 cm).

Economic analysis

The rate per unit of all inputs was determined based on the perception of the farmers in the Gajuri area. The price of okra, set at NRs 30 per kg, was established according to the local selling price in the Gajuri vegetable market.

With the use of BC, RF, BF, BVC, and BPM, the gross return increased by 34.35%, 83.115%, 135.37%, 154%, and 180.64% compared to CK (NRs 206100). Similarly, compared with CK (NRs 126100), net return increased by 42.18%, 111.94%, 178.31%, and 244.278% with the use of BC, RF, BF, and BPM, respectively (Table 10). However, the net return decreased by 28.5% in BVC compared to CK due to the high per-unit cost of vermicompost. The economic analysis of okra specifically concentrated on evaluating its performance based on yield. The B:C ratio was found to be in the range of 1.209 to 4.01 with various organic and inorganic amendments (Table 10). For BPM and BF treatment, the gross return and net return per hectare were observed to be higher, consequently resulting in a higher B:C ratio, as indicated in Table 10.

Table 7. Number of Primary Branches per Plant Influenced by Different Fertilizers.

Treatment	Number of primary branches per plant		
	45DAS	60DAS	75DAS
CK	1.27	2.14[d]	2.76[c]
RF	1.84	2.56[bcd]	3.17[bc]
BF	2.18	2.78[bc]	3.52[b]
BVC	1.98	2.89[b]	3.49[b]
BPM	2.36	3.50[a]	4.18[a]
BC	1.55	2.28[d]	2.96[bc]
LSD (0.05)	1.12	0.594	0.635
SEM (±)	0.066	0.082	0.087
F-probability	NS	**	**
CV (%)	17.22	14.78	12.71

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

Table 8. Different Yield Parameters and Productivity of Okra Influenced by Fertilizers.

Treatment	Pods per plant (number)	Average Fruit length (cm)	Fruit diameter (cm)	Fruit weight (gm)	Yield/ha (mt/ha)	Days to 50% flowering (d)	Days to 1st harvest (d)
CK	9.10[e]	12.23[d]	1.93	13.80[d]	7.13[d]	54.50[a]	59.00[a]
RF	14.60[c]	13.64[bc]	2.08	16.64[bc]	12.58[c]	50.00[b]	53.00[b]
BF	16.85[b]	13.38[bc]	1.98	15.65[c]	16.17[b]	50.25[b]	51.25[b]
BVC	17.75[ab]	14.41[a]	2.01	17.85[a]	17.46[ab]	48.50[b]	54.25[b]
BPM	18.70[a]	13.97[ab]	2.17	17.32[ab]	19.28[a]	49.50[b]	52.00[b]
BC	10.85[d]	13.02[c]	1.93	14.44[d]	9.23[d]	49.50[b]	54.00[b]
LSD (0.05)	1.60	0.728		1.076	3.11	2.461	2.837
SEM (±)	0.096	0.065	0.05	0.146	0.421	0.334	0.385
F-probability	**	**	NS	**	**	*	*
CV (%)	7.25	2.13	11.91	4.47	14.87	3.242	3.46
Grand mean	14.64	13.44	2.02	15.94	13.84	50.375	54.46

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; DAS: days after sowing; SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant; *:significant at 5% probability level; **: significant at 1% probability level; ***: significant at 0.1% probability level; CK : Control ; RF: Inorganic Fertilizer ; BF : Biochar + Fertilizer; BVC: Vermicompost + Biochar; BPM: Poultry Manure+ Biochar; BC: Biochar

Table 9. Cost of Production (NRs ha^{-1}) of Rizwan Variety of Okra Under Different Fertilizers.

S.N.	Particulars	Unit	Quantity	Rate (NRs)	Cost (NRs ha^{-1})
1)	Fixed cost			10000	10000
A)	Land lease	ha			
2)	variable cost				
A)	Seed	packet	77	400	30800
B)	Fertilizer				
	synthetic				36550
	• Urea	kg	270	40	10800
	• DAP	kg	387	50	19350
	• MOP	kg	128	50	6400
	Vermicompost	kg	11200	30	336000
	Poultry manure	kg	9333	5	46665
C)	Field preparation	man-hour	8	800	6400
D)	Tractor	hour	4	1200	4800
E)	Treatment application	man-hour	3	800	2400
F)	Intercultural operation	man-hour	8	800	6400
G)	Harvesting	man-hour	16	800	12800
H)	Biochar	ton	6	4000	24000

Table 10. Analysis of Benefit: Cost Ratio with Respect to Treatment.

S.N.	Treatment	Cost of cultivation per ha (NRs)	Market price of okra (NRs)	Gross return per ha (NRs)	Net return per ha (NRs)	B:C ratio
1	CK	80000	30	206100	126100	2.577
2	RF	110150	30	377400	267250	3.427
3	BF	134150	30	485100	350950	3.617
4	BC	97600	30	276900	179300	2.838
5	BVC	433600	30	523800	90200	1.209
6	BPM	144265	30	578400	434135	4.01

Discussion

Plant Morphological Traits

This study shows that the application of biochar-based fertilizer had a significant effect on the vegetative or morphological traits of okra. Application of BPM performed best in most of the growth parameters, such as plant height, number of leaves, number of primary branches, and number of nodes, which were closely followed by vermicompost treatment (Table 3 - 7).

The study results align with Wangmo et al. (2022) findings, showing that plant height was significantly higher in response to poultry manure and biochar in red chili, with the maximum plant height observed in BPM treatment (137.26 cm) and followed by BVC treatment (131.78 cm). Adhikari & Piya (2020) and Adekiya et al. (2020a) reported plant height being significantly greater in plants treated with poultry manure. Sharma et al. (2021) reported a significant increase in plant height of knolkhol with biochar applied in combination with vermicompost by 18.2%, and with cattle manure (FYM) by 15.8% compared to control, which corroborates our findings where biochar mixed with vermicompost, and poultry manure showed a superior effect on plant height. The increase in plant height could be attributed to improved soil pH, EC (electrical conductivity), and soil fertility, as well as plant-promoting effects and nutrient loadings stimulated by biochar (Acharya et al., 2022).

The number of leaves per plant was observed to be highest in BPM treatment (39.54) followed by BVC (Table 4). A higher number of leaves per plant in okra observed with the application of poultry manure followed by vermicompost, reported by Bhandari et al. (2019), corroborates the above finding. Sarma et al. (2017) reported a significant increase in the number of okra leaves per plant treated with biochar in combination with vermicompost and synthetic fertilizer, which corroborates our finding that BVC and BF had a higher number of leaves in comparison to other treatments except BPM.

However, stem diameter was found to be significantly higher in BVC and BF than in BPM at 60 and 75 DAS (Table 5). This finding is consistent with Acharya et al. (2022) study, which demonstrated that combining vermicompost, biochar, and cow urine led to increased stem girth. The ability to retain nutrients due to the low bulk density and high-water holding capacity of biochar could explain the improvement in crop performance by increasing the stem girth of the okra plant, as observed in the findings.

Biochar enriched with poultry manure showed a significantly higher number of primary branches (4.18) in comparison to other treatments (Table 7). This is in line with the findings of the study conducted by Adhikari & Piya (2020), where a higher number of primary branches in okra was observed in poultry manure. Similarly, the number of nodes in the main stem per plant was found to be significantly higher in BPM at 60 and 75 DAS in comparison to other treatments (Table 6).

The study also suggests that plots treated with biochar showed better growth parameters than non-biochar-added plots, particularly in the cases of BF, RF, BC, and CK. Although BF, RF, BC, and CK showed statistically similar results in all growth parameters, BF and BC showed better performance than RF and CK, respectively. Ahmed et al. (2017) reported significantly higher total branch/plant and higher node/meter in response to biochar combined with synthetic fertilizer in comparison to synthetic fertilizer alone. Similarly, Sarma et al. (2017) reported that biochar combined with vermicompost and synthetic fertilizer gave significantly higher plant height and leaf area for two consecutive years than their non-biochar counterparts did . Wu et al. (2019) reported that the application of potash fertilizer in combination with biochar in cotton significantly increased the number of effective branches, bolls, and buds compared to potash fertilizer alone. This finding illustrates the potential to improve the growth and development of crops through the co-application of fertilizer and biochar. This can be attributed to the ameliorative nature of biochar, which improves the physical, chemical, and biological properties of soil Murtaza et al. (2021), as well as its ability to store essential plant nutrients in its inner pore, making them available as and when needed by the plants (Dahal et al., 2021).

Reproductive and Phenological Parameters

The findings of the study show a significant effect of fertilizer on the yield parameters and productivity of okra. Productivity was found to be significantly higher in poultry manure and vermicompost applied in combination with biochar than in the control and other fertilized groups (Table 8). In accordance with this, Khan et al. (2022) reported that the combined application of biochar at 20 t/ha and poultry manure at 150 kg/ha increased the grain yield in wheat by 62.9% in comparison to control and other treatments. Higher okra yield in response to poultry manure was observed in studies conducted by Adhikari & Piya (2020) and Adekiya et al. (2020a). This is because of the low lignin content, low C:N ratio, and low lignin: N ratio of poultry manure, which results in faster mineralization and early nutrient release, especially beneficial for a short-duration crop like okra. As a result, the superior performance in growth parameters directly translated into a greater yield compared to other treatments. Similarly, the susceptibility of N losses through volatilization, run-off, leaching, and denitrification in synthetic fertilizer, in contrast to the ability of poultry manure to conserve and supply N for a long time, may also have resulted in a higher yield (Adekiya et al., 2020a). However, a higher yield was observed in ginger in response to biochar combined with synthetic fertilizer than in poultry by (Adekiya et al., 2018).

Yield parameters such as fruit length, fresh pod weight, and number of pods per plant were found to be significantly higher in BPM, while fruit diameter was found to be non-significant among all treatments (Table 8). Neither the addition of biochar nor the change in fertilizer affected the days to 50% flowering or days to first harvesting, as all treatments, except the control, showed statistical similarity (Table 8).

Similarly, the yield of BF was found to be significantly higher than that of RF, and that of BC was higher than that of CK, although they were statistically similar to each other in the latter (Table 8). These findings suggest that biochar-added plots gave superior performance and yield to their non-biochar counterparts. This is in line with the study conducted by Sarma et al. (2017), where, for two consecutive years, higher pod yields in okra were observed in plots fertilized with biochar only and synthetic fertilizer in combination with biochar than their respective non-biochar added counterparts. Remigius et al. (2022) found that plots fertilized with biochar either with organic or synthetic fertilizer gave better morphological parameters and yield than non-biochar fertilized plots for two consecutive years in rice under drip irrigation. Similar findings were reported by Timilsina et al. (2021), where biochar at 2 t ha-1 in combination with mineral fertilizer outperformed the sole application of mineral fertilizer in the curd yield of cauliflower. Yield improvement with the addition of biochar can be attributed to enhanced nutrient cycling, maintenance of soil pH via the liming effect, increased CEC, nutrient and water retention, their use efficiency, and microbial activity (El-Naggar et al., 2019). Schmidt et al. (2015), in a multi-farm trial, found maximum pumpkin yield in response to biochar enriched with cow urine—300% more than urine alone—and speculated that high water holding capacity, increased mineralization and retention of compost minerals, and reduced leaching were the causes of the increased yield. Studies by Acharya et al. (2022), Dahal et al. (2021) and Frimpong et al. (2021) reported an increase in soil pH, N, P, K, and organic matter (OM) in plots treated with biochar. They also identified positive correlations between the improved soil properties and crop yield. The presence of inner pores in biochar enables the storage and timely supply of nutrients to plants when needed and reduces leaching loss as well (Dahal et al., 2021; El-Naggar et al., 2019). This, in consequence, leads to higher soil fertility and increased crop yield. So, these illustrate a complementary interaction with the co-application of biochar with organic or inorganic amendments.

Economic Analysis

The economic analysis revealed BPM and BF treatment to be more profitable compared to other treatment as indicated by their higher B:C ratio and net return)(Table 9 -10). Although BVC ranked second in terms of gross return, higher cost of input associated with high price of vermicompost resulted in lower net return and lower B:C ratio. Dahal et al. (2021) also reported higher net return and B:C ratio with the application of biochar with compost and biochar with inorganic fertilizer which aligns with our result. In another similar study, Pandit et al. (2020) reported higher net return with the application of co-composted biochar at the rate of 60 ton ha^{-1} in case of maize. This indicates the potential of BPM and BF treatment to increase the farm income at the household level.

Conclusion

According to the study, okra's vegetative and reproductive development characteristics were greatly improved by using biochar in addition with vermicompost (BVC) and poultry manure (BPM). Application of biochar alone or in combination with synthetic fertilizer produced better results than non-biochar application, indicating the possible advantages of adding biochar for fertility, soil health, and crop productivity. Additionally, the economic analysis shows that the treatments using biochar and poultry manure (BPM) and fertilizer (BF) are more profitable than the other treatments, which means that farmers who want to maximize crop output and return on investment can consider them. These results suggest the complementary interaction between biochar and fertilizers, which leads to balanced soil pH, higher nutrient retention, and the timely release of essential plant nutrients while minimizing potential nutrient loss, all of which result in higher crop yield. Using biochar with organic fertilizer can reduce the reliance on inorganic fertilizers, while combining biochar with inorganic fertilizer can maintain high yields and mitigate negative environmental impacts.

Limitations of the study and suggestion for future

This research was carried out in specific soil type in a specific agricultural domain, which may limit the applicability of the findings to other soil types and agricultural settings. To, increase applicability, it would be beneficial for studies to investigate the agricultural and economic impacts of combining biochar with various organic and inorganic fertilizers across different types of soil and farming regions in Nepal. Conducting studies over years, in locations will offer more comprehensive insights and improve the overall applicability of the results.

Using biochar in grounded power form requires significant labor which could pose practical challenges. Therefore, it's important to look into different ways to apply biochar that would need less labor. Furthermore, further research is necessary to create biochar that is tailored to the needs of certain crops and soil fertility levels. This research should concentrate on preparation techniques and the best application rates.

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