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Effect of Biochar with Different Fertilizers on Growth and Yield of Bajhang Local Variety of Potato (*Solanum tuberosum* L.)

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Abstract: Low soil moisture and poor yields have been identified as key challenges in potato production. In 2023, a field experiment using a randomized complete block design was conducted to evaluate the effectiveness of various fertilizers enriched with biochar. The study included five treatments: Control (biochar only), NPK + Biochar, Farmyard Manure (FYM) + Biochar, Poultry Manure + Biochar, and Goat Manure + Biochar, with each treatment replicated four times. NPK was applied at 100:100:60 kg/ha, while poultry manure, goat manure, and FYM were applied at rates of 10 tons/ha, 6 tons/ha, and 20 tons/ha, respectively. Biochar and poultry manure resulted in superior growth performance, as indicated by increased plant height, canopy diameter, and the number of leaves and main stems per hill. Biochar combined with poultry or goat manure produced similar results for yield parameters (and fresh shoot weight, tuber diameter, weight, and number) and outperformed other treatments. The highest tuber yield was achieved with Poultry Manure + Biochar (52 tons/ha), followed by Goat Manure + Biochar (37.71 tons/ha). The lowest yield was observed under the control (25.71 tons/ha). The combination of biochar with poultry or goat manure proved to be more economically beneficial, demonstrating their potential to enhance potato yield and returns.

1 Introduction

The potato (*Solanum tuberosum* L.) is a herbaceous annual belonging to the Solanaceae family and has a fundamental chromosome number of x = 12. It is an important vegetable crop known for its nutritional value, which includes significant amounts of vitamin C, potassium, fiber and antioxidants (Robertson et al 2018, Gupta 2019, Sharma et al 2021). In addition to these nutrients, potatoes also contain phenolic compounds, anthocyanins, and flavonoids, as well as a variety of vitamins and minerals. These bioactive substances contribute to a range of health-promoting effects, including antioxidant, anticancer, and anti-inflammatory properties (Sahair et al 2018).

Potato cultivation faces various challenges worldwide, including rainfall variability, extreme temperatures, and nutrient-deficient soils (Karanja et al 2014). In Bajhang, potato production averages 15.36 metric tons per hectare, which is lower than the national average of 16.73 metric tons per hectare (MoALD 2022). According to potato farmers in Surma, high production costs, insufficient soil moisture, and limited precipitation are significant issues affecting potato farming. Organic fertilizers are typically more affordable than synthetic alternatives, making them accessible to resource-poor farmers (Kugbe 2019). In Surma, organic fertilizers such as poultry manure (PM), goat manure (GM), and farmyard manure (FYM) are readily available from local livestock. Furthermore, materials for biochar production can be easily sourced. Despite the benefits and cost-effectiveness of organic fertilizers, challenges in their management remain, including volatilization, leaching, and improper decomposition (Subedi and Dhakal 2018). These issues can be mitigated through the application of biochar, which contributes to carbon sequestration and reduces greenhouse gas emissions, positioning it as a promising strategy for addressing climate change (Laghari et al 2016). When combined with organic fertilizers, biochar enhances microbial activity, reduces greenhouse gas emissions, and immobilizes heavy metals (Guo et al 2020). Additionally, biochar helps in the removal of toxic metals and organic contaminants from soil and water (Bolan et al 2022).

Biochar is a carbon-rich, fine-textured material created through the pyrolysis of organic substances like wood, tree branches, agricultural residues, and cow manure (Pandit et al 2021). Its use improves soil characteristics, including nutrient content, water retention, and microbial activity, which can boost crop production and reduce the need for fertilizers (Allohverdi et al 2021). Furthermore, biochar enhances soil organic matter, promotes water infiltration, and improves nutrient retention (Kuryntseva et al 2023).

Poultry manure, a nutrient-rich byproduct of poultry production, provides significant benefits as a fertilizer for crop cultivation and can enhance both physical and biological soil properties, making it ideal for land application (Dróżdż et al 2020). Goat manure improves soil quality by increasing organic matter levels, enhancing water retention, and stimulating microbial activity. When applied to crops, goat manure boosts growth, yield, and nutrient status. Additionally, goat manure raises the effectiveness of inorganic fertilizers, especially phosphorus, through improved biological cycling (Gichangi et al 2010). Similarly, farmyard manure (FYM) offers several advantages in agriculture, including a rich supply of essential nutrients for plant growth and development (Chahal 2020). Biochar enhances soil characteristics, such as its structure, water-holding capacity, and cation exchange capacity (Chahal 2020, Goldan et al 2023). The application of farmyard manure (FYM) increases soil fertility, reduces erosion, helps manage plant diseases, and decreases reliance on synthetic fertilizers (Goldan et al 2023). Raising the application rates of FYM results in significant improvements in both crop yield and soil quality (Chandra et al 2021).

When combined with either organic or inorganic fertilizers, biochar can significantly enhance crop yields and soil quality, outperforming individual fertilizer applications (Glaser et al 2015, Bai et al 2022). These synergistic effects improve soil organic carbon, nutrient content, and water retention (Agegnehu et al 2016). The benefits of this combination are especially pronounced in acidic soils (Bai et al 2022). Furthermore, biochar promotes nutrient uptake, leading to increased levels of potassium (K), magnesium (Mg), and zinc (Zn), while simultaneously decreasing the uptake of sodium (Na), copper (Cu), nickel (Ni), and cadmium (Cd) in plants (Glaser et al 2015).

The use of biochar in combination with other fertilizers has been shown to significantly improve soil conditions, enhance crop yields, and reduce both environmental pollution and input costs. Nevertheless, studies investigating the combined application of biochar with both organic and synthetic fertilizers on potato agronomic performance are still limited. To address this knowledge gap, an experiment was conducted to assess the effects of biochar combined with artificial fertilizers, poultry manure, goat manure, and farmyard manure (NPK, PM, GM, and FYM) on the growth, yield, and profitability of the Bajhang Local potato variety. The primary objective was to identify the most economically viable and optimal combination of biochar and fertilizers for maximizing yield and profitability.

2 Materials and methods

2.1 Study area overview

The field study took place in Daulichaur, Surma Rural Municipality-1, within the Bajhang district of Sudurpaschim province, Nepal. This area is part of the Seti Zone in the Far Western region and is characterized by a sub-humid, subtropical climate. The site is situated at an elevation of 1,867 meters above sea level and spans an area of 270.8 square kilometers. The geographic coordinates of the study location are 29.69633°N latitude and 81.149100°E longitude. The region supports potato cultivation during the summer, as the climatic conditions are favorable for their growth during this season. The experiment was conducted from March 4 to July 24, 2023, spanning a period of 140 days. Climatic data for the study period are presented in **Fig 1**, and the location of the experimental field is shown in **Fig 2**.

2.2 Experimental design and treatment combinations

The experiment utilized a Randomized Complete Block Design (RCBD), which included five different treatments, each with four replicates, resulting in a total of 20 plots (5 treatments × 4 replicates). The treatments consisted of control (biochar only), biochar combined with NPK fertilizers, biochar combined with farmyard manure (FYM), biochar combined with poultry manure (PM), and biochar combined with goat manure (GM). The NPK mixture was applied at a standard rate of 100:100:60 kg/ha, using urea (46% nitrogen), diammonium phosphate (DAP) (46% phosphorus pentoxide, 18% nitrogen), and muriate of potash (MOP) (60% potassium oxide). Biochar, sourced from local households and produced from wood, tree branches, and agricultural residues, was applied at a rate of 6 tons per hectare per row. PM, GM, and FYM were applied at recommended rates of 10 tons/ha, 6 tons/ha, and 20 tons/ha, respectively, according to MoALD (2022). The amounts of fertilizers for each treatment were determined based on soil and manure analysis results, including nitrogen content and organic matter, ensuring compliance with the recommended application rates.

The experiment utilized the 'Bajhang Local' potato variety, which is favored by local farmers and recommended for cultivation in mid-hill and high-hill areas. Each experimental plot had an area of 4.375 m², with rows spaced 70 cm apart, plants spaced 25 cm apart within the rows, and a 20 cm border surrounding each plot, resulting in a total study area of 131.79 m². Each plot consisted of five rows, with five plants per row, totaling 25 plants per plot. The outermost row was excluded from the analysis, and data were collected from nine plants situated in the central area of each plot, with five plants specifically tagged for sampling.

The field was thoroughly tilled to break up the soil, followed by cultivation and planking to achieve the desired soil tilth. Fertilizers were combined with biochar for 24 hours, two days before sowing, and then incorporated into the soil one day before planting. The treatment materials were applied in rows at a depth of 7–8 cm, one day before sowing. Intercultural operations, including weeding, irrigation, and thinning, were conducted at regular intervals. Pest and disease management practices were uniformly implemented across all treatment plots as necessary.

2.3 Soil and manure sampling and analysis

Before applying fertilizer, soil samples were collected from a depth of 15-20 cm and analyzed for their physical and chemical characteristics. Additionally, the nutrient composition of all organic manures was examined in the laboratory at Sundarpur, Kanchanpur. The soil exhibited a sandy-loam texture with a neutral pH of 7.1 and was classified as having medium fertility, with 4.64% organic matter, 0.23% available nitrogen, 23.84 mg/kg phosphorus, and 244.8 mg/kg potassium. The quantities of manures and inorganic fertilizers were calculated based on the nutrient content and soil organic matter levels obtained from laboratory tests. The moisture content of the various manures used in this study ranged from 39.22% to 74.62%, as measured using moisture meters prior to the final testing. Farmyard manure (FYM) and goat manure were air-dried in a shaded, well-ventilated area to minimize nutrient loss during the drying process, achieving a moisture content similar to that of poultry manure. The oven-drying method was deemed impractical for all instances; thus, moisture meters were used to ensure uniform moisture content before the samples were sent for nutrient analysis in the laboratory. The detailed results of the soil tests are presented in **Table 1**, while the fertilizer test results are provided in **Table 2**.

2.4 Data collection methods

2.4.1 Vegetative parameters

The emergence rate was determined by counting the number of plants that emerged in each plot at 45 and 60 days after planting (DAP) and converting these counts into percentages based on a total of 25 plants per plot. Various plant parameters, including height (in centimeters), canopy diameter (in centimeters), number of leaves per hill, and number of main stems per hill, were recorded from five tagged sample plants at 45, 60, 75, and 90 DAP. Plant height was measured from the soil surface to the tip of the main stem using a measuring tape, and the number of stems emerging from the soil was counted for each of the five sample plants.

At 120 DAP, once the plants had reached full maturity and growth had stopped, dehaulming was performed to cure the potato tubers by removing the above-ground stems and leaves. The average shoot weight (in grams per hill) was calculated by cutting

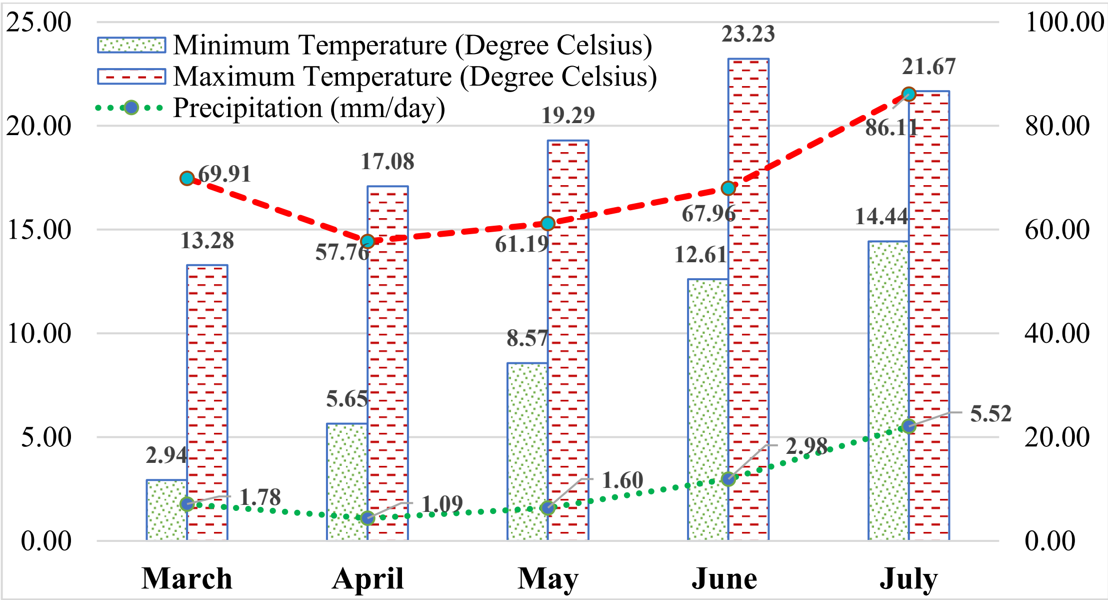

Fig 1. Chart showing the meteorological information for the duration of the study

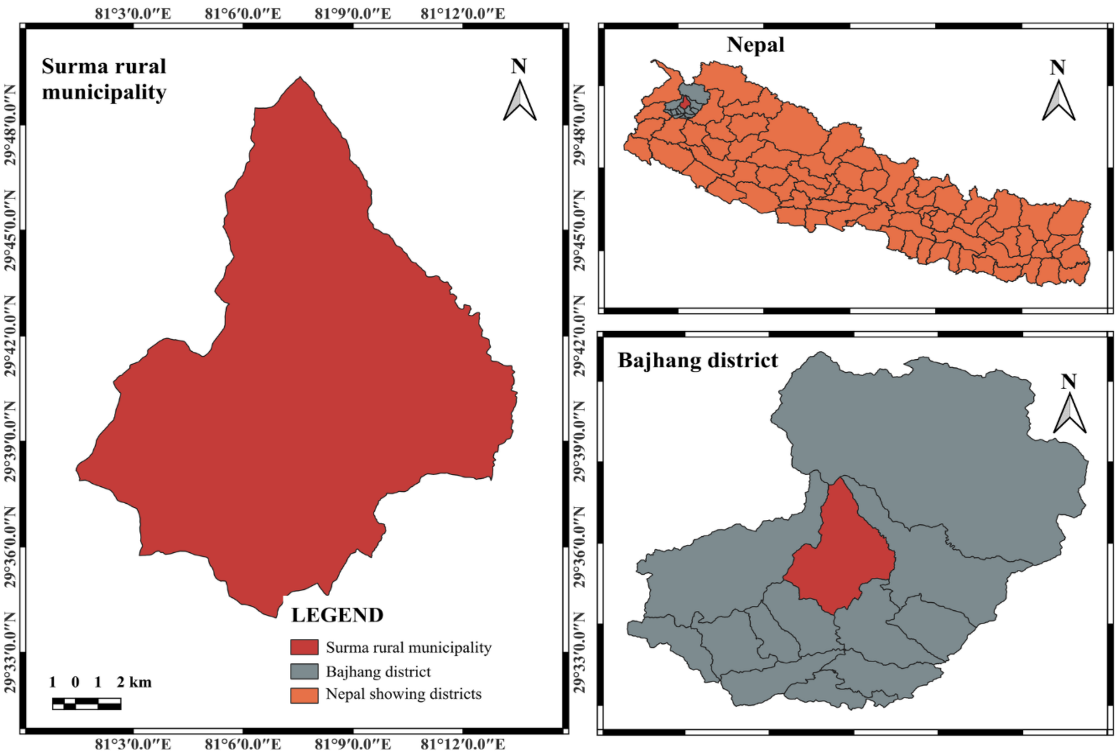

Fig 2. Location of the experimental site

Table 1. Soil analysis results

Characteristics	Organic Matter (%)	pH	Nitrogen (%)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Value	0.23	7.1	0.23	23.84	244.8
Result	Medium	Neutral	High	Low	Medium

pH	Organic matter	Nitrogen	P_2O_5 (kg/ha)	K_2O
Acidic: <6.5	Low: <2.5%	Low: <0.1%	Low: <31	Low:<110
Neutral: 6.5-7.5	Medium: 2.5-5%	Medium: 0.1-0.2%	Medium: 31-55	Medium: 110-280
Basic: >7.5	High: >5%	High: >0.2%	High: >55	High: >280

Source: Soil and Fertilizer testing laboratory, Sundarpur, Kanchanpur, 2023

Table 2. Organic fertilizer analysis results

Measured Parameters	FYM	Poultry Manure	Goat Manure
Initial Moisture (%)	74.62	27.82	39.22
Final Moisture (%)	30	27.82	29
pH	8.3	7.26	9.10
Organic Carbon (%)	45.55	34.39	32.58
N (%)	5.71	2.35	2.28
P (%)	0.2	0.07	0.08
K (%)	4.9	2.64	3.5
C:N ratio	7.97:1	14.63:1	14.28:1

Source: Soil and Fertilizer testing laboratory, Sundarpur, Kanchanpur, 2023

and weighing the shoots, including stems, branches, and leaves, from the five selected plants at physiological maturity. The canopy diameter, defined as the widest point of the foliage, was measured using a tape. Averages for all parameters were then calculated per hill and across all plots.

2.4.2 Yield parameters

Harvesting occurred 135 days after planting, with data collected from the five tagged sample plants in each plot. After removing the shoots, the tubers were left in the field for an additional 15 days to allow for further tuber growth and minimize the risk of fungal infections. Following this, the tubers were harvested and sorted into two groups: marketable (those weighing more than 25 grams) and non-marketable (those weighing less than 25 grams). Each group was counted and weighed separately; however, only the number of marketable tubers per hill was included in the analysis due to the limited number and small size of non-marketable tubers.

The recorded parameters included the number of marketable tubers per hill, total tuber weight per hill (in kilograms), and average tuber diameter (in centimeters). Tuber diameter was measured by wrapping a measuring tape around the widest part of each tuber, and the measurements were carefully documented. The average values for each parameter were subsequently calculated.

2.4.3 Economic analysis

The cost of cultivation means all estimated expenses related to potato farming, expressed in Nepalese Rupees (NPR) per hectare. The economic analysis consisted of two primary components: the estimation of total production costs and the evaluation of total revenue (gross return), along with the calculation of the benefit-to-cost (B: C) ratio for each treatment. Input costs were based on current market prices in the local area, with the price of potatoes set at NPR 40 per kilogram. The costs for chemical fertilizers, organic manures, and biochar were determined based on the prices prevailing at the time of the experiment. Total cultivation costs were calculated by adding together both fixed (general) costs and variable expenses. The Benefit-Cost (B:C) ratio was then determined using the equations outlined below:

Gross return (Total revenue) = Yield (kg/ha) x price per kg

Total cost = Cost of inputs, labor, machines, etc.

Net return = Gross return - Total cost

B: C ratio = Gross return/Total cost (Sai and Paswan 2024)

2.5 Data analysis

All data were carefully gathered and organized by treatment across three replicates using Microsoft Excel. Statistical analysis was performed using RStudio (version 2024.04.2+764), with an analysis of variance (ANOVA) conducted to assess treatment differences. The assumptions of the linear model were validated using the autoplot function from the R package 'ggfortify.' The primary objective of the ANOVA was to compare the means across treatments, with Duncan's Multiple Range Test applied using the R package 'agricolae.' This test was conducted at a 95% confidence level (α = 0.05) with 12 degrees of freedom. The results were organized, analyzed, and discussed in the results and discussion section. Since there were no local meteorological stations in the research area, climate data were obtained from external sources (NASA 2023), and **Fig 1** was created using this data in Microsoft Excel. **Fig 2** was generated using QGIS software (version 3.36.0).

3 Results

3.1 Emergence percentage

The fertilizer treatments used in the experiment did not significantly affect the emergence of potato plants at any of the observed stages (**Table 3**).

Table 3. Emergence percentage of potato influenced by different fertilizers

Treatments	Germination Percentage	
	45DAP	60DAP
Control (Biochar only)	82	91
NPK + Biochar	79	88
FYM + Biochar	79	92
Poultry manure + Biochar	78	87
Goat manure + Biochar	79	89
LSD (0.05)	3.63	2.48
SE (±)	1.11	0.76
F-probability	NS	NS
CV (%)	11.89	7.22

Note: SEM: standard error of mean; LSD: Least significant difference; CV: coefficient of variation; NS: Non-significant

3.2 Vegetative Parameters

The analysis revealed that plant height across various fertilizer treatments was significantly different at 90 days after planting (DAP), while no significant differences were observed at other growth stages (Error! Reference source not found.). At 90 days after planting (DAP), the combination of poultry manure and biochar resulted in the tallest plants, measuring 67 cm. Conversely, the control treatment exhibited the shortest plant height at 43.45 cm, which was statistically comparable to the heights observed in the other three treatments. Although not statistically significant, the highest plant heights were observed with the poultry manure and biochar combination at 45, 60, and 75 days after planting (DAP). In contrast, the lowest heights were recorded with goat manure and biochar.

Canopy diameter was significantly affected by the different fertilizer treatments only at 75 DAP, with no significant differences at other observation stages **(Table 5)**. At 75 DAP, the broadest canopy diameter was observed in the goat manure and biochar treatment (68.80 cm), which was statistically similar to the poultry manure and biochar treatment (68.05 cm) and the farmyard manure (FYM) and biochar combination (60.10 cm). In comparison, the control treatment exhibited the smallest canopy diameter at 53.75 cm, which was not significantly different from the NPK and biochar treatments (54.25 cm).

Fertilizer treatments significantly influenced the leaf count per hill at 90 DAP only **(Table 6).** While not significant at 45, 60, and 75 DAP, the highest leaf count was recorded under the poultry manure and biochar treatment. Goat manure and biochar displayed the lowest leaf counts at 45 and 60 DAP, whereas the FYM and biochar treatment had the lowest count at 75 DAP. At 90 DAP, the poultry manure and biochar treatment yielded the highest leaf count (119.20), which was statistically comparable to the goat manure and biochar treatment (90.80). Conversely, the control treatment had the lowest leaf count at 71.95.

Fertilizer treatments had a significant influence on the total number of main stems per hill at both 75 and 90 DAP (**Table 7**). The poultry manure and biochar treatment produced a notably higher number of main stems per hill than the other treatments, with 6.25 at 75 DAP and 7.33 at 90 DAP. In contrast, the control treatment had the lowest number of main stems per hill, with 3.5 at 75 DAP and 3.9 at 90 DAP.

The emergence percentage was determined to be non-significant among the various fertilizer treatments which is consistent with Carril et al (2023), who found that adding biochar to the soil did not significantly affect the germination rates. Similar observations were made by Free et al (2010), and Meschewski et al (2019). In contrast, Ali et al (2021) and Tu et al (2024) showed a beneficial effect of biochar on the germination percentage. The variability in biochar properties such as pH, nutrient content, and the presence of phytotoxic compounds can affect seed germination and emergence differently, depending on the type of biochar used and its application rate (Carril et al 2023).

Poultry manure and biochar together resulted in the tallest plants, measuring 67 cm, which was not significantly different from the height observed with goat manure + biochar at 52.6 cm, which is in line with the study by Dzvene et al (2019), which exhibited a notable increase in maize plant height when both poultry and goat manure were applied along with biochar. Similar findings were reported by Liu et al (2021) and Hayat et al (2023), who also recorded the highest plant heights with poultry manure + biochar for maize and rice, respectively. The observed increase in plant height can be attributed to improvements in soil pH, electrical conductivity (EC), soil fertility, as well as the nutrient contributions and growth-promoting effects of biochar (Acharya et al 2022).

The greatest canopy diameter was observed in the goat manure + biochar treatment (68.80 cm), which aligns with the findings of Kondrlova et al (2018), who reported increased canopy development from the use of biochar and nutrient amendments. Additionally, the highest leaf count per hill was noted under the poultry manure + biochar treatment, which was statistically similar to the goat manure + biochar treatment. This observation aligns with Rahayu et al (2022), who found an increase in leaf count with the co-application of biochar and poultry manure. Bhargavi et al (2022) also noted an increase in leaf count following the combined application of poultry manure and biochar. Furthermore, the number of main stems per hill was recorded as being highest under the poultry manure + biochar treatment, which was statistically comparable to the goat manure + biochar treatment. This finding supports the study by Mahmood and Salman (2018), which found an increase in the number of main stems per hill with the use of poultry manure.

This study underscores the potential of co-applying biochar and either poultry or goat manure to enhance the vegetative performance of potato plants. Previous research has demonstrated that applying poultry manure increases foliage area, plant cover, stem number, and tuber production compared to control treatments (El-Sayed et al 2007). The nutrients present in poultry manure, along with its capacity to enhance soil microbial populations and physicochemical properties, contribute to improved nutrient availability for plants, resulting in increased vegetative growth and higher yields of high-quality tubers (Agbede et al 2022). Adding biochar amplifies these benefits by enhancing the soil's physical, chemical, and biological properties (Murtaza et al 2021) and by storing essential plant nutrients within its pores, making them available to plants as needed (Dahal et al 2021).

3.3 Yield and Yield parameters

Fertilizer treatments had a significant effect on the total number of tubers and their weight per hill (kg). In contrast, tuber diameter (cm) and fresh shoot weight per hill (kg) showed no significant differences among the treatment groups **(Table 8).** The poultry manure and biochar treatment produced the highest average number of tubers per hill (24.8), which was statistically similar to the goat manure and biochar treatment (18.91). In comparison, the control treatment yielded the fewest tubers per hill on average (15.01).

Table 4. Plant height (cm) affected by different fertilizers

Treatments	Plant height (cm)			
	45DAP	60DAP	75DAP	90DAP
Control (Biochar only)	7.75	23.25	40.20	43.45^{b}
NPK + Biochar	8.25	23.25	42.30	50.00^{b}
FYM + Biochar	7.10	21.85	37.40	45.15^{b}
Poultry manure + Biochar	8.55	27.45	43.00	67.00^{a}
Goat manure + Biochar	7.60	20.80	34.95	52.60^{b}
LSD (0.05)	2.05	6.38	8.03	9.96
SE (±)	0.63	1.96	2.9	3.05
F-probability	NS	NS	NS	**
CV (%)	16.97	17.33	13.17	12.52

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; 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; NS: Non-significant

Table 5. Canopy diameter (cm) as affected by different fertilizers

Treatment	Canopy Diameter (cm)			
	45DAP	60DAP	75DAP	90DAP
Control (Biochar only)	18.90	50.00	53.75^{b}	62.40
NPK + Biochar	21.75	53.75	54.25^{b}	77.80
FYM + Biochar	18.90	47.50	60.10^{ab}	65.05
Poultry manure + Biochar	23.35	53.60	68.05^{a}	83.30
Goat manure + Biochar	18.80	44.70	68.80^{a}	74.40
LSD (0.05)	4.53	9.89	11.24	16.04
SE (±)	1.39	3.04	3.45	4.02
F-probability	NS	NS	*	NS
CV (%)	14.51	12.86	11.96	14.34

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; SEM: standard error of the 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; NS: Non-significant

Table 6. The number of leaves per hill as influenced by different fertilizes

Treatments	Number of leaves per hill			
	45DAP	60DAP	75DAP	90DAP
Control (Biochar only)	12.60	32.15	59.95	71.95^{b}
NPK + Biochar	17.10	42.05	73.35	76.35^{b}
FYM + Biochar	10.10	29.05	50.20	82.65^{b}
Poultry manure + Biochar	14.95	35.95	73.35	119.20^{a}
Goat manure + Biochar	9.10	28.75	52.30	90.80^{ab}
LSD (0.05)	7.42	10.69	13.55	13.55
SE (±)	2.27	3.28	4.16	4.16
F-probability	NS	NS	NS	*
CV (%)	37.74	20.66	14.23	9.73

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; 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; NS: Non-significant.

Table 7. Number of main stems per hill as influenced by different ferilizers

Treatment	No. of main stem per hill			
	45DAP	60DAP	75DAP	90DAP
Control (Biochar only)	3.20	3.35	3.50^{b}	3.90^{b}
NPK + Biochar	4.20	4.80	3.75^{b}	4.80^{b}
FYM + Biochar	3.10	3.40	4.15^{b}	4.10^{b}
Poultry manure + Biochar	3.75	3.70	6.25^{a}	7.33^{a}
Goat manure + Biochar	2.85	3.15	4.45^{b}	5.25^{b}
LSD (0.05)	1.15	1.45	1.37	1.62
SE (±)	0.35	0.44	0.42	0.5
F-probability	NS	NS	S**	S**
CV (%)	21.90	25.74	20.16	20.70

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; SEM: standard error of the 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; NS: Non-significant

Table 8. Yield parameters of potato as influenced by different fertilizers

Treatments	Tuber diameter (cm)	Number of tubers per hill	Weight of tubers per hill (kg)	Fresh shoot weight per hill (kg)
Control (Biochar only)	5.22[a]	15.01[b]	0.45[b]	0.28[a]
NPK + Biochar	4.96[ab]	15.84[b]	0.54[b]	0.45[a]
FYM + Biochar	4.96[a]	17.17[b]	0.57[b]	0.26[a]
Poultry manure + Biochar	5.37[a]	24.8[a]	0.91[a]	0.30[a]
Goat manure + Biochar	4.75[a]	18.91[ab]	0.66[ab]	0.20[a]
LSD (0.05)	0.76	6.33	0.26	0.24
SE (±)	0.23	3.77	0.13	0.74
F-probability	NS	S*	S*	NS
CV (%)	9.87	22.44	26.61	24.55

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; SEM: standard error of the 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; NS: Non-significant

Similarly, the maximum weight of tubers per hill was recorded under the poultry manure and biochar treatment (0.91 kg), which was statistically similar to the weight observed in the biochar and goat manure treatment (0.66 kg). However, the control treatment resulted in the lowest tuber weight per hill, at 0.45 kg. Although not statistically significant, the largest tuber diameter was measured in the poultry manure treatment (5.37 cm), while the smallest diameter was noted under the goat manure and biochar treatment (4.75 cm). Additionally, the highest vegetative yield per hill was observed in the NPK and biochar treatment (0.45 kg), whereas the lowest yield was recorded under the goat manure and biochar treatment (0.2 kg). Yield also varied significantly among the different fertilizer treatments (Error! Reference source not found.). The poultry manure and biochar treatment produced the highest yield at 52.37 tons per hectare, which was statistically similar to the yield from the goat manure and biochar treatment (37.43 tons per hectare). Conversely, the control treatment yielded the least at 25.57 tons per hectare, followed by the FYM and biochar treatment (32.47 tons per hectare) and the NPK and biochar treatment (30.71 tons per hectare).

3.4 Economic analysis

Error! Reference source not found presents the economic analysis of potato cultivation. The unit rates for all inputs were established based on farmers' perceptions in the Surma area, while the price of potatoes, set at NPR 40 per kg, reflects the local selling price in the vegetable market. In comparison to the control treatment (NPR 528, 571.43), the net margin increased by 34.21%, 44.84%, 179.14%, and 80.78% with the application of NPK + biochar, FYM + biochar, poultry manure + biochar, and goat manure + biochar, respectively. Similarly, when compared to the control (NPR 1,028,571.43), the gross return rose by 20%, 26.67%, 102.2%, and 46.67% with the use of NPK + biochar, FYM + biochar, poultry manure + biochar, and goat manure + biochar, respectively.

Table 9. Potato yield (tons/ha) as influenced by different fertilizers

Treatments	Yield
Control (Biochar only)	25.57 [b]
NPK + Biochar	30.71 [b]
FYM + Biochar	32.47[b]
Poultry manure + Biochar	52[a]
Goat manure + Biochar	37.43 [ab]
LSD (0.05)	14.61
SE (±)	20.10
F-probability	*
CV (%)	26.61

Note: Means followed by the same letter(s) in a column are not significantly different by LSD at 5% level of significance; SEM: standard error of the 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; NS: Non-significant

The economic analysis of potato cultivation focused on yield, with the benefit-to-cost (B:C) ratio ranging from 2.06 to 3.44 across the various organic and inorganic treatments. Notably, the combination of poultry manure and biochar yielded the highest gross and net returns per hectare, closely followed by the goat manure and biochar treatment, which also resulted in a favorable B:C ratio. These findings indicate that these two treatments could significantly enhance farm income for households.

Biochar-enriched fertilizers significantly improve yield parameters. The poultry manure + biochar treatment yielded the highest number of tubers per hill (data), which is in line with the results of Oustani et al (2015), who found the highest tuber count per hill (10.07) with poultry manure. Similarly, the maximum weight of tuber per hill was found under poultry manure + biochar (0.91 kg), closely followed by goat manure + biochar (0.66 kg). This result aligns with Agbede et al (2022), who identified the maximum tuber weight with the co-application of poultry manure and biochar. However, no significant differences were detected in tuber diameter and fresh shoot weight per hill across the various fertilizer treatments.

Productivity was significantly higher when goat manure and poultry manure were applied in combination with biochar compared to the control and other fertilized groups. In line with this, Khan et al (2022) found that the combined application of biochar at 20 t ha^{-1} and poultry manure at 150 kg ha^{-1} increased wheat grain yield by 62.9% relative to the control and other treatments. Similarly, Agbede et al (2022) found that the application of 10.0 t ha^{-1} of poultry manure combined with 30.0 t ha^{-1} of biochar led to a 220% increase in tuber yield compared to treatments that excluded both poultry manure and biochar. Additionally, Acharya et al (2022) observed the highest yield in response to the co-application of biochar and goat manure, further corroborating our findings. Research conducted by Awodun et al (2007) and Uwah and Eyo (2014) also reported the highest productivity following the application of goat manure.

The use of poultry manure as an organic fertilizer has been shown to enhance plant height, leaf area, chlorophyll content, and the number of marketable tubers per hill in potato cultivation, resulting in higher overall yields and better tuber quality (Abdulkadhum et al 2023). Similar results were observed in this study, where the combination of poultry manure and biochar exhibited superior vegetative performance and yield parameters. The increased yields associated with poultry manure can be attributed to its low lignin content and favorable carbon-to-lignin ratio. These factors promote faster mineralization and early nutrient release, resulting in enhanced growth and higher yields compared to other treatments. Additionally, poultry manure's ability to conserve and supply nitrogen more effectively, as opposed to synthetic fertilizers that are prone to nitrogen losses through volatilization, runoff, leaching, and denitrification, contributes to its superior yield performance (Adekiya et al 2020). Similarly, goat manure enhances soil properties, including organic matter content, water retention, and microbial activity. It also improves phosphorus cycling by increasing soil microbial biomass, thereby enhancing the efficiency of phosphate fertilizers (Gichangi et al 2010). This is due to 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, particularly 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, runoff, 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 contributed to a higher yield (Adekiya et al 2020).

The incorporation of biochar significantly enhances yield by improving nutrient cycling, maintaining soil pH, increasing cation exchange capacity (CEC), and enhancing both nutrient and water retention and use efficiency, as well as microbial activity (El-Naggar et al 2019). Biochar provides a carbon source for soil microorganisms, promoting faster mineralization of organic fertilizers such as poultry and goat manure (Akdeniz 2019). The inner pores of biochar store and supply nutrients to plants while reducing leaching losses (El-Naggar et al 2019). This ultimately leads to improved soil fertility and increased crop yield. These findings illustrate the synergistic effects of co-applying biochar with organic or inorganic amendments.

Table 10. Economic analysis of potato

Treatments	Yield (ton/ha)	Gross return (NRs/ha)	Cultivation cost (NRs/ha)	Net return (NRs/ha)	B:C ratio
Control (Biochar only)	25.71	1028571.43	500000.00	528571.43	2.06
NPK + Biochar	30.86	1234285.71	524897.73	709387.99	2.35
FYM + Biochar	32.57	1302857.14	537272.73	765584.42	2.42
Poultry manure + Biochar	64.57	2,080,046.01	604545.45	1,475,500.56	3.44
Goat manure + Biochar	37.71	1508571.43	553030.30	955541.13	2.73

Note: NPK: Nitrogen, Phosphorus and Potassium; FYM: Farmyard Manure; ton/ha: tons per hectare; NRs/ha: Nepali Rupees per hectare

4 Conclusion

The study The application of biochar combined with poultry manure (BPM) and goat manure (BGM) significantly enhances both vegetative and reproductive growth parameters in potatoes. The economic analysis further reveals that these treatments yield higher profitability compared to others, offering viable options for farmers aiming to maximize crop yields and financial returns. Incorporating biochar with organic fertilizers reduces dependence on synthetic fertilizers, while combining it with synthetic fertilizers helps sustain high yields and mitigate environmental impacts. The study has some limitations that require attention. Conducted over a single year, it may not account for seasonal climate variations; repeating it over multiple years would provide more robust results. Additionally, the research lacks data on key vegetative and tuber characteristics, including leaf area, chlorophyll content, nutritional status, tuber density, and starch content. Addressing these gaps could offer clearer insights into the effects of biochar and organic fertilizers on potato growth and yield. Future studies should evaluate the agronomic and economic impacts of biochar combined with organic and synthetic fertilizers across diverse soil types and agroecological zones in Nepal. Developing crop- and soil-specific biochar with optimized preparation methods and application rates, as well as exploring labor-efficient application techniques, is essential to enhance its adoption among farmers.

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