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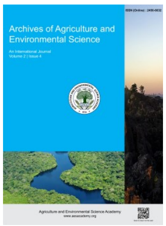

ORIGINAL RESEARCH ARTICLE

Effect of biochar blended organic fertilizers on soil fertility, radish productivity and farm income in Nepal

Shridhika Dahal[1*], **Shree Prasad Vista**[2], **Mitra Khatri**[3] **and Naba Raj Pandit**[4]

[1]Himalayan College of Agricultural Sciences and Technology, Kirtipur, Kathmandu, NEPAL
[2]National Soil Science Research Center (NSSRC), Nepal Agricultural Research Council, NEPAL
[3]Radhika Secondary School, Urlabari, Morang, NEPAL
[4]International Maize and Wheat Improvement Center, Lalitpur, NEPAL
[*]Corresponding author's E-mail: shridhikadahal443@gmail.com

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ABSTRACT

Declining soil fertility and nutrient availability are one of the major threats to reducing crop productivity in Nepal. A field experiment was conducted to assess the potential of biochar (10 t ha^{-1}) blended with organic and inorganic fertilizers on improving soil fertility and radish productivity in Morang district, Nepal. Biochar was prepared from locally available twigs, branches, and wood using the soil pit "Kon tiki" method. The experiment was laid out in Randomized Complete Block Design with 7 treatments having four replications *viz.*, control (CK), biochar (BC), biochar + cattle manure (CM), biochar + poultry manure (PM), biochar + cattle urine (CU), biochar + commercial biofertilizers (BF) and biochar + inorganic fertilizers (urea-N). The nitrogen rate used in all the treatments was equivalent to 100 kg ha^{-1}. The agronomic effect of biochar blended organic amendments was compared with control and inorganic urea-N treatments. Biochar amended plots showed significantly higher soil pH (6.5), organic matter (4%), total N% (0.8%), available P (80.1 kg ha^{-1}), and K (203.6 kg ha^{-1}) compared with control. CM increased marketable yield by 320% (63 t ha^{-1}) and biomass yield by 198% (100 t ha^{-1}) compared with control (15.0 t ha^{-1} and 34 t ha^{-1}) of marketable and biomass yield, respectively. CM increased marketable yield by 44% compared with the urea-N treatment (44 t ha^{-1}). Moreover, net return was observed highest with CM treatment among all the organic and urea-N treatments. The study suggests that the combination of biochar with locally produced cattle manure has the potential to increase radish productivity and could compete with mineral nitrogen fertilizers while producing similar or even higher crop yields and economic returns.

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INTRODUCTION

Radish (*Raphanus sativus* L.), a cool-season root vegetable belonging to the family Brassicaceae is cultivated in an area of 16915.7 ha with the productivity of 15.9 t ha^{-1} in Nepal (Shrestha *et al.*, 2018). Vegetable productivity including radish is low in Nepal, thus, relies mainly on vegetable import to meet the country's demand (Ojha, 2016). Low plant productivity is mainly driven by a condition of soil acidity and reduced soil fertility such as low organic carbon (OC), nitrogen (N), phosphorous (P), potassium (K), and cation exchange capacity (CEC) (Obemah and Baowei, 2014). Upadhyay *et al.*, 2020; Pandit *et al.*, 2018). Moreover, the imbalanced use of inorganic fertilizers practiced among Nepalese farmers and the lower supply of organic inputs has resulted in reduced productivity (Baral *et al.*, 2020; Pandit *et al.*, 2018). Thus, it is crucial to identify efficient soil fertility management strategies, which can improve soil pH, OC, available nutrients and increase crop productivity (Bajracharya and Sherchan, 2009).

One of the strategies to improve soil fertility could be the use of biochar in a productive acidic soil (Schmidt *et al.*, 2015; Cornelissen *et al.*, 2013). Biochar is a carbon-rich fine-grained material produced through pyrolysis of biomass in the absence or very low presence of oxygen (IBI Biochar Standards, 2015). Biochar addition in a low fertile soil has shown improved soil physico-chemical properties such as texture, bulk density, porosity, plant available water, pH, OC, CEC (Obia *et al.*, 2016; Pandit *et al.*, 2018; Martinsen *et al.*, 2014; Cornelissen *et al.*, 2013) and biological properties such as higher colonization rate of arbuscular mycorrhizal fungi. (Atkinson *et al.*, 2010). Moreover, the recalcitrant nature of biochar sequesters carbon for the long term which is crucial to combat ongoing global warming and climate change (Xie *et al.*, 2015; Lehmann *et al.*, 2006; Keith *et al.*, 2011).

In recent years, a mixture of biochar and organic manure has been found more efficient to improve soil fertility, nutrient retention capacity, and crop productivity (Schmidt *et al.*, 2017). This is due to the organic coatings formed in biochar surface which reduces hydrophobicity and enhance the nutrient retention capacity of biochar-manure mixtures, thus, acting as a slow-release mechanism supplying nutrient based on plant physiological requirement (Barrow, 2012; Brennan *et al.*, 2014; Berihun *et al.*, 2017). Application of biochar in combination with organic manure has shown increased soil organic carbon from 0.9% to 1.2%, CEC from 13 to 15.0 mg kg^{-1}, exchangeable K^+ from 0.57 to 0.76 cmolc kg^{-1}, Ca^{2+} from 2.34 to 2.38 cmolc kg^{-1}, Mg^{2+} from 0.87 to 1.40 cmolc kg^{-1}, and available P from 24.41 to 25.66 mg kg^{-1} (Sukartono *et al.*, 2011). Similarly, biochar-compost mixtures increased soil pH from 5.1 to 5.7 in a low productive moderately acidic soil (Pandit *et al.*, 2018). Moreover, higher nutrient retention capacity of the biochar mixture increases nutrient use efficiency (NUE) that can reduce a significant content of nutrient losses to the environment via leaching and emission unlike inorganic mineral fertilizers application in soil (Vista *et al.*, 2015; Vista and Khadka, 2017).

The application of biochar-organic manure mixtures could be of great significance to minimize the use of mineral fertilizers while producing similar or even higher yields at the same nutrient supply rate through improved water and nutrient retention capacity of biochar particles (Agegnehu *et al.*, 2015; Pandit *et al.*, 2018). Previous studies are well documented about the significant positive effect of biochar when co-applied with organic manures on crop yield (Vista *et al.*, 2015; Cornelissen *et al.*, 2013; Rollon, *et al.*, 2020; Schmidt *et al.*, 2017). An application of 60 t ha^{-1} co-composted biochar increased maize biomass by 243% as compared to mineral NPK fertilizers along with improved available soil nutrients (Pandit *et al.*, 2019). Biochar application (20 t ha^{-1}) in loamy sand, Nepal has shown higher biomass yield (63.2 t ha^{-1}) and root yield (46.8 t ha^{-1}) of radish as a function of improved soil OC, total N, available P, and K (Timilsina *et al.*, 2017). The co-application of biochar (50 t ha^{-1}) along with poultry manure (5 t ha^{-1}) showed the highest radish yield in which the root weight was increased by 193%, 252%, and 252%, compared with the sole application of biochar applied at the rate of 50 t ha^{-1}, 25 t ha^{-1} and 0 t ha^{-1} (poultry manure without biochar) respectively (Adekiya *et al.*, 2019). Previous studies have shown a beneficial effect of biochar and organic manure/compost mixtures on improving soil fertility and crop productivity. However, such studies are less compared with the mechanistic studies conducted with the mixture of biochar and mineral fertilizer at the different agricultural domains with different soil fertility statuses and biophysical factors. A study on biochar mixed with organic fertilizers has shown greater potential for agronomic and economic benefits compared with biochar blended with mineral fertilizers (Arif *et al.*, 2021). Biochar-based organic fertilizers amendment could significantly enhance soil fertility and crop productivity, which in turn, could mitigate the prevailing food insecurity of the country and contribute to meeting the sustainable development goals (Pandit *et al.*, 2021). In Nepal, there exist no or very few studies where both agronomic and economic effects of biochar in combination with various organic nutrients were investigated at local farm household level. Thus, this study was conducted to assess the agronomic and economic effect of biochar when combined with various organic and mineral fertilizers on radish productivity. The specific objective of the study was to test the potential of biochar blended organic and inorganic fertilizers on increasing soil chemical properties, available nutrients, and radish yield in silty loam soil, Nepal. Moreover, to compare the agronomic, and economic effect of these biochar-organic amendments with control and inorganic N fertilizer amendment.

MATERIALS AND METHODS

Biochar production

Feedstocks including woods, tree branches, and other agricultural wastes were collected from the nearby experimental site and kept for sundry before making biochar. Biochar was produced from flame curtain soil pit "Kon- tiki" kiln with a pyrolysis temperature of 500-700 °C (Schmidt and Taylor, 2014; Schmidt *et al.*, 2015). Dimension of soil pit kiln was 1 m high with a base and upper diameter of 60 cm and 120 cm respectively. A mixture of feedstocks was applied layer after layer until the soil pit was filled and the final pyrolyzed layer was quenched with water and kept for about 24 hours to cool down. The biochar was then ground into finer particles and used for experimentation.

Experimental setup

A field experiment was conducted on 16th October 2020 in the premises of Radhika Secondary School, Morang district (26.6649° North and 87.6137° East). The experiment was carried out under a plastic tunnel in an area of 72 m^2 (12 m × 6 m). The average maximum and minimum temperature of the experimental site were 25.°and 14.7 °C respectively (Climate-data.org, 2021). Seven treatments with four replications were arranged in a Randomized Complete Block Design (RCBD) (Table 1); four treatments were biochar in combination with different organic fertilizers viz. bio-fertilizers (BF), cattle manure (CM), poultry manure (PM), and cattle urine (CU), one treatment was biochar in combination with inorganic fertilizers (urea-N) and remaining two treatments were control (BC; without biochar and fertilizers) and sole application of biochar (BC). Biochar (10 t ha^{-1}) was applied equally in all the treatments except control (CK). The rate of various organic fertilizers was based on the equivalent N content in all the treatments (100 kg N ha^{-1}) (Table 1). For urea-N treatment, 100 kg N ha^{-1} was applied, which was recommended nitrogen rate for radish cultivation (Khatri *et al.*, 2019). The size of the treatment plot was 1×1.2 m^2, keeping a space of 0.5 m between each treatment and replication.

For land preparation, each plot was ploughed two times followed by hoeing, and levelling. Biochar, organic fertilizers (BF, CM, PM, and CU), and urea-N were applied in a line at a depth of 6-8 cm. For CU treatment, biochar was soaked in cattle urine beforehand and applied to the soil. For other treatments, biochar and fertilizers were mixed in the soil during planting. Two radish seeds (Mino early) were sown at a depth of 2 cm with a spacing of 20 cm × 20 cm, maintaining the population of 20 plants in each plot. The intercultural operations including irrigation, weeding, and thinning were performed at regular intervals. Other agronomical practices such as control of pests and diseases were consistent for all treatments and performed as and when needed.

Harvesting and biometric data

Radish was harvested manually when all the plants were matured, and shoots were ready for market 71 days after sowing. Five plants were tagged leaving 1 row and 1 column on each side i.e., border plants for data collection at 7, 15, 30, 45, 60, and 71 DAS (final harvest day). Plant height, leaf diameter, plant spread, shoot length and root length were measured with a measuring scale; root diameter by Vernier Calliper; root and shoot weight were weighted separately in weighing balance along with other parameters.

Soil analysis

Soil samples were collected from a different portion ("W" shape) in each plot from 10-15 cm depth to make one composite sample for each treatment. A total of 28 samples were collected from seven treatments after harvest. Soil samples were oven-dried at 40 ^{0}C for three days, passed through a 2 mm sieve, grounded, and analysed for soil pH, OC, total nitrogen (N), available phosphorus (P), and potassium (K). Soil pH was measured in 1:2.5 water suspension using a digital pH meter (buffering at pH 7 and 4). Soil OC was determined following Walkley and Black method. Total N was analysed through Kjeldahl's method where the soil sample was digested with conc. H_2SO_4 and later distilled with 40% NaOH followed by acidic titration. Available P was determined through modified Olsen's where soil samples were treated with $NaHCO_3$ and available K was determined using the flame photometer method treating soil samples with normal ammonium acetate.

Economic analysis

Cost of production includes both fixed (land lease) and variable costs (biochar, seed, fertilizers, field preparation, irrigation, intercultural operations, etc.) incurred during radish cultivation (Table 3). Gross return (GR), net return (NR), and benefit-cost (BC) ratio were calculated based on the yield data obtained from field trials. The selling price of radish was kept based on the local market price ($ 0.17 per kg). Gross return was the total return produced before deducting the expenses incurred during cultivation (Eq. 1) whereas net return was the return produced after deducting all expenses from the gross return (Eq. 2). The benefit-cost ratio was calculated as net returns divided by the total cost of production (Eq. 3).

GR, NR, and B:C ratio was calculated using the following formula:

Gross returns = Total marketable yield × Selling price of radish (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)

Statistical analysis

Data collected from field trials and laboratory (soil) were compiled and analysed using GenStat Version 15.0. One-way ANOVA was performed to assess the effect of various biochar blended organic treatments on soil chemical properties, growth parameters, and marketable yield. Significant differences between treatment means were analysed through Duncan's multiple range test (DMRT) at a 5% level of significance. The differences between various treatments were significant at $p < 0.05$ unless stated otherwise. Linear regression was performed to assess the relationship between soil chemical properties (pH, OC, total N, available P and K, and crop yield and further, to identify the relationship between marketable yield and biomass production.

RESULTS AND DISCUSSION

Effect on soil chemical properties

Biochar addition in combination with various organic amendments (CM, PM, CU, and BF) and urea-N fertilizer showed a significant positive effect ($p<0.05$) on soil chemical properties (pH, OM) and nutrient availability (total N, available P, and K) (Table 2). Soil pH was observed significantly higher with BC (6.0), CM (6.4), PM (6.3), CU (5.7), BF (6.4), urea-N (6.5) compared with the control plot (5.3). Soil organic matter was increased from 0.8% (CK) to 1.9%, 4.0%, 3.1%, 3.5%, 2.8%, and 3.0% upon addition of BC, CM, PM, BF, CU, and urea-N respectively, with highest value observed for CM (Table 2). Our results are in line with previous studies where biochar amendment in combination with organic and inorganic fertilizers have shown significant improvement on soil chemical properties (Martinsen *et al.*, 2014; Cornelissen *et al.*, 2013; Vista and Khadka, 2017; Pandit *et al.*, 2019; Schmidt *et al.*, 2017; Gautam *et al.*, 2017). A significant increase in soil pH and OM was reported in earlier studies upon biochar addition in a low productive acidic soil in Nepal (Timilsina *et al.*, 2017; Gautam *et al.*, 2017; Pandit *et al.*, 2019). The increase in soil pH

Table 1. Description of the treatments.

Treatments	Biochar (t/ha)	Fertilizer's amount (t/ha)	Total N% in fertilizers	Total N (kg/ha)
Control (CK)	0	0	-	-
Biochar (BC)	10	0	-	-
Biochar + Cattle manure (CM)	10	20	0.5	100
Biochar + Poultry manure (PM)	10	10	1	100
Biochar + Cattle urine (CU)	10	4	2.5	100
Biochar + Commercial Bio-fertilizers (BF)	10	1.15	8.7	100
Biochar + Inorganic fertilizers (Urea-N)	10	0.1	46	100

Table 2. Effect of various biochar blended organic and inorganic amendments on soil chemical properties (mean ± SD). Means within the column followed by the same letter are not significantly different at 5% level of significance (DMRT, $p<0.05$).

Treatments	Soil pH	Soil organic matter (%)	Total nitrogen (%)	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
CK	5.3 ± 0.35 a	0.8± 0.27 a	0.2 ± 0.15 a	18.9± 2.44 a	88.3 ± 8.27 a
BC	6.0 ± 0.12bc	1.9± 0.38 b	0.3± 0.11 ab	41.0± 3.17 b	117.1± 10.86 b
CM	6.4 ± 0.36 c	4.0± 0.56 d	0.4 ± 0.05 b	56.7± 5.37 c	166.7 ± 18.19 d
PM	6.3 ± 0.16 c	3.1± 1.02 cd	0.5± 0.09bc	80.1± 16.18 d	203.6± 13.55 e
CU	5.7 ± 0.20 ab	2.8± 0.86bc	0.6± 0.23 cd	47.1± 11.61bc	173.0± 11.50 d
BF	6.4 ± 0.60 c	3.5± 0.88 cd	0.5± 0.06 bc	55.4 ± 7.59 c	143.8 ± 24.92 c
Urea-N	6.5 ± 0.45 c	3.0± 0.34 cd	0.8± 0.15 d	37.9± 5.89 b	130.6 ± 17.94 bc
Grand Mean	6.1	2.78	0.50	48.2	146.2
P-value	0.002	<0.001	<0.001	<0.001	<0.001
F-value	5.52	9.48	12.14	22.94	26.32
S.E.M. (±)	0.19	0.35	0.05	3.96	7.5
CV(%)	6.3	25.2	23	16.4	10.3
LSD	0.57	1.04	0.17	11.77	22.29

Table 3. Correlation coefficient between total marketable yield and yield attributing characters of radish.

Parameters	Germination percentage	Leaf diameter (cm)	Leaf number	Plant Spread (cm^2)	Plant height (cm)	Root length (cm)	Shoot length (cm)	Root diameter (cm)	Biomass yield (t/ha)
Coefficient of determination (R^2)	0.76	0.31	0.50	0.57	0.74	0.62	0.59	0.73	0.53

and OM upon biochar addition could be due to the alkaline nature (high pH) and higher organic carbon content of biochar. Similar findings on the application of CM and biochar significantly ($P<0.05$) increased Soil OM from 2.0 ± 0.2 % (control) to 6.1 ± 0.2 % (Gautam *et al.*, 2017).

Similarly, total N was increased from 0.2% (CK) to 0.34%, 0.47%, 0.52%, 0.67%, 0.52% and 0.81% upon addition of BC, CM, PM, CU, BF, and urea-N respectively (Table 2). Available P was increased from 18.94 kg ha^{-1} (CK) to 41.05, 56.79, 80.16, 47.12, 55.45and 37.93 kg ha^{-1}upon addition of BC, CM, PM, CU, BF, and urea-N respectively (Table 2). Similarly, available K was increased from 88.3 kg ha^{-1}(CK) to 117.1, 166.7, 203.6, 173, 143.8, and 130.6 kg ha^{-1}upon addition of BC, CM, PM, CU, BF, and urea-N respectively (Table 2). This indicates that biochar acts as an absorbent of applied organic fertilizers and retains nutrients such as N, P, and K due to its larger porous surface area and functional groups (Hue, 2020). Observed higher total N, available P, and K upon biochar amendment in combination with both organic and inorganic fertilizers, are in line with previous studies (Kammann *et al.*, 2015; Pandit *et al.*, 2019; Sarfraz *et al.*, 2017). Kammann *et al.*, 2015 reported a higher quantity of N and P in soil solution when biochar was blended with organic fertilizers. This is mainly due to the formation of organic coatings in biochar pores, which can absorb and retain a higher amount of N and P in soil solution (Hagemann *et al.*, 2017; Kammann *et al.*, 2015). In another study, the application of biochar coated urea increased N availability and uptake by plants in rape oilseed (Jia *et al.*, 2021). A higher amount of P availability could be correlated with soil pH, which was improved upon biochar addition (Pandit *et al.*, 2018). In acidic soil, P may be adsorbed with Al and Fe making insoluble compounds (Al-P and Fe-P) and the addition of biochar increases soil pH towards neutral, which favours P availability in soil solution (Hale *et al.*, 2013). Moreover, higher available P could be due to ash in biochar, which promotes phosphorus solubilization through the microbial secretions of P-solubilizing acids in soil solution (Vassilev *et al.*, 2013). Biochar addition increased available K, which is possibly due to direct K^+ addition from biochar ashes. Gautam *et al.*, 2017, reported an increase in exchangeable K from 176 (control) to 264 cmolc kg^{-1} upon the addition of biochar blended cattle manure. Biochar application has been reported to enhance the growth of K-Dissolving Bacteria (KDB),

Table 4. Cost of production of minor early variety of radish (In NRs/ Hectare).

S.N.	Particulars	Unit	Quantity (Per Hectare)	Unit (NRs.)	Total cost (NRs.) (Quantity*Unit)	Total cost (USD)
1.	Fixed Cost					
i.	Land lease	Ha	1 hectare	100000	100000	869.6
ii.	Land Tax	Ha	1 hectare	3%	3000	26.1
	Total Fixed cost (A)				103000	895.7
2.	Variable Cost					
i.	Seed	Gm	250	5	1250	10.9
ii.	Fertilizer					
	Biofertilizers	Kg	1146.78	75	86008	747.9
	Cattle Manure	Kg	20000	5	100000	869.6
	Poultry Manure	Kg	10000	5	50000	434.8
	Cattle urine	Litre	4000	50	200000	1739.1
	Urea	Kg	217.29	50	10864.5	94.5
v.	Biochar	Ton	10	2650	26500	230.4
vi.	Field preparation	Man day	5	500	2500	21.7
vii.	Tractor	Hour	4	1200	4800	41.7
viii.	Treatments application	Man day	3	500	1500	13.0
ix.	Irrigation	Hour	8	12	96	0.8
x.	Intercultural operations	Man day	5	500	2500	21.7
xi.	Harvesting	Man day	4	500	2000	17.4
3.	Total variable cost (B)				486768.5	4232.8
4.	Total cost of production (A+B)				589768.5	5128.4

Note: The calculated fixed and variable cost is based on the perception and estimation of the farmers residing in Urlabari and the price of radish was based on the local selling price. $1 is equivalent to NRs. 115.

Table 5. Analysis of benefit: cost ratio with respect to treatments.

S.N.	Treatments	Cost of cultivation per ha. (USD)	Cost of radish per kg (USD)	Gross return per ha. (USD)	Net return per ha. (USD)	B:C ratio
1.	CK	1012.13	0.17	2608.69	1596.55	1.57
2.	BC	1242.57	0.17	5803.47	4560.90	3.67
3.	CM	2112.13	0.17	10960	8847.86	4.18
4.	PM	1677.35	0.17	8339.13	6661.77	3.97
5.	CU	2981.70	0.17	9445.21	6463.51	2.16
6.	BF	1990.46	0.17	7288.69	5298.22	2.66
7.	Urea-N	1337.04	0.17	7620.86	6283.82	4.69

and enhance mineral K weathering in soils making more K available in soil solution (Wang *et al.*, 2018). Thus, the application of biochar in combination with organic and inorganic fertilizers may have a synergistic effect, enhancing soil microbial activities and making more nutrients (P and K) bioavailable.

Effect on plant growth parameters

Application of biochar in combination with cattle manure (CM) performed best in most of the growth parameters of radish including germination percentage, leaf diameter, plant height. This is possibly due to the impregnation of organic coating to inner pores of biochar surfaces by the organic amendments, which enhance the efficiency of the biochar to capture and exchange plant nutrients and increase vegetative growth (Haider *et al.*, 2020). The maximum germination (97.5%) was observed for CM followed by CU (95.0%). CM increased seed germination percentage by 47% compared with CK (Data not shown). The result is in line with the results of highest germination, 91% in Triticale and 97% in Taşkent (cotton crop) when treated with the biochar at a rate of 40 t ha^{-1} (Uslu *et al.*, 2020). Similarly, the maximum leaf number (24 per plant) was found in PM followed by Urea-N and minimum in CK at 15, 30, 45, and 60 DAS (Figure 1a). The result is in accordance with the findings of Uddain *et al.*, 2010, where the maximum number of radish leaves per plant (22) was reported when treated with PM @25 t ha^{-1} at 75 DAS.

The leaf diameter also showed a significant result by CM treatment with the highest value of 10.4 cm at 60 DAS (Figure 1b). The maximum plant spread was found in BF and CF at 15 DAS, 60 DAS, and 30 DAS, 45 DAS (Figure 1c). Similarly, PM showed a significant increase in plant height at initial days but at later crop growth stages, plant height was observed higher in CM treatment (Figure 1d). It was found that biochar application along with organic amendments helps to enhance total leaf area, photosynthesis rate, and transpiration rate thereby decreasing leaf temperature and electrolyte leakage in leaf tissues of plants. Similar results coincided with an experiment conducted on capsicum, which revealed increased leaf area index values treated with 2.5 % dry weight biochar (Pokovai *et al.*, 2020). Moreover, the application of poultry manure biochar applied at the rate of 4 t ha^{-1} found a significantly higher plant height (Gimakalmi) of 26.1 ± 1.2 cm compared with control (16.7 ± 1.1) (Sikder and Joardar, 2019). Furthermore, growth parameters of

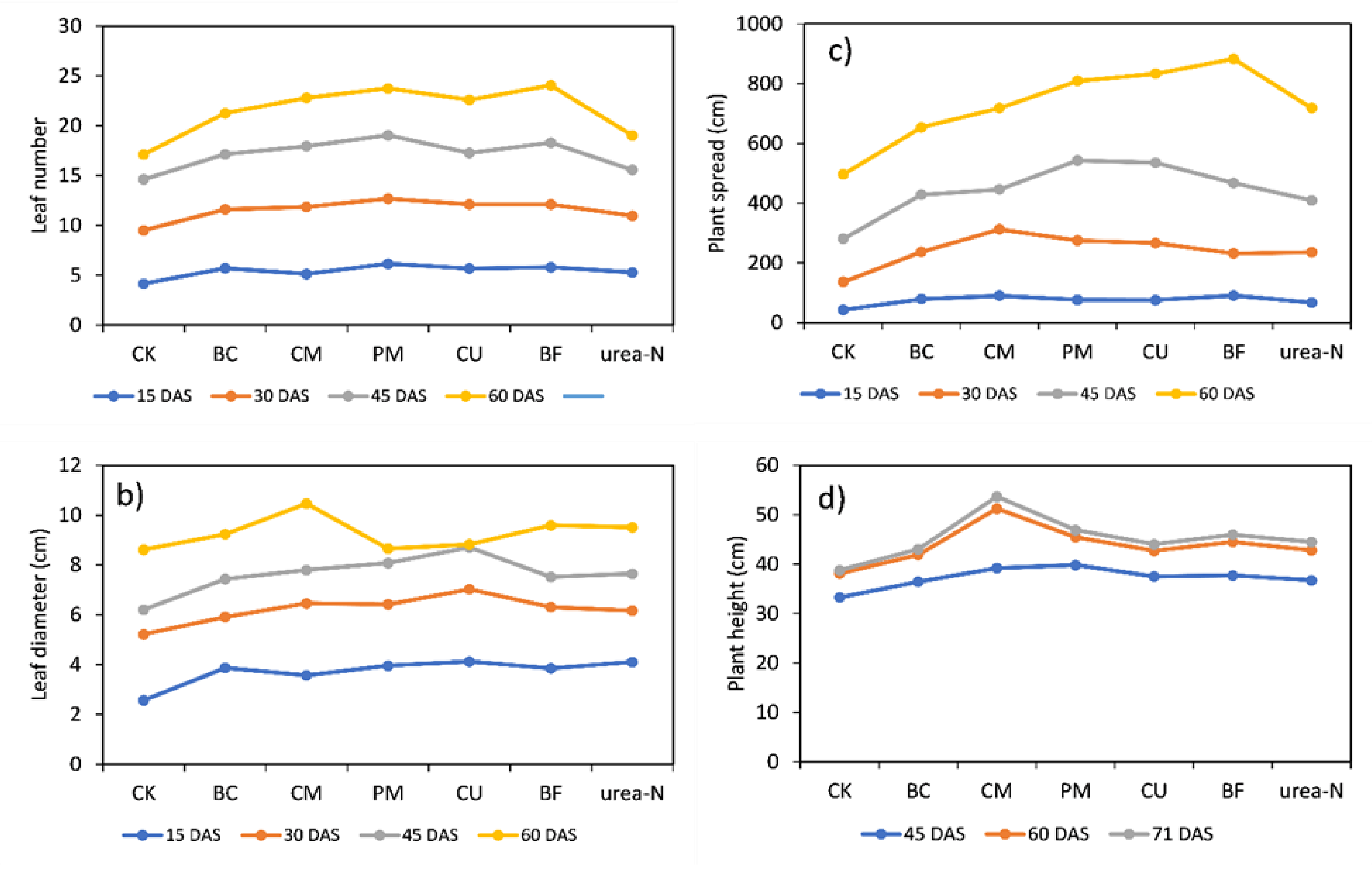

Figure 1. *Growth parameters of various BC organic amended plots.*

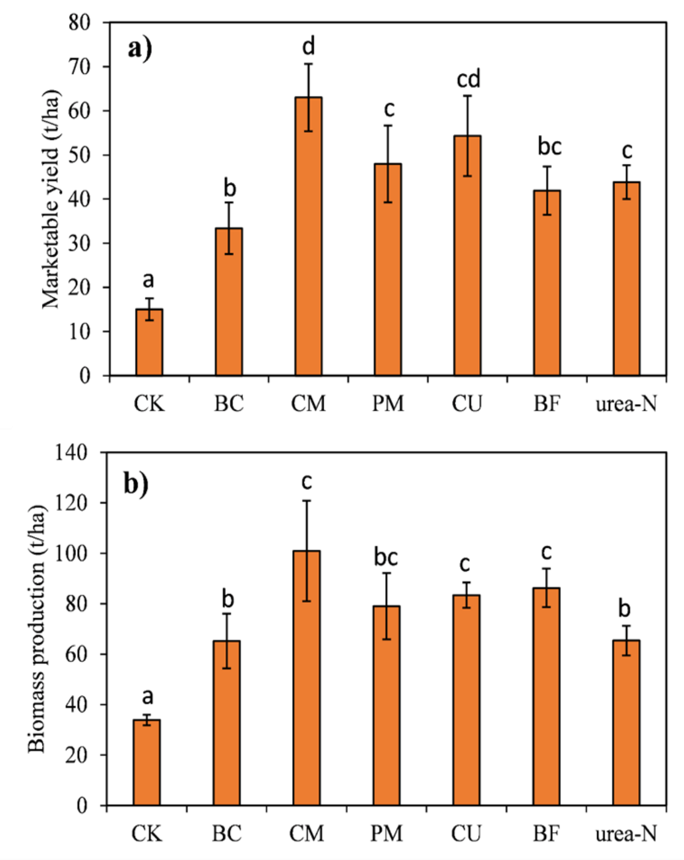

Figure 2. *Effect of various biochar blended organic amendments on radish marketable yield (a) and biomass production (b); mean ± SD, n = 4. Different letters inside the graph denote significant differences between the treatments followed by one factor ANOVA (post hoc test, p < 0.05).*

Glycine max (L) including plant height (34 cm), leaf area (431 cm^2), number of effective nodules per plant (5) stood out showing higher production with the combined application of 25% compost and 75% biochar (Senevirathne *et al.*, 2019). This illustrates that the organic fertilizers contain essential macro and micronutrients and their co-application with biochar help in retaining these nutrients in biochar pores and making them available as and when required by plants for better growth and development of the crop.

Effect on plant yield

Biochar mixed with cattle manure stood out and showed the highest marketable yield compared with other organic and urea-N fertilizers (Figure 2). BC, CM, PM, CU, BF and urea-N increased marketable yield by 122% (33 ± 6 t ha^{-1}), 320% (63 ± 7 t ha^{-1}), 220% (48 ± 8 t ha^{-1}), 262% (54 ± 9 t ha^{-1}), 179% (42 ± 5 t ha^{-1}) and 192% (43 ± 4t ha^{-1}) respectively compared to the control (15 ± 2 t ha^{-1}) (Figure 2a). Our results were consistent with earlier studies where the application of biochar (5 t ha^{-1}) along with cattle manure (20t ha^{-1}) in a coffee agroforestry system increased crop yield of radish, soybean, chilly, and garlic as compared with only cattle manure amendment soils (Gautam *et al.*, 2017). Increased yield could be attributed to the formation of organic coatings in biochar pores when mixed with manure, which can retain a higher amount of nutrients (nitrate and phosphate) and release slowly to plants as and when needed by the plants (Hagemann, 2017; Kamann *et al.*, 2015). Moreover, the co-application of organic fertilizer with biochar leads to enhanced microbial biomass, which in turn improves soil physio-

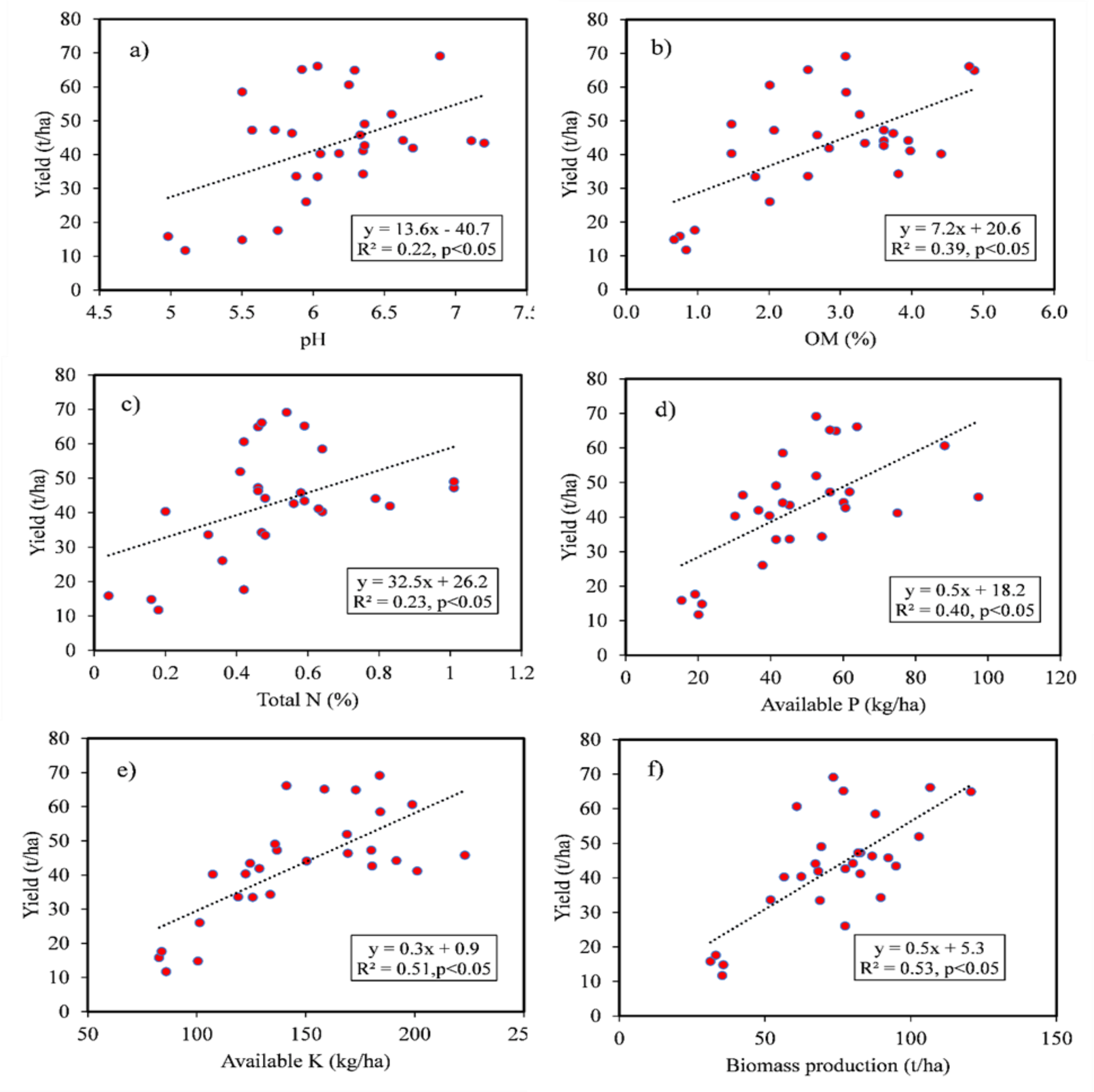

Figure 3. *Soil plant relationship, correlation between pH and Marketable yield (a) between organic matter and Marketable yield (b) Total Nitrogen and Marketable yield (c), between Available Phosphorus and Marketable yield (d) between Available Potassium and Marketable yield (e) and between Biomass yield and Marketable yield (f).*

chemical properties and increases crop growth (Steiner *et al.*, 2008). A study on the combined and sole application of biochar with fertilizers revealed that biochar increased crop yields by 15% but only with mineral fertilizers and did not contribute to greater crop yield at least in the short-term crop (Ye *et al.*, 2020). Similarly, BC, CM, PM, CU, BF, and urea-N increased total biomass yield by 92% (65 ±10t ha^{-1}), 198% (101 ± 19t ha^{-1}), 133% (79 ± 13t ha^{-1}), 152% (83 ± 5t ha^{-1}), 154% (86 ± 7 t ha^{-1}) and 93% (65 ± 6t ha^{-1}) respectively compared with control (34 ± 2t ha^{-1}) (Figure 2b). Biochar blended with CM showed significantly higher total biomass and marketable yield compared with a urea-N amendment. However, other organic amendments did not show a significant effect on yield over urea-N fertilizer. Among all the applied treatments, CM showed the highest marketable yield (Figure 2a). The result is in line with the findings of Timilsina *et al.*, 2020, where an addition of 2 t ha^{-1}biochar on cauliflower increased curd yield by 37% when compared with only application of NPK treatment (200:120:80 kg NPK ha^{-1}) and by 59% when compared with control plots. However, the application of biochar blended with locally produced cattle farmyard manure (FYM) increased the yield of peppers, a short duration crop, by 6%, 15%, and 20% in 1st, 2nd, and 3rd harvests respectively compared to the control treatment (Šimanský *et al.*, 2019). Furthermore, a demonstration field trial conducted in Nepal showed that the application of biochar @1 t ha^{-1} along with cow urine increase ginger yield by 30%. Similarly, the application of biochar @2.4 t ha^{-1} increases cabbage yield by 50% along with the addition or without the addition of compost. Biochar in combination with organic amendments is very effective in increasing tea yield by 33% in Barbote, Ilam (ADB Technical Assistance Consultant's Report, 2016). The maximum harvest index (0.65) was recorded in CM, CU, and Urea-N, and the minimum harvest index (0.44) was recorded in CK (data not shown). The result has coincided with the result of Oladele *et al.*, 2019, where the co-application of biochar and N fertilizers increased the harvest index of rice by 24% over 2 years, indicating a synergistic effect of biochar and N fertilizer. The obtained results suggested that the application of biochar in combination with both organic and inorganic amendments have positive effects on crop yield.

Soil plant relationship

All the growth, reproductive and soil parameters showed a significant positive relationship with the marketable yield. Germination percentage (R^2=0.76%), plant height (R^2=0.74%), root diameter (R^2=0.73%), biomass yield (R^2=0.53%) was found to have a positive relationship with total marketable yield (Table 3). Similarly, pH (R^2=0.22%), organic matter (R^2=0.39%), total Nitrogen (R^2=0.23%), available Phosphorus (R^2=0.40%), and available Potassium (R^2=0.51%) was found to have a positive relationship with total marketable yield (Figure 3). In this study, improved soil chemical properties upon biochar amendment showed a significant beneficial effect on marketable yield (Figure 3). Our results are in line with earlier studies where yield was positively correlated with improved soil chemical properties such as soil pH, organic carbon and, CEC, and essential available nutrients such as N, P, and K (Jien and Wang, 2013, Yamato *et al.*, 2006; Pandit *et al.*, 2018; Cornelissen *et al.*, 2013; Timilsina, 2017). A positive linear relationship was reported between soil pH and biochar alkalinity thereby improving the liming effect of acidic soil and enhancing the soil fertility ($R^2 = 0.95, p < 0.05$) (Yuan and Xu, 2011).

Relative economics

Cost of production: Gross margin with the use of BC, CM, PM, CU, BF, and urea-N was increased by122% 320%, 220%, 262%, 1,79%, and 192% respectively compared with control (USD 2608 per ha). Similarly, net returns with the use of BC, CM, PM, CU, BF, and urea-N were increased by 186%, 454%, 317%, 305%, 232%, and 294% respectively compared with control (USD 1596.56 per ha). The relative economic analysis of radish was calculated on a yield basis. B:C ratio was found in the range of 1.57 to 4.69 with various organic and inorganic amendments co-applied with biochar (Table 4 and 5). Among different treatments, gross return and net return per hectare were observed higher for CM (USD 8847.86) followed by Urea-N (USD 7620.86) treatments (Table 5), illustrating that these two treatments are more profitable for radish production at the local farm household level. A similar result of high net return (USD 1010) was obtained through the addition of 60 t ha^{-1} of co-composted biochar from a hectare of maize land (Pandit *et al.*, 2019).

Conclusion

Biochar addition showed a significant positive effect on improving soil chemical properties and available nutrients such as pH, organic matter, total N, available P, and K. Biochar in combination with CM stood out and showed significantly higher plant growth and marketable yield among all other organic and inorganic amendments. Similarly, farm economic return (net margin) was observed higher with the use of CM compared with urea N and other organic amendments. Thus, our study suggests that farmers could increase their crop productivity and fetch higher economic returns with the use of biochar and cattle manure mixtures, which could be easily produced by farmers at the local farm household level. This result indicated that the synergistic-interactive effect of biochar and cattle manure could retain and supply a higher amount of nutrients thereby increasing the crop produce. Production and application of such an efficient biochar-manure mixture could minimize the use of chemical N fertilizers, which can reduce both costs as well as environmental pollution. Since, the research was limited to only one type of soil representing a small specific agricultural domain, further research is suggested to explore the agronomic and economic effect of biochar in combination with various organic and mineral fertilizers in different soil types and agro-ecological domains in Nepal.

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Conflict of interest

The authors declare no conflict of interest.

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