Research Article:

INTEGRATION OF URINE-CHARGED BIOCHAR AND CHEMICAL FERTILIZERS ENHANCES CAULIFLOWER PRODUCTIVITY IN INCEPTISOLS

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ABSTRACT

Cauliflower (*Brassica oleracea* var. *botrytis*) cultivation in Nepal relies heavily on chemical fertilizers, degrading soil microbes and causing nutrient imbalances. Judicious organic-inorganic fertilizer use is vital for sustainable yields. A field experiment was conducted in Rampur, Chitwan, Nepal, (November-February 2019) to evaluate the effects of urine-charged biochar (UCB) and recommended dose of chemical fertilizers (RDF) on growth and productivity of cauliflower in Inceptisols. The experiment followed a Randomized Complete Block Design (RCBD) with six fertilizer treatments: control (no fertilizer), UCB 100%, RDF 100%, and their combinations (UCB 75% + RDF 25%, UCB 50% + RDF 50%, UCB 25% + RDF 75%), replicated four times. *Lantana camara* biochar, produced via low-cost Kon-Tiki slow pyrolysis, was mixed with cattle urine (1:1 w/w) and applied to the root zone. Plant height, leaf number, canopy diameter, stem weight, root length, root weight, and yield differed significantly ($p<0.05$) among treatments. The UCB 50% + RDF 50% treatment produced the highest yield (47.3 $Mtha^{-1}$) and biological yield (92.35 $Mtha^{-1}$), surpassing RDF 100% by 24.9% (yield) and 14.9% (biological yield), and UCB 100% by 9.8% (yield) and 7.0% (biological yield). The experiment demonstrates that combined UCB and chemical fertilizer application enhances cauliflower yield and yield attributes compared to sole applications.

Key words: Cattle urine, *Lantana camara*, nutrient management, yield

INTRODUCTION

Cauliflower is a nutritionally and economically vital crop in Nepal, occupying 13% of total vegetable area (MoALD, 2022; Shrestha et al., 2014), yet suffers from low productivity due to inefficient fertilizer use. While chemical fertilizers are costly and scarce, their sole application degrades soil health, whereas organic alternatives alone often fail to meet crop demands (Pandit et al., 2022). Given cauliflower's sensitivity to nutrient inputs, balanced fertilization is critical for maximizing yield (Devi et al., 2018). While chemical fertilizers are a key nutrient source, their high cost and periodic scarcity hinder agricultural productivity in Nepal (Takeshima et al., 2016). Integrating organic and inorganic fertilizers offers a sustainable solution, improving soil fertility while reducing reliance on synthetic inputs (Chapagain & Gurung, 2010).

Despite the potential of integrated soil fertility management, Nepal's crop productivity lags neighboring countries due to declining soil fertility and inefficient practices (Devkota et al., 2016). Farmers often overapply nitrogen (urea) while neglecting phosphorus, potassium, and organic inputs, further degrading soil health and nutrient use efficiency (Dhakal et al., 2021; Pandit et al., 2022). Biochar, a carbon-rich soil amendment derived from pyrolyzed biomass, has emerged as a promising tool to enhance soil properties and crop yields (Lehmann et al., 2006). Its porous structure improves nutrient retention, pH, and cation exchange capacity, fostering long-term soil health (Filiberto & Gaunt, 2013; Pandit et al., 2022; Saha et al., 2019; Schmidt et al., 2017). When enriched with nutrients like cattle urine, biochar can dramatically boost yields, as seen in pumpkin trials where it increased productivity by 300% (Schmidt et al., 2017). Yet, research on biochar's synergy with chemical fertilizers in cauliflower systems remains limited, particularly in Nepal's sandy loam Inceptisols.

This study evaluates the effects of combining UCB with RDF on yield and yield attributing characteristics of cauliflower in Inceptisol of tropical area of Nepal. We hypothesize that UCB-chemical fertilizer blends will outperform sole applications by enhancing nutrient availability, and yield attributes. By optimizing this integration, the study aims to address Nepal's fertilizer inefficiencies, offering farmers a cost-effective strategy to improve productivity while safeguarding soil sustainability. The findings could redefine nutrient management practices for cauliflower and similar high-value crops in resource-constrained regions.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted at the horticulture farm of the Agriculture and Forestry University (AFU), Rampur, Chitwan during the winter season of 2018. The site was situated at 27º 37' N and 84º 25' E and an altitude of 228 meter above sea level. Prior to transplanting, composite soil sample (0-30 cm depth) was collected and analyzed at the National Academy of Science and Technology (NAST) laboratory. The soil was classified as sandy loam with the following properties: pH 5.6, total nitrogen (0.1%), available phosphorus (104 kg ha^{-1}), available potassium (226 kg ha^{-1}), and organic carbon (1.71%). The recommended dose of NPK was 200:120:80 kg ha^{-1} (AITC, 2023).

Experimental details

The experiment was carried out in a RCBD with four replications and six treatments. The six treatments were the integration of UCB and RCBD. 24 plots were each 3 m in length and 2.5 m in breadth with 25 plants in each plot. Plants were spaced at 60 cm between rows and 50 cm between plants. The distances between the replications and between the plots were maintained at 1m and 0.5m, respectively. Each plot consists of an area of 7.5 m^2 and a net experimental area of 180 m^2. The different doses of NPK and UCB were applied at the recommended nitrogen rate (200 kg N ha^{-1}), as nitrogen is the most critical nutrient for cauliflower growth and yield (Table 1). The RDF was 200:120:80 kg ha^{-1} (AITC, 2023).

Table 1. Treatment descriptions of the experiment

S.N.	Treatments	Treatment symbols	Rate of N (g/plot)	Rate of P (g/plot)	Rate of K (g/plot)	Rate of UCB (kg/plot)
1	Control	T1	0	0	0	0
2	UCB (100%)	T2	0	0	0	22.72
3	RDF (100%)	T3	327	563	100	0
4	UCB (75 %) + RDF (25 %)	T4	82	0	0	17.64
5	UCB (50 %) + RDF (50%)	T5	164	0	0	11.36
6	UCB (25 %) + RDF (75 %)	T6	246	117	0	5.68

Intercultural operation

Snow mystique, a hybrid variety of cauliflower, was used as a test crop. It is a late variety that matures within 80-90 days after transplanting (DAT) (AITC, 2023). It is dome-shaped producing pure white curd. To make the soil more pulverized and ready for planting, experimental plots were prepared by deep plowing fifteen days before transplanting. After the second plowing and planking of soils on 29 November 2018, the seedlings at the stage of 3–4 leaves were transplanted on 2 December 2018. After transplantation, the field received frequent irrigation for five days using a rose cane to help the seedlings get established, and then once every three days after that. After that, during the head development, the plots were furrow-irrigated. On the 20th and 40th days after transplanting, weeds were physically pulled out, and then the soil was earthed. UCB, phosphorus, and potassium fertilizers were applied at full dose at the transplanting, while N was provided in split doses (half as basal application and the remaining half at 40 DAT.

Biochar Characteristics and its preparation

Biochar was prepared from *Lantana camara*-an invasive, fast-growing, and widely available weed-using a low-cost Kon-Tiki under pyrolytic conditions and quenched with water from the top. The prepared biochar was sun-dried and grinded in a 2 mm sieve grinder. The cost estimate of biochar was US$ 0.15 per kilogram and the conversion efficiency (η) of biochar was 23.5% which was calculated using the following formula:

Ƞ = Dry weight of biochar/ Dry weight of feedstock)×100%.

The prepared biochar was mixed with cattle urine in a 1:1 ratio based on weight and applied at the root zone of the cauliflower. The characteristics of biochar, urine-charged biochar, and urine were analyzed at NAST laboratory, Khumaltar and the result is presented in Table 2.

Table 2. Characteristics of biochar

Parameters	Biochar	Urine charged biochar (1:1)	Urine
Moisture %	24	71	-
pH	10.5	9.9	8.3
Organic carbon (%)	70.48	-	-
Nitrogen (%)	0.44	0.66	-
Phosphorous %	0.84	0.88	-
Potassium %	3.16	3.60	-

Measurement of Growth and Yield Parameters

The growth parameters i.e. plant height, leaf number, and canopy diameter were recorded from randomly selected five sampled plants in each plot at 25, 40, 55, and 70 DAT and at the harvesting stage. At the final harvesting stage, the whole plants were segregated into leaves, stem, roots, and curd and biological yield, curd yield, root length, root weight, stem length, stem weight, stem diameter, total leaf weight, leaf dry matter, curd diameter, curd height, and curd weight were recorded randomly from selected five sampled plants in each plot.

Economic analysis

Gross Return (GR)

Gross return=Price of cauliflower×Total yield of cauliflower

Total Variable Cost (TVC) Equation:

TVC=$\sum_{i=0}^{n} Ci = Cl + Ct + Cs + Cf + Cp + Cm + Cucb_{I}$

Where: *Cl* = Cost of labor; *Ct* = Cost of tractor use; *Cs* = Cost of seed; *Cf* = Cost of chemical fertilizer; *Cp* = Cost of pesticide; *Cm* = Cost of micronutrient *Cucb* = Cost of urine-charged biochar

Benefit-Cost Ratio (B:C ratio)

$$\text{B:C ratio} = \frac{\text{Gross Return}}{\text{Total Variable Cost}}$$

Data analysis

The data were initially tabulated in Microsoft Excel and analyzed using R. A one-way ANOVA was performed by Duncan's Multiple Range Test (DMRT) at a 5% significance level (Gomez & Gomez, 1984).

RESULTS

Effect of treatments on plant height

The treatments exhibited significant variations (p<0.05) in plant height across growth stages. At harvest, the highest plant height was recorded in UCB 50% + RDF 50%, while the lowest was observed in the control, reflecting a 16.3% increase in the combined treatment over the control. Compared to RDF 100%, UCB 50% + RDF 50% showed a 10.6% improvement. The progressive increase in plant height from 25 to 70 DAT further confirmed the superiority of UCB 50% + RDF 50%, The ANOVA and DMRT results (**F-test:) validated these differences, with UCB 50% + RDF 50% often statistically on par with UCB 75% + RDF 25% but significantly higher than RDF or control.

Table 3. Effect of UCB and chemical fertilizer on plant height at different growth periods of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Plant height (cm)				
	25 DAT	40 DAT	55 DAT	70 DAT	At Harvesting
Control	19.39±0.71^{b}	29.48±1.16^{b}	41.55±1.58^{b}	51.06±1.42^{c}	55.60±0.82^{c}
UCB 100%	19.59±0.50^{b}	31.90±1.0^{a}	45.15±1.27^{a}	56.03±1.34^{ab}	59.38±1.68^{b}
RDF 100%	22.43±1.14^{a}	32.90±0.29^{a}	45.40±0.69^{a}	54.78±0.71^{b}	58.80±1.25^{b}
UCB 75 % + RDF 25 %	20.80±0.84^{ab}	32.68±1.02^{a}	46.85±1.24^{a}	57.55±0.32^{a}	64.43±0.52^{a}
UCB 50 %+ RDF 50%	21.15±0.55^{ab}	33.65±0.49^{a}	48.00±0.68^{a}	58.09±1.22^{a}	65.06±1.42^{a}
UCB 25 % + RDF 75 %	21.72±0.72^{a}	32.85±0.83^{a}	46.15±0.29^{a}	55.99±0.94^{ab}	61.45±1.25^{b}
SEm (±)	0.49	0.60	0.90	1.03	1.47
LSD (=0.05)	1.91	2.32	2.86	2.36	2.92
F-test	*	*	**	**	**
CV, %	6.10	4.78	4.17	2.82	3.19
Grand Mean	20.85	32.24	45.52	55.58	60.78

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P< 0.05), ** Significant at 1% (P< 0.01) and Ns: not significantly different.

Effect of treatments on leaf number

Significant variations were observed in leaf number across treatments, with the highest values consistently recorded in UCB 75% + RDF 25% and UCB 50% + RDF 50% and the lowest in the Control at harvest. The UCB 50% + RDF 50% treatment overcame the Control by 19.7% at harvest (70 DAT: 16.6% higher). Notably, UCB 50% + RDF 50% matched the performance of UCB 75% + RDF 25%, both significantly surpassing RDF 100% and Control.

Table 4. Effect of UCB and chemical fertilizer on leaf number at different growth periods of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Leaf number				
	25 DAT	40 DAT	55 DAT	70 DAT	At harvesting
Control	5.18±0.38	7.45±0.28[c]	10.33±0.11[b]	12.25±0.28[b]	12.43±0.19[c]
UCB 100%	5.58±0.14	8.78±0.14[a]	12.10±0.38[a]	13.88±0.44[a]	14.10±0.39[ab]
RDF 100%	5.90±0.20	7.98±0.14[bc]	11.03±0.65[ab]	13.58±0.28[a]	13.75±0.24[b]
UCB 75 % + RDF 25 %	5.55±0.12	8.88±0.14[a]	12.23±0.13[a]	14.55±0.43[a]	14.88±0.28[a]
UCB 50 %+ RDF 50%	5.35±0.25	8.50±0.20[ab]	12.10±0.32[a]	14.28±0.48[a]	14.88±0.29[a]
UCB 25 % + RDF 75 %	5.73±0.31	8.15±0.40[abc]	11.60±0.47[a]	13.98±0.63[a]	14.43±0.51[ab]
SEm (±)	0.11	0.22	0.31	0.33	0.38
LSD (=0.05)	0.67	0.74	1.12	1.22	1.02
F-test	Ns	**	*	*	**
CV, %	8.02	5.91	6.45	5.88	4.79
Grand Mean	5.55	8.29	11.56	13.75	14.08

Means with the same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P<0.05), ** Significant at 1% (P< 0.01), and Ns: not significantly different.

Effect of treatments on Broad leaf weight, Total leaf Weight and Leaf dry matter

The treatments showed significant variations in broadleaf weight and total leaf weight (p<0.01), but not in leaf dry matter content (non-significant). The UCB 75% + RDF 25% treatment produced the highest broadleaf weight, which was 41.2% greater than the lowest (Control). Similarly, for total leaf weight, the UCB 75% + RDF 25% treatment recorded the highest value, 33.7% higher than the Control. Comparing UCB 50% + RDF 50% and RDF 100%, the UCB 50% + RDF 50% treatment had 12.0% higher total leaf weight and 15.8% higher broadleaf weight (Table 5).

Table 5. Effect of UCB and chemical fertilizer on broad leaf weight, total leaf weight, and leaf dry matter at the time of harvest of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Broadleaf weight (gram)	Total leaf weight (gram)	Leaf dry matter (percentage)
Control	81.40±2.75[b]	802.80±23.94[c]	9.97±0.96
UCB 100%	100.20±5.56[a]	1011.60±47.51[ab]	11.27±1.19
RDF 100%	97.60±7.49[ab]	949.30±38.88[b]	10.58±0.95
UCB 75 % + RDF 25 %	114.95±2.70[a]	1073.40±50.59[a]	12.38±0.75
UCB 50 %+ RDF 50%	113.00±5.85[a]	1063.40±65.86[a]	12.38±0.92
UCB 25 % + RDF 75 %	107.60±5.90[a]	1001.30±45.01[ab]	11.80±1.74
SEm (±)	5.10	40.58	0.40
LSD (=0.05)	16.63	99.79	1.81
F-test	**	**	Ns
CV, %	10.77	6.73	10.56
Grand Mean	102.46	983.63	11.40

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P< 0.05), ** Significant at 1% (P< 0.01) and Ns: not significantly different.

Effect of treatments on Stem length, Stem diameter, Stem weight, Root length, and Root weight

The UCB 50% + RDF 50% treatment produced the highest values in stem diameter, stem weight, and root length, while Control recorded the lowest values Compared to the Control, UCB 50% + RDF 50% increased stem length by 26.95%, stem diameter by 27.86%, stem weight by 15.39%, root length by 17.31%, and root weight by 37.86%. When compared to RDF 100%, UCB 50% + RDF 50% showed superior performance, with increases of 10.85% in stem diameter, 8.47% in stem weight, and 21.19% in root weight (Table 6).

Table 6. Effect of UCB and chemical fertilizer on Stem length, Stem diameter, Stem weight, Root length and Root weight at the time of harvest of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Stem length (cm)	Stem diameter (cm)	Stem weight (gram)	Root length (cm)	Root weight (gram)
Control	9.98±0.28[c]	3.23±0.15[c]	163.85±4.02[c]	13.81±0.59[c]	77.39±3.18[c]
UCB 100%	11.80±0.75[ab]	4.06±0.13[a]	178.25±5.21[ab]	16.37±0.58[a]	108.35±5.98[a]
RDF 100%	11.43±0.52[b]	3.56±0.11[b]	174.30±3.02[bc]	14.74±0.28[b]	88.00±5.73[b]
UCB 75 % + RDF25 %	12.67±0.62[a]	4.08±0.28[a]	189.05±4.56[a]	16.16±0.49[a]	107.10±5.94[a]
UCB 50 %+ RDF 50%	12.67±0.66[a]	4.13±0.23[a]	189.05±5.03[a]	16.20±0.51[a]	106.65±6.58[a]
UCB 25 % +RDF 75 %	11.57±0.27[b]	3.93±0.28[a]	175.90±6.43[abc]	14.93±0.74[b]	98.45±5.66[a]
SEm (±)	0.41	0.15	3.92	0.42	5.13
LSD (=0.05)	0.90	0.33	12.27	0.85	10.30
F-test	**	**	**	**	**
CV, %	5.10	5.70	4.56	3.67	7.00
Grand Mean	11.68	3.83	178.40	15.36	97.66

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% ($P< 0.05$), ** Significant at 1% ($P< 0.01$) and Ns: not significantly different.

Effect of treatments on Curd height, Curd diameter, Curd weight, and Curd dry matter

The treatments showed significant variations in curd height, diameter, and weight ($p < 0.01$), but not in curd dry matter. UCB 50% + RDF 50% produced the highest values in all significant parameters (curd height, curd diameter and weight), while the control recorded the lowest. Compared to the control, UCB 50% + RDF 50% increased curd height by 48.9%, diameter by 27.2%, and weight by 53.3%. When comparing UCB 50% + RDF 50% with RDF 100%, the increases were 26.4% (height), 12.8% (diameter), and 16.5% (weight).

Table 7. Effect of UCB and chemical fertilizer on curd height, curd diameter, curd weight and curd dry matter at the time of harvest of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Curd height (cm)	Curd diameter (cm)	Curd weight (kg)	Curd dry matter (percentage)
Control	9.46±0.28[d]	18.00±0.37[d]	0.92±0.04[c]	9.90±1.11
UCB 100%	12.84±0.69[b]	21.33±0.63[b]	1.29±0.03[ab]	10.82±0.56
RDF 100%	11.15±0.13[c]	20.30±0.47[c]	1.21±0.06[b]	10.07±0.49
UCB 75 % + RDF 25 %	13.86±0.47[ab]	22.60±0.73[a]	1.40±0.06[a]	11.58±0.59
UCB 50 %+ RDF 50%	14.09±0.32[a]	22.89±0.75[a]	1.41±0.06[a]	11.82±0.64
UCB 25 % + RDF 75 %	12.92±0.54[b]	21.53±0.49[b]	1.29±0.1[ab]	10.61±1.10
SEm (±)	0.72	0.73	0.074	0.32
LSD (=0.05)	1.11	0.86	0.17	1.52
F-test	**	**	**	Ns
CV, %	5.95	2.70	8.92	9.31
Grand Mean	12.38	21.11	1.26	10.80

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P< 0.05), ** Significant at 1% (P< 0.01) and Ns: not significantly different.

Effect of treatments on Yield and biological yield

The treatments showed significant variations in both yield and biological yield. UCB 50% + RDF 50% produced the highest grain yield, while the Control recorded the lowest, reflecting a 62.8% increase in yield with the combined treatment. Similarly, for biological yield, UCB 50% + RDF 50% outperformed the Control by 41.4%. Compared to RDF 100%, UCB 50% + RDF 50% yielded 24.9% higher grain production and 14.9% greater biological yield, demonstrating the superior efficacy of the integrated nutrient approach.

Table 8. Effect of UCB and chemical fertilizer on yield and biological yield at the time of harvest of cauliflower at Rampur, Chitwan, Nepal (2018/19)

Treatments	Yield (Mg ha^{-1})	Biological yield (Mg ha^{-1})
Control	29.05±1.49[d]	65.30±1.91[c]
UCB 100%	43.07±1.15[ab]	86.34±2.29[ab]
RDF 100%	37.87±2.07[c]	80.39±0.69[b]
UCB 75 % + RDF 25 %	46.82±1.88[ab]	92.48±2.93[a]
UCB 50 %+ RDF 50%	47.30±1.95[a]	92.35±3.48[a]
UCB 25 % + RDF 75 %	42.33±3.47[ab]	85.59±5.01[ab]
SEm (±)	2.78	4.13
LSD (=0.05)	4.40	7.45
F-test	**	**
CV, %	7.11	5.90
Grand Mean	41.07	83.74

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P< 0.05), ** Significant at 1% (P< 0.01) and Ns: not significantly different.

Effect of treatments on Total variable cost, Total gross return and Benefit-cost ratio

The treatments showed significant variations in total gross return with UCB 50% + RDF 50% yielding the highest return and the Control treatment showing the lowest. Comparatively, UCB 50% + RDF 50% outperformed the Control by 62.8%, demonstrating a substantial economic advantage. Additionally, UCB 50% + RDF 50% also surpassed RDF 100% by 24.9%, indicating that the combined application of biochar and reduced chemical fertilizers was more profitable than full-dose RDF alone. The benefit-cost ratio further supported this trend, with UCB 50% + RDF 50% being significantly higher than UCB 100% but slightly lower than RDF 100%.

Table 9. Effect of UCB and chemical fertilizer on Total variable cost, Total gross return, Total net return and Benefit-cost ratio of cauliflower production at Rampur, Chitwan, Nepal (2018/19)

Treatments	Total variable cost (NRs. ha^{-1})	Total gross return (NRs. ha^{-1})	Benefit-cost ratio
Control	335111	522960±26741^{d}	1.56±0.08^{bc}
UCB 100%	638044	775260±20630^{ab}	1.22±0.03^{d}
RDF 100%	361636	681660±37286^{c}	1.88±0.10^{a}
UCB 75 % + RDF 25 %	572279	842700±33801^{ab}	1.47±0.06^{c}
UCB 50 %+ RDF 50%	490514	851340±35177^{a}	1.74±0.07^{ab}
UCB 25 % + RDF 75 %	419244	761874±62370^{b}	1.82±0.15^{a}
SEm (±)		50057.5	0.10
LSD (=0.05)		79260.82	0.19
F-test		**	**
CV, %		7.11	7.86
Grand Mean	469472	739299	1.61

Means with same letter in columns do not differ significantly at p=0.05 by DMRT. * Significant at 5% (P< 0.05), ** Significant at 1% (P< 0.01) and Ns: not significantly different.

DISCUSSION

The integration of UCB and RDF demonstrated a significant influence on growth parameters among the treatments. During the early growth stages, chemical fertilizers predominantly governed plant height due to their rapid nutrient release, whereas combined applications of UCB and RDF exhibited stronger effects in later stages. This aligns with findings by Bhathal and Kumar (2016) who attributed such patterns to the immediate nutrient availability from RDF and the sustained release from UCB. Treatments combining UCB 50% + RDF 50% and UCB 75% + RDF 25% consistently promoted leaf number, likely due to enhanced nutrient retention and improved soil water-holding capacity (Carter et al., 2013; William & Qureshi, 2015).

The root length and root weight were significantly higher with the higher UCB application rate. Atkinson et al. (2010), stated that the biochar application reduces the soil bulk density while increasing porosity thereby promoting root proliferation and decreasing resistance to root penetration. These findings align with those of Timilsina et al. (2017). In the same way, Chan et al. (2008), indicated that biochar application increased the dry weight of radish due to more availability of nitrogen to the plants from the soil. However, Lehmann et al. (2007) observed contrasting results when biochar application exceeded 50 Mg ha^{-1}, attributing this to nutrient immobilization caused by adsorption onto biochar surfaces.

The observed enhancement in yield of cauliflower with combined biochar and NPK applications suggests a strong synergistic interaction between these soil amendments, consistent with findings from previous studies (Liang et al., 2006; Oram et al., 2014; Tammeorg et al., 2014). This synergy appears particularly effective at intermediate application ratios, where the complementary effects of biochar's nutrient retention capacity and NPK's immediate availability create optimal conditions for plant growth and yield formation. Chan et al. (2008) highlighted the fact that the biochar alone had limited effects on radish yield, its integration with N fertilization led to significant improvements. Similarly, Vista et al. (2015) reported that increased yields in biochar-amended fields for multiple crops, including cauliflower, cabbage, pumpkin, and chili, compared to untreated controls. Biochar's role in nutrient retention has been well-documented. Sadaf et al. (2017) noted that despite its low inherent nutrient content, biochar effectively reduces nutrient leaching and enhances soil nutrient availability. Haider et al. (2017) suggested that combining biochar with chemical fertilizers ensures a sustained nutrient supply, optimizing crop growth and yield performance.

From an economic perspective, the higher variable cost associated with the UCB 100 percent treatment, which results from small-scale biochar production, was balanced by the greater gross returns achieved with the combined UCB 50 percent plus RDF 50 percent application. This demonstrates the practical benefits of integrated nutrient management strategies. Reddy et al. (2018) has explained the cost estimate of biochar where large-scale production of biochar would reduce the price per unit. Furthermore, Roberts et al. (2010) emphasized that accounting for carbon sequestration benefits and greenhouse gas emission reductions would enhance the overall economic returns of biochar applications. The research carried out by Dunsin et al. (2016), revealed that the strong synergistic effect of chemical fertilizer and biochar results in higher yield which ultimately increases the total gross return.

CONCLUSION

The experimental findings suggest that the integration of urine-charged biochar and chemical fertilizers may represent an effective approach for enhancing cauliflower growth and yield. Biochar's unique physicochemical properties appear to improve chemical fertilizer utilization efficiency. Enrichment of biochar with cattle urine and application in marginal land will play a key role in sustaining agricultural productivity. Production and use of biochar are at an early developmental stage in Nepal, scaling up production would likely reduce per-unit costs. Future research should focus on biochar's optimal production, application methods, fertilizer substitution potential, and production economics for sustainable crop management.

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