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INFLUENCE OF BIOCHAR, COWDUNG AND POULTRY MANURE ALONG WITH REDUCED RATES OF FERTILIZERS ON CABBAGE YIELD AND SOIL HEALTH

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Abstract

Sole dependency on chemical fertilizers in traditional agriculture is a major concern owing to its negative effects on soil health and crop productivity. Organic manure, having numerous positive effects on soil quality, is an alternative source of chemical fertilizers in crop production. Therefore, a field experiment was conducted to assess the effect of biochar (BC), poultry manure (PM) and cowdung (CD) along with reduced rates of chemical fertilizers on cabbage yield and soil health. There were five treatments viz. T_0: control, T_1: 100% recommended dose of fertilizers (RDF), T_2: BC + RDF (IPNS), T_3: PM + RDF and T_4: CD + RDF; manure added @ 2 t ha^{-1}, the treatments arranged in a randomized complete block design (RCBD) with three replications. Results revealed that the application of PM along with fertilizers produced significantly the highest plant height (35.7 cm), head circumference (75.3 cm), head height (14.6 cm), SPAD (soil plant analysis development) value (75.1) and head yield (53.8 t ha^{-1}) of cabbage. The highest N (1.98%), P (0.36%), K (1.43%), S (0.17%), Zn (39 ppm) and boron (20 ppm) content of cabbage (dry weight basis) was found in T_3 treatment containing poultry manure. The same treatment (T_0) helped improve soil fertility in terms of higher organic carbon (1.32%), total N (0.24%), available P (32.8 ppm), exchangeable K (0.4 me%) and available S (28.2 ppm). Thus, combined application of poultry manure and chemical fertilizers following integrated plant nutrition system could be practiced to improve soil fertility and cabbage productivity.

Keywords: Biochar, Cabbage, Cowdung, Poultry manure, SPAD value

1. Introduction

Cabbage (Brassica oleracea var. capitata L.), a Cole crop belonging to the Cruciferae family, is globally an important leafy vegetable. China, , Japan, India, South Africa, and South Korea are the world's leading cabbage producing countries. It is a highly vitamin and minerals rich vegetable (Mabry *et al.,* 2021). Drozdowska *et al.* (2020) state, cabbage is a better source of carbohydrates, fiber, Ca, Mg, K, P, Na, S, Fe, Zn, Mn, Cu and glucosinolates in the human diet. Increasing crop production relies on soil quality and advanced techniques. In Bangladesh, yields are stagnating or declining due to improper soil management, intensive cropping, and unbalanced use of fertilizers. Declining soil fertility, worsened by overuse of chemical fertilizers and minimum use of organic matter, threaten agricultural productivity and environmental health (Hu *et al.,* 2022).

Continuous use of chemical fertilizers depletes soil organic matter and degrades soil quality, leading to hardened soil, reduced fertility, and environmental pollution. It can lower microbial activity, affects soil pH, increases pests, causes acidification, and reduces beneficial organisms, hindering plant growth and contributing to greenhouse gas emissions (Pahalvi *et al.,* 2021). Soil organic matter, vital for nutrient supply, has declined by 30-38.8% in Bangladesh from 2010 to 2020. Incorporating organic manure into soil increases organic carbon (OC), nitrogen (N), and crop yield by improving soil health and boosting microbial activity, which enhances nutrient availability (Rahman *et al.,* 2020). There has been an increasing interest in the use of organic nutrient sources and soil amendments on the point that they are a source of carbon (C) which plays a role in improving soil quality and climate change mitigation (Rayne and Aula, 2020). Organic manure provides essential nutrients, improves soil structure, aeration, root growth, and crop production. It enhances water retention, drainage, and reduces runoff, while biological compounds in manure aid plant growth and disease prevention (Choudhary *et al.,* 2022). Manure balances organic matter and microflora, improving soil's physical, chemical, and biological properties (Mohapatra et al., 2016). Due to application of organic manure, greater microbial load and growth regulators may have increased soil biomass, allowing for the accessibility and absorption of applied and native soil nutrients, resulting in improved crop growth and production (Boraiah *et al.,* 2017).

Applying cowdung (CD) and poultry manure (PM) enhances soil fertility by increasing N, P, K, S, and other nutrients, boosting cation exchange capacity (CEC) and biological activity. Biochar (BC) is a sustainable option to improve soil organic matter, offering high porosity, carbon sequestration, reduced nutrient leaching, and high water-holding capacity (Brtnicky *et al.,* 2021). Biochar is a charcoal-like product generated by pyrolysis in a low-oxygen environment at temperatures between 300 and 1000°C using organic biomass (e.g., agriculture residues, animal manure, and municipal wastes) as feedstock (Diatta *et al.,* 2020). In addition to its primary components (carbon, hydrogen, and oxygen), BC may also contain other nutrients such as N, P, K etc. (Alkharabsheh *et al.,* 2021). As a stable carbon-rich material, biochar promotes plant growth and increases crop yields by enhancing microbial activity as well (Kabir et al., 2023). Organic fertilizers have challenges: slow-release nature delays plant development, incomplete decomposition can harbor harmful microbes, and pathogens from animal manure pose health risks. In hot, humid climates, organic matter decomposes quickly, requiring frequent applications to maintain soil health and crop production.

Combining organic and inorganic fertilizers boosts crop productivity and maintains soil health. Poultry manure improves cabbage yield, soil stability, SPAD value, plant height, and nutrient uptake (Zhang et al., 2022; Wang et al., 2021). This approach enhances soil properties and farm income, sustaining productivity and stable yields. Moreover, compared with other organic manure poultry manure is more congenial to increase the yield. Keeping these facts in view, the present study was undertaken to determine the effect of organic manure and chemical fertilizer based nutrient management on the growth, yield and nutrient uptake of cabbage and soil health.

2. Materials and Methods

2.1 Experimental site

The experiment was conducted at the experimental field of Gazipur Agricultural University (GAU), Gazipur during the period from November 2022 to March 2023. The experimental site was located at 24.036° N latitude and 90.39° E longitude with the elevation of 8.2 meter from sea level. The experimental area has subtropical climate characterized by heavy rainfall during April to September and scanty rainfall during October to March. The soil of the experiment field belongs to the Salna series and has been classified as Shallow Red Brown Terrace Soil under the order Inceptisols, with a pH of around 5.9. It falls under Madhupur Tract (AEZ 28) which is characterized by heavy clays within 50cm from the surface and poor in chemical properties.

2.2 Preparation and characterization of soil and organic materials

Soil samples from a depth of 0-15 cm were collected from the experimental field before the experiment started and from every plot after harvesting of crops. The soil samples thus collected were air dried and ground to pass through a 2-mm sieve and stored in a plastic container for physical and chemical analyses. The soil physico-chemical properties were analyzed following standard methods (Page *et al.,* 1982) and the results are shown in Table 1.

Biochar was made from rice husk through a pyrolysis process at high temperature (400-500°C) in absence of oxygen or insufficient oxygen. A modified biochar preparation stove developed by the Department of Soil Science, GAU was used to prepare the biochar (Rahman *et al.,* 2020). One-month-old (accumulated in a pit and collected after a month) poultry manure and cowdung were procured from local farm. After collection the poultry manure and cowdung were dried to reduce the moisture percentage. Physico-chemical properties of biochar, poultry manure and cowdung are shown in Table 2.

Table 1. Physico-chemical properties and bacterial population in the experimental field

Parameters	Value	Method
Textural class	Silt loam	Hydrometer
Bulk density (gm cm^{-3})	1.38	Core sampler
pH (1:2.5 soil:water)	5.92	Glass electrode pH meter
OC (%)	1.02	Wet oxidation
Total N (%)	0.18	Kjeldahl
Available K (meq 100^{-1} g soil)	0.37	Ammonium acetate extraction
Available P (ppm)	15.3	Bray and Kurtz
Available S (ppm)	17.0	Turbidimetric
Available Zn (ppm)	0.93	Atomic Absorption Spectrophotometry
Available B (ppm)	1.69	Atomic Absorption Spectrophotometry
Bacterial population	3.66×10^6	Agar Plate Media

Table 2. Physico-chemical characteristics of cowdung, poultry manure and biochar

Organic Materials	Moisture (%)	pH	OC (%)	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Zn (%)	B (%)
Cowdung	23.5	7.08	22.9	1.02	0.33	0.25	0.13	1.20	0.35	0.02	0.06
P. manure	37.4	8.22	34.2	1.47	0.63	0.69	0.22	2.10	1.02	0.03	0.07
Biochar	-	7.80	42.0	0.50	0.42	0.53	0.29	0.65	0.55	0.005	0.004

2.3 Experiment setup

The land was prepared for good tilth using a tractor-driven disc plough, rotavator, and harrow. Clods were broken and weeds were removed to prepare experimental plots. The individual plot size was 8m^2 (4m × 2m) with 1m between plots and 0.5m drains. To each plot 1.6 kg cowdung, 1.6 kg poultry manure, and 1.6 g biochar each at 2 t ha^{-1} were applied before transplanting. Full amount of P and S, and half of N and K fertilizers were applied before transplanting as Urea, TSP, MoP, and Gypsum. The remaining N and K were added as ring method at 25 and 50 days after transplanting (DAT) and mixed thoroughly with the moist soil. Application rates of different organic materials and chemical fertilizers are depicted in Table 3.

Table 3. Application of organic manure and fertilizers as per treatment

Treatments	Chemical fertilizers (kg ha^{-1})			
	N	P	K	S
T_0 (Control)	0	0	0	0
T_1 (100% RDF)	201	73	58	20
T_2 (BC + RDF - IPNS)	195	71	47	14.2
T_3 (PM+ RDF - IPNS)	172	60	38	17.6
T_4 (CD+ RDF - IPNS)	181	66	53	17.4

BC = Biochar; PM = Poultry manure; CD = Cowdung; all added at 2 t ha^{-1}, IPNS = Integrated plant nutrition system

The experiment was laid out in a randomized complete block design with three replications. The treatments were randomly assigned to different plots of each block. The treatments under the experiment were: T_0 = Control; T_1 = 100% Recommended doses of fertilizers (RDF); T_2 = Biochar (BC) @ 2 t ha^{-1} + RDF (IPNS based); T_3 = Poultry manure (PM) @ 2 t ha^{-1} + RDF (IPNS based); T_4 = Cowdung (CD) @ 2 t ha^{-1} + RDF (IPNS based). The BARI Cabbage-1 variety was used as the test crop in this experiment. The cabbage seeds were sown on 01 November 2022, in a prepared seedbed. After nine days, seedlings with 3-4 leaves were transferred into poly bags containing a potting mix of soil, compost, and sand in a 3:1:1 ratio. Healthy cabbage seedlings were transplanted on 25^{th} of November 2022 and at maturity was harvested on 2^{nd} of March 2023. All the intercultural operations such as gap filling, weeding, irrigation, and insect and disease management were accomplished as and when necessary. Randomly five plants were tagged for data collection. Plant growth and yield contributing data such as plant height, SPAD (soil plant analysis development) value, number of unfolded leaves, head circumferences, head height, total weight of cabbage $plant^{-1}$, marketable weight of cabbage $plant^{-1}$, total yield of cabbage and marketable yield of cabbage were recorded.

2.4 Nutrient analysis of cabbage

Fresh plant samples were collected from the selected plants then washed, sun-dried and oven-dried at 65^0Cfor 72 hours and nutrient content was analyzed in the laboratory using standard methods. Fresh plants were collected. The dry samples were ground, sieved through a 10-mesh sieve, and stored in air-tied bags until chemical analysis.

2.5 Statistical analysis

The data were statistically analyzed by using Statistix 10.0 software to find out the significance of variation between treatments. The differences between the treatment means were judged by least significance difference (LSD) Test at 5% level of probability.

3. Results and Discussion

3.1 Effects of manure and fertilizers on the growth and yield of cabbage

The results are presented in Table 4. Significantly ($p<0.05$) the highest plant height (35.7 cm), head height (14.6 cm), total yield (53.8 t ha^{-1}) and marketable yield (51.3 t ha^{-1}) were recorded in T_3 treatment where 2 t ha^{-1} poultry manure was applied along with chemical fertilizers and the lowest results showing 22.0 cm, 8.0 , 20.5 t ha^{-1} and 18.3 t ha^{-1}, respectively. The SPAD values of cabbage leaves at both vegetative and harvesting stages were significantly varied with different treatments (Table 4). Significantly ($p<0.05$) the highest SPAD value (82.4) was obtained from T_3 treatment and it was statistically identical with T_4 (80.5) and T_2 (80.0) treatments and the lowest SPAD value was noted for T_0 (75.3) treatment. Similarly at the harvesting stage, the maximum SPAD value of cabbage leaves was observed in T_3 treatment (75.1) and it was statistically different from all other treatments except T_4

treatment (73.1); T_0 gave the lowest value (56.7) SPAD value. There was significant variation in the number of unfolded leaves plant^{-1} due to application of manure and fertilizers (Table 4). The highest number of unfolded leaves (15.7) was observed in T_0 treatment and the lowest in T_3 treatment (10.0.). It was also observed that the significantly highest cabbage weight (2.25 kg plant^{-1}) and marketable weight (2.15 kg plant^{-1}) were noted in T_3 treatment which was statistically similar with the T_4 treatment. On the contrary, the lowest cabbage weight (1.05 kg plant^{-1}) and marketable weight (0.96 kg plant^{-1}) were found in T_0 treatment.

Table 4. Effects of manure and fertilizers on the growth and yield of cabbage

Treatments	Plant height (cm)	SPADS value		No. of unfolded leaves	Head height (cm)	Total wt. (kg plant^{-1})	Marketable weight (kg plant^{-1})	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})
		Vegetative	Harvesting						
T_0	22.0	75.3	56.7	15.7	8.0	1.05	0.96	20.5	18.3
T_1	30.7	79.0	70.0	11.7	10.2	1.91	1.81	30.0	28.0
T_2	31.6	80.0	70.0	12.7	11.8	2.07	1.97	42.5	39.3
T_3	35.6	82.4	75.1	7.3	14.6	2.25	2.15	53.8	51.3
T_4	32.7	80.5	73.1	10.0	12.5	2.16	2.05	48.5	45.4
$LSD_{0.05}$	*0.3*	*4.3*	*3.3*	*3.2*	*0.7*	*0.13*	*0.14*	*0.9*	*0.9*
CV (%)	*0.60*	*2.86*	*2.55*	*15.02*	*3.03*	*3.67*	*4.14*	*1.28*	*1.32*

T_0= Control, T_1= 100% RDF, T_2 = Biochar+ RDF(IPNS), T_3= Poultry manure + RDF (IPNS), T_4= Cowdung + RDF (IPNS); all organics added at 2 t ha^{-1}.

Similar reports are available where growth and yield of cabbage increased significantly after adding poultry manure (Khanam *et al.,* 2022; Asomah *et al.,* 2021; Dahal *et al.,* 2021; Hussain *et al.,* 2020). Poultry manure is an organic fertilizer having higher nutrient contents such as N, P and K compared to other biochar and cowdung (Table 2). It is assumed that application of poultry manure improved soil water holding capacity, porosity, aggregation, bulk density, microbial activity and provided plant growth-promoting substances (Rayne and Aula, 2020) which had significantly increased cabbage growth and yield in treatment T_3. Increased SPAD value in T_3 treatment (Table 4) also contributed to the higher cabbage growth and yield in T_3 treatment as higher SPAD value indicates higher photosynthesis. Also, the study indicated that the SPAD value was higher at the vegetative stage of cabbage growth than at harvest, likely due to decreased photosynthetic capacity as the cabbage matured. As for yield and yield contributing characters of cabbage such as head circumferences, head height, total weight, marketable weight, total yield and marketable yield, higher plant growth and SPAD value and lower number of unfolded leaves (Table 4) could be attributed to the reason of higher yield of cabbage in poultry manure treated plots.

3.2 Effects of manure and fertilizers on nutrient content of cabbage

The concentration of different nutrients (N, P, K, S, Zn and B) of cabbage varied with the manure-fertilizer treatments. Treatment T_3 recorded the highest N concentration (1.98%), P (0.36%), K (1.43%), S (0.17%), Zn (39 ppm) and B (20 ppm) in cabbage while the lowest plant N, P, K, S, Zn and B concentrations showing 0.92%, 0.17%, 0.9%, 0.05%, 19 ppm and 10 ppm, respectively (Table 5). The findings of Zhang *et al.* (2022) and Kim *et al.* (2022) are in align with our study. The higher nutrient content of cabbage could be primarily attributed to the higher nutrient content of poultry manure (Table 2). In addition, poultry manure contains growth-regulating hormones like auxins, gibberellins, and cytokinins from diverse soil microorganisms (Zhang *et al.,* 2022) could enhance nutrient uptake by cabbage.

Table 5. Nutrient concentration of cabbage under different treatments

Treatments	N (%)	P (%)	K (%)	S (%)	Zn (ppm)	B (ppm)
T_0	0.92	0.167	0.90	0.050	19	10
T_1	1.48	0.237	1.08	0.120	26	14
T_2	1.75	0.263	1.30	0.130	31	18
T_3	1.98	0.360	1.43	0.170	39	20
T_4	1.79	0.293	1.31	0.150	34	17
$LSD_{0.05}$	*0.12*	*0.024*	*0.05*	*0.018*	*2*	*3*
CV%	*3.89*	*4.84*	*2.31*	*7.65*	*3.91*	*10.01*

T_0= Control, T_1= 100% RDF, T_2 = Biochar+ RDF(IPNS), T_3= Poultry manure + RDF (IPNS), T_4= Cowdung + RDF (IPNS); all organics added at 2 t ha^{-1}.

3.3 Effects of manure and fertilizers on post-harvest soil properties

Addition of organic manure and chemical fertilizers significantly influenced the post-harvest soil properties (Table 6). For bulk density (BD) of soil, T_3 treatment gave the lowest bulk density (1.35 g cc^{-1}) followed by T_2 (1.42 g cc^{-1}) and T_4 (1.47 g cc^{-1}) and then higher and statistically similar BD was noted for T_1 (1.56 g cc^{-1}) and T_0. Rahman *et al.* (2020) reported K level in organic material treated soils as compared to control treatment. The main reason behind lower soil BD in manure treated plots is lower BD of organic materials which when mixed with bulk soil of the plots had lowered its BD. In consideration of soil pH, application of biochar, cowdung and poultry manure significantly increased the pH of post-harvest. Significantly the highest pH was observed in T_3 (pH 6.18) treatment (Table 6) which was significantly different from others treatments. The lowest pH value was found in T_1 (pH = 5.95) treatment. These findings are in agreement with previous study (Rahman et al., 2020). The higher soil pH in poultry manure could be due to the higher content of basic cations such as Ca, Mg & K of poultry manure (Table 2). Significant variation was noticed in case of soil organic carbon (SOC) content of soils as influenced by the application of different organic along with inorganic fertilizers (Table 6). Among the treatments, T_2 treatment showed the highest organic carbon content (1.32%) followed by T_3 (1.26%) and T_4 (1.18%) treatment. On the other hand, the lowest organic carbon content (1.09%) was observed in T_0 treatment. Biochar is a carbon rich material obtained by biomass pyrolysis which result in a high soil organic carbon in soil thereby improving soil physic-chemical and biological properties (Kavitha *et al.,* 2018).

Generally, the soil nutrient content increases in post-harvest soil as compared to the initial soil. The highest total N (0.24%), available P (32.8 ppm), K (0.40 me%), S (28.2 ppm), Zn (1.02 ppm) and B (0.155 ppm) was found in T_3 treatment. Whereas, the lowest total N (0.19%), P (16.3 ppm), K (0.376 me%), S (17.6 ppm), Zn (0.94 ppm) and B (0.06 ppm) was found in T_0 treatment. Nutrient accumulation occurred in post-harvest soil due to mineralization of organic material, especially poultry manure where nutrient content was higher than that of biochar and cowdung (Table 2) Nevertheless, some nutrients in biochar was higher in amount compared to poultry manure and cowdung, due to the slow mineralization of biochar, it did not contribute to increase soil nutrient content.

Concerning bacterial population, the maximum counted bacterial colony (16.88×10^6 cfu g^{-1} soil) was observed with the T_3 treated plot followed by T_4 (11×10^6cfu g^{-1} soil) treatment. While, the lowest bacterial population (3.89×10^6cfu g^{-1} soil) was counted in the T_0 treated plots. Addition of organic materials provides organic matter, N, P, K and others. It also serves as a food source for soil bacteria. Meena *et al.,* (2019) found that supplementation of organic matter such as poultry manure was the best to lead higher counts of bacteria.

In summary, utilizing PM as a soil amendment enriches soil health and boosts cabbage yield. Its high nutrient content and ability to improve soil properties make it beneficial for higher marketable yields of cabbage. Although biochar is a stable source of carbon, but has less nutrient content compared to poultry manure. It is also possible, due to adsorption of nutrient ions (cations and anions) on the surface of biochar, cabbage might get less nutrients as compared to poultry manure treatment. Hence, the steady nutrient release from PM aligns with the steady nutrient uptake of cabbage, minimizing nutrient leaching and wastage appeared it as sustainable approach to improve cabbage production and soil health.

Table 6. Some physical, chemical and biological properties of post-harvest soils

Treatments	BD (g cc^{-1})	pH	OC (%)	N (%)	K (me%)	P (ppm)	S (ppm)	Zn (ppm)	B (ppm)	Bact. pop. (cfu g^{-1} soil)
T_0	1.54	6.01	1.09	0.19	0.376	16.3	17.6	0.94	0.061	3.89×10^6
T_1	1.56	5.95	1.11	0.21	0.384	19.5	19.3	0.97	0.082	4.77×10^6
T_2	1.47	6.12	1.32	0.22	0.390	23.0	23.5	0.97	0.115	7.96×10^6
T_3	1.35	6.18	1.16	0.24	0.400	32.8	28.2	1.02	0.155	16.90×10^6
T_4	1.42	6.04	1.18	0.23	0.395	28.3	26.6	0.98	0.131	11.20×10^6
$LSD_{0.05}$	0.03	0.03	0.04	0.03	0.006	3.1	1.5	0.03	0.004	1.27×10^6
CV (%)	0.91	0.29	1.81	6.79	0.78	6.75	3.42	1.49	1.96	16.9

T_0= Control, T_1= 100% RDF, T_2 = Biochar+ RDF(IPNS), T_3= Poultry manure + RDF (IPNS), T_4= Cowdung + RDF (IPNS); all organics added at 2 t ha^{-1}.

4. Conclusions

Application of poultry manure @ 2 t ha^{-1} along with IPNS based chemical fertilizers had significant positive effect on yield, yield contributing characters and nutrient content of cabbage as compared to cowdung and biochar used on IPNS basis or sole application of fertilizers. Addition of poultry manure supplemented fertilizers also improved soil properties including soil organic carbon, nutrients (N, P, S & others) and bacterial population.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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