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Enhancing the productivity of bush snap beans (*Phaseolus vulgaris* L.) using organic fertilizer amendments

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Abstract Result showed that the sole application of 10 tons ha^{-1} of processed chicken manure provided an immediate and significant yield enhancement in bush snap beans. Its combination with biochar and wood vinegar may provide an additional improvement in yield but may require a longer period of application. The addition of wood vinegar has a significant effect in controlling bean rust disease. The use of "*Bokod*" variety of bush snap bean produced a highly significant pod yield. For long-term and sustainable organic snap bean production, a combined application of 10 tons ha^{-1} of processed chicken manure, 10 tons ha^{-1} of biochar, and 5 ml L^{-1} water of wood vinegar is used to optimize yield.

Keywords: Biochar, Processed chicken manure, Wood vinegar

Introduction

Organic agriculture is a sustainable development option in addition to the conventional farming system. Republic Act 10068 promotes and supports the development and implementation of organic agriculture in the Philippines towards the enrichment of soil fertility, increase in farm productivity, and reduce pollution and destruction of natural resources (Philippine Laws and Jurisprudence Databank, 2010). Organic agriculture is aligned with the sustainable development goals of zero hunger, good health and well-being, climate action, and life on land. It encourages farmers to produce their food, sustain agricultural productivity while improving soil quality, increase income, and protect their health, including consumers' health through avoidance of chemical inputs in farming (Setboonsarng and Gregorio, 2017).

Snap bean (*Phaseolus vulgaris* L.) is an important vegetable crop cultivated in the Philippines. It is a good source of protein, carbohydrates, essential vitamins and minerals, β-carotene, and fiber (Myers *et al*., 2019).

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Green pods can be eaten as a side dish, or mixed in a stew with fish, meat, and other vegetables in different variations. Snap bean production in the year 2020 accounted for 13,420.83 metric tons cultivated in an area of 2,974.44 hectares. Cordillera Administrative Region remains the major producer of snap beans, it was able to contribute about 50% of the national snap bean production for the past five years (Philippine Statistic Authority, 2020). Farmers in this region considered it a cash crop, an additional source of income. Snap bean is among the vegetable crops where the organic production system is open for the transition from conventional farming.

At the heart of an organic vegetable production system is the application of organic fertilizers. This input supplies plants with nutrients needed for growth and development, improves the organic matter content of the soil thereby rebuilding soil fertility, and ensures the protection of environmental and natural resources. Among the organic inputs that can be integrated into the system are rice hull biochar, processed chicken manure, and wood vinegar. Rice hull biochar is a product of the pyrolysis of biomass in the absence of oxygen. It has the potential to sequester carbon into more stable organic carbon (Ghorbani *et al*., 2019; Liu *et al*., 2017; Ondo *et al*., 2017). Biochar is popularly used as a soil conditioner and a main ingredient in the production of organic fertilizer (Sarong and Orge, 2015). It has stability against decomposition, can stay in the soil for a long time, and can retain nutrients. Amendments with biochar improve soil quality by increasing soil pH, moisture holding capacity, cation exchange capacity, and microbial flora (Mensah and Frimpong, 2018). It also has an additive effect when combined with chicken manure for the efficient release of available nutrients (Agbede and Oyewumi, 2022).

Processed chicken manure (PCM) is a product of fully decomposed chicken manure with the aid of effective microorganisms. It contains macro and micronutrients and is high in organic matter which is essential for crop production. The application of processed chicken manure offers a great advantage in improving and sustaining crop yields (Adekiya *et al*., 2019; Agbede *et al*., 2017).

On the other hand, wood vinegar commonly known as "*mokusaku*" is an aqueous liquid produced from the pyrolysis of lignocellulose waste and biomass. It is used as a soil enhancer, compost activator, pest repellent, fungicide, and fertigation material (Shan *et al*., 2018; Theapparat, 2018). Wood vinegar can be applied as a soil drench or foliar spray and can be co-applied with biochar to efficiently stimulate seedling growth (Luo *et al*., 2019), improve nutritional quality, and increase soil nutrient availability (Zhang *et al*., 2020a, b).

Previous studies have indicated the beneficial combined effects of biochar and processed chicken manure, and also biochar and wood vinegar (Agbede and

Oyewumi, 2022; Liu *et al*., 2021a, b; Luo *et al*., 2019; Zhang *et al*., 2020a, b). However, combining processed chicken manure with biochar and wood vinegar has yet to be investigated. The study explored the influence of processed chicken manure, and in combination with different levels of biochar and wood vinegar on the productivity of bush snap beans.

Materials and methods

The study was carried out from July-October 2022 at Lagawe, Ifugao, Philippines. The experiment was laid out in a split-plot randomized complete block design (RCBD) with three replications. The experimental area measuring 225 square meters was divided into three equal blocks representing the replications. Each block was further subdivided into two plots, representing the main plots and was further subdivided into seven equal subplots measuring 1 m x 4 m. The distance between blocks and main plots were 50 cm and 30.48 cm, respectively. From these 42 sub-plots, the different combinations were randomly assigned.

NSIC BSnBn 2 "*Bokod*", and NSIC 2009 BSnBn 1 "*Sablan*", both varieties of bush snap beans were designated as main plots, while the sub-plots consisted of organic fertilizer amendments included: T1: C_5 (organic farmer's practice) T2: PCM_{10}, T3: $PCM_{10} + B_{10}$, T4: $PCM_{10} + B_{10} + WV_5$, T5: $PCM_{10} + B_{10} + WV_{10}$, T6: $PCM_{10} + B_{20} + WV_5$, T7: $PCM_{10} + B_{20} + WV_{10}$. Legend: C_5: Compost at 5 tons ha^{-1}; PCM_{10}: Processed chicken manure at 10 tons ha^{-1}; B_{10}: Biochar at 10 tons ha^{-1}; B_{20}: Biochar at 20 tons ha^{-1}; WV_5: Wood Vinegar at 5 ml L^{-1} of water; WV_{10}: Wood vinegar at 10 ml L^{-1} of water.

The biochar and compost were procured at Camat Organic Farm in Lamut, Ifugao. The processed chicken manure with nutrient analysis was sold commercially by Nadine's Marketing. It was procured at Malabing Valley Cooperative in Solano, Nueva Vizcaya. The wood vinegar was procured at the Municipal Agriculture Office of Tublay, Benguet. The bush snap bean seeds were procured at the Northern Philippine Root Crops Research and Training Center in Benguet State University.

A soil sample was collected randomly from the experimental site at 0-20 cm depth before applying organic fertilizer amendments. Then, one week after the application of organic fertilizer amendments, a composite of one kilogram soil sample from each treatment was collected before planting of bush snap bean seeds. The soil samples were air-dried, pulverized, and cleaned from roots and other foreign objects. The soil samples including the biochar and wood vinegar were sent to the Regional Soils Laboratory, Department of Agriculture, Region 03, San Fernando, Pampanga for analyses. The soil was analyzed for soil pH, organic matter, nitrogen, available phosphorus, and exchangeable potassium

(Table 2). The biochar and wood vinegar were analyzed for pH, organic carbon, organic matter, total nitrogen, total phosphorus, and total potassium content. The chemical analyses of the organic fertilizer amendments are shown in Table 1.

Table 1. Analyses of organic fertilizer amendments

Parameters	*Organic Fertilizer Amendments*		
	Processed Chicken Manure	Biochar	Wood Vinegar
Total Nitrogen (N), %	1.10	0.59	0.11
Total Phosphorus (P_2O_5), %	8.30	0.33	<0.01
Total Potassium (K_2O), %	1.70	0.37	<0.01
pH	-	7.84	4.19
Organic Matter (OM), %	22.20	9.04	3.38
Organic Carbon (OC), %	-	5.24	1.96
Moisture Content (MC),%	25.10	-	-

The experimental area was cleared of weeds, plots were constructed with the use of a hoe. One week after digging, the plots were dug to pulverize the soil, then the plots were raised to 20 cm above the ground level. The processed chicken manure and biochar were mixed per treatment. The compost combined processed chicken manure and biochar were incorporated per plot following the assigned treatments: Treatment 1 was 2 kgs; Treatment 2 was 4 kgs; Treatment 3, Treatment 4, and Treatment 5 were 8 kgs; Treatment 6 and 7 were 12 kgs. The application of wood vinegar started after the incorporation of processed chicken manure and biochar in the soil. A dilution of wood vinegar at 5 ml L^{-1} of water for Treatment 4 and Treatment 6-, and 10-ml L^{-1} of water for Treatment 5 and Treatment 7 were drenched at their respective plots at a volume of dilution of 4 liters per treatment. The succeeding application of wood vinegar dilution as foliar spray started two weeks after planting at 7 days interval. The volume of wood vinegar dilution applied per treatment were 1st and 2nd spraying: 2 liters; 3rd and 4th spraying: 2.6 liters; 5th to 7th spraying: 3.2 liters per plot. The application was done early in the morning.

One week after the application of organic fertilizer amendments, two seeds of bush snap beans were planted per hill at a depth of 2.5 cm in a double-row plot at a distance of 25 cm x 30 cm between hills and rows. It was planted in the morning. Watering was done in the morning using a sprinkler. Subsequent watering was done when there was no sufficient rainfall to irrigate the plants. Hilling up was done two weeks after planting, and weeding was performed to control the weeds. A one-meter height trellis was set up per hill to support the bush snap beans and prevent them from lodging. For pest management, infected leaves were pruned, and neem oil was blanketly applied to all the plants to control fungal disease observed in the area. Harvesting of green pods started 47 days after planting. Pods that were marketable in size and seeds partially developed were harvested using a pair of scissors. Harvesting was done in the morning every three days and ended in the fourth priming. The data gathered were plant height, stem diameter, percentage of survival, pod length, pod diameter, number of pods per plant, weight of individual pod, pod yield per plot, pod yield per hectare, pod borer, and bean rust incidence. Soil analyses before and after application of organic fertilizer amendments were also gathered. Agrometeorological data were monitored in the area throughout the duration of the study. Data were analyzed using the Analysis of Variance (ANOVA) for Split plot design in Randomized Complete Block Design (RCBD). The significant differences among the treatment means were tested using Duncan's Multiple Range Test (DMRT) at a 0.05 level of probability.

Results

Agrometeorological data during the conduct of the study

The temperature, relative humidity, and rainfall data were obtained from the World Weather Online for Lagawe, Ifugao (2022). The average weekly temperature recorded from July to 1st week of September 2022 ranged from 20.86°C to 24.14°C. The highest temperature was noted on the 4th week of July and the lowest temperature was noted on the 1st week of August. The average relative humidity incurred during the study ranged from 78.86% to 96%. The highest relative humidity was noted on the 3rd week of August and the lowest relative humidity was noted on the 3rd week of July. The weekly sum of rainfall ranged from 6.30 mm to 37.30 mm where the highest rainfall was noted on the 2nd week of August and the lowest rainfall was noted on the 3rd week of July (Figure 1).

Soil analyses before and after application of organic fertilizer amendments

The result of the soil analyses before the conduct of the study showed that the soil was slightly alkaline having a pH level of 7.81; high organic matter content of 5.49%; nitrogen content of 0.24%; low content of phosphorus of 22.50 ppm, and low level of exchangeable potassium of 0.92 cmol kg^{-1}. The analyses of the soil after the application of organic fertilizer amendments showed that the different treatments had obtained a soil pH ranging from 7.53-7.87 indicating a slightly alkaline pH value; an organic matter content of 5.59%-5.83% implicating a high content of organic matter; a nitrogen content ranging from 0.22% to 0.36%; a high phosphorus content of 47.03 ppm-154.84 ppm; and a low level to moderate level of exchangeable potassium of 1.58 cmol kg^{-1} to 2.34 cmol kg^{-1}.

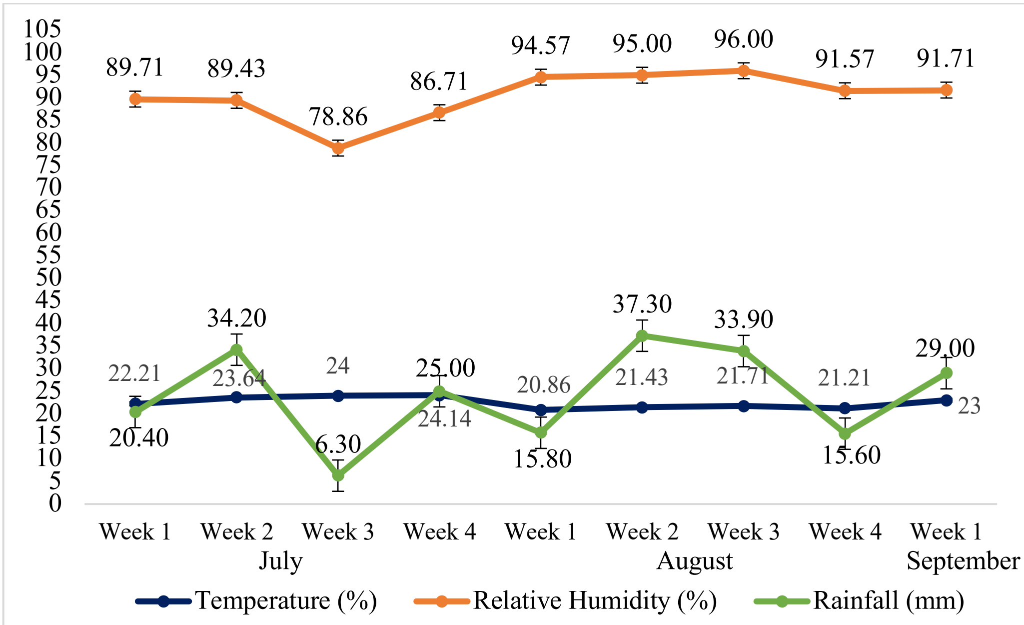

Figure 1. Average weekly temperature (°C), average weekly relative humidity (%), and the weekly amount of rainfall (mm) incurred in the study from July 4-September 4, 2022

Table 2. Soil Analyses before and after application of organic fertilizer amendments

Treatments	pH	Organic Matter (OM) %	Total Nitrogen (N)%	Available Phosphorus (P), ppm	Exchangeable Potassium (K), cmol kg^{-1}
Before the application of organic fertilizer amendments	7.81	5.49	0.24	22.50	0.92
After the application of organic fertilizer amendments					
T1- C_5-Organic Farmer's practice	7.75	5.70	0.22	47.03	1.58
T2-PCM_{10}	7.65	5.67	0.30	144.79	2.34
T3-PCM_{10} + B_{10}	7.71	5.59	0.28	154.84	2.23
T4-PCM_{10} + B_{10} + WV_5	7.71	5.70	0.29	139.42	3.02
T5-PCM_{10} + B_{10} + WV_{10}	7.87	5.70	0.32	152.56	2.17
T6- PCM_{10} + B_{20} + WV_5	7.74	5.83	0.32	152.56	2.32
T7- PCM_{10} + B_{20} + WV_{10}	7.53	5.60	0.36	143.62	2.42

Plant height

The study showed that the use of processed chicken manure alone and in combination with biochar and wood vinegar at different levels had a highly significant influence on the height of bush snap bean varieties as compared to organic farmer's practice. Treatment 7 (PCM_{10} + B_{20} + WV_{10}) provided the highest plant height of 60.54 cm but was statistically comparable with Treatment 4, Treatment 6, Treatment 5, Treatment 2, and Treatment 3. The lowest plant height was observed in Treatment 1 (C_5) of 51.51 cm. In terms of variety, a significant difference was observed in plant height (cm) wherein the "*Bokod*" variety was significantly taller (58.23 cm) than the "*Sablan*" variety (56.58 cm) as presented in Table 3.

Stem diameter

The result showed a highly significant effect on the stem diameter of bush snap beans as influenced by organic fertilizer amendments. Treatments 2 to Treatment 7 applied with processed chicken manure alone and in combination with different levels of biochar and wood vinegar had a comparable stem diameter ranging from 4.23 mm to 4.61 mm as compared to compost of 3.78 mm (Table 3).

Percentage of survival

The organic fertilizer amendments had no significant influence on the percentage of survival of bush snap bean plants. The survival rate of the bush snap beans applied with different treatments ranged from 93.23% to 95.83% (Table 3).

Pod length

The application of organic fertilizer amendments showed a highly significant influenced on the pod length of bush snap beans. Treatment 6 (PCM_{10} + B_{20} + WV_5) produced the highest pod length of 12.10 cm but was statistically comparable with Treatment 4, Treatment 7, Treatment 2, and Treatment 5. The shortest pod length was observed in Treatment 1 (C_5) of 10.87 cm.

Table 3. Summary data on the growth parameters of bush snap bean varieties as influenced by organic fertilizer amendments

Treatment	Plant height (cm)	Stem diameter (mm)	Percentage of survival (%)
Factor A (Varieties)			
V1-"*Bokod*" variety	58.23[a]	4.39	96.21
V2-"*Sablan*" variety	56.58[b]	4.3	93.16
F-Test	*	ns	ns
C.V (%)	1.59	5.43	5.07
Factor B (Fertilizers)			
T1- C_5(Organic Farmer's practice)	51.51[b]	3.78[b]	93.75
T2- PCM_{10}	57.50[a]	4.41[a]	95.31
T3- $PCM_{10} + B_{10}$	56.09[a]	4.23[a]	93.23
T4- $PCM_{10} + B_{10} + WV_5$	59.11[a]	4.69[a]	95.57
T5-$PCM_{10} + B_{10} + WV_{10}$	58.20[a]	4.23[a]	94.27
T6- $PCM_{10} + B_{20} + WV_5$	58.90[a]	4.48[a]	95.83
T7- $PCM_{10} + B_{20} + WV_{10}$	60.54[a]	4.61[a]	94.79
F-Test	**	**	ns
C.V (%)	4.36	5.01	1.87
Interaction effect			
A x B	1.86 ns	1.05 ns	0.54 ns

ns- not significant, *- significant, **- highly significant at 5% level of significance

Pod diameter

Statistical analysis revealed a not significant effect on pod diameter of bush snap beans as influenced by organic fertilizer amendments. The pod diameter obtained from the different treatments ranged from 7.66 mm to 8.05 mm. In terms of variety, highly significant difference was observed in pod diameter wherein "*Bokod*" variety out-sized the "*Sablan*" variety (Table 4).

Number of pods per plant

Statistical analysis was not significantly different in the number of pods per plant as influenced by organic fertilizer amendments and varieties. The number of pods per plant ranged from 11.42 to 18.46 (Table 4).

Table 4. Summary data on the yield and yield components parameters of bush snap bean varieties as influenced by organic fertilizer amendments

Treatment	Pod length (cm)	Pod diameter (mm)	No. of pods per plant	Weight of Individual pod (g)	Pod yield per plot (kg)	Pod yield per hectare (t/ha)
Factor A (Varieties)						
V1-"*Bokod*" variety	11.86	8.27[a]	18.1	2.99	2.90[a]	7.24[a]
V2-"*Sablan*" variety	11.21	7.41[b]	15.98	2.61	2.01[b]	5.03[b]
F-Test	ns	**	ns	ns	**	**
C.V. (%)	11.78	2.94	11.88	12.75	8.37	8.37
Factor B (Fertilizers)						
T1- C_5 (Organic Farmer's practice)	10.87[c]	7.68	15.67	2.49[c]	1.91[b]	4.77[b]
T2- PCM_{10}	11.56[abc]	7.66	16.46	2.89[abc]	2.47[ab]	6.18[ab]
T3- $PCM_{10} + B_{10}$	11.35[bc]	7.82	11.42	2.59[bc]	2.43[ab]	6.07[ab]
T4- $PCM_{10} + B_{10} + WV_5$	11.73[ab]	8.03	18.46	3.02[ab]	2.95[a]	7.37[a]
T5-$PCM_{10} + B_{10} + WV_{10}$	11.53[abc]	7.73	15.69	2.62[abc]	2.04[b]	5.11[b]
T6- $PCM_{10} + B_{20} + WV_5$	12.10[a]	8.05	17.57	3.05[a]	2.82[a]	7.06[a]
T7- $PCM_{10} + B_{20} + WV_{10}$	11.61[ab]	7.88	17.01	2.95[ab]	2.56[ab]	6.40[ab]
F-Test	**	ns	ns	**	**	**
C.V. (%)	3.54	3.38	11.66	9.25	16.04	16.04
Interaction effect						
A x B	1.12ns	0.70ns	1.11ns	1.68ns	0.63ns	0.42ns

ns- not significant, *- significant, **- highly significant at 5% level of significance

Weight of individual pod

The result showed a highly significant effect of organic fertilizer amendments on the weight of individual pods. The bush snap beans applied with Treatment 6 obtained the highest weight of individual pods of 3.05 g, but were comparable with Treatment 4, Treatment 7, Treatment 2, and Treatment 5. The lowest weight of individual pod was produced in Treatment 1 of 2.49 g. (Table 4).

Pod yield per plot and pod yield per hectare

A highly significant effect of organic fertilizer amendments on pod yield per plot and pod yield per hectare were observed. Treatment 4 and Treatment 6 produced the highest pod yield per plot of 2.92 kg and 2.82 kg, and pod yield per hectare of 7.37 tons and 7.06 tons, respectively. These mean values were indicated to be comparable with each other and with pod yield per plot and pod yield per hectare obtained in Treatment 7, Treatment 2, and Treatment 3, but significantly different from Treatment 1 and Treatment 5. In terms of variety, statistical analysis revealed a highly significant difference in pod yield of the two bush snap bean varieties. A mean comparison showed that the "*Bokod*" variety outweighed the "*Sablan*" variety (Table 4).

Pod borer occurrence

The result of the study showed that organic fertilizer amendments did not influence pod borer incidence in bush snap beans. The treatments showed an average mean ranging from 1.67 to 2.00 indicating a mild resistance to pod borer (Table 5).

Table 5. Summary data on the pest and disease occurrences of bush snap bean varieties incurred during the conduct of the study

Treatment	Pod borer Occurrence	Bean rust Occurrence
Factor A (Varieties)		
V1-"*Bokod*" variety	1.62	1.67
V2-"*Sablan*" variety	1.90	2.33
F-Test	ns	ns
C.V. (%)	30.34	46.92
Factor B (Fertilizers)		
T1- C_5 (Farmer's practice)	2.00	2.17[a]
T2- PCM_{10}	1.83	2.00[ab]
T3- $PCM_{10} + B_{10}$	1.83	2.33[a]
T4- $PCM_{10} + B_{10} + WV_5$	1.50	1.67[b]
T5-$PCM_{10} + B_{10} + WV_{10}$	1.83	2.17[a]
T6- $PCM_{10} + B_{20} + WV_5$	1.67	1.67[b]
T7- $PCM_{10} + B_{20} + WV_{10}$	1.67	2.00[ab]
F-Test	ns	*
C.V. (%)	17.52	19.16
Interaction Effect		
A x B	0.82ns	1.14ns

Bean rust occurrence

A significant effect of organic fertilizer amendments on bean rust incidence was noted. The bush snap beans applied with Treatment 4 ($PCM_{10} + B_{10} + WV_5$) and Treatment 6 ($PCM_{10} + B_{20} + WV_5$) were comparable obtaining the lowest bean rust incidence of 1.67. These were followed by Treatment 7 and Treatment 2 indicating a bean rust incidence of 2.00 which were statistically similar to each other. The highest bean rust incidence was obtained from Treatment 3 (2.33), Treatment 5, and Treatment 1 (2.17), respectively (Table 5).

Discussion

Based on the agrometeorological data observed, the temperature incurred in the study which ranged from 20.86°C to 24.14°C met the optimum requirement for bush snap bean production of 18°C to 29°C (Department of Agriculture-Bureau of Plant Industry, 2021). Obtaining an optimum temperature requirement will enhance the growth and development of plants such that the vegetative development increases as temperature rises to an optimum level. In terms of relative humidity and rainfall, higher relative humidity (91.57% to 96%), and highest rainfall (37.30 mm) occurred during the pod development stage of bush snap beans. This weather condition favored the development of fungal disease in the leaves of bush snap beans. According to Tamil Nadu Agricultural University (2021), high relative humidity causes a high incidence of insect pests and diseases in plants as it favors the fungal germination in plant leaves. Likewise, too much rainfall coupled with high levels of humidity resulted in more plant disease (He, 2016).

The application of organic fertilizer amendments particularly the processed chicken manure combined with biochar to the alkaline soil had a slight decrease in soil pH value (0.28). Biochar when applied to alkaline soil decreased soil pH (Liu and Zhang, 2012; Mostafa *et al.*, 2019). The decrease in soil pH may be caused by the oxidation of biochar and organic matter. The soil organic matter and the nitrogen element increased with the application of processed chicken manure and biochar (Widowati *et al.*, 2020). The phosphorus content of the soil tremendously increased especially in the treatments applied with processed chicken manure, and in combined with biochar. The result indicated that most of the treatments exceeded the optimum level of phosphorus of 30 to 50 ppm for agronomic crops (Beegle and Durst, 2017). The abundance of phosphorus was associated with the high phosphorus content (8.30%) found in processed chicken manure. For exchangeable potassium, all the treatments applied with processed chicken manure, and in combination with biochar increased and obtained a moderate level of exchangeable potassium ranging from 2-5 cmol kg^{-1} (University of New South Wales, 2007).

The use of processed chicken manure alone significantly enhanced the growth and yield of bush snap beans. Benefits from the addition of biochar although not conclusively shown in the result of one season evaluation may imply the requirement for long-term application. According to Adekiya *et al*. (2019) and Sistani *et al*. (2019), the benefits of biochar could not be achieved immediately in its first year of application in crop production but could be noticed in its second year of production making it useful in the llong-termproduction. Biochar is a slow-release fertilizer as it delays the availability of nutrients for uptake by the plants. It prolongs the availability of nutrients, making fertilizer more efficient, and avoiding nutrient loss and leaching into the environment. On the other hand, wood vinegar necessitates its use at low concentrations for plant growth and development. Wood vinegar co-applied with combined processed chicken manure and biochar at the rate of 5 ml L^{-1} of water through foliar spraying attributed to the increase in pod yield of bush snap beans. The study confirmed the observation of Ofoe *et al*. (2022) and Yuan *et al*. (2022) that wood vinegar co-applied with biochar at low concentrations led to higher yield. The enhancement in yield could be attributed to the enhanced nutrient availability and the slow-released active acid in wood vinegar adsorbed by biochar. Furthermore, the phenolic content of wood vinegar exhibited antifungal activity, at low concentration was also effective in controlling bean rust that could influence pod yield (Oramahi *et al*., 2018; Shan *et al*., 2018; Sistani *et al*., 2019). In terms of varietal performance, "*Bokod*" variety performed better than "*Sablan*" variety and produced a high significant yield which in confirmed with the observation of Tandang (2017). The result could be attributed with the genetic characteristic of the two varieties that influenced productivity. The study concluded that the application of organic fertilizer amendments influenced the growth and yield performances of bush snap beans. The used of processed chicken manure alone provided an immediate and significant yield enhancement of bush snap bean plants. For long-term and sustainable snap bean production: the application of 10 tons ha^{-1} of processed chicken manure, combined with 10 tons ha^{-1} of biochar, and wood vinegar at 5 ml L^{-1} of water is recommended to optimize the effect and benefits of biochar on yield, and the efficacy of wood vinegar in controlling fungal disease such as bean rust. Another study may be conducted on the long-term effect of combined applications of processed chicken manure, biochar, and wood vinegar on soil and in different horticultural crops.

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