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Utilization of Livestock Waste as Biochar and Poschar to Increase Soil Organic Matter and Red Chili Yields

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A B S T R A C T

This study examines the impact of biochar and poschar fertilisers derived from livestock manure on red chilli yields and soil organic matter variations. The results demonstrated that the interaction between biochar and poschar substantially affected the fresh chili pod weight per plant and organic matter content. Applying biochar and poschar organic fertilisers derived from animal manure substantially influenced plant height, fresh fruit weight per plant, and soil organic matter. The interaction between cow manure and poschar from poultry manure produced the highest yield of chili fruit weight per plant, or an increase of 323.88% compared to the absence of biochar and poschar. The organic matter content of the soil underwent a significant change, with the highest organic matter content resulting from the interaction between chicken biochar and chicken poschar, which increased by 143,00% compared to the control group.

1. INTRODUCTION

1.1. Research Background

Chili is an important horticultural commodity and has economic value. Chili (*Capsicum annum L.*) is a Solanaceae family member known for its strong aroma, spicy taste, and coloring matter [1]. Chili plants can grow and produce well on agricultural land, rich in nutrients and organic matter. Chili productivity in Indonesia is still low because it is caused by climate change and inappropriate cultivation technology [2]. The main problem in tropical agricultural land is the low content of soil organic matter due to the high rate of weathering of minerals and organic matter, soil erosion caused by soil erodibility, climate erodibility, terrain, and soil cover [3], also intensive nutrient leaching. Hence, fertilization applications become ineffective and efficient. The addition of organic matter must continue to be done to maintain soil fertility because the soil has a function that can recycle nutrients that can degrade chemicals [4]. The low condition of soil organic matter is also caused by the absence of efforts to return organic matter after harvesting so agricultural land is degraded yearly.

The organic matter content is generally less than 10% in the soil. The availability of organic matter will determine soil fertility to support agricultural production. Soil fertility refers to the ability of soil to maintain favorable conditions within its biological, physical, and chemical properties to facilitate long-term plant growth [5]. Soil organic matter is very important, as primary soil grains become a binder in forming stable aggregates, reducing water stress [6, 7]. Soil organic matter, both its stable and transient components, can significantly improve nutrient availability and acquisition by higher plants. Organic matter in the soil also significantly impacts nutrient storage and availability [8]. Soil organic matter consists of simple and complex carbon compounds [9] that are important for maintaining soil fertility by improving the soil's physical, biological, and chemical conditions.

Biochar application to agricultural soils has great potential benefits in waste management, carbon sequestration, greenhouse gas reduction, water and soil remediation, soil fertility, and crop production [10]. Applying organic compost and biochar to the soil can improve soil's physical and chemical properties [11] and crop productivity [12]. Under oxygen-limited conditions, biomass resources such as agricultural residue, food processing waste, solid waste, animal waste, and municipal sludge are thermally decomposed through pyrolysis [13]. The application of compost and biochar generally carries out the return of soil organic matter as a restoration in the soil. The raw materials for making compost and biochar generally come from agricultural waste and livestock manure, which is very abundant, but this waste has not been used properly. Several studies have shown the positive effect of applying 10-15 tons/ha of biochar and compost from livestock manure on increasing soil fertility and chili yields [14, 15].

1.2. Research Objective

This study aims to evaluate the effect of biochar and poschar from various livestock manures on changes in soil organic matter and red chili yield.

2. MATERIALS AND METHODS

2.1. Place, time and research material

This research was conducted on farmers' land in Buduk Village, Mengwi Badung District, Bali. The materials used in this study were red chili seeds of the Pilar F1 variety, biochar, compost, and poschar from cow, goat, and chicken manure.

Biochar is produced from incomplete combustion of livestock manure with simple pyrolysis technology at a temperature of 250-500 °C. Burning 100 kg of dry manure into charcoal takes about 1-2 hours to produce 30-60 kg of biochar charcoal.

The compost used in this study is made from the dominant raw materials: cow, goat, and chicken manure. The compost material comprised 80% livestock manure, 10% husk charcoal, 5% husk ash, 5% Gamal leaves, 2% dolomite. To speed up the composting, all the ingredients were watered evenly with a mixed solution of EM4 and molasses, then covered with a tarpaulin, and harvested after being fermented for 30 days. The results of the laboratory analysis of biochar, compost, and soil before the study are presented in Tables 1 and 2. The soil characteristics, biochar, and compost were analyzed at the Soil Laboratory, Faculty of Agriculture, Udayana University, Denpasar.

Table 1. The characteristics of the soil before research

Analysis type	Soil
pH	6.90
C-org (%)	3.40
N (%)	0.19
P (ppm)	62.15
K (ppm)	313.88
Organic matter (%)	5.86
C/N	17.89
Bulk density (g/cm3)	1.05
Porosity (%)	58.00
Texture	Clay

Poschar is a mixture of compost and biochar in a balanced ratio. After making biochar and compost, 50% and 50% biochar are mixed. This study used various types of biochar and poschar from cow, goat, and chicken manure at an application dose of 15 tons/ha. For poschar, 7.5 tons/ha of compost and 7.5 tons/ha of biochar are mixed. The experimental plot size with an area of 2 m x 1.2 m = 2.4 m^2. Then the dose per plot for a dose of 15 tons/ha = (2.4 m^2 / 10,000 m^2) x 15,000 kg = 3.6 kg. So for poschar application per plot, 1.8 kg of compost + 1.8 kg of biochar are used.

Table 2. Characteristics of biochar and compost before research

Analysis type	Biochar			Compost		
	Cow	Goat	Chicken	Cow	Goat	Chicken
pH	7.50	6.70	7.70	8.20	7.50	7.40
C-org (%)	28.82	22.39	24.07	12.89	29.66	17.44
N (%)	0.14	0.19	0.16	0.78	0.56	0.43
P (ppm)	383.09	420.62	391.04	422.68	746.74	782.62
K (ppm)	159.64	175.20	232.36	366.80	364.9	368.70
Organic matter (%)	49.69	38.60	41.50	22.22	51.13	30.07
C/N	205.86	117.84	150.44	16.53	52.96	40.56

2.2. Experimental Design

This study used a factorial randomized block design. The first factor is the type of biochar which consists of 4 levels, namely: without biochar (Bo), cow manure biochar (B1), goat manure biochar (B2), and chicken manure biochar (B3). The second factor is the type of poschar which consists of 4 levels, namely: without poschar (Po), cow manure poschar (P1), goat manure poschar (P2), and chicken manure poschar (P3). The treatment was repeated 3 times to obtain 48 experimental units.

2.3. Research variable

The variables observed in this study were plant height, fresh weight of harvested fruit, and organic matter content. Analysis of soil samples and samples of biochar and compost in the laboratory (Table 1), including pH H_2O (pH meter), C-organic (Walkey and Black method), N-total (Kjedhal method), P-available (Bray method), K-available (HCl extract), soil texture (pipette method), specific gravity (gravimetric method), soil porosity (gravimetric method), and scanning electron microscope (SEM).

2.4. Statistical Analysis

The research data were statistically processed using the Excel 2011 for windows program. The collected data were analyzed statistically using analysis of variance, followed by the Least Significant Difference (LSD) test for a single effect and Duncan's Multiple Range Test (DMRT) for the interaction effect.

3. RESULT AND DISCUSSION

3.1. Result

3.1.1. Plant height

The statistical analysis of variance showed that the significance of the interaction treatment had no significant effect ($P \geq 0.05$). Still, the biochar and poschar treatments significantly affected plant height ($P<0.01$). The average plant height in the biochar and poschar treatments is presented in Table 3.

From Table 3, it can be seen that the best results in plant height were obtained in the treatment of cow biochar (91.95 cm), followed by chicken biochar (91.22 cm), and goat biochar (89.34 cm), which were not significantly different from without biochar (84.89 cm). While the highest plant height yield was obtained in the treatment of chicken poschar (94.83 cm) which was

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significantly different compared to the lowest plant height yield obtained without poschar (84.24 cm).

Table 3. The average height of chili plants in the treatment of biochar and poschar

Treatment	Plant height (cm)
Type of Biochar:	
Without Biochar (Bo)	84.89 b
Cow Biochar (B1)	91.95 a
Goat Biochar (B2)	89.34 a
Chicken Biochar (B3)	91.22 a
LSD 5%	3.58
Poschar type:	
Without Poschar (Po)	84.24 b
Cow Poschar (P1)	86.95 b
Goat Poschar (P2)	91.39 a
Chicken Poschar (P3)	94.83 a
LSD 5%	3.58

The numbers followed by the same letter in the same column are not significantly different in the 5% LSD test

3.1.2. Fresh weight of chili fruit per plant

The results of the statistical analysis of variance showed the significance of the interaction treatment (BxP) and the treatment of biochar and poschar types had a very significant effect ($P<0.01$) on chili fruit weight per plant. The average weight of chili fresh fruit per plant on the interaction between biochar and poschar types is presented in Table 4.

Table 4. Average fresh fruit weight per plant (g) on the interaction between biochar and poschar

Treatment	Po	P1	P2	P3
Bo	325.54 g	721.97 f	868.81 ef	931.65 e
B1	773.10 ef	1003.20 de	1298.29 ab	1379.92 a
B2	907.18 e	1090.06 cd	1093.43 cd	1290.86 ab
B3	1019.74 de	1124.65 cd	1213.20 c	1269.70 ab

Numbers followed by the same letter mean they are not significantly different in the 5% DMRT test.

Table 4 shows that the highest yield of chili fruit weight per plant was obtained at the interaction between cow biochar and chicken poschar (B1P3) as much as 1379.92 g which was not significantly different from B2P3, B3P3, and B1P2. The weight of the highest chili fruit in the B1P3 treatment increased by 323.88% compared to that of the chili fruit in the lowest interaction without biochar and poschar (B0P0) as much as 325.54 g.

3.1.3. Soil organic matter content

The results of the statistical analysis of variance showed the significance of the interaction treatment (BxP) and the treatment of biochar and poschar types had a very significant effect ($P<0.01$) on chili fruit weight per plant. The average soil organic matter content on the interaction between biochar and poschar is presented in Table 5.

Table 5 shows that the highest soil organic matter content was obtained at the interaction between chicken biochar and chicken poschar (B3P3) of 14.03% which was not significantly different from the interaction between goat biochar and chicken poschar (B2P3) of 13.99%. Still, with treatment other interactions were significantly different. The highest soil organic matter content was found in the B3P3 and B2P3 interaction treatments, which increased by 143.00% and 142.00%, respectively, compared to the lowest organic matter content in the interaction without treatment (B0P0), which was 5.77%.

Table 5. Average soil organic matter content (%) on the interaction between biochar and poschar

Treatment	Po	P1	P2	P3
Bo	5.77 f	5.91 ef	7.78 de	5.82 ef
B1	7.01 ef	5.99 ef	10.70 c	6.32 ef
B2	6.74 ef	9.66 cd	5.97 ef	13.99 ab
B3	6.27 ef	11.42 c	6.78 ef	14.03 a

Numbers followed by the same letter mean that they are not significantly different in the 5% DMRT test.

3.2. Discussion

The results showed that the highest yield of chili fruit weight per plant was obtained at the interaction between cow biochar and chicken poschar (B1P3) 1379.92 g increased by 323.88% compared to chili fruit weight in the lowest treatment at the interaction without treatment (B0P0) 325.54 g (Table 4 and Figure 1). The improvement in experimental field conditions caused the increase in fresh fruit weight due to the application of biochar and compost as soil enhancers, which led to an increase in plant growth and organic matter content in the soil. The results of soil analysis at the research site (Table 1) show clay textured soil, very high bulk density of soil with neutral soil pH, C-organic (3.40%) and organic matter (5.86%) classified as high, total N content moderate (0.19%), very high available P content (62.15 ppm), high available K (313.88 ppm), and good decomposition rate with a C/N ratio of 17.89. The characteristics of the experimental soil, in this case, the soil fertility are relatively good. The results showed that the application of biochar and poschar (compost + biochar) from various livestock manures (cow, goat, and chicken) was able to recover soil organic matter and increase the yield of red chili compared to no treatment (control).

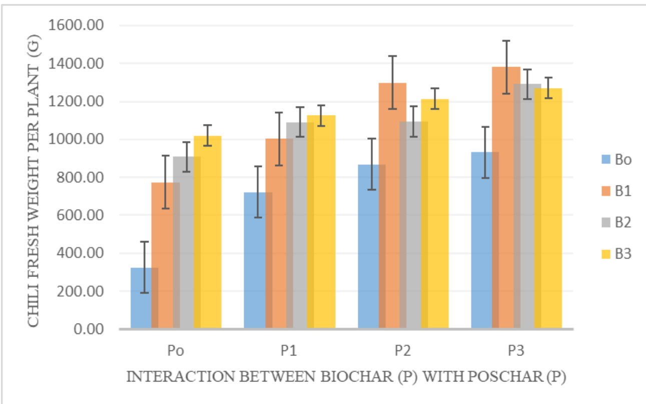

Fig. 1. The interaction relationship between biochar and poschar with chili fruit weight per plant

The increase in organic matter changes in the soil which can positively affect chili yields due to the application of biochar and poschar is supported by the *scanning electron microscopy* (SEM) analysis as shown in Figure 2.

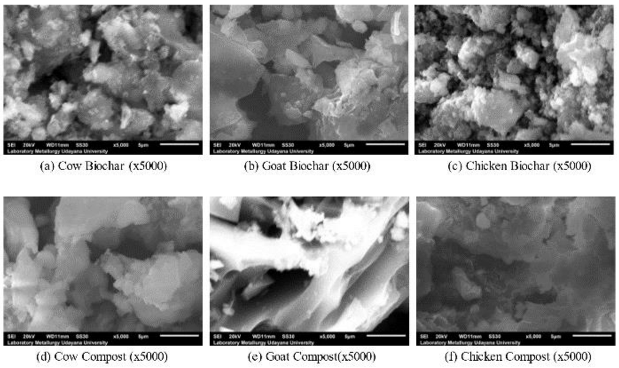

Fig. 2. SEM images (×5000) of (a) cow biochar, (b) goat biochar, (c) chicken biochar, (d) cow compost, (e) compost goat, and (f) chicken compost.

Physical properties of the surface of biochar (cows, goats, and chicken) and chicken poschar (P3) on SEM image with x5000 magnification looks better than cow compost and goat compost. The difference in morphology of biochar and compost from chicken manure can also be seen in the micropore structure and the distribution of pores on the surface (Figure 2). The surface pore structure on the SEM image of compost and biochar (poschar) from chicken manure shows that the pore distribution is broad and consistent compared to SEM from compost and biochar (poschar) from goat and cow manure. The structure of the biochar pores on the surface is very consistent with the nature of the natural pores [16, 17]. The morphology of compost and biochar (poschar) from chicken manure in the SEM image shows the surface area and pore distribution which is thought to increase the circulation of water and air in the soil. This situation will encourage the activity of soil microorganisms in the process of decomposition of organic matter to release nutrients needed by plants. Biochar made from manure is typically more nutrient-dense, has a higher pH, and has a higher specific surface area than biochar made from highly cellulosic feedstock such as wood [18]. The good ability of biochar in binding nutrients and water in the soil is due to changes in the content of organic matter which causes nutrients and water to become more available, the soil becomes looser and fertile. Biochar contains a high concentration of aromatic structures, which make it stable and resistant to chemical and biological degradation in soil. Because of their higher mineralization rates, manure, green compost, and other organic amendments are expected to have a higher amendment rate to maintain soil organic carbon than biochar [19]. When compost and biochar are combined (poschar), it will get a higher plant weight than without biochar treatment. Carbon-rich biochar is a fine grain of porous charcoal that can retain nutrients and water in the soil [20, 21, 22]. Nutrient and water retention affect the addition of nutrients and water availability in the soil. The beneficial effect of biochar can also be reduced by overburdening the nutrient availability caused by fertilizer addition, which can indirectly reduce microbe growth rates [23]. Poschar, a balanced mixture of compost and biochar, will also increase nutrient and water retention [24, 25] and improve soil fertility and red chili yields [26, 27]. Organic soil amendments, such as biochar, can help with an effective management strategy. Biochar improves soil physicochemical and biological properties and carbon sequestration [28]. Applying biochar and poschar can also reduce soil hardness, and increase porosity and microbial activity in the soil. Biochar, which is a very porous fibrous and charcoal material, plays a role in binding carbon and can hold nutrients and water in the soil [29, 30].

The best changes in soil organic matter (Figure 3). were found in the interaction treatment of chicken biochar and chicken poschar (B3P3) and the interaction between goat biochar and chicken poschar (B2P3) which increased by 143.00% and 142.00%, respectively, from no treatment (B0P0). Combining biochar with organic matter becomes a strong factor in explaining the potential positive effects of organic amendments on higher plants [31]. The best chili fruit weight per plant was obtained from the interaction of cow biochar and chicken poschar (B1P3), the interaction of goat biochar and chicken poschar (B2P3), and the interaction of chicken biochar and chicken poschar (B3P3) or each increased by 323.88%, 296.53%, and 290.03% compared to the treatment (B0P0). The high fresh weight of chili fruit per plant in the interaction treatment of cow biochar with chicken poschar was supported by a positive and very significant correlation between the variables of plant height and soil organic matter. The increase in the fresh weight of chili fruit per plant in the interaction treatment of cow biochar and chicken poschar was due to its ability to bind nutrients and water in the soil. Biochar made from biomass residues has the potential to improve soil physical, chemical, and biological conditions, reduce greenhouse gas emissions, and increase crop yields [32]. From this study, it was found that the application of biochar and poschar had led to changes in the increase in soil organic matter content and gave better chili yields.

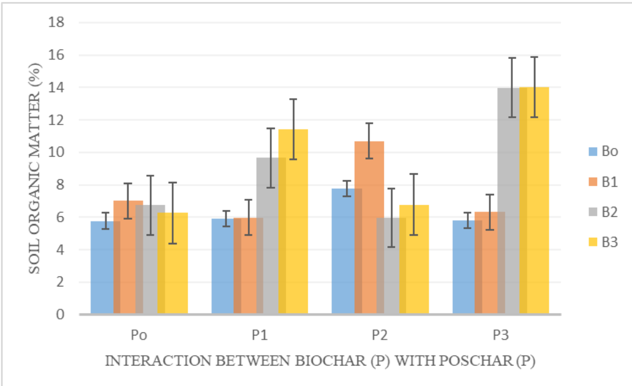

Fig. 3. The interaction relationship between biochar and poschar with soil organic matter content

4. CONCLUSION

Based on the results of this study, we obtained several findings. The application of biochar and poschar and their interactions significantly affect the fresh weight of red chili and the content of organic matter. The interaction of the application of chicken biochar with chicken poschar and the interaction of goat biochar with chicken poschar gave the best soil organic matter content value. The best results of chili fruit weight per plant were found in the interaction of cow biochar with chicken poschar application, goat biochar interaction with chicken poschar, and chicken biochar interaction with chicken poschar.

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