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Article

Fertilizers Based on Biochar and Compost from Various Livestock Manures Increase Soil Fertility and Red Chili Yields

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Abstract: Abundant animal manure in livestock areas has the potential to be used as organic fertilizer which can restore soil fertility by turning it into compost and biochar. The goal of this study was to assess how well soil fertility and red chili yield might be increased by using biochar and poschar made from various animal wastes. In this investigation, a factorial pattern and randomized block design were used. The first factor was the biochar treatment type, which included no biochar, biochar made from cow manure, biochar made from goat manure, and biochar made from chicken manure. The second factor was the type of poschar, which included no poschar, poschar made from cow manure, poschar made from goat manure, and poschar made from chicken manure. The findings of this study suggest that using biochar in conjunction with poschar can significantly improve soil parameters such as soil water content, pH, EC, humic acid, fulvic acid, C, N, P, K, and CEC. Red chilies grow and yield more per hectare when different types of biochar and poschar are used. The use of biochar from cow manure together with poschar from chicken manure shows the best agronomic effectiveness.

Keywords: organic fertilizer; livestock waste; compost; charcoal; agronomic effectiveness

1. Introduction

Tropical agricultural land is currently faced with the problem of low organic matter content in the soil so fertilization becomes ineffective and inefficient. High rates of weathering of mineral and organic matter, soil erosion, and heavy leaching of nutrients are the causes. Therefore, to maintain soil fertility, several simple and complex carbon molecules contained in soil organic matter are needed [1]. Soil improvement with organic waste is an effort to restore soil fertility, quality, and health. Organic materials known as soil conditioners can restore the ecological function of the soil, starting with physical improvements, followed by improvements in soil biology and chemistry. Increased soil organic matter can affect microbial community structure, nutrient mineralization, biomass, and soil microclimate [2]. The important role of organic matter is mainly to promote sustainable agriculture by restoring soil fertility. Improvement of soil fertility includes restoration of soil compaction, bulk density, texture, structure, water retention capacity (soil physical properties), nutrient availability, cation exchange capacity, reduction of aluminum toxicity, allelopathy (soil chemical properties), and bacteria from nitrogen mineralization, nitrous fixation, mycorrhizal fungi, and microbial biomass (soil biological properties) [3].

Indonesia as a wet tropical country has a very abundant potential source of organic matter, both from agricultural waste biomass and livestock waste such as manure that has not been used optimally by farmers. The use of manure as a raw material for making organic fertilizers such as compost, biochar, and poschar can increase agricultural production, reduce environmental pollution and land degradation, restore soil fertility, and sustainable land productivity. Organic fertilizers based on biochar and compost are known as soil enhancers which in the long run can increase crop productivity and in-

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crease soil fertility [4-7] as well as provide economic benefits [8,9]. Analysis of the topsoil carbon balance indicates that approximately 40% of the carbon-rich biochar appears to have been lost through mineralization, erosion, or vertical displacement [10]. Stabilization of soil carbon through a single application or a combination of compost and biochar can maintain and increase total organic carbon and inhibit soil carbon loss due to basal respiration [11]. Similar to biochar as a soil conditioner, compost is very effective in improving soil structure and soil pore characteristics. As an adhesive for soil granules, compost is also able to chelate nutrients in the soil, as well as increase the activity of microorganisms which causes the soil to become looser and more fertile [12]. The effect of compost activity increases with the addition of biochar in nature in the composting process which can overcome the lack of biochar nutrients and help improve the nutrient cycle on an agricultural scale [13]. As a soil conditioner, biochar can improve soil aeration, soil aggregate stability, permeability, organic content, and the capacity of the soil to retain water and nutrients so that plants can absorb them.

Biochar is generally produced by pyrolysis [14-16] through incomplete combustion of agricultural biomass under anaerobic conditions to produce stable and carbon-rich biochar. Animal manure can also be produced into biochar through incomplete combustion at low temperatures of less than 400 ^{0}C [17]. Depending on the porosity and surface charge of the biochar, this increases soil nutrient stores. Physical and hydraulic features of semi-arid agricultural land can be improved by the amendment of biochar, maintaining water supply for crops [18]. The source of the feedstock, the dosage used, the care of the plants, and the type of soil all have an impact on how well biochar research performs. Biochar can increase and stimulate the growth and production of red chili plants [19,20]. Biochar has been used by numerous researchers to boost soil fertility and carbon sequestration [21,22]. The highest fresh weight yield of harvested chilies was obtained with the application of compost, biochar, and poschar (15 t ha^{-1}) made from chicken manure. These yields increased significantly by 39.16%, 41.72%, and 46.48% in comparison to the control [23]. Compost and biochar synergistically boosted chili yield and restored soil fertility, as shown by a significant correlation between chili fresh weight and base saturation, total pore space, pH, organic-C, total-N, and available-P and K [24].

Research on the use of organic matter from manure needs to be increased from time to time to maintain soil fertility. Utilization of livestock waste into biochar and poschar from various livestock manures to restore soil fertility and red chili (*Capsicum annuum* L.) yields continues to be encouraged and evaluated through testing and research in various locations. The research on compost and biochar from animal manure was carried out in three phases which took place from 2019-2021. The results of the first and second-phase studies have been reported and published [23,24]. This study is part of the third phase, which aims to evaluate the effects of biochar and poschar from various livestock wastes and their effectiveness in restoring soil fertility and red chili yields.

2. Materials and Methods

2.1. Research site

This research was conducted from March to September 2021 in a farmer's garden in Buduk Village, Mengwi District, Badung Regency, Bali., at coordinates -8.06378 South Latitude and 115.150361 East Longitude, at a height of around 500 meters above sea level. Table 1 displays the pre-experiment soil characteristics and the outcomes of the lab analysis.

2.2. Materials and Tools

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The research material is red chili seeds of the F1 Pillar variety, biochar and compost produced from cow, goat, and chicken manure, as well as pest and disease control materials (pesticides, insecticides, herbicides). The tools used are tractors, hoes, harrows, black silver plastic mulch, sprayers, and bamboo poles. Table 2 shows the results of examining the characteristics of biochar and compost sourced from cow, goat, and chicken manure.

Table 1. Field analysis results where the research is located

Type of Analysis	Level
Water content:	
- Air Dry (%)	8.95
- Field capacity (%)	40.94
Bulk density (g cm^{-3})	1.05
Porosity (%)	58.00
Texture:	
- Sand (%)	23.45
- Dust (%)	4.68
- Clay (%)	71.88
pH H_20	6.90
EC (mmhos cm^{-1})	0.55
C-organic (%)	3.40
N-total (%)	0.19
P-available (ppm)	62.15
K-available (ppm)	313.88
Organic matter (%)	5.85
C/N ratio	17.89

Source: Soil Laboratory, Faculty of Agriculture, Udayana University

Table 2. Characteristics of biochar and compost made from cow, goat, and chicken manure

Research material	pH H_20	C-org (%)	N (%)	P (ppm)	K (ppm)	CEC (me/100g)	C/N Ratio	HA (%)	FA (%)
Cow manure biochar	7.5	28.82	0.14	383.09	159.64	20.50	205.86	1.18	37.17
Goat manure biochar	6.7	22.39	0.19	420.62	175.20	16.16	117.84	1.30	36.05
Chicken manure biochar	7.7	24.07	0.16	391.04	232.36	16.06	150.44	2.08	39.78
Cow manure compost	8.2	12.89	0.78	422.68	366.80	21.05	16.53	0.75	33.49
Goat manure compost	7.5	29.66	0.56	746.74	364.90	18.24	52.96	1.22	39.45
Chicken manure compost	7.4	17.44	0.43	782.62	368.70	18.35	40.56	1.24	37.09

Note: CEC = Cation Exchange Capacity, HA = Humic Acid, FA = Fulvic Acid.

2.3. Desain Eksperimental

This study used a factorial randomized experimental group design. The first factor was made up of four different levels of biochar: B0 as a control, B1 from cow manure, B2 from goat manure, and B3 from chicken manure. The second factor consists of 4 levels of poschar, namely without poschar (Po), poschar from cow manure (P1), poschar goat manure (P2), and poschar chicken manure (P3). The two factors with 4 levels each resulted in 16 treatment combinations. All treatment combinations were repeated 3 times, resulting in 48 experimental units. Testing biochar treatment from cow, goat, and chicken manure each using a dose of 15 t ha^{-1}. Meanwhile, poschar which is a combination of compost and biochar fertilizer each uses an application dose of 7.5 t ha^{-1}.

2.4. Research Variables

The observed soil properties variables are soil moisture content (gravimetric method), soil texture (pipette method), soil volume weight (gravimetric method), soil porosity (gravimetric method), humic and fulvic acids (IHSS), pH H_2O (pH meter), Electrical Conductivity (EC), C-organic (Walkey and Black method), N-total (Kjedhal method), P-available (Bray method), K-available (HCl extract), and CEC (NH_4Ac 1N pH 7 method).

The following variables were measured in this experiment: plant height, leaf number, fruit number, fresh fruit weight per ha, harvest index, and RAE (Relative Agronomic Effectiveness) value. The RAE value is obtained by calculating the ratio between the increase in yield due to the use of fertilizers and the increase in yield using standard 100.

2.5. Statistical Analysis

Statistical evaluation of the collected data was performed using the variance analysis, and further testing was done using Duncan's Multiple Range Testing (DMRT) for interaction effects and the Least Significant Difference (LSD) for single effects. The closeness of the relationship between soil and plant variables in the treatment of biochar, poschar, and their interactions was also examined using a correlation test. The following variables were measured in this experiment: plant height, leaf number, fruit number, fresh fruit weight per ha, harvest index, and RAE value.

3. Results

3.1. Physical Characteristics of Soil

Based on statistical analysis, it was found that the real effect of interaction between biochar and poschar types on soil physical variables such as water content, sand, dust, and clay, but the volume weight and total soil pore space did not show any real interaction between biochar and poschar. The average value of several soil physical characteristics on the interaction between types of biochar and poschar is presented in Table 3.

Table 3. Soil physical characteristics of various combinations of biochar and poschar types

Treatment	WC (%)	BD (g/cm^3)	TPS (%)	Sand (%)	Dust (%)	Clay (%)	ST
BoPo	10.49 ± 0.35^{defgh}	1.24 ± 0.03^{a}	53.08 ±1.13^{a}	19.44 ± 4.06^{f}	22.85 ± 2.92^{cdef}	57.72 ± 1.14^{a}	*Clay*
BoP1	10.14 ± 0.28^{fghi}	1.05 ± 0.01^{a}	60.38 ±0.37^{a}	24.43 ± 1.49^{ef}	29.89 ± 1.03^{cde}	45.68 ± 2.52^{bcde}	*Clay*
BoP2	10.23 ± 0.15^{efghi}	1.04 ± 0.01^{a}	60.75 ±0.39^{a}	25.71 ± 4.93^{def}	26.81 ± 5.66^{cdef}	47.49 ± 10.58^{abcd}	*Clay*
BoP3	10.95 ± 0.8^{bcde}	1.01 ± 0.04^{a}	61.98 ±1.54^{a}	24.61 ± 1.59^{ef}	26.24 ± 5.30^{cdef}	49.15 ± 6.89^{abc}	*Clay*
B1Po	9.92 +0.28^{ghi}	1.07 ± 0.01^{a}	59.76 ±0.43^{a}	36.98 ± 6.49^{ab}	20.05 ± 0.64^{ef}	42.98 ± 12.86^{cde}	*Clay*
B1P1	11.37 ± 0.16^{b}	0.98 ± 0.08^{a}	62.97 ±0.74^{a}	20.52 ± 0.36^{ef}	26.88 ± 7.72^{cdef}	52.61 ± 8.08^{abc}	*Clay*
B1P2	9.93 ± 0.32^{ghi}	0.95 ± 0.06^{a}	64.31 ±2.21^{a}	33.69 ± 5.89^{abcd}	28.30 ± 3.65^{cdef}	38.02 ± 2.17^{def}	*Clay-Loam*
B1P3	10.60 ± 0.08^{cdefg}	0.96 ± 0.02^{a}	63.72 ±0.74^{a}	26.89 ± 2.43^{cdef}	46.12 ± 3.72^{a}	26.99 ± 3.85^{fg}	*Loam*
B2Po	11.28 ± 0.40^{bc}	1.06 ± 0.00^{a}	60.06 ±0.09^{a}	24.56 ± 0.57^{ef}	19.49 ± 0.71^{f}	55.96 ± 10.15^{ab}	*Clay*
B2P1	10.37 ± 0.54^{defghi}	0.91 ± 0.11^{a}	65.69 ±4.09^{a}	25.93 ± 0.61^{def}	39.74 ± 13.65^{ab}	34.35 ± 4.25^{efg}	*Clay-Loam*
B2P2	10.98 ± 0.36^{bcd}	0.94 ± 0.08^{a}	64.58 ±3.11^{a}	38.75 ± 10.90^{a}	23.23 ± 8.17^{cdef}	38.03 ± 0.93^{def}	*Clay-Loam*
B2P3	10.71 ± 0.23^{bcdef}	0.94 ± 0.05^{a}	64.66 ±2.03^{a}	35.50 ± 3.14^{abs}	39.69 ± 1.70^{ab}	24.83 ± 1.45^{g}	*Loam*
B3Po	9.71 ± 0.15^{f}	1.04 ± 0.01^{a}	60.60 ±0.26^{a}	26.21 ± 1.05^{def}	28.68 ± 0.90^{cdef}	45.12 ± 1.94^{bcde}	*Clay*
B3P1	9.88 ± 0.57^{ghi}	0.97 ± 0.01^{a}	63.22 ± 0.43^{a}	29.01 ± 6.14^{bcde}	28.72 ± 7.65^{cdef}	42.29 ± 3.79^{cde}	*Clay*
B3P2	12.16 ± 0.19^{a}	0.95 ± 0.01^{a}	63.96 ±0.43^{a}	27.63 ± 6.51^{cdef}	32.51 ± 5.67^{bc}	39.86 ± 2.18^{de}	*Clay*
B3P3	9.85 ± 0.42^{hi}	0.92 ± 0.04^{a}	65.17 ±1.45^{a}	19.12 ± 6.29^{f}	47.09 ± 5.22^{a}	33.80 ± 8.92^{efg}	*Dusty-clay*
F-test	**	ns	ns	**	**	**	

Note: Each value in the Table represents the standard deviation of the average over three replicates (SD). There was no statistically significant difference between numbers in the same column that was preceded by the same lowercase letters at 5% DMRT ($p>0.05$). WC = Water Content, BD = Bulk Density, TPS =Total Pore Space, ST = Soil Texture.

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The highest soil moisture content value was obtained at the interaction between chicken manure biochar and goat manure poschar (B3P2), bulk density and soil clay content at the interaction between no biochar and no poschar (BoPo), total pore space in the interaction between goat manure biochar and cow manure poschar (B2P1), sand content in the interaction goat manure biochar and goat manure poschar (B2P2), dust content in the interaction chicken manure biochar and chicken manure poschar (B3P3), and soil clay content in the interaction between no biochar and no poschar (BoPo). However, a better texture was obtained, namely dusty clay in the interaction of chicken biochar with chicken poschar (B3P3), as well as clay in B1P3 and B2P3. Biochar interaction with poschar typically has a clay texture class characterized by dense and hard soil (Table 3).

3.2. Chemical Characteristics of Soil

The interaction of biochar and poschar from various animal wastes had a significant to a very significant effect on all variables of soil chemical properties (Tables 4 and 5). From the interaction of various biochar and poschar from animal manure, the highest and most significant results were obtained from soil chemical properties when compared to no treatment (BoPo), namely: pH increased by 5.47% in B2P1, EC increased by 585.86% in B2P3, fulvic acid increased by 88.99% in B3P3, humic acid increased by 23.50% in B1Po, C-organic increased by 143.23% in B3P3, N content increased by 145.95% in B2P3, P content increased by 322.45% in B3P3, K content increased by 30.46% in B3P2, C/N increased by 33.29% in B3P3, and CEC increased by 11.90% in B3P2.

Table 4. Average values of pH, EC, FA, HA, and CEC on the interaction of various biochar and poschar from animal waste

Treatment	pH	EC mmhos/cm	FA (%)	HA (%)	CEC me/100g
BoPo	6.15 ±0.13^{bcde}	0.50 ±0.06^{c}	33.31 ±1.72^{fgh}	0.70 ±0.08^{cdef}	36.69 ±1.67^{cde}
BoP1	5.84 ±0.07^{f}	0.89 ±0.40^{c}	29.99 ±1.70^{j}	0.73 ±0.02 ^{bcdef}	36.12 ±0.79^{de}
BoP2	6.41 ±0.18^{b}	1.27 ±0.31^{c}	33.13 ±0.43^{fghi}	0.62 ±0.09^{f}	38.58 ±0.05^{abcde}
BoP3	6.21 ± 0.12^{bcde}	0.62 ±0.10^{c}	35.35 ±2.44^{def}	0.82 ±0.12^{abcd}	35.61 ±0.52^{e}
B1Po	6.30 ±0.19^{bcd}	0.82 ±0.46^{c}	38.18 ±0.03^{ab}	0.88 ±0.09^{a}	40.85 ±3.45^{ab}
B1P1	5.91 ±0.50^{ef}	0.65 ±0.21^{c}	31.96 ±0.00 ^{hij}	0.68 ±0.01^{def}	39.87 ±2.84^{abc}
B1P2	6.05 ±0.06^{def}	2.50 ±1,08^{ab}	34.57 ±2.03 ^{efg}	0.77 ±0.17^{abcdef}	39.13 ±2.31^{abcd}
B1P3	6.13 ±0.08^{bcde}	0.70 ±0.03^{c}	35.99 ±0.75^{cde}	0.80 ±0.16^{abcd}	37.94 ±3.24^{bcde}
B2Po	6.13 ±0.01^{bcde}	0.94 ±0.49^{c}	37.45 ±0.96^{bcd}	0.76 ±0.11^{abcdef}	40.63 ±1.51^{ab}
B2P1	6.49 ±0.10^{a}	1.02 ±0.45^{c}	30.87 ±0.26^{ij}	0.81 ±0.05^{abcd}	38.87 ±2.40^{abcde}
B2P2	6.27 ±0.04^{bcd}	0.68 ±0.20^{c}	35.96 ±1.35^{cde}	0.72 ±0.03^{cdef}	36.41 ±1.01^{de}
B2P3	6.31 ±0.12^{bc}	3.40 ±1.94^{c}	33.29 ±0.14^{fgh}	0.78 ±0.04^{abcde}	38.52 ±1.91^{abcde}
B3Po	6.21 ±0.20^{bcde}	0.76 ±0.23^{c}	36.26 ±0.57^{bcde}	0.66 ±0.02^{ef}	38.27 ±1.39^{abcde}
B3P1	6.10 ±0.13^{cdef}	1.11 ±0.49^{c}	32.78 ±0.50^{ghi}	0.72 ±0.04^{cdef}	35.49 ±0.07^{e}
B3P2	6.13 ±0.04^{cdef}	1.46 ±0.84^{bc}	37.91 ±1.51^{abc}	0.87 ±0.03^{ab}	41.05 ±0.07^{a}
B3P3	5.97 ±0.01^{ef}	1.30 ±0.15^{bc}	39.63 ±0.00^{a}	0.83 ±0.07^{abc}	36.58 ±0.69^{cde}
F-test	**	**	**	*	*

Note: Numbers followed by the same lowercase letters in the same column are not significantly different at 5% DMRT. EC = Electrical Conductivity, FA = Fulvic Acid, HA = Humic Acid, CEC = Cation Exchange Capacity.

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Table 5. The average C, N, P, K, and C/N values on the interactions between various biochar and poschar made from animal manure

Treatment	C (%)	N (%)	P (ppm)	K (ppm)	C/N Ratio
BoPo	3.35 ±0.48f	0.19 ±0.01f	114.48 ±1.39i	450.07 ±127.37bcde	18.70 ±2.91bcd
BoP1	3.43 ±0.01ef	0.23 ±0.02ef	142.39 ±9.06hi	325.46 ±4.67f	15.31 ±0.98cdef
BoP2	4.51 ±0.21de	0.35 ±0.03bcd	246.98 ±33.15de	331.78 ±7.27f	12.93 ±0.51fg
BoP3	3.37 ±0.33f	0.25 ±0.01def	153.44 ±41.75ghi	347.34 ±11.41ef	13.21 ±0.71efg
B1Po	4.07 ±0.66ef	0.30 ±0.09cdef	366.70 ±30.55c	355.12 ±1.38def	14.33 ±1.91def
B1P1	3.48 ±0.00ef	0.22 ±0.02ef	148.96 ±17.64hi	358.59 ±10.76cdef	15.93 ±1.47bcdef
B1P2	6.21 ±0.34c	0.39 ±0.18abc	242.78 ±12.23e	351.87 ±4.63def	19.82 ±8.14b
B1P3	3.67 ±0.22ef	0.22 ±0.00ef	122.38 ±1.83i	344.53 ±10.76ef	16.66 ±0.98bcdef
B2Po	3.91 ±0.48ef	0.34 ±0.10bcde	181.27 ±11.94fgh	315.77 ±27.90f	12.25 ±2.04fg
B2P1	5.61 ±0.03cd	0.43 ±0.02ab	112.52 ±9.20i	454.76 ±123.07bcd	13.06 ±0.53fg
B2P2	3.46 ±0.44ef	0.41 ±0.01ab	142.78 ±33.40hi	526.69 ±55.17ab	8.42 ±0.87g
B2P3	8.12 ±0.80ab	0.46 ±0.02a	427.22 ±19.00b	369.71 ±26.90cdef	17.80 ±1.16bcde
B3Po	3.64 ±0.22ef	0.25 ±0.01def	213.44 ±16.22ef	354.77 ±28.30def	14.83 ±0.58cdef
B3P1	6.63 ±1.90c	0.35 ±0.09bcd	388.31 ±0.93bc	461.84 ±141.55bc	19.00 ±0.81bc
B3P2	3.93 ±0.43ef	0.25 ±0.01def	208.39 ±84.68efg	587.16 ±21.74a	15.68 ±1.09bcdef
B3P3	8.14 ±0.65a	0.33 ±0.02bcde	483.62 ±12.84a	483.60 ±69.03b	24.93 ±0.93a
F-test	**	**	**	**	**

Note: Numbers in the same column that are immediately followed by the same lowercase letter do not differ significantly in DMRT 5%.

The rise in nutrient status caused by the use of biochar and poschar results from changes in the chemical characteristics of the soil, where nutrients are released gradually as a result of the soil's improved physical and biological properties. In the control treatment, the C-organic value was 3.35%, but it was >3.35% in the treatment using various forms of biochar and poschar. The highest organic C content of 8.14% was achieved in the treatment of chicken biochar and chicken poschar (B3P3) which differed unnoticeably from the interaction treatment of chicken biochar and cow poschar (B3P1) and differed markedly from the treatment of its other interactions (Table 5 and Figure 1).

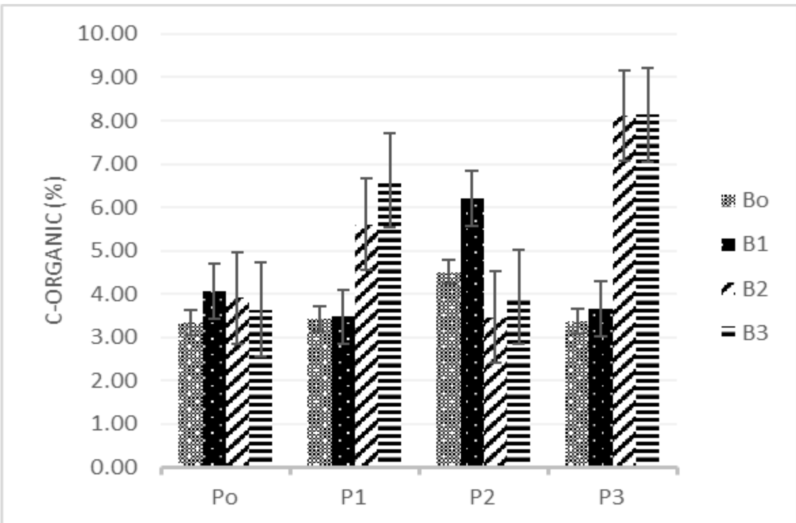

Figure 1. Relationship of interaction between biochar and poschar with soil organic C

3.3. Growth and Yield of Red Chili

Variable plant height growth in the interaction treatment of biochar from cow manure and poschar from chicken manure (B1P3) had a positive and significant correlation with the number of leaves per plant (0.93**), root fresh weight per plant (0.96**), number of fresh chilies per plant (0.92**), fresh weight of chilies per ha (0.97**), and harvest index (0.85**). The fresh chili weight per hectare in the biochar from cow manure and poschar from chicken manure interaction treatment (B1P3) had a positive and significant relationship with plant height (0.97**), number of plant leaves per plant (0.90**), fresh root weight per plant (0.88**), number of fresh chilies per plant (0.97**), and harvest index (0.93**) (Table 6).

Table 6. The impact of interactions between biochar and poschar on the correlation coefficient (r) between plant variables

Variable	Plant height	Number of leaves	Weight of fresh roots	Number of fresh chilies	Fresh weight of chili per ha
Number of leaves	0.93**				
Weight of fresh roots	0.96**	0.93**			
Number of fresh chilies	0.92**	0.94**	0.94**		
Fresh weight of chili per ha	0.97**	0.97**	0.97**	0.98**	
Harvest index	0.85**	0.90**	0.88**	0.97**	0.93**

r (0.05; 46; 1) = 0,285 r (0.01; 46; 1) = 0,368

3.3.1. Plant Height

From Table 7, the best plant height yield was obtained on chicken biochar fertilizer (93.80 cm), followed by cow biochar (93.55 cm), and goat biochar (92.71 cm) which did not differ significantly from without biochar (85.96 cm). While the highest plant height yield obtained at the chicken poschar treatment (96.76 cm) differed significantly from the lowest plant height yield obtained without poschar (85.14 cm).

3.3.2. Number of Leaves

The most leaves were obtained from chicken biochar (292.08 strands), then from goat biochar (284.08 strands), and finally from cow biochar (277.27 strands), all of which significantly outperformed no biochar (232.04 strands). While the highest number of leaves was found in chicken poschar (290.75 strands) followed by goat poschar (288.13 strands) and cow poschar (271.25 strands) which differed significantly from the lowest number of leaves without poschar (235.35 strands).

3.3.3. Fresh Weight of Roots per Plant

The application of biochar made from chicken dung yielded the highest root fresh weight per plant; it did not differ significantly from applications of biochar made from goat and cow manure, but it did differ significantly from applications without biochar. While chicken poschar treatment was not significantly different from goat poschar, and significantly different from cow poschar and without poschar to the highest root fresh weight per plant.

3.3.4. Number of Fresh Fruits per Plant

Based on Table 7, the interaction between cow manure biochar and chicken manure poschar (B1P3) produced the highest number of chilies per plant but was not significantly different from other interactions (B2P3, B3P3, B1P2, B2P2, and B3P2). The B1P3 treatment increased fruit production by 172.97% when compared to plants that weren't given biochar and poschar (BoPo).

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Table 7. Response of growth and yield of red chili on the application of biochar and poschar and their interactions

Treatment	Plant height (cm)	Number of leaves (strands)	Fresh weight of roots per plant (g)	Number of fresh chilies per plant (fruit)	Fresh weight of chili per ha (ton)	Harvest index (%)
Biochar (B)						
Bo	85.96 ±6.27[b]	232.04 ±44.66[b]	23.28 ±4.56[b]	56.40 ±15.65[b]	11.87 ±3.90[b]	72.87 ±5.08[b]
B1	93.55 ±9.80[a]	277.27 ±63.10[a]	28.53 ±3.91[a]	77.51 ±9.72[a]	18.56 ±4.34[a]	78.52 ±2.43[a]
B2	92.71 ±5.52[a]	284.08 ±19.42[a]	28.06 ±5.22[a]	77.81 ±6.40[a]	18.26 ±2.47[a]	78.48 ±2.24[a]
B3	93.80 ±5.51[a]	292.08 ±32.25[a]	29.31 ±3.42[a]	80.40 ±5.97[a]	19.28 ±1.99[a]	78.94 ±1.71[a]
LSD 5%	5.02	32.31	3.03	4.11	1.08	1.90
F-test	**	**	**	**	**	**
Poschar (P)						
Po	85.14 ±7.16[b]	235.35 ±50.84[b]	22.99 ±6.01[c]	61.04 ±18.39[c]	12.61 ±4.67[d]	74.06 ±5.98[b]
P1	90.12 ±4.38[b]	271.25 ±40.66[a]	26.83 ±3.02[b]	70.41 ±10.21[b]	16.42 ±3.05[c]	77.32 ±2.95[a]
P2	94.02 ±5.90[ab]	288.13 ±37.68[a]	28.53 ±4.32[ab]	78.82 ±8.61[a]	18.64 ±2.89[b]	78.61 ±1.52[a]
P3	96.76 ±7.72[a]	290.75 ±40.26[a]	30.83 ±1.78[a]	81.84 ±8.28[a]	20.30 ±3.28[a]	78.83 ±2.89[a]
LSD 5%	5.02	32.31	3.03	4.11	1.08	1.90
F-test	**	**	**	**	**	**
Interaction (BP)						
BoPo	77.59 ±3.24[a]	183.17 ±6.51[a]	17.10 ±1.05 [a]	31.75 ±2.88[g]	5.43 ±0.54[h]	65.08 ±1.60[c]
BoP1	85.75 ±4.02[a]	238.33 ±19.66[a]	23.57 ±4.00[a]	55.58 ±3.79[h]	12.03 ±0.72[g]	73.36 ±1.88[d]
BoP2	88.71 ±6.69[a]	252.25 ±29.92[a]	23.53 ±2.82[a]	68.50 ±11.14[ef]	14.48 ±1.08[efg]	76.90 ±0.74[abcd]
BoP3	91.81 ±3.68[a]	254.42 ±51.91[a]	28.90 ±1.91[a]	69.75 ±7.66[def]	15.53 ±3.00e	76.14 ±4.91[bcd]
B1Po	85.27 ±4.63[a]	218.00 ±68.55[a]	23.90 ±3.38[a]	65.42 ±3.39[g]	12.89 ±1.30[fg]	75.77 ±2.81[cd]
B1P1	88.68 ±3.21[a]	276.58 ±74.52[a]	26.92 ±1.13[a]	72.19 ±2.48[def]	16.72 ±1.68[de]	78.38 ±1.74[abc]
B1P2	97.40 ±6.78[a]	306.08 ±59.32[a]	31.15 ±1.99[a]	85.78 ±2.41[ab]	21.64 ±0.78[ab]	79.91 ±1.99[ab]
B1P3	102.86 ±12.63[a]	308.42 ±12.66[a]	32.17 ±1.04[a]	86.67 ±2.52[a]	23.00 ±1.13[a]	80.02 ±0.24[a]
B2Po	88.07 ±9.00[a]	267.58 ±16.15[a]	24.62 ±9.49[a]	71.50 ±6.38[def]	15.12 ±1.53[ef]	76.96 ±3.98[abcd]
B2P1	92.03 ±3.39[a]	273.42 ±9.45[a]	27.67 ±2.52[a]	75.94 ±3.31[cd]	18.17 ±0.47[cd]	79.27 ±1.90[abc]
B2P2	93.78 ±3.56[a]	293.75 ±22.77[a]	28.93 ±4.47[a]	78.67 ±5.13[abcd]	18.22 ±0.37[cd]	78.27 ±0.44 [abc]
B2P3	96.98 ±0.79[a]	301.58 ±5.15[a]	31.02 ±1.00[a]	85.11 ±1.17[ab]	21.51 ±0.37[ab]	79.42 ±1.44[abc]
B3Po	89.63 ±6.37[a]	272.67 ±32.13[a]	26.33 ±4.73[a]	75.50 ±2.63[cde]	17.00 ±0.05 [de]	78.44 ±1.84[abc]
B3P1	94.02 ±2.74[a]	296.67 ±20.50[a]	29.18 ±1.05[a]	77.92 ±8.77[bcd]	18.74 ±2.41[cd]	78.26 ±2.33[abc]
B3P2	96.18 ±4.64[a]	300.42 ±13.70[a]	30.50 ±4.09[a]	82.33 ±0.63[abc]	20.22 ±0.76[bc]	79.35 ±0.25[abc]
B3P3	95.39 ±7.68[a]	298.58 ±57.58[a]	31.22 ±1.81[a]	85.83 ±4.07[ab]	21.16 ±0.68[ab]	79.73 ±2.20[abc]
F-test	ns	ns	ns	**	**	*

Note: Numbers in the same column followed by the same lowercase letter are not significantly different in the 5% LSD (single effect) and 5% DMRT (interaction effect)

3.3.5. Weight of Fresh Chili per Hectare

The highest yield in terms of weight of chili fruit per hectare was found in the interaction between cow biochar and chicken poschar (B1P3) as much as 23.00 tons which were not significantly different from B2P3, B3P3, and B1P2, but significantly different from other interaction treatments. The highest chili fruit weight per hectare in the B1P3 treatment increased by 323.88% compared to the chili fruit weight per hectare in the lowest treatment in the interaction without biochar and poschar (BoPo) of 5.43 tons (Figure 2).

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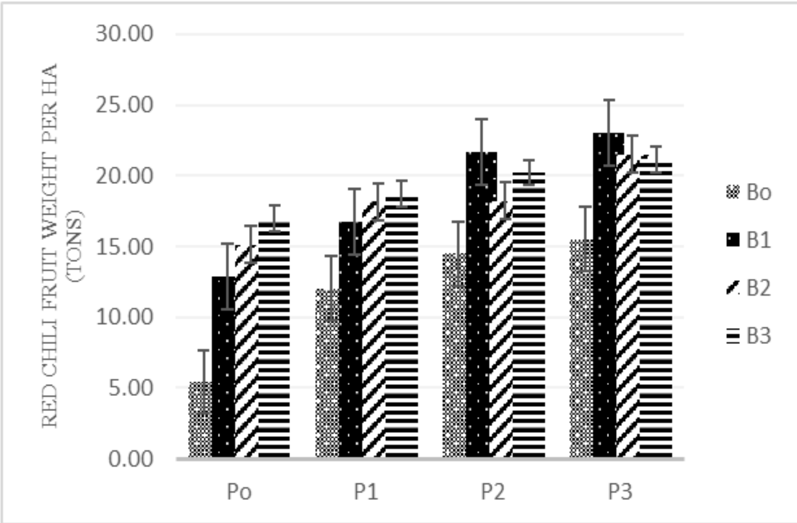

Figure 2. Relationship of interaction between biochar and poschar with chili weight per ha

3.3.6. Harvest index

From Table 7, it can be seen that the harvest index obtained from the interaction of cow biochar with chicken poschar (B1P3) was 80.02%, not significantly different from B2P3, B3P3, B1P3, B2P2, B3P2, B2P1, and B3P1 so that it did not differ significantly from other interactions. The harvest index at B1P3 improved by 22.96% when compared to the lowest-yielding treatment without biochar and poschar (BoPo).

3.4. Soil fertility and yield of red chili

The close relationship between soil properties and chili fresh weight per hectare due to the interaction effect between biochar and poschar can be seen in Table 8. The close relationship between soil variables and yield illustrates how soil properties can increase chili yield.

Table 8. The correlation coefficient (r) between soil and plant characteristics is a consequence of the interaction between various biochar and poschar types.

	WC	TPS	pH	EC	FA	HA	C	N	P	K	C/N	CEC
TPS	0.10											
pH	-0.04	0.07										
EC	-0.05	0.42**	0.11									
FA	0.11	0.08	0.00	-0.05								
HA	0.18	0.34*	0.06	0.17	0.50**							
C	-0.36*	0.51**	0.07	0.70**	0.06	0.24						
N	-0.15	0.58**	0.52**	0.62**	-0.06	0.10	0.65**					
P	-0.40**	0.28	-0.02	0.54**	0.37**	0.27	0.80**	0.39**				
K	0.32*	0.26	0.08	-0.03	0.25	0.29*	0.17	0.14	0.10			
C/N	-0.37**	0.05	-0.48**	0.35**	0.14	0.19	0.64**	-0.12	0.58**	0.10		
CEC	0.39**	0.06	0.18	0.20	0.28	0.27	-0.11	0.07	-0.01	-0.09	-0.17	
Chili yield	0.08	0.91**	0.00	0.50**	0.26	0.33*	0.53**	0.45**	0.34*	0.18	0.22	0.12

r (0.05; 46; 1) = 0,285 r (0.01; 46; 1) = 0,368

According to Table 8, total pore space (TPS) in the interaction between poschar and biochar fertilizers exhibited a positive and significant link with EC (0.42**), humic acid (0.34*), C (0.51**), N ratio (0.58**), and chili yield (0.91**). A positive and highly significant correlation on the observed variables such as total pore space (0.51**), EC (0.70**), N (0.65**), P (0.80**), C/N (0.64**), and chili yield (0.53**) supports the presence of carbon

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nutrients (C) in the interaction between biochar fertilizer and poschar fertilizer. The presence of N nutrients is also supported by a positive and highly significant relationship with total pore space (0.58**), pH (0.52**), EC (0.62**), N (0.65**), P (0.39**), and chili yield (0.45**) in the interaction treatment of biochar and pos-char fertilizers. As with soil characteristics and chili yields, humic acid in the biochar and poschar treatments demonstrated a significant correlation with total pore space (0.34**), fulvic acid (0.50**), K (0.29*), and chili yield (0.33*).

A positive and significant correlation on observed variables, such as total pore space (0.91**), EC (0.50**), acid humate (0.33*), C (0.53**), N-total (0.45**), and P (0.34*), supported the high fresh chili weight per hectare during the treatment interaction between biochar and poschar.

3.5. Relative agronomic effectiveness

The relative agronomic effect (RAE) of biochar and poschar on the variable yield of red chili can be seen in Table 8. The RAE value or agronomic efficiency of chili weight per hectare due to biochar and poschar treatment obtained ranged from 26.46%-100.12%. The highest RAE value of fruit weight per hectare was obtained by giving cow biochar with chicken poschar (B1P3) of 100.12% and the lowest yield was obtained by chicken biochar with cow poschar (B3P1) of 26.46%.

Table 8. The interaction value of RAE of biochar combined with poschar on the variable yield of red chili.

Interaction	The yield of red chili per hectare	RAE
	(ton)	(%)
BoPo	5.43	-
BoP1	12.03	-
BoP2	14.48	-
BoP3	15.53	-
B1Po	12.89	-
B1P1	16.72	58.04
B1P2	21.64	96.67
B1P3	23.00	100.12
B2Po	15.12	
B2P1	18.17	46.13
B2P2	18.22	34.28
B2P3	21.51	63.30
B3Po	17.00	
B3P1	18.74	26.46
B3P2	20.22	35.61
B3P3	21.16	41.24

From Table 8, the variable fresh weight of chili per hectare can be seen that the combination of various biochar and poschar significantly improved agronomic effectiveness compared to without the application of biochar and poschar. The best RAE value was achieved in the combination of various types of biochar with chicken poschar (BP3). The best agronomic effectiveness is found in cow biochar combined with chicken poschar (B1P3) with an RAE value of 100.12%, followed by a combination of goat biochar and chicken poschar (B2P3) with an RAE value of 63.30% and a combination of chicken biochar and chicken poschar (B3P3). obtained an RAE value of 41.24%. This proves that livestock waste processed into biochar and poschar can be used to restore soil fertility and red chili yields.

4. Discussion

The soil at the research location has a clay texture, a very high bulk density, a neutral pH, a high classification for C-organic (3.40%), and a moderate classification for N (0.19%). However, the P content (62.15 ppm) was classified as very high, K (313.88 ppm) was high, and the decomposition rate (C/N) of 17.89 was quite good (Table 1). This nutrient state shows that the experimental soil is classified as having relatively good fertility, but the texture of clay has the property of hardening the soil during the dry season and waterlogging when it rains. Characteristics of compost and biochar from various animal manures (Table 2) used in the study showed that the pH was neutral, C-organic was very high, N content was low to very high, P content was very high, and K and CEC nutritional status was high. Based on the characteristics of the soil at the research site, it turns out that compost and biochar from chicken manure are relatively better than compost and biochar from cow and goat manure. In addition to enhancing soil fertility and chili yields, experiments with biochar and poschar on clay proved the soil's physical and chemical adjustment.

4.1. Physical characteristics of soil

A drop in soil volume was followed by an increase in soil porosity and water availability, which led to an improvement in the soil's physical qualities when organic fertilizers like biochar and poschar made from cow, goat, and chicken dung were applied. In this study, the variable soil porosity or total soil pore space in the treatment of biochar ameliorant combined with poschar fertilizer had a positive and significant correlation with electrical conductivity, humic acid, organic C, total N, and chili yield. With a much better reduction in bulk density values and better soil porosity, the amelioration treatment has a considerable impact on improving the physical characteristics of the soil. Biochar also produces a much higher aeration pore than without treatment. Biochar's pore distribution and particle size may be crucial for carbon sequestration and water retention [25]. The application of biochar to soil alters some soil physicochemical properties due to its unique surface area. After adding biochar to clay, there have been noticeable changes in water retention, soil aggregate stability, and pore size distribution [26]. Therefore, it is advised to add biochar to enhance the clay's poor physical qualities, preserve the soil's quality physical characteristics, and maintain the clay's pore space status.

The raw material and production temperature which affect the main characteristics of biochar, such as surface area, porosity, pH, and soil texture seem to be the result of physicochemical and soil biological changes caused by biochar. In comparison to biochar made from woody biomass, biochar made from manure or plant leftovers tends to boost microbial abundance. Biochar from lignocellulosic-rich wood tends to affect future soil microbial counts (≥60 days) compared to biochar from plant residues and manure [27]. The enhancement of soil's physicochemical and biological qualities brought about by biochar can increase crop production [28]. Under drought conditions, biochar restores soil structure, water storage capability, and surface area [29,30].

4.2. Chemical characteristics of the soil

Organic carbon is essential for maintaining soil fertility because it serves as both a source of nutrients and an absorber of nutrients in the soil. In soil ecosystems, several microorganisms have different properties to degrade organic carbon fractions in the soil such as cellulose, hemicellulose, lignin, chitin, and lipids. Microorganisms have a major role in mediating the breakdown of organic materials, although the rate and extent are affected by soil temperature, available oxygen, nitrogen, carbon substrate, and soil management [1]. As a result of the biochar addition and the modification of compost fertilizer supplemented with biochar, soil chemical parameters like pH, electrical conductivity (EC), C-organic, N, P, and K, as well as base saturation, have improved [8]. When both compost and biochar are applied more frequently, the EC value will rise, but the soil pH will drop as a result [31]. The acidity level at the ideal soil pH can increase the supply of N, P, and K in the soil [32] and increase soil water retention [33]. It is generally agreed upon that soil quality should be improved by using organic amendments. Soil moisture, the total organic carbon in the soil, total nitrogen, accessible phosphorus, nitrate nitrogen, ammonia nitrogen, and cation exchange capacity, can be increased by organic modification and the physicochemical characteristics of soil [34]. Increasing pH, water-holding capacity, CEC, and the external microbiota through biochar changes can improve soil health [35,36]. The humic and fulvic acids in the soil have a close relationship with the significant chemical properties of soil organic matter. Nutrient molecules are chelated by humic acid [37] to improve the soil's availability of plant nutrients. Humic acids in the soil have chelating capabilities that can lessen the need for fertilizers and pesticides while promoting better and healthier plant development and yields. Fulvic acid can dissolve the remnants of chemical fertilizers in the soil so that the soil becomes loose and fertile again, stabilizes pH, regulates the movement of nutrients in the soil, and creates a good environment for microorganisms [38].

4.3. Growth and yield of red chili

The increase in fresh weight of chilies per hectare in the interaction of biochar from cow dung and chicken poschar is suspected that this fertilizer contains complete nutrients, both macro, and micronutrients, especially humic and fulvic acids which can increase soil cation exchange and microorganism activity. Poschar fertilizer derived from chicken manure gave a positive response to plant growth because the soil's N availability was improved. Improved C retention in the soil may result from high N fertilizer because it might slow the breakdown of unstable manure [39]. Chicken manure is usually rich in nutrients from food residue that is still contained in the fertilizer. The high nutritional value of chicken manure can also increase the phosphorus availability in poultry manure, which can then be composted and used as organic fertilizer [40]. Chicken manure is relatively quickly decomposed and contains quite a lot of nutrients compared to the same unit amount as other fertilizers. Compost enriched with biochar (poschar), especially made from chicken manure, increases soil fertility and nutrient absorption by plant roots for plant growth. This is indicated by the growth of the vegetative component of the plant, such as plant height and the number of leaves with the most when biochar and poschar react in the soil.

This increase in plant vegetative growth increases the ability of leaves to block sunlight due to photosynthesis, which is transferred to plant organs that carry out metabolic processes up to the development of roots, stems, and leaves. Plants grow and develop better; this affects the yield and weight of fresh chili. The anabolic distribution of plants in the sink can be seen from the increase in the value of the harvest index in the application of biochar and poschar in chicken manure. The harvest index on the interaction of biochar from cow manure with poschar from chicken manure increased by 22.96% compared to the lowest yield index without treatment. Plant nutrition and growth are benefited from biochar [41]. The porous and carbon-rich fertilizer, which can keep moisture and nutrients in the soil, is assumed to be the cause of the rise in the fresh weight of chilies per hectare in the interaction of biochar from cow dung and poschar from chicken feces. Poschar's ability to successfully bind nutrients and water in the soil raises the availability of these elements, increases soil porosity, and boosts the activity of soil microorganisms, all of which promote improvements in soil fertility and chili yields.

4.4. Soil fertility and red chili yield

This correlation analysis's findings demonstrate that using biochar and poschar together improved soil fertility and red chili harvests. The application of biochar increases agricultural productivity by reducing soil acidity and base saturation. Increase CEC and efficiency of fertilizer use, as well as water content available to plants [42]. Applications of biochar have favorable effects on soil's physical and chemical characteristics, microbial activity, biomass production, crop yields, and the ability to lower greenhouse gas emissions [43].

As organic fertilizers, biochar and poschar have different characteristics in the weathering process, generally, poschar decomposes faster than biochar in the soil. Biochar [44] is usually more weather-resistant and stable so it lasts longer in the soil to improve and maintain soil looseness. In addition, along with the weathering process in the soil, poschar can slowly provide macro and micronutrients that can increase soil fertility and crop yields. The key factors that contribute to improving soil fertility when using biochar are the addition of organic carbon, the gradual release of nutrients from chelation effects, increasing the soil's water-holding capacity, and the increasing porosity [45]. The wide pores in this biochar improve drainage, aeration, and the soil's capacity to absorb ions and air. While carbon has little impact on the physical properties of soil, such as bulk density and water retention, ash provides minerals and elevates pH, and the current microbial population can exploit unstable carbon as a carbon source [46,47]. Crop yields, water use effectiveness, and the hydrological characteristics of the soil all benefit from the addition of biochar to compost [48]. As a soil conditioner, biochar is believed to have long-lasting effects on the chemical, physical, and biological properties of the soil. Biochar has a larger surface area than other organic compounds, which makes it more resistant to weathering and may help it absorb nutrients and water more effectively. The use of biochar can store long-term stable carbon, reduce nutrient leaching and soil acidity, and increase soil water content, P and K nutrients, CEC, and agricultural yields. The study's findings led to an increase in the output of red chili when coupled with biochar and poschar. Growth in plant height, fruit length, fruit weight per plant, and yield per hectare can all be boosted by applying this organic fertilizer.

4.5. Relative agronomic effectiveness

Due to their special abilities as soil enhancers, biochar and poschar are particularly effective in increasing soil fertility and chili production. The addition of biochar to the soil has a variety of interactions, especially with its physical, chemical, and biological properties, which help to create healthy soil. Biochar formulation combined with compost can increase P availability, K availability, total soil microbes, micropore distribution, soil quality, and agronomic effectiveness [8]. Although biochar is high in carbon, it does not give enough nutrients for plants to grow [49]. The addition of biochar to chemical fertilizers and compost increases the water storage capacity of the soil and the stability of soil aggregates [50]. Physical and hydrological qualities are expected to be improved by high carbon content, porosity, surface area, and biochar microparticles [51]. Improved soil characteristics include structure, agglomeration, bulk density, and water-holding capacity [52]. By raising soil pH, CEC, base saturation, base exchange, and carbon content as well as lowering Al saturation in acidic soils and minimizing nitrogen leaching, biochar also enhances soil chemistry. This condition keeps the soil healthy while reducing the need for lime and fertilizer. Changes in the soil's physical and chemical characteristics brought on by biochar ultimately have an impact on the soil's biological characteristics by creating a more friendly environment for microorganisms. The microbial activity in low-fertility soils is stimulated by biochar. Research on biochar and soil factors that influence biochar decomposition shows that biochar can persist in soil for a very long time and has a favorable effect on soil dynamics and organic matter's capacity to absorb carbon [53].

5. Conclusions

Soil physical and chemical characteristics can be improved with biochar and poschar-based fertilizers from cow, goat, and chicken manure. The impact of biochar and poschar-based fertilizers on soil characteristics such as soil texture, water content, pH, EC, fulvic acid, humic acid, C, N, P, K, CEC, and C/N can improve soil fertility. In the application of biochar combined with poschar, it was found that soil properties such as total pore space, EC, humic acid, C, N, P, and K were significantly correlated with an increase in red chili yields per hectare. Various types of biochar combined with poschar were able to increase the yield weight of fresh chilies per hectare with agronomical effectiveness of 26.46-100.12% compared to no treatment. The application of biochar soil enhancer from cow manure combined with poschar fertilizer from chicken manure can increase chili yields per hectare with an RAE of 100.12%.

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