



Original article

The impact of corncob biochar and poultry litter on pepper (*Capsicum annuum* L.) growth and chemical properties of a silty-clay soilSairan Majeed M. Ali Jaaf^a, Yunzhou Li^{b,*}, Elif Günel^c, Hesham Ali El Enshasy^{d,e,f}, Saleh H. Salmen^g, Abdulkadir Sürücü^{h,*}^a Directorate of Agricultural Research in Sulaimani, Iraq^b Department of Plant Pathology, College of Agriculture, Guizhou University, Guiyang 550025, Guizhou, China^c Department of Soil Science and Plant Nutrition, Tokat Gaziosmanpasa University, Tokat, Turkey^d Institute of Bioproduct Development (IBD), Universiti Teknologi Malaysia (UTM), Skudai 81310, Johor Bahru, Malaysia^e School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), Skudai 81310, Johor Bahru, Malaysia^f City of Scientific Research and Technology Applications (SRTA), New Bur Al Arab, Alexandria 21934, Egypt^g Department of Botany and Microbiology, College of Science, King Saud University, PO Box -2455, Riyadh 11451, Saudi Arabia^h Harran University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Şanlıurfa, Turkey

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ABSTRACT

Red pepper (*Capsicum annuum* L.) is one of the most commonly cultivated vegetable in the Mediterranean region. This study evaluated the effects of biochar derived from corncob and poultry litter on growth of red pepper (*Capsicum annuum* L.) and some chemical properties of a silty clay soil. The experiment consisted of two factors, i.e., biochar doses (0, 0.5, 1.0 and 2%) and poultry litter doses (0, 0.5, 1.0 and 2%). The number of days to 50% flowering, plant height, stem diameter, total number of leaves per plant, the number of main branches per plant, fresh root weight, root length, dry shoot weight, macro (P and K) and micro (Fe, Zn, Cu and Mn) nutrient concentrations of leaves were determined to compare the efficiency biochar and poultry litter. Moreover, post-harvest soil analysis was conducted to measure pH, organic matter, and macro and micronutrient contents. Biochar had varying impact on plant growth parameters, whereas poultry litter alone or in combination with biochar increased macro and micronutrient concentrations of soil and improved most of the growth parameters of red pepper. In contrast, sole biochar application had no significant impact on most of the growth parameters. Wider C/N ratio (107.7) of corncob derived biochar restricted the nitrogen supply for plant growth. The combination of 0.5% biochar and 2% poultry litter resulted in the highest plant height (36.7 cm) and stem diameter (0.69 cm). The results revealed that application of single biochar derived from corncob is insufficient to supply adequate nutrients for optimal plant growth. The application of biochar alone enhances carbon sequestration in soils, however most biochars like corncob biochar do not contain sufficient available plant nutrients. Therefore, biochars should be applied along with mineral fertilizers or organic materials such as poultry manure which is rich in available plant nutrients.

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1. Introduction

Biochar, produced from heating of a biomass via pyrolysis in an oxygen-limited environment, is a stable, carbon-rich and resistant solid material, capable of improving various soil functions (Gul et al., 2015). Conversion of organic wastes into biochar is a potential solution to increase organic carbon content of soils, improve soil quality and overcome management problem of excess organic wastes. Biochar can be produced from various forestry and food industry residual biomass, crop wastes and animal manures (Günel et al., 2019). Biochar is preferred to minimize the environmental impact and to overcome the problems associated with the

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handling and disposal of agricultural wastes and animal manure (Sikder and Joardar, 2019). Pyrolysis of biomass into biochar is a reliable, safe and effective solution to overcome the management problem of excess waste produced in agricultural production (Günel et al., 2019).

Accumulation of large amount of litter, including rice husk or straw, wood chips, feathers, and excretory materials (Shaukat et al., 2020) is a major problem of poultry industry. Poultry litter is a beneficial organic amendment for plant growth due to high macro and micronutrients contents. Application of poultry litter to agricultural land is the most common practice of recycling the organic matter and nutrients in the manure. However, the improper management and overuse of manure may cause environmental problems due to volatilization of ammonia, mineralization of nitrogen, leaching of nutrients and contamination of surface water by excessive phosphorus (Reddy et al., 2008). In addition to environmental problems, short residence time in soil due to its rapid decomposition results in short term beneficial effects (Abbasi and Anwar, 2015).

Consistent and positive effects of biochar on long-term carbon storage, soil fertility, nutrient use efficiency, biological activity and water holding capacity of soils have been reported (Jeffery et al., 2011, Anderson et al., 2011, Günel et al., 2018). Contradicting growth and yield responses of different crops have been reported because of single biochar application or co-application with organic-and inorganic fertilizers. In a meta-analysis, Jeffery et al. (2017) indicated that the main driver of biochar impact on crop yield is the interaction of biochar with soil pH. Therefore, biochar application in temperate regions caused a significant decrease (approximately 3%) in crop yield, whereas increased crop yield in tropical regions (approximately 25%). The heterogeneity in yield responses to biochar application revealed that the effects of biochar on crop yield cannot be extrapolated from tropical to temperate regions (Cornelissen et al., 2013). Some other reports (Abbasi and Anwar, 2015) attributed the plant growth to the increased nutrient supply and improved soil physical and chemical properties (Gul et al., 2015).

Red pepper (*Capsicum annum* L.), which has different varieties is one of the most produced vegetables in Turkey. Annual red pepper production of Turkey in 2018 was almost 2.782.354 ton (TUİK, 2019). Although application of biochar recently has attracted considerable interest to improve soil fertility under several cropping system, studies on the effect of corncob biochar and poultry litter on growth parameters of red pepper (*Capsicum annum* L.) are rare. Biochar application may increase the availability of plant nutrients; thus, may improve plant growth and functioning ability of soils. In addition, the use poultry litter in vegetable production as in red pepper cultivation may enhance soil nutrient content that may induces plant growth. Therefore, this study was carried out to evaluate the effects of corncob biochar and poultry litter on growth parameters of red pepper and some chemical properties of a clayey soil.

2. Materials and methods

The experiment was carried under greenhouse condition located in the Agricultural Research Centre of Sulaimani, Bakrajo, Iraq. The soil used in the experiment was collected from 0 to 30 cm depth of a fallow field in Zhalla district located at the southeast of Sulaimani (542537.3 °E; 3927490.5 °N). The soil used in the experimental was silty clay, slightly alkaline, non-saline, highly calcareous, low in organic matter, available phosphorus (P) and zinc (Zn) concentrations, and rich in potassium (K) and sufficient in iron (Fe). The pot experiment was designed as a factorial randomized block with three replications to test the individual and

interactive effects of corncob biochar and poultry manure doses on growth parameters of red pepper (*Capsicum annum* L.) and some chemical characteristics of a clayey soil. The treatments of the study composed of four single biochar doses (0, 0.5, 1 and 2% indicated as B₀, B₁, B₂ and B₃), four single poultry litter doses (0, 1, 2 and 4% indicated as P₀, P₁, P₂ and P₃) and 16 biochar × poultry litter interactions (B₀P₀, B₀P₁, B₀P₂, B₀P₃, B₁P₀, B₁P₁, B₁P₂, B₁P₃, B₂P₀, B₂P₁, B₂P₂, B₂P₃, B₃P₀, B₃P₁, B₃P₂ and B₃P₃).

The poultry manure was taken from a local commercial poultry farm (Shamal farm, in Sulaimani), and composted for 4 weeks for mineralization. Corncobs were collected from a local farm. Corncob biochar was produced by slow pyrolysis (heating rate of approximately 10 °C min⁻¹) at 500 °C, which was sieved to pass through 4 mm sieve prior to pyrolysis. The poultry manure and biochar were ground and sieved through 4 mm sieve before incorporation into the soil. The biochar and poultry litter were analyzed for pH, electrical conductivity (EC), total carbon (C) and nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) concentrations (Table 1). The pH and EC were determined in 1:5 biochar:water mixture. Total C and N contents of corncob biochar and poultry litter were determined using a Leco CN-2000 analyzer (Leco Corp., St. Joseph, MI, USA) at 1200 °C. Potassium, P, Zn, Fe, Cu, and Mn concentrations were analyzed following digestion in H₂O₂-HNO₃ acid mixture and burned in a microwave (Mars 6). The K and P concentrations were determined by Atomic Absorption Spectrophotometer (AAS-Agilent 240 FS). Physical and chemical characteristics of experimental soil, biochar and the poultry litter were presented in Table 1.

The biochar was composed of 42% C, and 0.39 % N with a C:N ratio of 107.7. Poultry litter had higher total N (5.44%) and lower total C (34%) content. The biochar contained 390 mg kg⁻¹ of available P, 9530 mg kg⁻¹ of extractable K, 84.5, 41.1, 13.8 and 321.4 g kg⁻¹, DTPA extractable Zn, Mn, Cu and Fe content (Table 1). Similar to P and K; Zn, Mn, Cu and Fe contents of corncob biochar were substantially lower than poultry litter. The pH of biochar (9.21) was alkaline, while the pH of poultry litter (6.75) was neutral.

Air-dried 2 kg soil was filled into the pre labelled plastic pots with a dimensions of 6.7 cm diameter top, 12.5 cm diameter base and 13.2 cm depth. The biochar and poultry litter doses were incorporated and mixed thoroughly with the soil. One red pepper seedling (30 days old) was planted into each pot, and pots were irrigated daily up to 80% of the water holding capacity of the soil. The pepper plants were harvested 70 days after transplanting. The plants were harvested by cutting the above ground biomass from approximately 2.5 cm above the soil surface.

Table 1

Physical and chemical characteristics of soil, corn cob biochar and poultry litter used in the experiment.

Properties	Soil	Corn Cob Biochar	Poultry Litter
Sand%	11.7	–	–
Silt %	40.7	–	–
Clay%	47.6	–	–
pH (1:1)	7.93	9.21(1:5)	6.75 (1:5)
Electrical Conductivity dS m ⁻¹	0.62	9.30 (1:5)	12.25 (1:5)
Organic Matter %	1.65	–	70.74
Total Nitrogen %	–	0.39	5.44
Total Carbon %	–	42	34
C:N ratio	–	107.7	6.3
Calcium Carbonate %	23.26	–	–
Phosphorus (mg kg ⁻¹)	7.0	390	21,000
Potassium (mg kg ⁻¹)	352.67	9530	27,000
Zn (mg kg ⁻¹)	0.49	84.5	291
Mn (mg kg ⁻¹)	48.50	41.1	453
Cu (mg kg ⁻¹)	2.91	13.8	310
Fe mg kg ⁻¹)	7.02	321.4	3365

2.1. Soil analysis

Soil samples were collected from each pot after harvesting the plants. Soil samples were air dried and crushed gently to pass through a 2-mm sieve for chemical analysis. Soil reaction (pH) and electrical conductivity (EC) were determined in 1:1 soil water mixture using a pH-EC meter (Richards, 1954). Organic matter content was determined by Walkley and Black method using the dichromate wet oxidation method (Nelson and Sommers, 1996). Calcium carbonate content was measured volumetrically using the Scheibler apparatus (Allison and Moodie, 1965). The concentration of extractable P with sodium bicarbonate was determined using the Olsen method (Olsen and Sommers, 1982). Exchangeable K was measured with 1 M ammonium acetate at pH 7.0 by standard methods described in Helmke and Sparks (1996). The concentrations of DTPA-extractable iron, zinc, manganese and copper were determined according to Lindsay and Norvell (1978).

2.2. Plant growth parameters

Ten plant growth parameters were determined to evaluate the effects of applied treatments. The number of days to 50% flowering was determined as the number of days from planting to the date when 50% of plants had at least one open flower. Plant height was recorded in centimeters from the base of the plant to the apical point of plants. The stem diameter was measured three centimeters above the ground with a Vernier caliper immediately after harvesting. Total number of leaves per plant was counted in each plant at harvest time. The number of main branches per plant were counted for each plant in each treatment. The leaves and stem of the plant at harvest were separated and washed under tap water, then with distilled water and weighed to record biomass production. For determining fresh root weight; after removal of shoots, the roots of each plant were collected, washed under tap water to remove the debris, then with distilled water, dried by a paper towel and weighted fresh. The root length was recorded in centimeters from the bottom of each plant to the apical point of root. For dry shoot weight; all fresh leaves and stem in each plant were collected separately, washed under tap water, then with distilled water and dried at 65 °C in an oven. After attaining a constant weight, the material was weighed. For dry root weight; the roots were placed into an oven and dried in an oven at 65 °C until a constant weight. The material was then weighed to recorded root dry weight.

2.3. Plant analysis

The leaves of plants were washed under tap water, then with distilled water and dried at 65 °C in an oven. The dried leaf samples were ground in a Willey Mill, and ground samples were kept for plant analysis. Macro (P and K) and micro (Fe, Zn, Cu and Mn) plant nutrient concentrations were determined by combusting 0.5 g oven-dried and ground plant samples, digesting in HNO₃ in the microwave (MARS 6 240/50). Total concentrations of P, K, Fe, Zn, Cu and Mn were determined by an inductively couple plasma spectrophotometer (Kalra, 1998). Total N content of plant samples was determined by Dumas combustion method (Bremner, 1996) using the Dumatherm system (C. Gerhardt GmbH & Co. KG, Königswinter, Germany).

2.4. Statistical analysis

Two-way analysis of variance (ANOVA) was carried out to determine the effect of organic amendment and application rate and their interactions on plant growth parameters, nutrient concentrations and soil properties. Normality and homogeneity of variance for dependent soil variables were tested using the

Shapiro-Wilk test and Bartlett's test, respectively prior to ANOVA. The treatment means were compared using least significant difference (LSD) test. The differences were considered to be significant if $p < 0.05$. Statistical analyses were performed using JMP statistical software.

3. Results

3.1. Plant responses

The plant growth characteristics measured in response to sole poultry litter, corncob biochar and combined use of biochar and poultry litter treatments were given in Table 2–4. The effect of biochar on all plant growth parameters investigated was not statistically significant (Table 2–4). In contrast to the biochar, poultry litter application caused significant differences in all plant growth parameters (except root length). The interactive effect of biochar × poultry litter was significant on plant height, fresh and dry weights of stems and leaves, and days to 50% flowering (Table 2).

The stem diameter of plants in poultry litter applications slightly increased ($P < 0.05$) compared to the control treatment. However, the increase in stem diameter was not proportional to the increase in poultry litter doses. The improved nutrient availability and increased organic matter content in poultry litter amended soil (Tables 5 and 6) led to a significant improvement in plant height, stem diameter, fresh and dry weights of the stem. The application of poultry litter alone, or in combination with biochar significantly ($P < 0.01$) increased the fresh and dry stem weights (Table 2). The results reported by Maru et al. (2015) were in good agreement with our findings. The researchers stated that co-application of poultry litter biochar and urea increased nutrient availability of soil and improved most of the plant growth parameters of rice. The highest fresh (15.88 g) and dry stem weights (3.90 g) were recorded in B₁P₁ treatment, while the lowest values (2.50 and 0.57 g) were noted in B₁P₀ interaction. The fresh and dry stem weights in B₀, B₁ and B₃ treatments sharply increased with the addition of 1% poultry litter (P₁), but the higher doses of poultry litter did not increase the stem weight. The increase in plant growth parameters with the poultry litter application can be attributed to the increase in concentrations of macro and micronutrients in soil (Tables 5 and 6).

Corn cob biochar application did not cause a significant difference in the number of leaves, fresh and dry weights of leaves and number of main branches, while poultry litter application significantly changed these traits (Table 3). The fresh and dry leaf yields of pepper plants were reduced at 0.5% biochar application relative to control, in contrast, increased at 1 and 2% doses. Therefore, the lowest fresh and dry leaf weights were obtained in B₁ × P₀ and the highest weights were recorded in B₃ × P₂ treatments. The variation in number of leaves per plant was like the fresh and dry leaf weights. Biochar application at 0.5% decreased the number of leaves, while further increase in biochar doses increased the number of leaves per plant. Poultry litter applications with or without biochar even at the lowest rate significantly increased the number of leaves. The increasing N, P, K and Zn concentrations in soil with the increasing poultry litter application rates (Table 6) may explain the better plant growth as indicated by the higher values of plant growth parameters (Tables 2 and 3).

Sole application of corncob biochar did not cause any significant changes in fresh and dry weights of roots, number of main branches and days to 50% flowering. In contrast to sole biochar, poultry litter alone had a significant effect on fresh and dry weights of roots, number of main branches and days to 50% flowering. The effect of biochar and poultry litter interaction had only significant effect on the number of days to 50% flowering (Table 4).

Table 2
Effects of biochar and fresh poultry litter on plant height, stem diameter, stem fresh and dry weights of red pepper.

Biochar %	Poultry litter %					Poultry litter %				
	Plant height (cm)					Stem diameter (cm)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	20.7de†	32.3abc	33.0abc	25.0b-e	27.8	0.46	0.60	0.58	0.52	0.54
0.5 (B₁)	16.7e	34.7ab	36.7a	30.7a-d	29.7	0.43	0.69	0.69	0.61	0.61
1 (B₂)	24.3bce	30.8a-d	26.3a-e	30.3a-d	28.0	0.54	0.56	0.55	0.61	0.56
2 (B₃)	30.0a-d	33.3abc	27.0a-e	23.0cde	28.3	0.50	0.61	0.61	0.55	0.57
PM Mean	22.9c	32.8a	30.8ab	27.3b	Mean**	0.48b	0.63a	0.60a	0.57a	Mean**
LSD	Biochar Poultry Litter Interaction					Biochar Poultry Litter Interaction				
Sig.	NS 3.83** 10.45**					NS 0.08* NS				
Biochar %	Fresh stem weight (g)					Dry stem weight (g)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	3.96de	14.74ab	13.85ab	8.90a-e	10.36	0.92ef	3.53ab	3.07abc	1.70c-f	2.30
0.5 (B₁)	2.50e	15.88a	15.24a	13.12abc	11.69	0.57f	3.90a	3.47a-d	2.69a-d	2.66
1 (B₂)	6.02cde	10.92a-e	10.93a-d	14.11ab	10.49	1.38def	2.54a-d	2.76a-d	2.76a-d	2.17
2 (B₃)	7.40b-e	15.49a	12.40abc	7.08b-e	10.59	1.66c-f	3.39ab	2.90abc	1.36def	2.33
PM Mean	4.97c	14.26a	13.11ab	10.80b	Mean**	2.13	3.32a	2.89a	2.13b	Mean**
LSD	Biochar Poultry Litter Interaction					Biochar Poultry Litter Interaction				
Sig.	NS 2.81** 7.69**					NS 0.55** 1.5**				

**p < 0.01; *p < 0.05; ns = not significantly different. †Mean within column followed by the same letter are not significantly different at p < 0.05.

Table 3
Effects of biochar and poultry litter on the number of leaves per plant, fresh and dry weights of leaves and root length of red pepper.

Biochar %	Poultry litter %					Poultry litter %				
	Fresh leaf weight (g)					Dry leaf weight (g)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	6.45ef†	19.25abc	22.51ab	16.80bcd	16.26	1.32e	3.94abc	4.42ab	2.72b-e	3.1
0.5 (B₁)	4.43f	21.85ab	22.04ab	21.37ab	17.42	0.86e	4.87a	4.3ab	4.17abc	3.55
1 (B₂)	9.35def	16.43bcd	19.12a-d	24.36ab	17.32	1.91de	3.3a-d	3.43a-d	4.37ab	3.25
2 (B₃)	11.31a-f	23.49ab	26.79a	15.02b-e	19.15	2.31c-e	4.68a	5.02a	2.67b-e	3.67
PM Mean	7.89b	20.26a	22.61a	19.39a	Mean**	1.6c	4.2a	4.29a	3.48b	Mean**
LSD	Biochar Poultry Litter Interaction					Biochar Poultry Litter Interaction				
Sig.	NS 27.7** NS					NS 0.69** 1.89**				
Biochar %	Number of leaves per plant					Number of main branches				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	55.67	103.33	129	85.67	95.92	2.00	2.67	3.00	2.67	2.58
0.5 (B₁)	48.33	123.67	87.0	100.67	89.92	2.00	3.00	2.67	2.33	2.5
1 (B₂)	71.33	107	127	105	102.58	2.00	2.33	3.33	2.67	2.58
2 (B₃)	79.33	97.67	104.33	79.67	90.25	2.33	2.67	3.33	2.33	2.67
PM Mean	63.67b	107.92a	111.83a	95.25a	Mean**	2.08b	2.67ab	3.08a	2.5ab	Mean**
LSD	Biochar Poultry Litter Interaction					Biochar Poultry Litter Interaction				
Sig.	NS 3.6** 9.85**					NS 0.71** NS				

**p < 0.01; *p < 0.05; ns = not significantly different. †Mean within column followed by the same letter are not significantly different at p < 0.05.

Table 4
Effects of biochar and poultry litter on fresh and dry weights of roots, number of branches per plant and days to 50% flowering of red pepper.

Biochar %	Poultry Litter %					Poultry Litter %				
	Fresh weight of roots (g)					Dry weight of roots (g)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	6.94	10.37	9.15	6.09	8.14	1.13	1.86	1.89	1.33	1.55
0.5 (B₁)	5.08	11.03	12.26	5.37	8.43	0.93	2.15	2.15	1.22	1.61
1 (B₂)	6.73	8.63	8.99	10.44	8.70	1.45	1.5	1.52	1.79	1.57
2 (B₃)	9.80	9.25	13.20	5.30	9.39	2.1	2.34	2.31	1.22	1.99
PM Mean	7.14b	9.82ab	10.90a	6.80b	Mean**	1.40b	1.96a	1.97a	1.39b	Mean**
LSD	Biochar Poultry Litter InteractionNS 3.24** NS					Biochar Poultry Litter InteractionNS 0.54** NS				
Sig.										
Biochar %	Root Length (cm)					Days to 50% flowering				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B₀)	25.0	23.67	21.67	17.33	21.92	72a†	57c	60bc	70ab	65
0.5 (B₁)	23.67	23.33	22.0	23.67	23.17	69ab	57c	61bc	68ab	64
1 (B₂)	25.67	22.33	25.67	23.0	24.17	66a-c	63a-c	69ab	68ab	67
2 (B₃)	23.67	26.0	31.67	18.67	25.0	68ab	63a-c	66a-c	73a	68
PM Mean	24.5	23.83	25.25	20.67	Mean**	69a	60c	64b	70ab	Mean**
LSD	Biochar Poultry Litter InteractionNS NS NS					Biochar Poultry Litter InteractionNS 3.6** 10.11*				
Sig.										

**p < 0.01; *p < 0.05; ns = not significantly different. †Mean within column followed by the same letter are not significantly different at p < 0.05.

Table 5
Effects of biochar and poultry litter on pH, EC, organic matter and calcium carbonate content of experimental soil.

Biochar %	Poultry litter %					EC (dS m ⁻¹)				
	pH					EC (dS m ⁻¹)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B ₀)	8.01cde	8.18ab	8.15abc	8.17ab	8.13a	1.01a-d	1.04a-d	1.07a-d	1.22ab	1.10
0.5 (B ₁)	8.01cde	8.10b-e	8.27a	8.14a-d	8.13a	1.14a-d	1.02a-d	0.97 cd	1.14a-d	1.07
1 (B ₂)	8.00de	8.08b-e	8.09b-e	8.08b-e	8.06b	1.11a-d	1.01bcd	1.12a-d	1.23a	1.12
2 (B ₃)	7.96e	8.11bcd	8.14a-d	8.15abc	8.09ab	1.09a-d	1.18abc	0.93d	1.23ab	1.10
PL Mean	8.00b	8.12a	8.16a	8.14a	Mean **	1.11b	1.06bc	1.02c	1.20a	Mean **
LSD	Biochar PL Interaction					Biochar PL Interaction				
Sig.	0.05** 0.05** 0.15*					NS 78.57** 215.06*				
Biochar %	Organic Matter (%)					Calcium Carbonate (%)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B ₀)	1.70ab	1.59ab	1.94ab	2.32a	1.89ab	25.1a	24.6a	23.3a	21.0a	23.5a
0.5 (B ₁)	1.73ab	2.05a	2.24a	2.26a	2.07a	21.0a	18.2ab	17.3ab	18.7a	18.8b
1 (B ₂)	1.62ab	1.27b	2.03ab	1.74ab	1.66b	23.3a	18.0ab	17.3ab	21.0a	17.9b
2 (B ₃)	2.24a	1.81ab	1.95ab	1.67ab	1.92ab	21.0a	22.4a	25.1a	22.4a	22.7a
PL Mean	1.82ab	1.68b	2.04a	2.00a	Mean **	22.6a	18.8b	20.8ab	20.8ab	Mean *
LSD	Biochar PL Interaction					Biochar PL Interaction				
Sig.	0.28** 0.28** 0.76**					3.06** 8.37** 3.06*				

**p < 0.01; *p < 0.05; ns = not significantly different. †Mean within column followed by the same letter are not significantly different at p < 0.05.

Table 6
Effects of biochar and poultry litter on available P, extractable K, DTPA extractable Zn, Mn, Fe and Cu concentrations of experimental soil.

Biochar %	Poultry litter %					K (mg kg ⁻¹)				
	P (mg kg ⁻¹)					K (mg kg ⁻¹)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B ₀)	5.67f	16.33ef	42.00de	101.00a	41.25	455.06efg	378.26 g	510.42b-f	1839.69a	795.86a
0.5 (B ₁)	3.67f	20.67ef	30.00ef	83.67ab	34.50	470.00def	443.28 fg	475.20c-f	580.53b	492.25c
1 (B ₂)	1.67f	34.67def	45.33c-e	80.00abc	40.42	527.83b-e	518.11b-f	517.34b-f	554.27bc	529.39b
2 (B ₃)	5.33f	49.00b-e	31.00ef	67.33a-d	38.17	518.89b-f	577.07b	540.28bcd	441.15 fg	519.35bc
PL Mean	4.08c	30.17b	37.08b	83.00a	Mean **	492.94bc	479.18c	510.81b	853.91a	Mean **
LSD	Biochar PL Interaction					Biochar PL Interaction				
Sig.	NS 13.19** 36.11**					29.07** 29.07** 79.58**				
Biochar %	Zn (mg kg ⁻¹)					Mn (mg kg ⁻¹)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B ₀)	1.08	2.36	2.90	4.94	2.82a	26.97	50.97	52.27	54.97	46.29a
0.5 (B ₁)	0.92	2.04	2.29	3.87	2.28b	21.63	49.00	45.27	68.60	46.13ab
1 (B ₂)	1.12	1.89	2.61	3.14	2.19b	26.50	35.47	35.67	42.77	35.10b
2 (B ₃)	1.20	1.69	1.93	3.98	2.2b	25.90	41.33	50.33	55.17	43.18ab
PL Mean	1.08c	1.99b	2.43b	3.98a	Mean **	25.25c	44.19b	45.88ab	55.38a	Mean **
LSD	Biochar PL Interaction					Biochar PL Interaction				
Sig.	0.53** 0.53** NS					1.04** NS 1.04*				
Biochar %	Fe (mg kg ⁻¹)					Cu (mg kg ⁻¹)				
	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}	0 (P ₀)	1 (P ₁)	2 (P ₂)	4 (P ₃)	Mean ^{NS}
0 (B ₀)	6.75a-c	6.41a-c	7.89a-c	7.85a-c	7.23ab	2.69	2.43	2.77	2.93	2.71
0.5 (B ₁)	6.16bc	7.39a-c	5.87c	6.33bc	6.44b	2.71	2.65	2.52	2.65	2.63
1 (B ₂)	6.83a-c	5.98c	7.16a-c	9.16a	7.28ab	2.58	2.33	2.69	2.21	2.45
2 (B ₃)	7.56a-c	8.87ab	7.01a-c	7.98a-c	7.86a	2.51	2.50	2.30	2.82	2.53
PL Mean	6.82	7.17	6.98	7.83	Mean^{NS}	2.62	2.48	2.57	2.65	Mean^{NS}
LSD	Biochar PL Interaction					Biochar PL Interaction				
Sig.	1.01** NS 2.77**					NS NS NS				

**p < 0.01; *p < 0.05; ns = not significantly different. †Mean within column followed by the same letter are not significantly different at p < 0.05.

In all biochar doses, the flowering was significantly advanced on the pepper plants grown in P₁ treatments compared to the other treatments. Further increases in poultry litter delayed the flowering. The shortest mean flowering time was 57 days and recorded for B₀P₁ and B₁P₁ treatments, while the longest flowering time (73 days) was recorded in B₃P₃ treatment (Table 4).

3.2. Effects of poultry litter and biochar applications on soil chemical properties

The pH of single biochar amended soils ranged between 8.01 and 7.96, while it was between 8.01 and 8.18 in single poultry litter treatments (Table 5). The lowest pH levels were recorded in sole biochar applied soils, whereas soil pH in all poultry litter application doses were higher than the single biochar applica-

tions. The desired pH and EC levels for pepper are reported as 5.6–6.5 and 0.75 dS m⁻¹ (Havlin et al., 2016). Biochar application slightly decreased soil pH, while it was increased with poultry litter applications. The lowest and highest pH and EC values were 7.96 (B₃P₀), 0.93 dS m⁻¹ (B₃P₂) and 8.27 (B₁P₂), 1.23 dS m⁻¹ (B₂P₃), respectively (Table 5). All pH values were higher than the stated threshold values of pH and EC. Studies on biochar application to soils which have pH < 7.0 mostly reported an increase in soil pH and availability of some plant nutrients through sorption-desorption processes (Chan et al., 2008, Agbede et al., 2020). Despite significant impacts of biochar application on soil pH, the increase in single biochar doses did not substantially change the soil pH (Table 5). Therefore, the effect of biochar addition on plant nutrient availability due to the change in soil pH was not in question in this study.

The highest organic matter content in single applications was recorded in the highest biochar (2.24%) and poultry litter (2.32%) doses. The organic matter content in the highest poultry litter and the biochar application doses were similar to each other. In contrast, Abbasi and Anwar, 2015, Sikder and Joarder (2019) found higher soil organic carbon content in poultry litter biochar applied soil compared to poultry litter treated soil. In contrast to organic matter content, calcium carbonate content of soil was decreased with the increase in both single biochar and poultry litter applications (Table 5).

3.3. Effects of poultry litter and biochar applications on Macro and micro nutrient concentrations of soil

Application of biochar significantly changed the concentrations of K, Zn, Mn and Fe in soil. In addition to K, Zn, Mn and Fe concentrations, poultry litter application significantly increased the available P concentration of soil (Table 6). Similar to the results of chemical soil properties, Adekiya et al. (2019) indicated that poultry litter addition significantly increased soil N, P, K, Ca, Mg and organic matter contents and soil pH, and the highest values were obtained at 5 t ha⁻¹. The researchers stated that P, K, Ca, Mg, organic matter and pH increased only at higher rate (50 t ha⁻¹), while N increased even at lower application rates. Nutrients released to soil during decomposition of organic components in poultry litter caused higher nutrient contents in poultry litter applied soils. The interaction of biochar × poultry litter had also significant impact on P, K, Mn and Fe concentrations of soil (Table 6). Plant nutrient concentrations in the soil amended with biochar and poultry litter were higher than the single biochar amendment, which may imply that the biochar didn't supply an equivalent amount of these nutrients as of poultry litter.

Available P concentration of soil was consistently higher in poultry litter applications compared to the control biochar treatments. The lowest mean P concentration (1.67 mg kg⁻¹) was recorded in B₂P₀ treatment, while the highest mean P concentration (101.0 mg kg⁻¹) was obtained in B₀P₃ treatment (Table 6).

4. Discussion

The nutrient content of corncob biochar was insufficient for plant production, while poultry manure contained sufficient nutrients for growth and development of red pepper plants. Although Knoepp et al. (2005) indicated that P in feedstock starts to volatilize at temperatures > 770 °C, available P and also K contents in corn biochar were significantly lower than poultry litter. The results reported by Cely et al. (2015) are in agreement with our data, though P content in most of the studies were lower in biochars compared to the feedstocks (Sikder and Joarder, 2019). The pH of biochar is generally higher compared to the feedstocks. High pyrolysis temperature causes an increase in pH which is in accordance with the results of Günal et al. (2019). The EC of poultry litter (12.25 dS m⁻¹) was slightly higher than the EC of biochar (9.30 dS m⁻¹).

The effects of biochar, poultry litter and poultry litter × biochar interaction on plant growth and chemical soil properties have been presented in Tables 2–6. The increase in biochar or poultry litter doses caused an increase and a decrease in plant height. Similar to our findings, heterogeneous responses of crops to biochar applications have been reported depending on characteristics of biochars, application rates, soil type, climate and crops tested (Jeffery et al., 2011, Crane-Droesch et al., 2013). The decrease in plant growth in biochar applications was mainly attributed to the reduced nutrient availability (Ghezzehei et al., 2014). The highest plant height (36.67 cm) was obtained in the B₁P₂ treatment,

while the lowest plant height (16.67 cm) was recorded in the B₁P₀ interaction (Table 2). In contrast to our findings, Sikder and Joarder (2019) reported significantly higher plant height in Gima kalmi (*Ipomoea aquatica*) plants treated with poultry litter biochar than that of poultry litter. The stem diameter of pepper plants ranged from 0.43 (B₁P₀) to 0.69 cm (B₁P₁ and B₁P₂).

In a similar experiment, Adekiya et al. (2019) attributed to the improvement in radish growth parameters and increased plant nutrient concentrations in poultry litter additions to low C:N ratio (7:2). The C:N ratio of poultry litter in current study was even smaller (6.3) (Table 1), which can explain the higher nutrient content and better plant growth performances in single poultry litter or in combination with corncob biochar applications. High macro and micro nutrient concentrations and the low C:N ratio of the poultry litter used in this study might have induced the mineralization of poultry litter and release of nutrients which improved the plant growth.

Similar to our results, Adekiya et al. (2019) reported that single biochar application without poultry litter did not provide expected benefit for radish growth within the first year of the application. However, the highest radish yield was obtained with the application of 50 t ha⁻¹ biochar, produced from hardwoods such as *Parkia biglosa*, *Khaya senegalensis*, *Prosopis Africana* and *Terminalia glaucescens*, and 5 t ha⁻¹ poultry litter and the root weight increased by 192 and 250% compared with single biochar at 50 and 25 t ha⁻¹ rates. In contrast to our findings on the effects of corncob biochar application on plant growth, Chan et al. (2008) indicated significantly higher radish yield even at low poultry litter derived biochar application doses. The results were attributed to the increasing N uptake of radish plants with the increasing biochar application rates due to the ability of biochar to supply N.

Similar to our findings on the effect of biochar, Revell et al. (2012) reported no significant impact of poultry litter derived biochar addition on pepper yield in silt-loam and sandy-loam soils. The addition of poultry litter significantly increased the fresh and dry weights of roots. The increase in most of plant growth indicators in poultry litter application can be attributed to the higher total N content of poultry litter (5.44%) compared to that of the biochar (0.39%). The results indicated the necessity of N fertilizer application along with the biochar which is not rich in N. Because, most of the N in the corncob is lost, while increasing the temperature during pyrolysis process due to emissions of pyrolysis gasses containing ammonia and other N rich volatile organic compounds (Novak et al., 2009). Similarly, the results reported by Anderson et al. (2011) confirmed that biochar amendment without N fertilizer had no significant effect on grain yield and biomass production of wheat and rice under greenhouse condition.

The effects of biochar, poultry litter and their interactions on soil pH, EC, organic matter and calcium carbonate content were statistically significant (except biochar on EC). Studies on the effects of biochar application on plant growth and crop productivity were mostly concentrated on the interaction with soil pH and nutrient introduction to soil (Jeffery et al., 2017). The findings are in agreement with the previous results which indicated that the release of elements or soil pH changes in biochar application caused significant changes in soil chemical properties (Gul et al., 2015, Sikder and Joarder, 2019). The mechanism responsible for the increase in soil pH with the application of poultry litter has been attributed to the replacement of terminal OH⁻ of Al₃⁺ or Fe₂⁺ hydroxyl oxides with organic anions released during decomposition of poultry litter (Adekiya et al., 2019) and the basic cations of the poultry litter released during microbial decarboxylation (Agbede et al., 2020).

The results revealed that non-significant effects of biochar application on plant growth parameters are related to the slight change of soil pH in single biochar applications. In most studies,

the main driver of yield increase in biochar application to acidic soils was attributed to the increase in soil pH (Crane-Droesch et al., 2013). Extensive use of conventional tillage and high temperatures in summer in Iraq decreased the organic matter content of soils, thereby, reduced the productivity almost 40% in the last two decades (Hussein et al., 2007). The results revealed that both poultry litter and corncob biochar are effective to increase the organic matter content of experimental soil. Positive effect of biochar and poultry litter interaction on higher nutrient contents in soil was attributed to the facilitation of surface oxidation on biochar particles by the addition of poultry litter (Adekiya et al., 2019). In addition, Kuzyakov et al. (2009) stated that high microbial activity due to the poultry litter incorporation changes biological properties of biochar and fastens the co-metabolic decay during the degradation of available carbon sources.

In contrast to the reports indicating an increase in available P concentration with the biochar additions to soils (Agbede et al., 2020), the available P concentration in all biochar treatments was lower compared to the control treatment (P_0). Soil and plant nutrient concentrations obtained in this study are partially concurrent with the earlier findings (Novak et al., 2009), since there was an increased concentrations of K, Zn and Fe and decreased concentrations of P, Mn and Cu compared to the biochar unamended soil. Despite the increased concentration in B_2 and B_3 applications, Zn and Fe concentrations in B_1 treatment were lower than the control.

5. Conclusion

The results of this study revealed that single biochar application did not significantly increase the red pepper biomass yield and other growth parameters even at the highest application rate. High C/N ratio of biochar compared to the poultry litter probably limited the nutrient supply and hence the growth of red pepper plants. The combined application of biochar with poultry litter increased the growth of red pepper compared to alone biochar application. High macro and micro nutrient concentrations and improved plant growth parameters in combination of biochar × poultry litter application clearly demonstrated the importance of co-application of biochar with poultry litter to improve the availability of plant nutrients in the poultry litter.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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