Journal of Agricultural Science; Vol. 14, No. 6; 2022
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Carbon Dioxide Emission, Soil Properties, Intercropping of Cucumber-Tomato and Carrot-Cabbage Crops Performance Affected by Application of Biochar, Urea, and Rock Phosphate

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Received: February 7, 2022 Accepted: April 12, 2022 Online Published: May 15, 2022

doi:10.5539/jas.v14n6p40 URL: https://doi.org/10.5539/jas.v14n6p40

Abstract

Application of biochar soil amendment is a good practice to store carbon dioxide (CO_2) in the soil to mitigate climate change, rock phosphate and urea fertilizer increase soil fertility to enhance food security. This greenhouse experiment aimed to evaluate the effect of biochar, rock phosphate, and urea on cucumber-tomato intercrop and evaluate the carbon dioxide (CO_2) emission in the soil grown with cabbage-carrot intercrop. The first experiment was carried out using varying levels of rock phosphate (25, 50 kg ha^{-1}), biochar (25, 50, 100 kg ha^{-1}) and urea (30, 60 kg ha^{-1}) and control with no fertilizer application. The treatment combinations were replicated three times resulting in twenty-one experimental pots. The second experiment involved the application of biochar at different levels of application (25, 50, 100 kg ha^{-1}) and control with no fertilizer application, all the pots across the experiment received an equal application of urea at a rate of 30 kg ha^{-1} and rock phosphate at a rate of 25 kg ha^{-1} replicated three times resulting in 12 experimental pots for cabbage-carrot intercrop while 15 pots with an extra biochar application of 120 kg ha^{-1} for cabbage only. Results showed that High nitrogen plus High phosphorus (N + P) including Low phosphorus plus Medium biochar (Low P + MC), Low nitrogen plus Low phosphorus plus High biochar (Low N + Low P + HC), and Low nitrogen plus Low biochar (Low N + Low C) supported the height of cucumber while Low nitrogen plus Low biochar (Low N + Low C) and High nitrogen (High N) positively influenced height of tomato. There was no significant difference in the number of cucumber fruits produced since the control and high N treatments significantly got the same number of cucumber fruit. In contrast, Low nitrogen plus Low biochar (Low N + LC) treated to tomato crop got the highest number of tomato fruits. In the second experiment, the Highest biochar including High biochar and Low C (Low biochar), favoured cabbage's height while no significant effort in the treatments to support carrot height. It was estimated that the High C treatment gave the highest carbon dioxide emission while the Highest C treatment stored carbon dioxide in the soil.

Keywords: food security, climate change, biochar, rock phosphate, urea, intercropping

1. Introduction

Climate change has caused a lot of environmental setbacks. Carbon dioxide (CO_2) emissions from the soil contribute to climate change (Lal, 2016). There are microfauna and microflora that influence carbon diode emission from the soil due to the increase in respiration (Xinjia et al., 2013; Xingang & Fengzhi, 2021). There is a great need to reduce or eliminate CO_2 emissions from the soil. Carbon sequestration would mitigate climate change (Rahman, 2013). Furthermore, the cropping system and nutrient management would be able to increase carbon sequestration. Biochar is the pyrolysis of wood and other waste materials from animals at a high temperature of more than 400 degrees Celsius with or without oxygen (Claudia et al., 2017; Xingang & Fengzhi, 2021). This wood ash is a good source of soil organic amendment. Biochar reduces greenhouse emissions (Claudia et al., 2017). Biochar holds nutrients, moisture, and beneficial microbes in the soil for plant growth, development, and yield (Xinjia et al., 2013; Li et al., 2018; Wei Shi et al., 2019; Xingang & Fengzhi, 2021). Moreover, biochar improves soil quality and increases nutrient availability in the soil, especially phosphorus (Glaser & Lehr, 2019). The Cropping system could be used to reduce carbon emissions. Xinjia et al. (2021) confirmed that monoculture and intercropping with biochar improved soil physicochemical states and plant nutrient absorption and regulated soil microbial communities in the pot experiment of tomato monoculture and tomato/potato-onion intercrop treated with control, 0.3, 0.6, and 1.2% biochar concentrations. It has also been proved that Intercropping system improves soil and plant health in a peanut intercropped with the medicinal herb Atractylodes lancea (Li et al., 2018).

The use of biochar and rock phosphate increase soil fertility and plant nutrition (Glaser & Lehr, 2019). Rock phosphate (RP) was originally mined from igneous and sedimentary rock suitable for direct application to field crops and raised bed garden crops as organic fertilizer (Chien & Menon, 1995b). However, the application of PR to the field has been confirmed beneficial to crops. Rock phosphate is naturally occurring on the earth's surface; it can be used as a source of organic fertilizer. Furthermore, it releases phosphorus slowly into the soil for plant use, unlike water-soluble mineral P fertilizer (Chien & Menon, 1995b; Rajan et al., 1996; Zapata, 2003). Rock phosphate organic fertilizer improves soil fertility and reduces soil degradation caused by climate change (Chien & Menon, 1995b). Rock phosphate influenced the availability of other nutrients for plant use (Zapata, 2003). It has high residual phosphorus in the soil that plants can use in subsequent seasons (Flach et al., 1987; Kamh et al., 1999; Hocking, 2001; Montenegro & Zapata, 2002; Chien, 2003; Onanuga et al., 2021). Glaser and Lehr (2019) confirmed that biochar produced at less than 600 ^oC and quantity up to 10 mg ha^{-1} increased phosphorus availability in agricultural soils and cation exchange capacity in the soil. Furthermore, applying biochar with ammonium nitrogen increased the retention of ammonium N against leaching, thereby increasing the maize root growth (Wei et al., 2020). Joseph et al. (2010), Jindo et al. (2014), Jaafar et al. (2015), Lehmann and Joseph (2015), Bian et al. (2016), and Li et al. (2018a) stated that biochar retained nutrients, especially nitrogen, for easy crop uptake. However, biochar nutrient retention, such as nitrogen, depends on feedstock, temperature, and production method (Li et al., 2018b). Applying a large quantity of biochar could produce a negative outcome in crop production (Clare et al., 2014, 2015). Bian et al. (2014), and Liu et al. (2019) confirmed that the application of biochar within the range of 20 and 50 $tons^{-1}$ is good for crop production and soil fertility. Joseph et al. (2013) affirmed that a small quantity of biochar blended with mineral fertilizer increased plant growth and yield. The hypothesis for this research effort was to maintain the soil fertility that would sustain food security in our community and fight against climate change. Therefore, the main objective of this research was to evaluate the influence of urea, rock phosphate, and biochar soil amendment on the growth and yield of cucumber-tomato intercrop and estimate carbon dioxide emission and soil properties in a carrot-cabbage intercrop grown in varying levels of biochar in the greenhouse.

2. Materials and Methods

2.1 Site Description

The experiment was conducted in Red Crow Community College Greenhouse. Red Crow Community College is in Standoff, Alberta. Standoff is a first nations Kainai Blood Tribe (KBT) reserve community. It is located on latitude 49^o North and longitude 113^o West. Its location is on Hwy 2, 43 km Southwest of Lethbridge. The annual average temperature and rainfall are -1 to 12 ^oC and 515 mm, respectively. Standoff soil is a Brown Chernozemic soil found in the Southern part of Alberta. The greenhouse temperature and relative humidity were recorded from April to September. The minimum greenhouse temperature was 14 ^oC while the maximum was 32 ^oC and relative humidity minimum was 35%, while the maximum was 65%.

2.2 Physico-chemical Properties of the Soils

Soil samples at 0-15 cm were taken for Physico-chemical analysis (Table 1). Nitrate-Nitrogen was extracted in the soil using 0.01 M calcium chloride, and a colourimeter detected N. The phosphorus was extracted using modified Kelowna, read by auto flow colourimeter, while potassium was extracted from the soil using 1 N neutral ammonium acetate. Micronutrients were extracted from the soil using DTPA and measured by atomic absorption spectrophotometry (AAS).

Table 1. Physico-chemical properties of greenhouse soil

Properties	2021 Soil
N (kg ha^{-1})	47.10
P (kg ha^{-1})	100.90
K (kg ha^{-1})	2149.80
S (kg ha^{-1})	16.80
Ca (ppm)	4549.00
Mg (ppm)	550.00
Zn (ppm)	1.10
B (ppm)	0.50
Cu (ppm)	1.20
Fe (ppm)	17.50
Mn (ppm)	9.10
Na (ppm)	19.70
OM (%)	4.30
pH	7.80
EC	0.50
Saturated Bases (%)	
Ca	78.90
K	5.10
Mg	15.70
Na	0.30
ECEC	28.80
K/Mg	0.33
Sand (%)	15.20
Silt (%)	42.00
Clay (%)	42.80
Textural class	Silty clay

Table 1 shows the Physico-chemical analysis of the soil used in this experiment. The major essential nutrients: Nitrogen (N) was deficient in the soil, and Phosphorus (P) was optimum. Potassium was excess. Moreover. Secondary nutrients such as Calcium (Ca) and Magnesium (Mg) were optimum, whereas Sulphur (S) was deficient in the soil. Micronutrients such as Zinc (Zn), Boron (B), Copper (Cu), and Sodium (Na) were low in the soil, while soil Iron (Fe) and Manganese (Mn) were excess. The pH of the soil was 7.8 (1:1 soil:water). Soil texture was done using Sodium Hexametaphosphate, measured by hydrometer. The soil texture was silty clay.

2.3 Biochar Properties

Biochar was 100% wood burnt with 500 ^{o}C for 30 minutes. Biochar pH was 9.4, Carbon at or above was 80%, moisture and total ash (dry basis) were 11% and 3%, respectively. Nitrate N, available P, and K were 12.9, 32.2, and 1570 mg/kg, respectively. Total Carbon was 86.8% by combustion method.

2.4 Experimental Design

The patio snacker Cu381B cucumber and tomato cherry sweet million TM781 were planted in the nursery on March 31, 2021. The tomato crop is tall with long trusses of little sweet red tomatoes variety. Patio snacker is very compact and bushy and produces big, tasty fruits. Cucumber and tomato seedlings were transplanted into 2.8 kg of soil on May 25, 2021. The automatic sprinkler irrigation was set up to irrigate the seeding up to harvest time. The water was sprinkled on cucumber and tomato crops in the morning, afternoon, and evening at 6 a.m., 12 noon, and 6 p.m., respectively. Fertilizer was banded around the crops on June 1, 2021. The nitrogen fertilizer inform of urea was applied in two levels of 30 N kg ha^{-1} (low) and 60 N kg ha^{-1} (high) while Phosphorus inform of rock phosphate was applied in two levels, 25 P kg ha^{-1} (low) and 50 P kg ha^{-1} (high). Biochar was applied in three levels, 25, 50, and 100 kg ha^{-1} (low, medium, and high, respectively) to low N and P application rates and control with no fertilizer application. The treatment combinations were control (no fertilizer application), Low nitrogen plus low biochar (Low N + Low C), High nitrogen (High N), Low phosphorus plus medium biochar (Low P + Medium C), High phosphorus (High P), Low nitrogen plus low phosphorus plus high biochar (Low N

+ Low P+ High C), and High nitrogen plus high phosphorus (High N + High P) using cucumber-tomato intercrop as test crop. These treatments were replicated three times resulting in twenty-one experimental pots.

In the second experiment, biochar was applied at a rate of 25 kg ha^{-1}, 50 kg ha^{-1}, and 100 kg ha^{-1} (Low, Medium, and High levels, respectively). All the pots received the equal application of urea (N) and rock phosphate (P) at a rate of 60 kg ha^{-1} and 50 kg ha^{-1}, respectively. The treatment combinations were control (no fertilizer application), Low biochar (Low C), Medium biochar (Medium C), and High biochar (High C) treated to cabbage-carrot intercrops. The highest biochar (highest C) application at 120 kg ha^{-1} was applied to cabbage crops only since cabbage is a heavy nutrient feeder than carrot. The early Jersey Wakefield CB236 cabbage variety and carrot CR312B Canada Fi variety seedlings were transplanted on May 25, 2021, into 12 pots for carrots and 15 pots for cabbage, each pot contained 2.8 kg of soil. The cabbage and carrot crops in each treatment replication were bulked together to analyze NPK nutrients uptake by cabbage and carrot crops after harvest. Nitrogen in the plant tissue was measured using the Kjeldahl method, P was measured using the Spectrophotometric vanadium phosphomolybdate method, and K was estimated using a flame photometer. Moreover, soil samples were taken in each treatment to measure carbon dioxide-Carbon (CO_2-C) burst, macro, and micronutrients in the soil after harvest. The macro and micronutrients in the soil were determined through the method explained above. Carbon dioxide is naturally released from the soil due to the activity of the soil microbes through microbial respiration. As the available carbon increases in the soil, microbial respiration will increase. The CO_2-C burst is naturally released from the soil due to the activity of the soil microbes through microbial respiration. Carbon dioxide-Carbon burst from the soil samples was measured by dry combustion using an elemental analyzer. The other agronomic parameters taken were plant height, number of leaves, number of flowers, number of fruits for tomato and cucumber, while plant height, number of leaves, fresh and dry biomass yield for cabbage and carrot. Dry biomass yield for cabbage and carrot were measured by oven drying the plant materials in the oven for three days at a temperate of 60 ^{o}C and weighing the dried materials with a sensitive electronic weighing scale (Sartorius Lab. Instruments, GMBH &Co, Germany-ENTRIES 2202-1SUS).

2.5 Statistical Analysis

The agronomic parameters measured were subjected to a one-way analysis of variance (ANOVA), separation of treatment means was done using Duncan's Multiple Range Test (DMRT).

3. Results

Table 2 shows the Influence of biochar, rock phosphate, and urea on cucumber plant height over time. The effect of the treatments was not significant at 84 and 89 days after sowing (DAS). However, from 103 to 148 DAS, the effect of treatments was significantly positive influenced, High N + P supported the highest vine height than other treatments, although treatments received Low P + MC, Low N + P + HC, and Low N + LC significantly the same with treatment that supported the highest treatment (High N + P). The pots treated to High N and High P, including control, had the least vine height. The same trends were observed throughout the experimental period.

Table 2. Influence of biochar, rock phosphate, and urea on cucumber plant height over time

Treatment	2021 Cropping Season					
	Intercrop Cucumber Plant Height (cm)					
	Days After Sowing (DAS)					
	84	89	103	118	132	148
Control	20.10	30.00	62.70b	67.70b	86.00b	88.80b
Low N + LC	10.70	46.00	86.00ab	113.30ab	123.00ab	128.70ab
High N	23.90	33.30	51.30b	67.30b	72.70b	74.30b
Low P + MC	16.90	55.00	106.00ab	113.30ab	132.30ab	143.00ab
High P	20.40	56.00	67.70b	77.30b	83.70b	88.30b
Low N + P + HC	43.70	76.30	91.30ab	104.70ab	108.00ab	109.70ab
High N + P	20.30	72.30	148 .00a	156.00a	163.70a	162.00a
SE	15.04(NS)	20.10(NS)	30.70	29.70	30.30	30.00

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 3 shows the Influence of biochar, rock phosphate, and urea on cucumber leaves over time. The effect of the treatments on cucumber leaves was obvious at 89 DAS, all the treatments, including control, favoured leaves production except High N. It was noticed at 118 DAS that all the treatments positively influenced leaves production except the control experiment. It was also observed that the number of leaves in the control pot was not different from the other treatments except High N + P. At 148 DAS, Low P + MC and Low N + LC significantly outclassed other treatments.

Table 3. Influence of biochar, rock phosphate, and urea on cucumber leaves overtime

Treatment	2021 Cropping Season					
	Intercrop Cucumber Leaves					
	Days After Sowing (DAS)					
	84	89	103	118	132	148
Control	6.00	11.30ab	12.30	14.70b	17.00	12.70bc
Low N + LC	4.30	12.70ab	18.30	20.70ab	20.00	17.00ab
High N	7.00	9.00b	12.70	18.00ab	20.70	5.70c
Low P + MC	6.30	15.30ab	23.00	21.70ab	24.70	21.00a
High P	6.70	13.00ab	19.00	16.30ab	18.30	12.30bc
Low N + P + HC	9.30	18.70a	24.70	26.30ab	23.00	13.70b
High N + P	5.80	13.30ab	24.30	27.70a	27.30	11.00bc
SE	2.50(NS)	3.80	7.00(NS)	5.30	6.0(NS)	3.20

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 4 reveals the Effect of biochar, rock phosphate, and urea on the cucumber number of flowers over time. The treatments applied failed to support the number of flowers throughout the experiment. However, it was seen in Table 5 that the effect of biochar, rock phosphate, and urea on cucumber number of fruits at 132 DAS was positively influenced by the treatments applied, all the treatments, including control, favoured fruit production except pot treated to Low P + MC and High P that produced least fruit, but not different from other treatment except High N.

Table 4. Effect of biochar, rock phosphate, and urea on cucumber number of flowers overtime

Treatment	2021 Cropping Season					
	Intercrop Number of Flowers					
	Days After Sowing (DAS)					
	84	89	103	118	132	148
Control	1.00	4.70	8.00	7.70	5.70	5.00
Low N + LC	1.30	5.70	16.00	16.70	14.00	4.00
High N	1.30	7.00	10.30	12.00	10.00	1.70
Low P + MC	3.30	4.30	13.30	15.70	9.30	2.30
High P	5.00	7.00	8.00	8.30	3.30	4.00
Low N + P + HC	5.00	8.00	17.30	19.00	7.70	1.30
High N + P	3.80	6.30	13.30	14.30	6.30	0.00
SE	2.80(NS)	3.00(NS)	4.60(NS)	6.70(NS)	4.70(NS)	2.50

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 5. Effect of biochar, rock phosphate, and urea on cucumber number of fruits

Treatment	2021 Cropping Season				
	Intercrop Cucumber Number of Fruits				
	Days After Sowing (DAS)				
	89	103	118	132	148
Control	0.00	2.30	3.00	5.00ab	1.00
Low N + LC	1.70	4.70	3.00	4.00ab	2.00
High N	0.30	3.70	4.30	10.00a	0.70
Low P + MC	2.00	5.00	5.70	2.70b	1.70
High P	4.00	3.30	2.00	1.70b	1.70
Low N + P + HC	1.30	3.00	3.30	2.70b	4.70
High N + P	2.00	3.70	5.70	4.30ab	1.70
SE	2.30(NS)	3.20(NS)	1.90(NS)	3.10	2.20

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 6 shows the effect of biochar, rock phosphate, and urea on the height of tomatoes over time. The pot that received Low N + LC treatment gave the highest height than other treatments, but Low N + LC and High N significantly gave the same high while Low P + MC, High P, Low N + P + HC, and High N + P gave the shortest height than other treatments at 68 DAS. There was no significant effort for the treatments to support plant height at 89 and 103 DAS. The same results were observed at 118 and 132 DAS, pots treated to Low N + LC, High N, and High P significantly outclassed other treated pots, including control. There was no treatment effect to support tomato height at 148 DAS.

Table 6. Effect of biochar, rock phosphate, and urea on the height of tomato overtime

Treatment	2021 Cropping Season					
	Intercrop Tomato Height (cm)					
	Days After Sowing (DAS)					
	68	89	103	118	132	148
Control	18.30c	45.00	99.30	70.30b	82.00b	94.30
Low N + LC	43.50a	70.00	93.70	107.30a	116.70a	122.30
High N	37.00ab	50.70	90.70	111.70a	119.00a	87.70
Low P + MC	20.50bc	43.00	56.30	64.30b	68.30b	71.70
High P	33.60abc	55.30	82.70	88.30ab	101.00ab	104.30
Low N + P + HC	27.20bc	58.70	57.00	62.30b	76.30b	82.30
High N + P	20.50bc	55.70	68.30	75.00b	82.00b	84.00
SE	7.00	11.30(NS)	19.40(NS)	12.60	14.40	24.70

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 7 reveals the effect of biochar, rock phosphate, and urea on tomato number of leaves over time. There was no significant effort of the treatments to favoured number of leaves.

Table 7. Effect of biochar, rock phosphate, and urea on tomato number of leaves overtime

Treatment	2021 Cropping Season					
	Intercrop Tomato Number of Leaves					
	68	89	103	118	132	148
Control	6.40	10.30	9.00	11.70	18.70	15.70a
Low N + LC	6.70	11.70	17.00	16.30	16.70	12.00ab
High N	6.70	10.30	13.70	12.70	11.00	11.30bc
Low P + MC	6.30	10.30	10.70	10.30	15.70	10.30bc
High P	7.30	11.00	12.70	14.30	12.30	15.70a
Low N + P + HC	7.30	12.00	14.00	14.30	12.30	7.30c
High N + P	6.00	13.70	15.70	16.30	14.70	8.30bc
SE	0.80(NS)	2.20(NS)	3.50(NS)	2.90(NS)	3.70(NS)	1.80

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

It was obvious in Table 8 that High N, Low N + LC, High P, and High N + P treatments jointly produced more flowers than Low N + P + HC treatment. The Low N + P + HC treatment was significantly the same with pots treated to Low P + MC, and High P and control at 118 DAS. It was noticed that the pot treated to Low N + LC gave more fruits than other treated pots, including control at 132 DAS.

Table 8. Effect of biochar, rock phosphate, and urea on tomato number of flowers and fruits overtime

Treatment	2021 Cropping Season									
	Intercrop Tomato Number of Flowers and Fruits									
	No of Flowers					No of Fruits				
	89	103	118	132	148	89	103	118	132	148
Control	0.00	0.00	1.30bc	7.70	2.00ab	0.00	0.00	0.70	0.30b	1.30
Low N + LC	1.70	13.00	7.70ab	9.00	0.00b	2.30	3.70	5.70	5.70a	6.70
High N	0.67	8.70	11.30a	3.30	1.30ab	0.00	0.70	2.70	0.70b	3.70
Low P + MC	1.30	2.70	3.00bc	10.70	1.00ab	0.00	0.30	0.70	2.00b	2.70
High P	0.67	6.00	6.30abc	3.30	4.70a	0.00	1.30	2.70	1.30b	3.70
Low N + P + HC	3.30	5.00	0.00c	3.30	0.70b	0.00	1.00	1.30	1.30b	1.30
High N + P	2.30	7.00	6.70ab	8.70	1.30ab	0.00	0.30	1.00	1.00b	0.70
SE	1.50	5.40	2.80	3.70	1.60	1.20	2.20	3.10	1.30	3.70

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar; NS: not significant.

Table 9 shows the NPK nutrients in the plant tissue after harvest. The control experiment had the highest N uptake by tomato crop than other treated pots, while High N treated pot had the least. The pots treated to Low N + LC and Low P + MC had the highest K uptake by tomato crop, while High N treated pots gave the least K uptake by tomato crop. However, pots treated to Low P + MC had the highest P-uptake by tomato plants while pots treated to Low N + LC and High N + P jointly had the least.

Table 9. Nitrogen, Phosphorus, Potassium uptake by tomato and cucumber crops at harvest

Treatment	2021 Cropping Season					
	Nutrient Uptake					
	Tomato Nutrient Uptake (%)			Cucumber Nutrient Uptake (%)		
	N	P	K	N	P	K
Control	1.36	0.24	2.78	1.37	0.42	1.72
Low N + LC	0.76	0.14	2.92	1.08	0.41	2.09
High N	0.61	0.20	2.07	1.09	0.33	1.78
Low P + MC	0.95	0.30	2.92	1.07	0.44	2.02
High P	0.69	0.22	2.63	0.80	0.45	1.60
Low N + P + HC	0.67	0.20	2.10	0.89	0.27	1.38
High N + P	0.88	0.14	2.15	1.11	0.25	1.72

Note. N: nitrogen; LC: low biochar; P: phosphorus; MC: medium biochar; HC: high biochar.

In contrast, Control gave the highest quantity of N uptake by cucumber crop while High P treated pot produced the least quantity. It was observed that the High P treatment gave the highest P uptake by cucumber crop while High P + N treatment gave the least P uptake by cucumber crop. The Low N + LC treatment supported the highest K uptake by cucumber crop, whereas Low N + P + HC treatment gave the least K uptake.

Table 10 reveals the influence of different levels of biochar on cabbage height over time. It was noticed that Highest C, High C, and Low C favoured cabbage height at 104 DAS only while the least height was noticed in the control experiment, but control had the same height with pot treated to Low C, Medium C, and High C.

Table 10. Influence of different levels of biochar on cabbage height over time

Treatment	2021 Cropping Season			
	Cabbage Plant Height (cm)			
	Days After Sowing (DAS)			
	64	90	104	134
Control	7.30	14.30	17.00b	18.80
Low C	10.00	14.70	19.30ab	30.30
Medium C	10.30	13.70	17.00b	25.00
High C	7.03	15.30	20.00ab	23.30
Highest C	11.30	20.30	24.30a	31.30
SE	3.30	3.00	2.30	4.60

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; Low C: low biochar; Medium C: medium biochar; High C: high biochar; Highest C: highest biochar; NS: Not significant.

Table 11 shows the effect of different levels of biochar on cabbage number of leaves over time. The Highest C and Medium C biochar treatments produced more leaves than control, Low C, and High C treatments at 64 DAS. The effect of the treatments was noticed at 104 DAS, where all the treated pots with biochar had a greater number of leaves than the control experiment. However, the control experiment was significantly the same with pots treated to Medium C and High C. The effect of the treatments was also noticed at 134 DAS, where Low C, Medium C, and Highest C biochar treatments produced the highest number of leaves, whereas High C treatment and control produced the least number of leaves.

Table 11. Effect of different levels of biochar on cabbage number of leaves over time

Treatment	2021 Cropping Season			
	Cabbage Plant Number of Leaves			
	Days After Sowing (DAS)			
	64	90	104	134
Control	4.00b	5.00	7.00b	8.00bc
Low C	4.30b	6.30	8.30a	12.70a
Medium C	6.00ab	7.30	8.70ab	10.70ab
High C	4.70b	8.30	8.70ab	6.00c
Highest C	8.00a	8.30	9.70a	10.30ab
SE	1.10	2.10	2.10	1.80

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; Low C: low biochar; Medium C: medium biochar; High C: high biochar; Highest C: highest biochar; NS: Not significant.

Tables 12 and 13 show the effect of different levels of biochar on carrot height and the number of leaves over time. The effect of the treatments was not significant throughout the experimental period.

Table 12. Carrot plant height treated with different levels of biochar over time

Treatment	2021 Cropping Season				
	Carrot Plant Height (cm)				
	Days After Sowing (DAS)				
	68	90	104	134	141
Control	20.30	31.30	34.70	41.30	45.00
Low C	20.40	28.70	29.00	27.30	27.70
Medium C	20.40	29.00	23.30	45.30	46.30
High C	21.10	38.30	42.00	46.00	49.50
SE	2.90	5.60	7.80	12.20	12.20

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; Low C: low biochar; Medium C: medium biochar; High C: high biochar; NS: Not significant.

Table 13. Carrot number of leaves treated with different levels of biochar over time

Treatment	2021 Cropping Season				
	Carrot Number of Leaves				
	Days After Sowing (DAS)				
	68	90	104	134	141
Control	4.80	10.70	11.30	11.30	9.70
Low C	6.00	8.30	7.70	6.00	6.30
Medium C	4.30	15.00	16.30	10.00	9.70
High C	6.30	19.70	21.00	9.30	13.00
SE	1.60	6.20	6.20	2.40	2.80

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; Low C: low biochar; Medium C: medium biochar; High C: high biochar; NS: Not significant.

Table 14 shows the application of different levels of biochar on cabbage and carrot fresh and dry biomass after harvest. There was no significant effect favouring fresh cabbage fresh and dry weight because all the treatments had the same biomass weight, including control. However, the high C treatment had a greater carrot fresh weight biomass than other treated pots, including control. It was also noticed that the control experiment with medium C and High C treatments gave higher dry biomass than other treated pots.

Table 14. Fresh and Dry Biomass affected by application of different levels of biochar

Treatment	2021 Cropping Season			
	Biomass Yield (g)			
	Cabbage		Carrot	
	Fresh Weight	Dry Weight	Fresh Weigh	Dry Weight
Control	10.70	3.30ab	48.60b	7.60ab
Low C	13.20	2.30b	6.40b	1.20b
Medium C	13.80	1.80b	49.80b	7.20ab
High C	26.70	10.30a	116.40a	15.20a
Highest C	10.70	1.70b	-	-
SE	7.80	3.30	26.20	4.10

Note. Means with different letters are significantly different according to Duncan's Multiple Range Test (DMRT) $p < 0.05$; SE: standard error; Low C: low biochar; Medium C: medium biochar; High C: high biochar; Highest C: highest biochar; NS: Not significant.

Table 15 reveals Carbon diode-Carbon burst and soil properties affected by different levels of biochar application. The carbon dioxide C burst (CO_2-C) emission increased in the pot treated to different levels of biochar in order of Highest C > Medium C > Control > Low C > High C. The carbon dioxide emission was noticed in the pot treated to High C.

Table 15. Carbon diode-Carbon burst and soil properties affected by different levels of biochar application

Soil Properties	Soil Treatment				
	Control	Low C	Medium C	High C	Highest C
N (mg/g)	1	4	3	4	2
P (mg/g)	36	41	32	29	29
K (mg/g)	138	121	105	97	101
Mg (mg/g)	381	335	317	402	250
Ca (mg/g)	1278	1310	1009	1478	781
Na (mg/g)	41	27	41	65	25
C (mg/g)	212	257	259	415	248
Fe (mg/g)	95	126	83	39	52
Al (mg/g)	73	95	75	58	71
OC (mg/g)	212	257	259	414.6	248
ON (mg/g)	7.3	7.6	8.6	14.3	8.7
C/N	29	33.8	30.1	29	28.6
OM (%)	20.1	10.70	11.6	24	8.3
CEC (meq/100)	28.3	30.00	29.60	28.90	27.8
pH	7.8	7.9	7.9	7.9	8.0
CO_2 (ppm CO_2-C)	179	222	176	493	144

Note. Low C: low biochar; Medium C: medium biochar; High C: high biochar; Highest C: highest biochar.

The primary residual nutrients NPK in the soil were estimated after harvest. It was observed that Nitrogen in the soil after harvest increased in the pots treated with biochar in this order control > Highest C > Medium C > Low C and High C. The Low C and High C treatments had Highest N left in the soil than other biochar treated soil after harvest. Moreover, residual Phosphorus was noticed in increasing order of Highest C/High C > Medium C > control > Low C. The Low C-treated soil had the highest residual P. The residual potassium level in the soil increase in the order of High C > Highest C > Medium C > Low C > Control. The control experiment got the highest residual K in the soil.

The soil's residual secondary nutrients, Mg and Ca, were estimated after harvest. It is noticed that magnesium in the soil increase in the order of Highest C > Medium C > Low C > Control > High C. The High C treatment got the highest residual magnesium than other treated soil. Furthermore, increasing order of residual calcium was noticed in the Highest C > Medium C > Control > Low C > High C. After harvest, the high C treatment got the highest residual calcium in the soil.

The soil's residual micronutrients, sodium, and iron were evaluated in the soil after harvest. Sodium in the soil decreased in High C < Medium C/Control < Low C < Highest C. The High C treated pot had the highest sodium accumulation in the soil after harvest. However, iron in the soil after harvest decreases in Low C < Control < Medium C < Highest C < High C. The treatment Low C got the highest iron accumulation.

The highest residual aluminium in the soil was noticed in the soil treated to Low C biochar than other treated pots, whereas High C treated pot had the least. Nevertheless, the highest residual carbon was detected in the pot treated to High C treatment while the control had the least.

The highest residual level of Soil organic carbon, organic nitrogen, C/N ratio, and organic matter was observed in the soil treated to High C, High C, Low C, and High C treatments, respectively. In contrast, control, Highest C, and Highest C treatments, respectively, had the least.

The soil cation exchange capacity (CEC) and soil pH were estimated to be highest in the soil treated to Low C and Highest C treatments, respectively, while soil treated to Highest C and control, respectively, had the least.

4. Discussion

4.1 Influence of Biochar, Rock Phosphate, and Urea on the Growth of Cucumber and Tomato Crops

Current results showed that sustainable use of fertilizer should be taken into consideration. The low rock phosphate fertilizer application at 25 kg ha^{-1} and low urea application at 30 kg ha^{-1} and low biochar application at a rate of 25 kg ha^{-1} favoured cucumber and tomato growth, although there was no difference between low and high fertilizer rates applications. It is obvious from the data collected that biochar application at 25 kg ha^{-1} supports a high concentration of nitrogen and phosphorus in the soil against leaching that enhances the growth of cucumber and tomato crops. This result is also in line with Joseph et al. (2013), Bian et al. (2014), and Liu et al. (2019) used low biochar application at 20-50 t ha^{-1} with mineral fertilizer to improve soil fertility. Furthermore, Wei Shi et al. (2020) confirmed that biochar retained the nitrogen nutrient in the soil solution for effective uptake by plants against the leaching of nutrients into the environment of the soil.

4.2 Effect of Biochar, Rock Phosphate, and Urea on Yield of Cucumber and Tomato Crops

The treatment's effect failed to support cucumber yield because of competition for nutrients between two heavy feeder crops (tomato and cucumber). Our results suggest a higher application rate for N and P than the current rate applied. This would provide more nutrient concentration in the soil that would support yield. However, the effect of the treatments on tomato crops was positively influenced the crop yield. The pots treated to Low N treatment and low application of biochar outclassed those treated with high application of N, P, and biochar. Our results showed that tomatoes override cucumber in the intercrop due to effective absorption of nutrients for yield by the tomato crop. This signifies tomato crop had greater competitive ability over the cucumber crop. Therefore, interspecific competition occurred between tomato and cucumber intercropped. This result confirmed the report of Wu et al. (2016) that intercropping tomatoes with potato-onion promoted the growth of tomatoes. Furthermore, this result is also in line with other crops investigated by Li et al. (1999) that intercropping maize with Faba beans, the total yield and grain yield were higher than sole maize and beans crop. Li et al. (2001) also confirmed an increase in yield and nutrient acquisition when intercropped wheat, maize, and soybean rather than sole wheat, maize, and soybean.

4.3 The Nitrogen, Phosphorus, and Potassium Nutrients Uptake by Tomato and Cucumber Crops

The treatments applied did not favour N uptake by tomato and cucumber crops because the control experiment (no fertilizer application) performed better than treated pots. The pot treated to Low P + MC had the highest P uptake by tomato crop while the pot treated to Low N + LC and Low P + MC had the highest K uptake by tomato. However, the high P treatment gave the highest P uptake by cucumber crops than other treatments, while Low N + LC treatment gave the highest K uptake by cucumber crops than other treatments. Results showed that nitrogen application did not positively affect nitrogen uptake by tomato and cucumber. It may be due to the fact that the nitrogen fertilizer applied was not enough. Our previous study applied 280 kg ha^{-1} of urea fertilizer to the same soil, which boosted the yield of potato crops (Onanuga et al., 2021). It was also observed that high P treatment (50 kg ha^{-1}) influenced P uptake; however, high P treatment applied in this study cannot be compared to high P applied at 100 kg ha^{-1} previously to the same soil (Onanuga et al., 2021).

Application of low P and medium biochar at 25 and 50 kg ha^{-1}, respectively, with the addition of urea fertilizer at 30 kg ha^{-1}, influenced P and K nutrients uptake by tomato. These results confirmed early assertions made by Joseph et al. (2013) that a small quantity of biochar blended with mineral fertilizer increased nutrient uptake, increasing plant growth and yield. The present report applied 25 and 50 kg ha^{-1} for low P and medium biochar application. In contrast, Bian et al. (2014), and Liu et al. (2019) confirmed that between 20 and 50 tons ha^{-1} biochar application could increase soil fertility.

4.4 Influence of Different Levels of Biochar on Cabbage Growth

It was noticed that the highest application of biochar promotes cabbage growth. The highest level of 120 kg ha^{-1} supported the height of cabbage while Low C, Medium C, and Highest C treatments favoured leaves of cabbage. Moreover, biochar application in the range of 25 kg ha^{-1} (0.03 ton ha^{-1})-120 kg ha^{-1} (0.13 ton ha^{-1}) influenced the height and production of leaves. Bian et al. (2014), and Liu et al. (2019) reported between 20 and 50 ton ha^{-1} biochar quantity for other crop production such as rice. The difference in the application rate of the present study and previously reported rates may be due to biochar properties and production (Li et al., 2021; Liu et al., 2019).

4.5 Effect of Different Levels of Biochar on Carrot Height and Number of Leaves

Biochar application rates failed to support the experiment's height and the number of leaves. This may be due to interspecific competition when intercropped cabbage with carrots. The same report was recorded for other crops such as wheat intercropped with maize and soybean (Li et al., 2001), and tomato intercropped with potato-onion (Wu et al., 2016).

4.6 Different Levels of Biochar on Cabbage and Carrot Fresh and Dry Biomass After Harvest

The effect of biochar was not effective on fresh biomass, and dry biomass except for the fresh biomass of carrot where high C biochar applied at 100 kg ha^{-1} (0.11 ton ha^{-1}) promoted fresh carrot weight, other researchers reported between 20 and 50 ton ha^{-1} for different crops (Bian et al., 2014; Liu et al., 2019).

4.7 Effect of Biochar, Rock Phosphate, and Urea on Soil Properties and Carbon Diode Emission From the Soil

It was observed that carbon dioxide (CO_2) emission was high in the pot treated to high biochar at a rate of 100 kg ha^{-1} while carbon dioxide was stored in the soil treated with biochar at a rate of 120 kg ha^{-1}. This signifies that with more biochar application, more carbon dioxide is stored in the soil. The CO_2 in the soil increases if the rate of carbon inputs exceeds the rate of microbial decomposition (Lal, 2016).

Biochar applied to the soil treated to high C (100 kg ha^{-1}) increased nitrate N in the soil, and low C application at 25 kg ha^{-1} enhanced available P in the soil. There was a considerable amount of N and P in the biochar due to the pyrolysis that biochar was made. The present studies used wood material heated to 500 ^oC as biochar. The biochar method of production influenced the increase in N and P in the soil. Li (2021) confirmed the same report using hardwood pyrolyzed at 700 ^oC to retain N concentration in the soil. Liu et al. (2019) asserted that biochar with stable high C and method of production could retain P in the soil. Furthermore, Li et al. (2021) also confirmed that biochar retention in the soil could vary with feedstocks and pyrolysis temperature used for biochar production. The control experiment with no biochar application got the highest K due to an excess of K in the soil (Table 1).

Biochar has a large surface area that can absorb mineral nutrients. The addition of biochar with urea and rock phosphate at 60 N kg ha^{-1} and 50 P kg ha^{-1} respectively enhances mineral nutrient accumulation (residual) in the soil after harvest. Laird et al. (2021) stated that biochar addition to soil might increase the long-term ability of soils to retain nutrients and reduce nutrient loss such as Mg, Ca, and Fe. Biochar reduces metal in the soil such as Al and Na, the alkalinity nature of biochar may inhibit Al and Na accumulation (Jorge et al., 2020). The biochar application at 100 kg ha^{-1} influenced soil organic carbon, organic nitrogen, and soil organic matter. Application of High C biochar at 100 kg ha^{-1} enhanced Mg, Ca, and Na accumulation in the soil after harvest. In contrast, the Low C application favoured Fe and Al, and the High C application supported residual carbon levels in the soil. Application of biochar increase soil organic matter in the soil. Igalavithana et al. (2015) reported that biochar application increase soil organic carbon, soil organic nitrogen, and organic matter in the soil, but this increase depends on the method of biochar production. Biochar application at 25 kg ha^{-1} positively enhanced high C/N ration and CEC, but the highest biochar application at 120 kg ha^{-1} favoured soil pH. These soil properties are dependent on the biochar type, the application rate, and soil type (Igalavithana et al., 2015). Nguyen et al. (2017)

also stated that biochar produced from debarked wood chips had a higher C:N ratio than biochar produced from poultry litter. Our current study used biochar produced from wood burnt at 500 ^oC for 30 minutes.

5. Conclusion

This current study reveals the potential of biochar to boost the growth and yield of cucumber and tomato intercrop and carrot and cabbage intercrop. Our results showed that the application of biochar at a rate of 25 kg ha^{-1} with the use of low-level application of mineral fertilizer such as urea and rock phosphate at the rate of 30 and 60 kg ha^{-1}, respectively, could increase the growth and yield of tomato-cucumber and cabbage-carrot intercropped. However, interspecific competition occurred in the intercrop. Carbon dioxide is stored in the soil when more biochar was applied to the soil at a rate of 120 kg ha^{-1}. It was also observed that biochar increases the accumulation of mineral nutrients such as Mg, Ca, decreases the presence of metals such as Al and Na, and increases organic carbon, organic nitrogen, and organic matter in the soil after harvest. The pH increases with an increased level of 120 kg ha^{-1} biochar application. This experiment will be repeated using higher N and P applications, as well as monocropping instead of intercropping to ascertain the effect of biochar on the cropping system.

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