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Effects of biochar and inorganic fertiliser on the growth and yield of beetroot (*Beta vulgaris* L.) in Kenya

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Summary: Beetroot (*Beta vulgaris* L.) is a root vegetable packed with many nutritional benefits such as minerals and vitamins. Despite its importance in Kenya, farmers get about 30-35 t/ha which is significantly lower than the potential yield (68 t/ha). This is mostly attributed to low soil fertility. This study aimed to determine the response of the beetroot growth and yield on biochar and NPK. A 3×4 factorial experiment was carried out at Egerton University farm over two seasons to test the effects of biochar and NPK (17-17-17), under supplemental irrigation. Biochar (0, 5, 10 t/ha) was combined with NPK (0, 200, 300, 400 kg/ha). The combination of Biochar and NPK increased significantly ($p \leq 0.05$) beetroot growth and yield in two seasons. Treatment B10N400 showed the tallest plants (79.2 cm) at 90 days in season two, while the control resulted in the shortest (27.6 cm). Treatment B10N200 showed the biggest (213.2 cm^2) leaves at 90 days. The treatment B5N300 recorded the highest marketable yield (84 t/ha) in season two and the lowest was B0N0 with 2.6 t/ha. Sole application of NPK rates (200, 300, 400 kg/ha) increased significantly the growth and yield of beetroot compared to the control in both seasons. In season one, N300 (300 kg/ha) had 61.9 t/ha of the total yield, the control had the lowest. In season two, 300 kg/ha had 83 t/ha of total yield. Biochar increased beetroot growth and yield in season 2. Treatment B5 recorded the highest marketable yield of 61.2 t/ha, while the control showed the lowest of 53 t/ha.

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Key words: beetroot (*Beta vulgaris* L.), biochar, growth, NPK, soil amendment, yield

Introduction

Beetroot (*Beta vulgaris* L.) is a vegetable that has an origin in Germany. It belongs to the family of *Chenopodiaceae* (Yordanova & Gerasimova, 2016). Although it is typically grown as an annual crop, beetroot is biennial (Pandita et al., 2020). Beetroot is an important crop in Kenya due to its economic and health benefits among small-scale farmers (Muthini et al., 2020a). It has shown tremendous importance in human health such as cancer prevention and regulation of blood pressure (Pandita et al., 2020). This is due to its mineral content and antioxidant properties. Beetroot can produce 40 tonnes per acre when proper farm management is applied (Vallespir et al., 2018). However, low soil fertility and leaching of nutrients which are major problems in sub-Saharan Africa (SSA), contribute to the decrease in beetroot productivity and result in food scarcity (Tibesigwa et al., 2017). For instance, Jones et al. (2003) and Oladele et al. (2019) revealed that population increase, climate change and the tremendous pressure on the soil to boost crop productivity lead to low production of the crop. Beetroot performs better under cool climate conditions and can also be cultivated successfully nearly all year round. It is more popular in Nakuru, Kiambu, and Tharaka-Nithi counties in Kenya (Muthini et al., 2020b).

Beetroot requires macronutrients (nitrogen, phosphorus and potassium) and micronutrients (zinc, boron) to be available in the soil for its development (Omara et al., 2022). This is why, without the use of organic materials and inorganic fertiliser, prospective beetroot potential yield is no longer possible (Wada et al., 2022). More so, Kimani et al. (2021) stated that Kenyan farmers get low beetroot growth and yield (30-35 t/ha), which is far below the 68 t/ha (Omara et al., 2022) potential yield of the crop. This is because farmers tend to apply inappropriate fertilisers due to their high cost and demand which lead to low soil fertility. Since synthetic fertilizer is very expensive, farmers are forced to use organic manure to increase beetroot development. It is still difficult because they do not have enough information on the beetroot fertilisation process (Musyoka et al., 2019). However, this is a challenge in Kenya, because it makes the soil to become less fertile which leads to food insecurity and poverty among small-scale farmers (Sileshi et al., 2019). Investigating sustainable methods to maintain soil fertility in East African countries to improve or maximize potential agricultural output becomes crucial. To make this a reality, the soil will need to be amended with a biologically inert substance like biochar, known for its ability to stabilise nutrients in the soil and improvement of soil aggregation (Arfaoui et al., 2019). Biochar is the end product of the pyrolysis process (burning of agricultural waste and biomass in anaerobic conditions) (Zhang et al., 2020). However, its application can be a solution to the low soil fertility problem in East African countries like Kenya (Simms et al., 2020).

Biochar's chemical and physical properties make it appropriate for application as a soil amendment and contribute to carbon sequestration (Weidemann et al., 2018; Rasafi & Haddioui, 2020). Biochar application improves the pH, soil structure, water-holding capacity and bulk density (Sahoo & Remya, 2022). Previous studies including Usevičiūtė &

Baltrėnaitė (2021); Knoblauch et al. (2021); Zhang et al. (2020) and Abhilash et al. (2016) also have demonstrated that the application of biochar with NPK improves the growth and yield of the crops. This is a result of improved nutrient use efficiency (Mondal et al., 2022). Despite this highlighted importance, in Kenya, studies of biochar and chemical fertiliser (NPK) to improve the growth and yield of beetroot are missing, so this is the first experimental field on the topic. In this regard, this research was designed to assess the effects of acacia charcoal dust (Biochar), and NPK fertiliser and their interaction on beetroot growth and yield.

Materials and methods

Site description

The study was conducted at the Horticulture Research Field Three at Egerton University, Njoro, Kenya. The site lies at a latitude of 0^{o} 23’ S, a longitude of 35^{o} 35’ E at an altitude of 2238m above sea level. It is in agroecological zone III of Kenya. The site receives annual precipitation of approximately 1000 mm with average temperatures of 16 ^{o}C to 22 ^{o}C (Jaetzold et al., 2012). The major soil type in this experimental area is Mollic Andosols, characterised by a dark to black colour, moderate organic matter and low phosphorus content (Jaetzold et al., 2012). The site provided suitable conditions for beetroot growth. The experiment was conducted in two seasons, season one started on the 26th of March to the 23rd. June 2022 and the second started from 2nd August to 2nd November 2022 with supplement irrigation.

Soil analysis

Soil samples were collected at 0-20 cm depth using a Zig Zag method to represent the whole field. Seven samples were collected by the soil auger and a bucket was used to carry the samples and allow easy mixing to get a composite sample for analysis. The samples were air-dried and passed through a 2mm sieve to remove roots and stones. Total nitrogen was determined by the use of the Kjeldahl method (Anglov et al., 2003) and Mehlich Double Acid was used to analyse phosphorus, potassium, sodium, calcium, magnesium and manganese (Okalebo et al., 2002). Soil pH was measured using a pH meter at a soil: water ratio of 1:1 (volume/volume). Organic carbon was analysed using the Walkey and Black method as described by Okalebo et al. (2002).

Biochar production

Biochar which was obtained from Cooks Well Company in Nairobi, Kenya, was the waste product of mostly acacia trees through the pyrolysis process. The temperature used to burn the acacia trash is 250 ^{o}C and the process of burning took approximately one hour and fifteen minutes.

Experimental layout

The study was set in a randomized complete block design in a factorial experiment with two factors (3×4) replicated three times. Each block had twelve (12) treatments. Each plot was 1.8×1.6 m^2 with six rows, the spacing between rows was 30 cm and the spacing between plants within the same row was 20 cm. Biochar and inorganic fertiliser (NPK) were each applied at three levels of 0, 5 and 10 t/ha and four levels of 0, 200, 300, and 400 kg/ha respectively, giving 12 treatment combinations (***Table 1***). The land was prepared on the 25th and 26th of February, 2021 for season one. In season two, the land was prepared from the 28th and 30th of July using conventional tillage tools. In every experimental plot, biochar was mixed with the soil with the use of a hoe and rake in the corresponding plots. Before planting, the different rates of NPK were also applied in the corresponding experimental plots. The seeds of ‘Detroit's dark red’ were drilled uniformly into the rows within the plots, followed by thinning after two weeks after planting to maintain plant spacing.

Table 1. Treatment combinations

Treatment (TRT)	**Biochar level (t/ ha)**	**NPK levels** (kg/ ha)	**TRT combinations***
1	0	0	B0N0
2	5	0	B5N0
3	10	0	B10N0
4	0	200	B0N200
5	0	300	B0N300
6	0	400	B0N400
7	5	200	B5N200
8	10	200	B10N200
9	5	300	B5N300
10	10	300	B10N300
11	5	400	B5N400
12	10	400	B10N400

Where * B is the Biochar levels and N is the NPK levels

Crop management

Weeds were controlled regularly by hand weeding throughout the growth period to keep the crops free of weeds. Whenever insect pests appeared cypermethrin 25% EC was sprayed and it has been sprayed thrice to control pests after planting. The crop was rain-fed with supplemental irrigation provided during dry spells using a drip irrigation system. The growth parameters (number of leaves, plant height and leaf area index) were measured 30, 45, 75 and 90 days after planting in each season on 8 sample plants in the middle rows. The number of leaves was counted manually. A meter ruler was used to measure the plant height starting at the base of the plant to the leaf apex. The length (from the end of the petiole to the leaf apex) and width from the right margin to the left margin of the average leaf were measured to estimate the leaf area index and it was estimated using the formula $LA = L \times W \times 0.75$ developed by Varga et al. (2021). Where L is the length of the leaf and W is the width of the leaf and 0.75 is the correction factor. The harvesting of the sample plants in the middle rows in each respective plot was done after 3 months in every season; it was done by uprooting the tubers from the soil and removing the soil by the use of hands. A portable electronic weighing balance (EK300I-JA 300 g, AND, Beijing, China) was used to measure the weight of the roots from the sampled plants in the middle rows to determine the yield of beetroot in each plot.

Statistical analysis

The data obtained from this study were tested for normality using the *Shapiro-Wilk* test. They were subjected to the analysis of variance using the SAS 9.4 General Linear Model (GLM) technique (Hodges et al., 2022) to check the significant difference between treatments. Where treatments were found significant, means separation for the sole effects and of biochar and NPK as well as their interaction was done using Tukey's Honestly Significant Difference at $p \leq 0.05$.

Results and discussion

Soil and biochar analysis

Laboratory analysis results revealed that the biochar used in this study was alkaline because it was having high pH (8.3). The alkalinity properties of biochar were because it contained high ash concentration which had high magnesium, calcium, potassium and carbon content and also based on the results from the laboratory it was clear that soil had low phosphorus content (***Table 2***).

Table 2. Initial Characterization of soil and biochar.

Parameters	Soil	Biochar
	0-20 cm	
pH (H_2O)	5.7	8.3
Total nitrogen %	0.3	0.1
Organic carbon %	2.8	3.1
Available phosphorus (cmol/kg)	20.0	0.6
Potassium (cmol/kg)	1.2	0.7
Calcium (cmol/kg)	5.2	3.3
Magnesium (cmol/kg)	3.1	0.1
Manganese (cmol /kg)	0.4	663.0
Copper (cmol/ kg)	1.0	8.3
Iron (cmol /kg)	114.0	1343.0
Zinc(cmol/kg)	11.2	76.7
Sodium (cmol/kg)	0.6	not determined

Effects of biochar and NPK on beetroot height

The different applied combined rates of fertilizers (biochar and NPK) significantly increased the beetroot height at $p \leq 0.05$ at 75 days and 90 days after planting in season two. At 75 days, the treatment B5N200 showed the tallest plants at 42.1 cm on average, while B0N0 had the shortest plants at 22.5 cm. The plots that received treatment B10N400 showed the tallest plant averaged 79.2 cm and the control recorded the smallest average of 27.6 cm at 90 days (***Table 3***). The observation showed that the sole application of biochar at different rates increased significantly the growth of beetroot in season two, but there was no significant difference in season one. In season two, treatment B10 showed the tallest plant averaging 59.6 cm, followed by B5 averaging 46.3 cm and the control showed the shortest averaging 38.1 cm at 90 days (***Figure 1a-b***). On the other hand, the sole application of NPK also recorded a significant increase in beetroot height in both seasons. In season one, the different rates of NPK (200, 300, and 400 kg/ha) were not statistically different, but statistically different compared to the control. In season two, at 45, 60, 75 and 90 days after planting. In season two, the rates of NPK were statistically different from each other at 75 days. The plots that received NPK at 300 kg/ha produced the tallest plants averaging 42.2 cm, while the shortest plants were observed in the control treatment averaged 23 cm (***Figure 2a-b***).

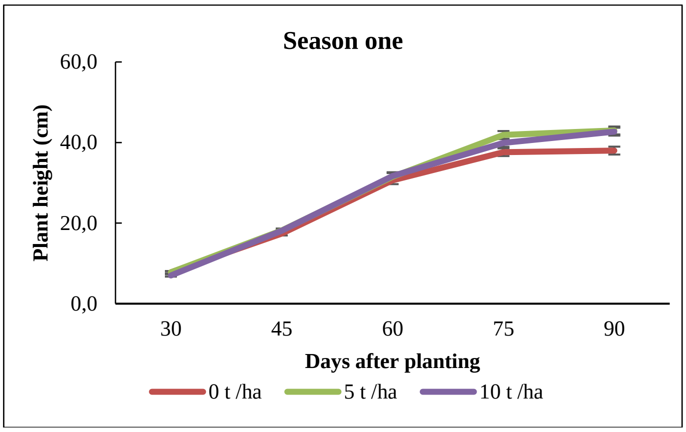

Figure 1a. Effects of biochar on beetroot plant height.

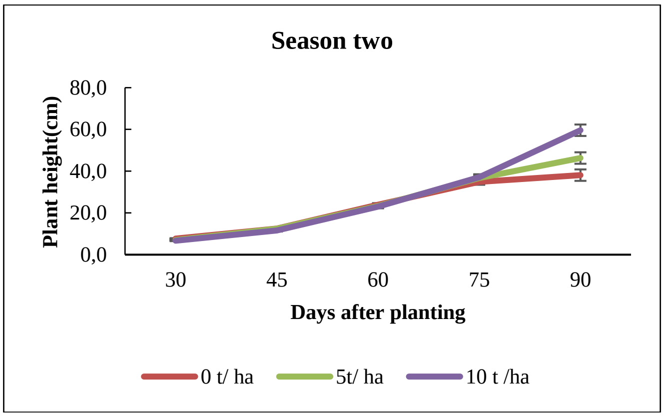

Figure 1b. Effects of biochar on beetroot plant height.

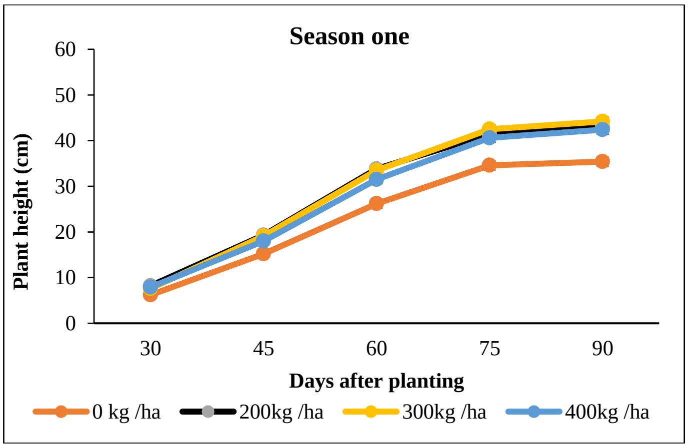

***Figure 1*a.** Effects of NPK on the beetroot plant height.

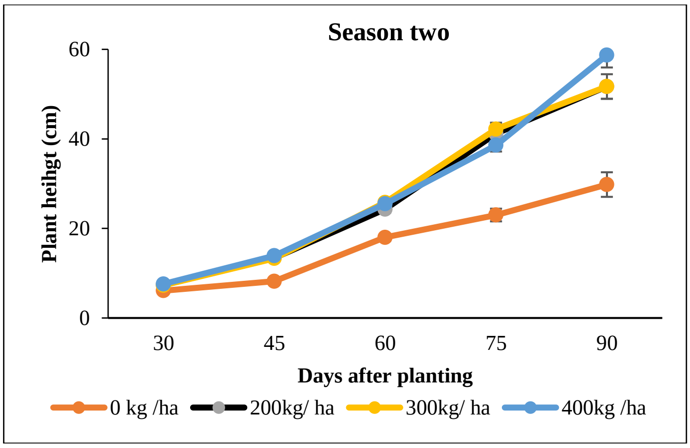

***Figure 2*b.** Effects of NPK on the beetroot plant height.

Table 3. Effects of co-application of biochar and NPK on beetroot plant height.

Biochar	NPK	Season one					Season two				
		Days after planting					Days after planting				
t/ha	kg /ha	30	45	60	75	90	30	45	60	75	90
0	0	6.1	15.8	26.8	32.1	31.5	6.2	7.6	18.1	22.5cd	27.6e
0	200	8.6	19.6	34.9	39.1	41.1	7.8	13.8	24.1	40.2ab	43.5ed
0	300	8.2	17.5	31.0	38.7	39.8	8.0	14.0	26.7	40.2ab	40.8ecd
0	400	8.4	16.9	29.9	37.9	39.7	8.7	14.5	26.6	36.8b	40.4ecd
5	0	6.3	16.2	28.0	37.0	37.8	6.0	8.1	18.5	18.5d	28.7e
5	200	9.2	20.2	34.3	43.4	44.9	8.1	14.7	24.1	42.1ab	53.4bcd
5	300	8.3	19.4	34.2	45.9	46.7	6.8	12.5	25.9	46a	46.7bcde
5	400	7.1	16.9	29.2	41.3	42.5	7.3	14.5	24.9	40.0ab	56.4abc
10	0	6.3	13.7	23.8	32.1	36.8	6.2	8.7	17.4	27.8c	33.2ed
10	200	6.9	18.1	32.3	41.9	42.7	6.3	11.8	24.6	41.2ab	58.3abc
10	300	6.3	20.3	35.2	43.1	46.0	7.2	13.5	24.9	40.2ab	67.6ab
10	400	8.2	20.2	35.4	42.5	45.0	7.1	12.5	25.2	39.0ab	79.2a
Significance		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**	*

NS: Not significant; *significant at $p>0.05$; ** significant at $p>0.01$
Means in the same column with the same letter are not significantly different at $p\leq0.05$.

Table 4. Effect of the interaction of biochar and NPK on the beetroot leaf area.

		Leaf area									
Biochar	NPK	Season one					Season two				
		Days after planting					Days after planting				
T/ ha	kg /ha	30	45	60	75	90	30	45	60	75	90
0	0	5.6	26.4	80.0	116.0	119.7	3.4	8.2	48.4	70.7d	81.8d
0	200	13.1	56.0	122.3	183.5	184.5	4.7	29.3	104.5	157.6c	121.7cd
0	300	12.0	56.8	119.8	190.6	188.7	5.7	24.7	120.2	162.2cb	140.3cb
0	400	11.6	58.4	119.1	186.6	194.9	6.9	30.3	96.0	162.1cb	149.1cb
5	0	11.0	39.9	101.0	156.2	157.8	3.1	9.1	52.7	61.3d	82.7d
5	200	14.6	56.2	125.5	198.0	199.3	6.8	36.4	112.4	182.7abc	193.6ab
5	300	13.2	64.3	165.1	209.2	227.0	5.1	21.1	101.0	189.7abc	187.5ab
5	400	8.9	48.3	121.2	196.7	197.8	6.0	33.8	112.3	186.4abc	189.0ab
10	0	7.0	31.3	81.2	134.3	137.6	3.0	12.4	55.3	75.6d	105.2cd
10	200	11.6	54.8	115.1	205.3	208.0	3.9	21.5	104.5	211.7a	213.2a
10	300	12.2	67.4	155.1	193.5	212.9	5.2	31.2	113.3	193.2ab	204.5a
10	400	11.2	68.3	122.3	180.4	182.3	5.5	24.5	91.3	190.8abc	193.0ab
Significance		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	*	*

NS: Not Significant; *significant at $p>0.05$
Means with the same letter within the column are not statistically different at $p\leq0.05$

Leaf area

The combined application of biochar and NPK significantly increased the leaf area of beetroot in season two, at 75 and 90 days after planting. The treatment B10N200 recorded the biggest leaves (211.7 cm^2), while B0N0 resulted in the smallest leaves (70.7 cm^2) at 75 days. At 90 days B10N200 showed the biggest leaves (213.2 cm^2) while B0N0 resulted in the smallest leaves (81.8 cm^2) (***Table 4***). The sole application of biochar significantly increased the leaf area in season one at 90 days after planting and at 75, and 90 days in season two. The treatment B5 was not statistically different from B10 but significantly different from the control and recorded an average leaf size of 195.5 cm^2, which was the largest leaf size among the others. In season two, B5 and B10 were statistically different from each other, and also different from the control, where B10 showed the highest leaf area index averaging 167.8 cm^2 at 75 days after panting. The treatments B5 and B10 were not statistically different from each other, but different from the control at 90 days (***Figure 3a-b***). In season one, the sole applications of NPK at the different rates (200, 300, 400kg/ha) were not statistically different from each other but were statistically different from the control at 30, 75, and 90 days after planting. But the trend was not the same at 60 days. The application of NPK at 300kg/ha recorded the biggest leaves averaging 146.7 cm^2 followed by the treatments NPK at 200 kg/ha and 400 kg/ha, which were not statistically different from each other. The control recorded the smallest leaves averaging 87.4 cm^2. In season two, the rates of NPK were not statistically different from each other but different from the control, throughout the season (***Figure 4a-b***).

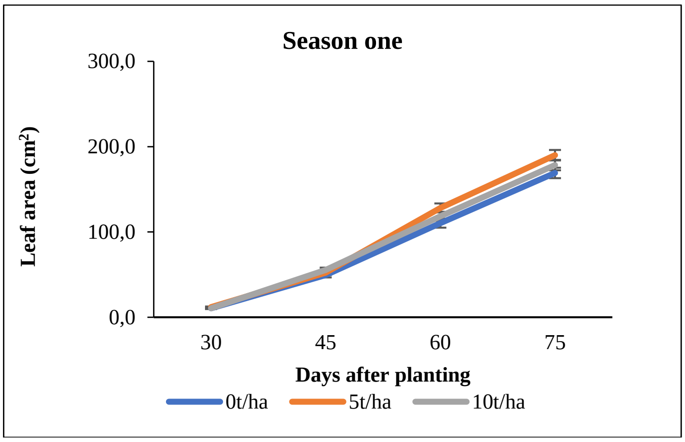

Figure 3a. Effect of biochar on the beetroot leaf area.

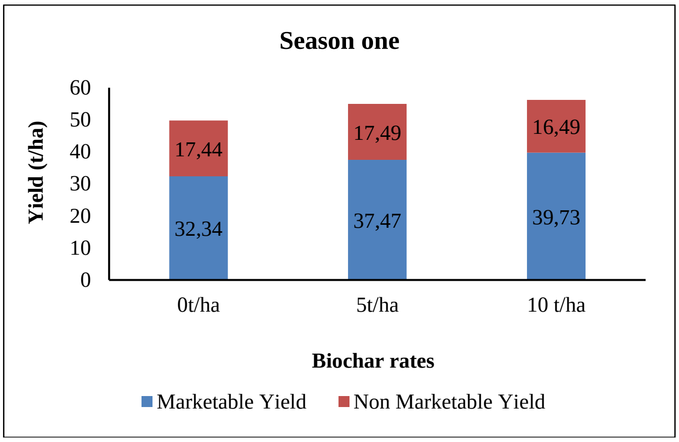

Figure 3a. Effect of biochar on the beetroot yield.

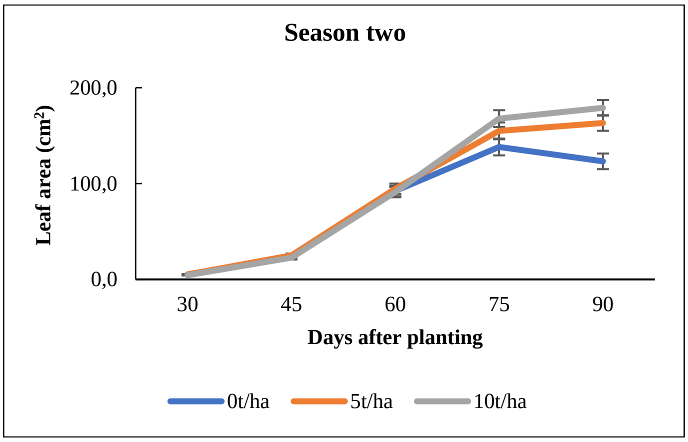

Figure 3b. Effect of biochar on the beetroot leaf area.

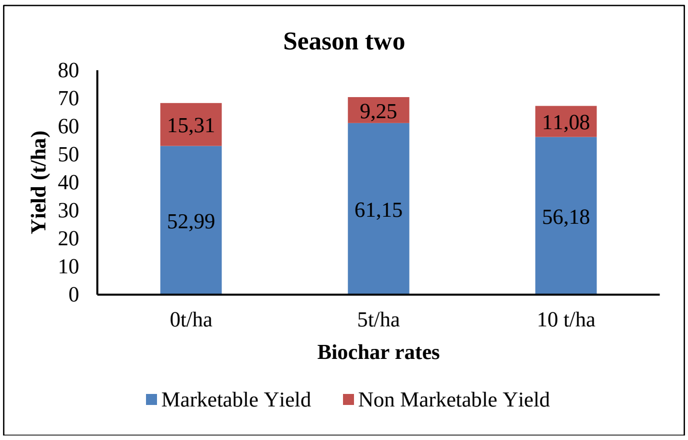

Figure 4b. Effect of biochar on the beetroot yield.

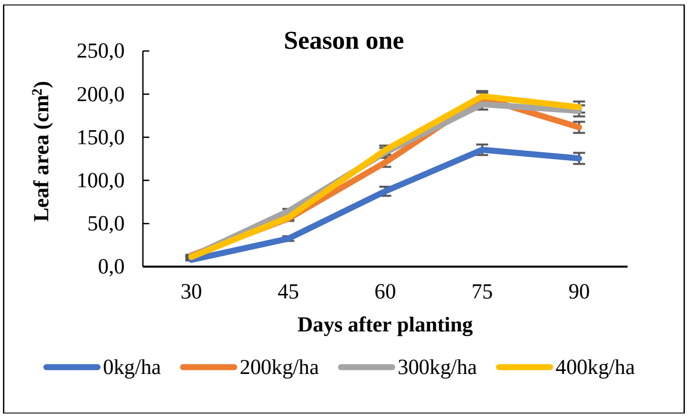

Figure 4a*.* Effect of NPK on the beetroot leaf area.

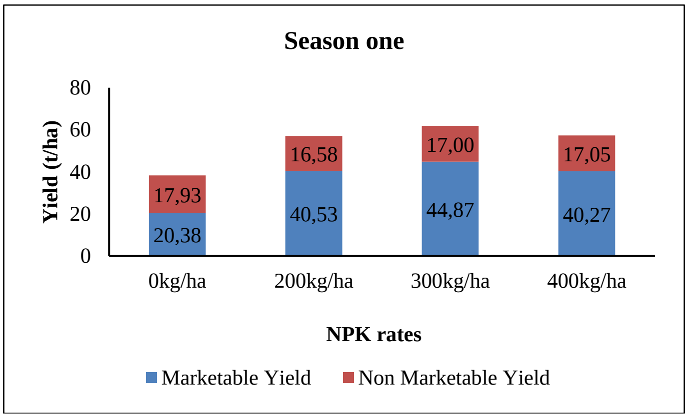

Figure 5a. Effects of NPK on the beetroot yield.

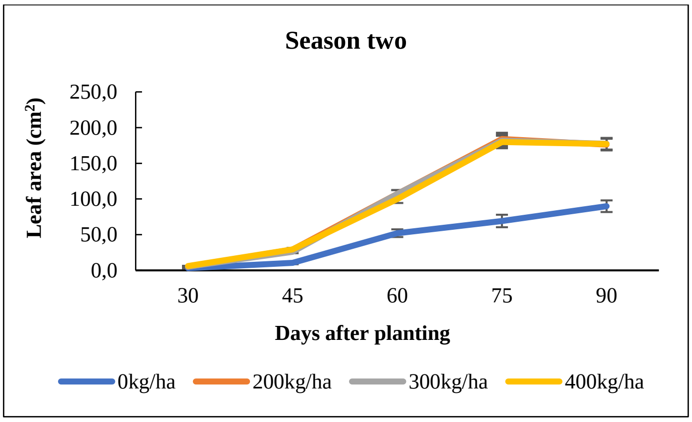

Figure 4b*.* Effect of NPK on the beetroot leaf area.

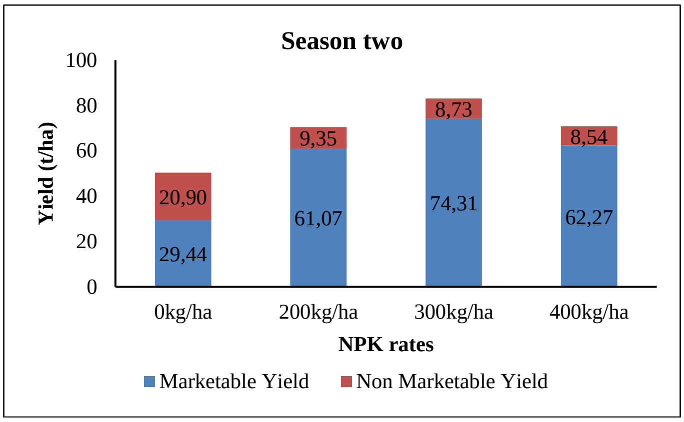

Figure 6b. Effects of NPK on the beetroot yield.

Table 5. Effect of the interaction of biochar and NPK on the total yield of beetroot.

Biochar	**NPK**	**Total yield**		**Marketable yield**		**Non-marketable yield**	
t /ha	**kg /ha**	**Season 1**	**Season 2**	**Season1**	**Season 2**	**Season1**	**Season2**
0	0	33.0	46.3	16.0	2.6c	17.0	43.8a
0	200	54.6	78.0	38.2	71.7ab	16.4	6.3b
0	300	56.1	73.9	38.4	66.3ab	17.7	7.6b
0	400	55.4	75.0	36.7	71.4ab	18.7	3.6b
5	0	44.1	56.9	25.3	48.3ab	18.8	8.7ab
5	200	59.9	67.5	43.3	60.1ab	16.6	7.4ab
5	300	61.8	94.4	44.2	84.0a	17.6	10.3b
5	400	54.0	62.8	37.2	52.2ab	16.9	10.6ab
10	0	37.7	47.8	19.8	37.5b	17.9	10.3ab
10	200	56.9	65.8	40.1	51.4ab	16.7	14.4b
10	300	67.7	80.8	51.9	72.6ab	15.8	8.2ab
10	400	62.6	74.7	47.1	63.2ab	15.6	11.5ab
Significance		**NS**	**NS**	**NS**	***	**NS**	**

NS: Not significant; ** significance at $p>0.01$; *** significance at $p>0.001$
Means with the same letter in the column are not statistically different at $p\leq0.05$

Effects of biochar and NPK on the yield of beetroot

The combined application of biochar and inorganic fertilizer (NPK) did not show a significant increase in the total yield of beetroot in both seasons one and two. However, the co-application of biochar and NPK had a significant effect on the marketable and non-marketable yield of beetroot in season two. The treatment B5N300 recorded the highest average of 84 t/ha, and the control recorded the lowest average of 2.6 t/ha (***Table 5***). On the other hand, the B0N0 recorded the highest non-marketable yield averaging 43.8 t/ha, and the B0400 recorded the lowest average of 3.6 t/ha. The sole application of biochar increased significantly the marketable yield in season 2. The Plots that received biochar at 5 t/ha (B5) recorded the highest average of 61.2 t/ha, and the control showed the lowest average of 53 t/ha (***Figure 5a-b***). On the other hand, the application of NPK at the rates of 200, 300 and 400 kg/ha significantly increased the total yield of beetroot compared to the control (0 t/ha) in seasons one and two. The plots that received 300 kg/ha of NPK recorded the highest total yield of 61.9 t/ha (***Figure 6a-b***) and a marketable yield of 44.8 t/ha in season one. In season two, the application of NPK (300 kg/ha) recorded a total yield of 83 t/ha and a marketable yield of 74.3 t/ha. The control recorded the lowest total yield in both seasons one and two (38.3 and 50.3 t/ha respectively) and marketable yield (20.9 and 29.4 t/ha respectively) (***Figure 6a-b***).

Discussion

Effects of biochar and NPK on beetroot growth

Plant height and leaf area were greatly influenced by the sole application recommended rate of NPK or its combination with biochar at 5 and 10 t /ha. Moreover, the combination of biochar at 5 and 10 t/ha with all the rates of NPK (0, 200, 300, 400) performed better than the sole application of biochar or NPK. This is because combining biochar with inorganic fertilizer has a synergistic impact, which contributes to the improvement of nutrient absorption by plant roots. Similar findings were reported by Walter & Rao (2015) who reported an increase in the height of sweet potatoes after combining biochar at 7 and 12 t/ha with inorganic fertilisers at 350 and 500 kg/ha and they attributed this growth to biochar's capacity to improve microbial activity and increasing soil aeration which allows root penetration to absorb beneficial nutrients to the plant. Results by Oladele et al. (2019) in Nigeria also revealed an increase in the growth of rice when biochar was combined with urea at 450 kg/ha. Similarly, Hamzah & Shuhaimi (2018) reported that when biochar at 8 t/ha was combined with nitrogen fertilizers (NPK) at 300 kg/ha, maize plants grew taller when compared to the control. Similar results were reported by Arif et al. (2017) who documented a significant increase in the height of maize after the application of the combined biochar and chemical fertiliser. They attributed their results to the ability of biochar to recycle organic matter in the soil. They have also reported that biochar as a soil amendment contributes to the absorption of heavy metals in agricultural soil. This explains clearly that biochar combined with inorganic fertilizer provided more nutrients for growth. This is because biochar applied as the soil amendment has the potential to improve some of the soil's chemical properties like pH, organic matter (OM), and microbial activity. As a consequence of the change in chemical properties, key soil processes like carbon mineralization and nutrient transformations could be increased in the soil (Summa et al., 2021).

Studies by Pandian et al. (2016) and Ghorbani et al., (2019) demonstrated the synergistic impact between biochar and inorganic fertilisers in promoting crop growth. The utilisation of biochar together with inorganic fertiliser demonstrated a great impact to increase beetroot growth due to its capability to increase the soil's macro and micronutrients as well as soil texture. Both B5N300 and B10N300 recorded a significant increase in beetroot growth. However, B10N300 improved growth more than B5N300 and this could be attributed to the amount of nutrients made available by the increase of biochar from B5N300 to B10N300. Another reason for the increase in beetroot height after the application of biochar and NPK could be due to its large surface area of biochar which might provide a conducive environment for beneficial micro-organisms to grow. This affects several processes in the soil like N cycling which improves fertility. Inorganic fertiliser NPK provided the nutrients needed for beetroot growth as seen by both the leaf area and plant height. Inorganic fertilisers have more nutrients easily available for plants. Hence, the application of N200 did not increase beetroot growth as N300 and N400 because of the reduced supply of nutrients. The application of 5 or 10 t/ha biochar alone increased beetroot growth with time; this might be explained by the biochar's ability to reduce soil bulky density to allow deep penetration of the roots for nutrient absorption. Findings by Carpenter & Nair (2014) revealed that the utilisation of charcoal dust as the soil conditioner increased the growth of the carrots with time and they attributed this to the increase of macronutrients and the type of biochar. An increase of sole biochar from B5 to B10 resulted in an improvement in beetroot growth because of the rise in nutrient content.

Effects of biochar and NPK on the yield of beetroot

The application of charcoal dust (biochar) and inorganic fertiliser (NPK) significantly increased the yield of beetroot. The results from this study recorded a slight increase in the growth and yield of beetroot with a sole application of biochar. This is validated by Manka et al. (2019) who documented a slight increase in the yield of carrots when biochar was applied alone at the rates of 5 t/ha in Burkina Faso. However, an increase in beetroot yield was recorded following a co-application of biochar and NPK, indicating a strong harmonizing effect of this pairing. This might be attributed to both the plant's greater access to nutrients provided by NPK and the capability of biochar to reduce soil acidity. The soil type in our study was slightly acidic (pH = 5.73) which was lower than 6.5 the ideal pH of beetroot, suggesting that it would benefit from biochar's liming properties as well as perhaps counteracting the acidic condition that results from its co-application with NPK. This soil conditioning brought on by the application of biochar is anticipated to also ameliorate the physical properties of the soil, promote prodigious growth of the root, and increase the chemical properties such as soil nutrients availability(Arabi et al., 2018). Additionally, the beneficial effects of biochar contributed to the improvement of soil microbial colony which normally plays a big role decomposition process leading to the increase in organic matter content in the soil.

Studies by Karer et al. (2013); Akoto et al. (2019); Gao et al. (2022) and Diatta et al. (2020) have documented that biochar plays a very great influence on soil nutrient availability such as carbon and nitrogen as well as increasing the activities of the enzymatic in the soil which greatly affect the environment for crop growth. The studies by Lychuk et al. (2015) and Sekar et al. (2014) also documented a rise in crop yield following an application of biochar and NPK. The results from our study are in line with results by Prapagdee and Tawinteung (2017), who reported that the combined application of biochar and chemical fertiliser in infertile soil was proven to have a more positive influence on the yield of green beans than when fertiliser or biochar applied alone. This may be attributed to the biochar amendment's positive effects of improving the soil chemical and physical properties of the soil and fertiliser use efficiency (Frišták et al., 2014; Rizhiya et al., 2020). The strong interactive effects of biochar rates (5, 10 t/ha) and NPK rates (200, 300, 400 kg/ha) on beetroot production can be attributed to the ability of biochar and NPK to supply nutrients to beetroot plants, condition the soil and increase fertiliser-use-efficiency of the beetroot cultivar in this study (Ahmed & Schoenau, 2015).

Conclusions

This research's findings prove that adding biochar to the soil could help enhance beetroot growth and yield, provided that it is combined with NPK fertiliser. In comparison with the application of sole synthetic fertiliser (NPK), biochar at (5-10 t/ha) and NPK fertiliser at (200, 300 and 400 kg/ha) contributed better to the increase of the growth and yield of beetroot. The combination of biochar at 5 t/ha and 300 kg/ha of NPK can be recommended to the farmers and other stakeholders involved in beetroot production. This is because it indicated the highest yield compared to the other treatments.

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