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The Role of Biochar and Phosphorus in the Growth and Yield of Potatoes

D A Mohammed, and B R Sarheed

Department of Soil Science, College of Agriculture, University of Anbar, Anbar, Iraq.

Corresponding author's e-mail: ag.bassam.ramadhan@uoanbar.edu.iq

Abstract. Two experiments were conducted, first was a laboratory to prepare plant charcoal from three different sources: rice straw, corn cobs, and sugarcane (B1, B2, and B3), with the aim of loading them with phosphorus from the superphosphate fertilizer source (21% P) at three levels of phosphorus: 50% , 75% and 100% of the recommended fertilizer for potatoes (F1, F2, and F3). Then, tested in a field experiment conducted at the agricultural research station of Anbar University's College of Agriculture in Albu Etha-, located at longitude E43.32.65 and latitude N33.45.37 in the fall season of 2022. The soil texture was sandy clay loam and the irrigation system was drip irrigation. Burren potato variety was planted to study the effect of adding three types of plant charcoal, supported with different levels of phosphorus, and using them as slow-release fertilizers on the availability of phosphorus and some properties and growth and yield of potato. The experiment followed a randomized complete block design with three replicates. The results showed a significant superiority of all plant charcoals supported with phosphorus compared to the treatment without adding charcoal. The treatment that added sugarcane waste charcoal (B3) recorded the highest value in all studied plant characters and yield (plant height, chlorophyll content of leaves, number of aerial branches, dry matter yield, total tuber yield, and marketable tuber yield).

1. Introduction.

Due to the high content of carbonates, especially calcium carbonates, and the low organic matter content, especially in the central and southern soils of Iraq, the availability of many macro and micro nutrients, especially phosphorus, has decreased due to its exposure to adsorption and deposition. This leads to its transformation into insoluble compounds in water and not available absorbable by plants [1]. Therefore, there is a need to add phosphorus as a mineral fertilizer, such as triple superphosphate fertilizer. Phosphorus is one of the main nutrients after nitrogen for plants. It is involved in the composition of nucleic acids, which play a major role in enzymatic reactions in plants, such as DNA, RNA, tRNA, and Ribosomal RNA. It is also involved in the composition of essential enzymes in energy reactions, including respiration and photosynthesis [2]. Additionally, it is involved in the composition of some phosphorus-rich energy compounds and lipids, such as ATP and ADP, and contributes to the formation of nuclear proteins, stimulating the growth of fibrous and lateral roots [3]. Phosphorus is one of the most important elements that suffers from deficiency in gypsum soils, and as a result, it undergoes many transformations in these soils due to its association with calcium, which is present in high concentrations in gypsum soils. Therefore, most of the added phosphate fertilizers undergo adsorption and deposition reactions. Research indicates that the plant absorbs about (15-20) % of the amount of fertilizer added, and the rest is either fixed chemically with soil compounds and colloids, or transformed into organic forms in the bodies of microorganisms (biological fixation), or absorbed onto soil aggregates and minerals. The phosphorous adsorption capacity of soil to adsorb phosphorus (PSC) can be very large, but it is not unlimited. [4] mentioned that the fact that the rate of conversion of plant-available phosphorus to non-available forms tends to decrease over time is often overlooked.



3. Studies have shown that the use of biochar is of great importance as a source of carbon that increases the activity of microorganisms, in addition to increasing the availability of essential plant nutrients, including phosphorus. [5] and [6] have shown that biochar reduces soil reaction and increases the effectiveness of living microorganisms, which work to increase nutrient release, including phosphorus, making it readily available for plant absorption. [7] pointed out that the use of biochar increases the availability of phosphorus, as it reduces the binding of calcium with phosphorus, thus increasing the availability of phosphorus for the plant. [8] have shown that due to the large number of pores in biochar, it has the ability to trap essential nutrients and retain them, reducing losses and fixation of these nutrients in the soil. Biochar can trap approximately 19-65% of phosphorus, and therefore increasing plant growth and yield. The potato *Solanum tuberosum* L. belongs to the Solanaceae family, and it is a tuberous crop. It comes in the fourth sequence in terms of economic and consumption importance after wheat, rice, and corn. It is one of the main crops in the diet of all the world's population, being a food source rich in energy of proteins, carbohydrates, starch, and amino acids. The main and also important minerals for human nutrition, Therefore the study aims were to investigate the effect of charcoal types on the growth and yield of potatoes and to determine the best type of biochar to reduce the levels of phosphorus used.

2. Materials and Methods

2.1. Laboratory experiment

2.1.1. Charcoal collection and preparation

A laboratory experiment was conducted to prepare phosphorus-supported plant-based charcoal. Plant residues were collected, including rice straw from rice fields in the south of Iraq's Basra governorate, corn stalks from the western Anbar governorate in the city of Rawah, and sugarcane from the east of the governorate, on the edge of the Euphrates River on Khaldiyyah Island. The plant residues were air-dried. On July 17, 2022, the plant residues were separately formed into piles for each of the three types used in the study and burned for a period of time between 6-7 hours for each pile, to reach a temperature of 300-380 degrees Celsius at the beginning of combustion. Then, water and soil were gradually added to the pile to close the ventilation ports and create small openings in different places for ventilation, causing the pile to burn slowly. Then, the temperature gradually decreases until it reaches 60 degrees Celsius in the middle of the burning time. When the color of the fire coming out of the pile's openings turns from black to blue, it indicates the completion of the combustion process, and then it is left to cool completely and become ready for use. To increase the speed of the burning process, the number of ventilation ports for the pile is increased.

2.1.2. The process of supporting charcoal with phosphorous.

Superphosphate mineral fertilizer with a phosphorus content of 21% P was used as a source of phosphorus. After calculating the amount of phosphorus for each experimental unit and for the three study levels (50, 75, and 100% of the recommended potato fertilization), 120 kg P ha⁻¹ was added [9] Additionally, charcoal was added at a rate of 1% of the experimental unit area (2.4 m), and the amount of charcoal for each experimental unit was calculated. The phosphorus was dissolved in distilled water, and then reinforced with plant-based charcoal by placing it in cylinders with a diameter of 10 cm to obtain the highest concentration of mineral fertilizer..

2.2. Field experiment

2.2.1 Experimental site

The study was conducted at the Agricultural Research Station of Anbar University - College of Agriculture during the fall season of 2022 in the Anbar Governorate - Al-Ramadi district - Al-Bu Atha area, located on longitude E43.32.65 and latitude N33.45.37. The soil was sandy-clay loam texture, classified as Typic Torrifluvents according to the modern US classification system (USDA, 2010). Soil samples were taken from the field before planting, from a depth of 0-30 cm, and from different locations. A representative sample of the field soil was taken and sieved with a 2 mm sieve to perform some physical and chemical properties before planting (Table 1).

The land was prepared by plowing it with a moldboard plow to a depth of about 0.30 m, followed by soil leveling, smoothing, and dividing it into three symmetrical blocks. Potatoes (*Solanum tuberosum* L.) of the Burren variety were planted on 26/9/2022 on furrows, where the length of each furrow was 3 m, the distance between furrows was 0.8 m, the distance between potato tubers was 0.25 m, and the number of tubers in each experimental unit was 36 tubers, distributed over three furrows per experimental unit. The area of each experimental unit was 4.2 m², with a distance of 1 m between experimental units and 2 meters between blocks to prevent the transfer of fertilizers between treatments.

Table 1. Some physical and chemical properties of the experimental field soil before planting

Character	Unit	Value
pH 1:1		7.02
EC 1:1	Desi Siemens m ⁻¹	4.76
Soil Organic Matter	g kg ⁻¹	5.40
CaCO ₃	%	10.30
Bulk density	µg m ⁻³	1.30
CEC	cmol kg ⁻¹ of soil	23.80
Cationic dissolved ions	Ca ²⁺	meq L ⁻¹
	Mg ²⁺	6.23
	Na ⁺	3.89
	K ⁺	5.60
Anionic dissolved ions	SO ₄ ⁻²	1.39
	HCO ₃ ⁻	7.52
	Cl ⁻	1.69
		6.70
Available N	mg kg ⁻¹ of soil	25.00
Available P		10.30
Available K		90.80
Soil separates	Sand	g kg ⁻¹ of soil
	Silt	684
	Clay	112
Soil texture	Sandy clay loam	204

Analyzed in the laboratories of the College of Agriculture - University of Anbar

2.2.2. Study factors

Factorial experimental (4x3) was conducted according to a complete randomized block design, which included the following factors: First factor: Types of charcoal (B)

- 1- Without adding charcoal (B0)
- 2- 2- Rice husk charcoal (B1)
- 3- 3- Corn cob charcoal (B2)
- 4- 4- Sugarcane charcoal (B3)

Second factor: Phosphorus levels (F)

- 1- Full recommended dose of fertilizer (triple superphosphate) adding 100% P (control) (F1)
- 2- Adding 75% of the recommended dose of P (F2)
- 3- 3- Adding 50% of the recommended dose of P (F3)

This resulted in 12 treatments with three replications each, for a total of 36 experimental units. Nitrogen fertilizer was added at a level of 240 kg N ha⁻¹ in the form of urea with two applications, and potassium fertilizer was added at a level of 400 kg K ha⁻¹ in the form of potassium sulfate with two applications (9). Phosphate fertilizer treatments were added at a level of 120 kg P ha⁻¹, which is the recommended 100% dose (9). added at three levels according to the factors of the study inoculation at the time of cultivation.

2. Results and Discussion

3.1. Plant Height (cm)

The results of the statistical analysis revealed a significant effect of adding all types of supported coal with different ratios of phosphorus on the potato plant height (Table 2). Treatment of adding sugarcane charcoal (B3) achieved the highest value of 41.23 cm, with an increase of 38.91% compared to the

treatment without adding charcoal (B0), which had the lowest value of 29.68 cm. The reason for this is due to the specifications of sugarcane charcoal, which has many basic nutrients for the plant such as phosphorus, nitrogen, and potassium. It also improves the physical and chemical properties of the soil and enhances microbial activity by providing a well-ventilated environment. Sugarcane charcoal has a low reactivity level (pH) of 4.03 and a high cation exchange capacity of up to 37.29 cmol kg⁻¹. It also has numerous pores that increase nutrient retention inside them, thereby increasing the availability of nutrients during charcoal production at temperatures up to 250°C. These results are consistent with Jasim [10].

As shown in the table, there is a significant difference when adding mineral phosphorus at the full recommendation (100%), which achieved the highest plant height value (36.74 cm). This did not differ significantly from adding half the recommended amount of phosphorus (50%), but both were significantly different from the level of adding phosphorus at a rate of 75%, which resulted in the lowest plant height (34.26 cm).

The results of the table also demonstrate the significant interaction effect between the study factors, as treatment F3B3, which represents the addition of sugarcane charcoal supported with 50% of the recommended fertilizer phosphorus, achieved the highest plant height value of 44.93 cm, with an increase of 60.4% compared to treatment F3B0, which had a plant height of 28.00 cm.

Table 2. The effect of adding phosphorus-fortified charcoal on the plant height (cm)

Charcoal type (B)	Recommended fertilizer (F)			Mean
	100% (F1)	75% (F2)	50% (F3)	
No charcoal added (B0)	31.4	29.6	28.0	29.68
Charcoal (B1)	33.9	35.7	37.4	35.69
Charcoal (B2)	40.0	34.5	36.4	37.00
Charcoal (B3)	41.6	37.1	44.9	41.23
Mean	36.7	34.2	36.7	
L.S.D 0.05%	F = 2.1	B = 2.1		FB = 5.019

2.2. Chlorophyll Content of Leaves (SPAD)

The statistical analysis indicated a significant effect of adding all types of plant-based charcoal supported by different levels of phosphorus on the chlorophyll content of leaves (Table 3), as the treatment of adding sugarcane charcoal (B3) achieved the highest value of 43.95 SPAD units and an increase percentage of 18.43% compared to the control treatment (B0), which had the lowest value of 37.11 SPAD units. The results are consistent with Jasim [10], which showed that all sugarcane charcoal treatments outperformed the control treatment in terms of chlorophyll content in okra leaves.

The results also showed a significant difference when adding mineral phosphorus at the recommended rate (100%) and achieved the highest value of chlorophyll content in leaves (41.59 SPAD units). This value was not significantly different from adding phosphorus at a rate of 75%, but it was significantly different from adding phosphorus at a rate of 50%, which resulted in the lowest increase in plant height and chlorophyll content in leaves (40.93 SPAD units).

Furthermore, the results showed a significant interaction effect between the study factors, as the treatment F3B3, which represents the addition of sugarcane charcoal supported by 50% of the recommended phosphorus fertilizer, achieved the highest value of chlorophyll content in leaves (44.90 SPAD units) and a percentage increase of 25.41% compared to the treatment F3B0, which achieved 35.80 SPAD units.

Table 3. The effect of adding phosphorus-fortified charcoal on the Chlorophyll Content of Leaves (SPAD)

Charcoal type (B)	Recommended fertilizer (F)	Mean
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	100 (F)	75 (F)	50 (F)	
No charcoal added (B0)	38.	36.	35.	37.11
Charcoal (B1)	41.	42.	41.	41.80
Charcoal (B2)	42.	41.	41.	41.82
Charcoal (B3)	43.	43.	44.	43.95
Mean	41.	40.	40.	
L.S.D 0.05%	F = 1	B = 1		FB = 3.441

3.3. Number of main branches (branch plant⁻¹)

The results showed a significant effect of adding all types of plant charcoal supported by different proportions of phosphorus on the number of main branches (Table 4). The treatment of adding sugarcane bagasse charcoal (B3) achieved the highest value of 3.20 branch plant⁻¹, with an increase percentage of 85.83% compared to the control treatment (B0) which reached the lowest value of 1.722 branch plant⁻¹. This is due to the specifications of sugarcane charcoal, which possesses many essential plant nutrients such as phosphorus, nitrogen, and potassium, as well as improving soil physical and chemical properties and enhancing microbial activity by providing a well-ventilated environment. It also has a low reactivity degree (pH) of 4.03 and a high cation exchange capacity of 37.29 cmol kg⁻¹, as well as large pores with numerous numbers that increase the reservation of nutrients, thus increasing their availability when producing charcoal at temperatures up to 250°C. These results are consistent with Jassem [10].

The results indicate a significant difference when adding 75% of mineral phosphorus, which achieved the highest value of 2.658 branch plant⁻¹ and was not significantly different from adding 50% recommended phosphorus or 100% added phosphorus level, which obtained the lowest number of main branches (2.367 branch plant⁻¹).

Furthermore, the results show the significant effect of the interaction between the study factors. The treatment of adding sugarcane charcoal supported by 50% recommended phosphorus achieved the highest value of 3.533 branch plant⁻¹, with an increase percentage of 135.5% compared to the treatment of adding charcoal without phosphorus (F2B0) at 1.50 branch plant⁻¹.

Table 4. The effect of adding phosphorus-fortified charcoal on number of main branches (branch plant⁻¹)

Charcoal type (B)	Recommended fertilizer (F)			Mean
	100%	75%	50%	
No charcoal added (B0)	2.133	1.500	1.533	1.722
Rice straw charcoal (B1)	2.300	3.000	2.600	2.633
Corn cobs charcoal (B2)	2.300	2.800	2.833	2.644
Sugarcane charcoal (B3)	2.733	3.333	3.533	3.200
Mean	2.367	2.658	2.625	1.722
L.S.D 0.05%	F = 0.268	B = 0.309		FB = 0.536

3.4. Dry matter yield of for the vegetative part (g plant⁻¹)

The results showed a significant effect of adding all types of plant charcoal supported by different proportions of phosphorus on the dry matter yield of for the vegetative part (Table 5). The treatment of adding sugarcane charcoal (B3) achieved the highest value of 81.75 g plant⁻¹, with an increase percentage of 57.21% compared to the control treatment (B0) with the lowest value of 52.00 g plant⁻¹. This is due to the specifications of sugarcane charcoal, which possesses many essential plant nutrients such as phosphorus, nitrogen, and potassium, as well as improving soil physical and chemical properties and enhancing microbial activity by providing a well-ventilated environment. It also has a low reactivity degree (pH) of 4.03 and a high cation exchange capacity of 37.29 cmol kg⁻¹, as well as large pores with

numerous numbers that increase the reservation of nutrients, thus increasing their availability when producing charcoal at temperatures up to 250°C. These results are consistent with [10], who found that all types of plant charcoal outperformed, with the highest dry weight of 9.31 g plant⁻¹, while [11], found that the treatment of adding plant charcoal supported by phosphorus had a superior dry weight yield of for the vegetative part of 10.26 g dry matter pot⁻¹.

The result also indicates a significant difference when adding mineral phosphorus, as the treatment of adding 50% recommended phosphorus achieved the highest value of dry matter yield of for the vegetative part (75.25 g plant⁻¹) compared to adding 75% recommended phosphorus or 100% added phosphorus level, which obtained the lowest dry matter yield of for the vegetative part (64.5 g plant⁻¹).

Furthermore, the result shows the significant effect of the interaction between the study factors. The treatment of adding sugarcane charcoal supported by 50% recommended phosphorus achieved the highest value of dry matter yield of for the vegetative part (97.41 g plant⁻¹), with an increase percentage of 109.8% compared to the treatment of adding charcoal without phosphorus (F3B0) which reached 46.41 g plant⁻¹.

Table 5. The effect of adding phosphorus-fortified charcoal on dry matter yield of for the vegetative part (g plant⁻¹)

Charcoal type (B)	Recommended fertilizer (F)			Mean
	100% (F1)	75% (F2)	50% (F3)	
No charcoal added (B0)	56.5	53.00	46.41	52.00
Rice straw charcoal (B1)	56.83	69.08	82.08	69.33
Corn cobs charcoal (B2)	69.83	66.16	75.08	70.33
Sugarcane charcoal (B3)	74.83	73.08	97.41	81.75
Mean	64.5	65.3	75.25	
L.S.D 0.05%	F = 0.1669 B = 0.1927			FB = 0.3337

3.5. Total tuber yield (Mg ha⁻¹)

Total tuber yields significantly influenced by adding different types of charcoal fortified with varying levels of phosphorus, as shown in Table (6). The treatment of adding bagasse coal (B3) achieved the highest yield of 27.55 µg ha⁻¹ with an increase percentage of 39.39% compared to the control treatment (B0), which recorded the lowest value of 19.77 µg ha⁻¹. This can be attributed to the specifications of bagasse coal, as it contains many essential plant nutrients such as phosphorus, nitrogen, and potassium. Additionally, it improves the physical and chemical properties of the soil and enhances microbial activity by providing a well-ventilated environment. Bagasse coal also has a low reactivity degree, reaching 4.03, a high cation exchange capacity of 37.29 cmol/kg, and a large number of internal pores that increase the retention of nutrients, thus increasing the availability of nutrients during coal production at temperatures up to 250°C. These results are consistent with Jassim [10]

Results also indicates a significant difference when adding mineral phosphorus (Table 6), as the treatment of adding 50% of the recommended fertilizer dose achieved the highest value of total tuber yield (24.86 µg ha⁻¹), which was significantly higher than the treatments of adding 100% and 75% phosphorus, which recorded total tuber yield of 23.40 and 23.33 µg ha⁻¹, respectively.

Moreover, the results of the table show the significant effect of the interaction between the study factors, where the treatment of adding sugarcane charcoal fortified with 50% of the recommended fertilizer dose (F3B3) achieved the highest value of total tuber yield, reaching 31.81 µg ha⁻¹ with an increase percentage of 77.51% compared to the treatment of adding sugarcane charcoal without adding any phosphorus (F3B0), which recorded a value of 17.92 µg ha⁻¹.

Table 6. The effect of adding phosphorus-fortified charcoal on total tuber yield (µg ha⁻¹)

Charcoal type (B)	Recommended fertilizer (F)	Mean
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	100% (F1)	75% (F2)	50% (F3)	
No charcoal added (B0)	21.53	19.86	17.92	19.77
Rice straw charcoal (B1)	22.92	24.44	25.42	24.26
Corn cobs charcoal (B2)	23.89	23.47	24.31	23.89
Sugarcane charcoal (B3)	25.28	25.56	31.81	27.55
Mean	23.40	23.33	24.86	
L.S.D 0.05%	F = 2.251	B = 2.600		FB = 4.503

3.6. Marketable Tuber Yield ($\mu\text{g ha}^{-1}$)

The statistical analysis results showed a significant effect of adding all types of phosphorus-supported plant charcoal on the marketable tuber yield (Table 7), where the treatment of adding sugarcane charcoal (B3) achieved the highest value of $24.68 \mu\text{g ha}^{-1}$ with a percentage increase of 48.05% compared to the control treatment (B0), which reached the lowest value of $16.67 \mu\text{g ha}^{-1}$. This is due to the specifications of sugarcane charcoal, which contains many essential plant nutrients such as phosphorus, nitrogen, and potassium. It also improves the physical and chemical properties of soil and enhances microbial activity by providing a well-ventilated environment. Additionally, it has a low reactivity level (pH) of 4.03 and a high cation exchange capacity of $37.29 \text{ cmol kg}^{-1}$, as well as large pore spaces with numerous counts, which increase the absorption of nutrients and thus increase the availability of nutrients when producing charcoal at temperatures up to 250°C . These results are consistent with Jasim [10]

The table also indicates a significant difference when adding mineral phosphorus at a rate of 50%, which achieved the highest value for the marketable tuber yield ($21.94 \mu\text{g ha}^{-1}$) and did not differ significantly from the recommended rate of phosphorus addition at 100%, nor did it differ significantly from the level of phosphorus addition at 75%, which resulted in the lowest tuber yield ($19.17 \mu\text{g ha}^{-1}$).

Moreover, the results show a significant effect of the interaction between the study factors, as the treatment of adding sugarcane charcoal supported by phosphorus fertilizer at a rate of 50% of the recommended fertilization rate (F3B3) achieved the highest value for the marketable tuber yield at $29.86 \mu\text{g ha}^{-1}$, with a percentage increase of 93.64% compared to the control treatment (F3B0), which reached $15.42 \mu\text{g ha}^{-1}$.

Table 7. The effect of adding phosphorus-fortified charcoal on Marketable tuber yield ($\mu\text{g ha}^{-1}$)

Charcoal type (B)	Recommended fertilizer (F)			Mean
	100% (F1)	75% (F2)	50% (F3)	
No charcoal added (B0)	15.42	16.81	15.42	16.67
Rice straw charcoal (B1)	21.39	18.89	21.39	20.00
Corn cobs charcoal (B2)	21.11	18.47	21.11	19.81
Sugarcane charcoal (B3)	29.86	22.50	29.86	24.68
Mean	21.94	19.17	21.94	
L.S.D 0.05%	F = 2.187	B = 2.525		FB = 4.373

4. Conclusion

We recommend recycling plant waste and converting it into biochar (especially cane waste) fortified with 50% of the fertilizer recommendation.

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