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Interaction between Biochar Sources and Phosphorus Rates on Maize Growth and Yields in Acrisols and Ferralsols of Bungoma County, Western Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors made substantial contributions from conception to design. Author MCO was responsible for the study implementation in the field, data collection and analysis, Interpretation of the data and drafted the article. Author MNF assisted with agronomical aspects of the study. Author KAC assisted in the research layout, design and Biochar pyrolysis while Author MJ handled the literature reviews, soil profile characterizations and interpretation of both agronomic and soil data. All authors read and approved the final manuscript.

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ABSTRACT

Large proportion of phosphate fertilizer applied to acrisols and ferralsols soils reacts with aluminum (Al) and iron (Fe) to become unavailable for plant uptake. Biochar has been proposed to increase the bioavailability of phosphorus and other nutrients in the soil. The study aimed to increase maize production in low phosphorus (P) soils by evaluating the availability of phosphorus (P) in soils amended with different sources of biochar mixed with different rates of phosphorus in Acrisols and Ferralsols. Biochars were produced from three sources of feedstock: sugarcane bagasse (SB) from Butali sugar factory, wood sawdust (WS) from sawmills within Kakamega town and coffee husk (CH) from Kimukung'i coffee factory in Bungoma county. The feedstocks were pyrolysed using fabricated kilns at Kalro Kakamega. The agronomic evaluation of the fertilizers was carried out in two successive seasons of long rains and short rains of 2023 on maize crops Z*ea mays* l.) In Kibabii site (Acrisols) and Chwele site (Ferralsols) field experiment using a split plot design with three replications. Biochar sources formed the main plots and the subplots were assigned phosphorus (P) rates. The treatments consisted of three sources of biochar (wood sawdust (WS), sugarcane bagasse (SB), coffee husk (CH) and three fertilizer use recommendation project (FURP) phosphorus (P) rates (0, 13, and 26 kg P/ha) on two soil types (Acrisols and Ferralsols). Treatments were applied simultaneously in plots measuring 2.5 m x 4.5 m in all the sites. Maize hybrid 513 at seed rate of 125 kg /ha was planted at a spacing of 75 cm x 25 cm giving a maize population of 53,333 per hectare. Nitrogen fertilizer was applied at the rate of 75kg/ha^{-1} Nitrogen in two split applications of 35 kg/ha^{-1} Nitrogen at planting and 40 kg/ha^{-1} Nitrogen as topdressing at mid vegetative stage per season. Phosphorus rates and biochar sources interactions on maize grain yields were significant differences (P≤0.05). Maize stover and grain yields in Kibabii and Chwele was significantly high under a combination of coffee husks biochar with 26 kg/ha^{-1} phosphorus treatment. The study concludes that the interaction of biochar sources and phosphorus (P) rates was highly significant in Ferralsols soils and not significant in Acrisols soils. This may be due to chelation of sesquioxides in ferralsols which enhances fixed phosphorus release thereby leading to improved crop development.

Keywords: Biochar; Acrisols; Ferralsols; coffee husk; wood sawdust; sugarcane bagasse.

1. INTRODUCTION

Western Kenya is one of the densely populated regions in the Kenya, with about 700 humans per km^2 with farm sizes averaging 0.5 ha (Opala et al., 2018) of which about one – third is planted to maize (staple food in the region). Over 95% of the total farming community in this region are smallholder who often harvest maize yields below 1 t ha^{-1} season^{-1} (Kisinyo et al*.,* 2024). The low maize crop production in this region, particularly in areas under rainfed agriculture, is mainly attributed to the low soil fertility that continues to decline and low use of either inorganic or organic fertilizers (Ngomea et al., 2013).

Phosphorus applied to soils having insufficient amounts of the element for crop production is fixed by the soil thereby becoming unavailable for use by the crop (Thomas et al.,2019). This leads to large amounts being supplied to cater for fixation and to leave some for use by crops. Phosphate fertilizers are expensive and farmers may not afford, therefore becomes uneconomical and unsustainable. Phosphorus is present in the soil as inorganic (Pi) and organic (Po) forms. Total Phosphorus amounts range from 0.1 to 0.4 per cent, but values upto 0.7 per cent have been found in some arable soils in East Africa (Omenyo 2013). This total Phosphorus content in soils also varies considerably, mainly as a result of the influence of the underlying parent materials and climatic variations. Due to low inherent soil fertility in the highly weathered Ferralsols and Acrisols, their nutrient phosphorus is well-known to be widely deficient. Efforts to improve their Phosphorus nutrient content is a problematic due to Phosphorus fixation. To solve the problem of Phosphorus fixation, the use of biochar as a soil amendment was proposed.

Biochar is a solid material of pyrolysed biomass under low or no oxygen environment (Santos Dos et al., 2019). It is a carbon-rich solid. Biochars are produced from a wide range of organic feedstocks under different thermochemical conditions. It has been reported that biochar can increase the cation exchange capacity (CEC) in soils, change soil pH and influences plant access to soil P. Because biochar properties can differ widely, it is important to examine which characteristics of biochar have an influence on Phosphorus availability in Acrisols and Ferralsols of Western Kenya.

The experiment conducted by Santos Dos et al., (2019) in a green house in Brazil and found that simple association of soluble phosphate fertilizer (TSP) with the biochars did not increase the phosphorus use efficiency by maize cultivated in a clayey soil with high P-fixing capacity. However, in a field experiment under temperate climate (Glaser et al., 2015), it was demonstrated that low biochar amounts (1.0 t ha-1) combined with mineral fertilizer had better performance compared to pure fertilizers (Glaser et al., 2015). In this experiment biochar was made from maize digestate, soils were Cambisols and Chernozems and fertilizers were DAP, Urea and Potassium Oxide. While Santos Dos et al., (2019) did not find Phosphorus use efficiency by maize in greenhouse experiment, Glasier et., (2015) reports better performance of maize in the field when both used biochar. There is need for further field experiment on the performance of maize on Ferralsols and Acrisols treated with biochar. This experiment determined the effect of biochar (produced from locally available feedstock sources) mixed with phosphorus on stover and grain yields performance of maize crop in Acrisol and Ferralsols soils.

2. MATERIAL AND METHODS

2.1 Description of Experimental Sites

The experiments were laid out in Acrisols within Kibabii University and Ferralsols in a farmer field. Kibabii University is located at 0°37′3″N 34°31′25″E. The Ferralsols site was located at 0.72105^0N, 34.57255^0E. The two sites are found within Bungoma County which has two main agroecological zones, namely: Humid and Sub-humid (County Government of Bungoma, 2013; Jaetzold and Schmidt, 2012). The county covers a land area of 3032.4 km^2, of which 618 km^2 is gazetted forest reserve, 61 km^2 is nongazetted forest, and 50.7 km^2 is Mt. Elgon National Park. The topography of the county is characterized by a succession of lowland and highlands. The altitude of the county ranges from 1,200 m above sea level to 4,321 m above sea level at the summit of Mt. Elgon with the dominant soil types being Acrisols, Ferralsols and Nitisols (County Government of Bungoma, 2018).

The long rains season, which runs between February and June, is wetter than the second rainy season, experienced between late July and December. A dry season (characterized by fewer than 80 mm rainfall) is experienced from December to February. April and May receive the highest rainfall (more than 200 mm per month). The experiment was done during the growing seasons. The annual average precipitation in the county is 1100-1700 mm. Most of the county receives an annual average precipitation of more than 1400 mm (Ministry of Agriculture, Livestock, Food Security and Cooperatives. 2021).

The annual average temperature range for Bungoma is between 10-25°C, although elevation affects temperatures and most of the land area experiences an annual average temperature of more than 20°C. The County has a population of 1,670,570 people, of which 49% are males and 51% are females (KNBS, 2019a). The population density is 454 people/km^2, making the county the fifth most populated in Kenya. Agriculture is the backbone of county, with 78% of households engaged in crop and livestock farming (KNBS, 2019b). About 50% of people living in the county earn their income directly from the agricultural sector hence the need for increased food production through introduction of the use of P fertilizers amended with Biochar.

2.2 Experimental Design, Treatments and Crop Management

The treatments consisted of three levels of Phosphate fertilizer (0, 13, 26 kg/ha^{-1} phosphorus), three sources of biochar (Wood sawdust, Coffee husk, Sugarcane bagasse) on two types of soils (Acrisol and Ferralsols) resulting to 9 treatments as shown in Table 1).

The treatments were applied in a Split plot design with three replicates whereby the biochar sources were the main plot and the subplots assigned P rates (i.e. two factors; biochar sources and P rates).

The 2.5 m by 4.5 m plots were laid out in three blocks. Each block contained a main plot which was allocated treatment: Sugarcane Biochar, Coffee husk Biochar and Wood sawdust Biochar. The sub plots were allocated three different rates of phosphate application (0, 13 and 26 kg/ha^{-1} phosphorus) ±Biochar. These were randomly applied to the plots. The plots were separated with a 0.5 m path, with the blocks

Table 1. Treatments used in the field study

Plot Number	Code	Treatment combinations
P1	WS P_0	Phosphorus at 0 kg/ha with Wood sawdust Biochar.
P2	WSP13	Phosphorus at 13 kg/ha with Wood sawdust Biochar.
P3	WSP26	Phosphorus at 26k g/ha with Wood sawdust Biochar.
P4	CH P_0	Phosphorus at 0kg/ha with Coffee husk Biochar.
P5	CHP13	Phosphorus at 13 kg/ha with Coffee husk Biochar.
P6	CHP26	Phosphorus at 26 kg/ha with Coffee husk Biochar.
P7	SB P_0	Phosphorus at 0 kg/ha with Sugarcane Biochar.
P8	SBP13	Phosphorus at 13 kg/ha with Sugarcane Biochar.
P9	SBP26	Phosphorus at 26 kg/ha with Sugarcane Biochar.

being separated with a 1 m path between them. This gave rise to a 45.5 m long by 8.5 m wide experimental farm size.

The treatments were applied simultaneously in plots measuring 2.5m x 4.5m in all the sites. To do away with the possible deficiency of the commonly limiting nitrogen, all experimental units received a blanket application of 75 kg/ha^{-1} Nitrogen (FURP, 1994). The plots received nitrogen as Calcium Ammonium Nitrate (CAN) in two applications: 35 kg/ha^{-1} Nitrogen at planting and 40 kg/ha^{-1} Nitrogen as topdressing at mid vegetative stage per season. The source of Phosphorus was from Diammonium Phosphate (DAP) fertilizer. Biochar was applied at a rate of $5t/ha^{-1}$ (Yeboah et al., 2016) by thoroughly mixing it with the soil. The applied fertilizers were covered with some soil before placing the seeds to avoid direct contact of seed with fertilizer.

Hybrid 513 from Kenya Seed Company, which is recommended for medium altitude areas of Kenya (Akinyi,2019), was planted in all the sites at a spacing of 75 cm (inter-row) and 25 cm (intra-row) to give a maize population of 53,333 per hectare. Two seeds of maize were planted per hole and later thinned to one at two weeks after emergence. The crops were sprayed to control pests during growth. They were also weeded three times and harvested at physiological maturity for all the seasons in the sites. The yields of the crops were reported on dry weight basis.

2.3 Data Collection and Analysis

Harvesting of grains were done after the crop has reached physiological maturity. Grain yields in each treatment was determined from a net plot of $6m^2$. The cobs were removed, counted, and recorded. Eight cobs were randomly selected and fresh weight determined. The grains of the 8 selected cobs were separated and their fresh weights determined separately. The grain sub-sample were oven dried (at 60ºC for 48 hours) and reweighed to determine moisture content. After drying to 12.5% moisture content the final dry weight was determined and recorded. The above data was used in yield estimation using the equation:

$$\text{Yield (kg/ha)} = (\text{Yield/plot} \times 10{,}000m^2) / \text{Effective area } (m^2) \text{ (Omenyo 2013)}$$

The available soil phosphorus was analysed using procedures as per Okalebo et al., (2002).

Maize crop yields and available P data obtained were subjected to analysis of variance (ANOVA) using GenStat 14th edition 2012 and means separated by Least Significant Difference (LSD) for a significant different variable. Analysis of variance (ANOVA) was carried out to determine whether there were significant differences among factors (Biochar sources, P rates, and their interaction) on Acrisols and Ferralsol soil types on plant yield parameters over the entire growth period. Fisher's LSD (t-test) was used to separate means at $P<0.05$. For this analysis, however, the factorial scheme 3 x 3 (three sources of Biochar vs three doses of P) was adopted. Correlation analysis was done to establish the relationship between plant growth parameters and grain yield. The results are presented graphically.

3. RESULTS AND DISCUSSION

3.1 Initial Physical and Chemical Characteristics of the Soils at Study Sites

The initial soil characterization revealed acidic soils with a soil pH 5.96 and 4.69 in Acrisols and Ferralsols respectively (Table 2).

Table 2. Initial soil properties (0-15 cm depth) of the experimental sites

	Acrisols	Ferralsols
pH (1:2.5 soil: water)	5.96	4.69
Olsen P (mg kg^{-1})	9.2	3.4
% Nitrogen (N)	0.128	0.215
% Carbon (C)	2.342	1.292
C:N ratio	10.093	10.893
Exchangeable acidity (**mg kg^{-1}**)	0.493	0.934
Exchangeable bases (mg kg^{-1}) (Mehlich extraction)		
Ca	3.749	3.488
K	0.648	1.896
Mg	0.831	0.61
Micronutrients (mg kg^{-1}) (EDTA extraction)		
Zn	0.205	0.199
Fe	2.391	2.56
Cu	0.072	0.143
Soil Texture (Bouyoucos Hydrometer method)		
% Content		
Sand	57	76
Clay	24	11
Silt	19	13
Textural class	Sandy clay loam	Sandy clay loam
WRB Soil Classification	Orthic Acrisol	Rhodic Ferralsol

The experimental locations at Chwele and Kibabii have soils categorized as Ferralsols and Acrisols, respectively. According to (Keino et al., 2015), these soils are worn and extremely acidic. Leaching may be the cause of the cations concentration rising in Ferralsols soils down the profile, a phenomenon same as in Acrisols. Even with leaching, some sites have basic cation concentrations below suggested levels (Okalebo et al., 2002), which is typical of these soils with low CEC. According to Okalebo, 2009), these soils are known to contain 2:1 low activity clays that are abundant in hydrous Fe, aluminum oxides, and aluminum hydroxides.

3.2 Effect of Biochar and Phosphorus on Maize Grain Yield

There were significant interactions ($P<0.05$) between biochar sources and phosphorus rates on maize grain yield (Table 3). Maize grain yield was high in Acrisols under coffee husks biochar (26 kg P/Ha) treatment having 6.293 t/ha in season one (Table 3). This was followed by sugarcane bagasse at 26 kg P/Ha having 6.272 t/ha of maize grain. However, these two treatments did not differ significantly ($P\leq0.05$) in terms of maize grain yield in season one. The least mean maize grain yield was recorded under sawdust biochar at 0 kg P/Ha, that had 1.595 t/ha (Table 3). A similar trend was recorded in season two in Acrisols site. The least mean maize grain yield was recorded under control treatment using sawdust biochar at 0 kg P/Ha, that had 1.506 t/ha (Table 3). Also in season two, maize grain yield was high under coffee husks biochar at 26kg/Ha^{-1} Phosphorus treatment having maize grain yield of 5.876 t/ha. This was followed by biochar from sugarcane bagasse at 26kg/Ha^{-1} Phosphorus having 5.859 t/ha of maize grain. Similar to the previous season, the two treatments did not differ significantly ($P\leq0.05$) in terms of maize grain yield in season one. The least mean maize grain yield was recorded under sawdust biochar at 0kg/Ha^{-1} Phosphorus, that had 1.595 t/ha (Table 3).

In season one, maize grain yield in Chwele was high under coffee husks biochar (26 kg P/Ha) treatment having 3.067 t/ha in season one (Table 3). The least mean maize grain yield was recorded under coffee husks biochar at 0 kg P/Ha, that had 0.979 t/ha (Table 3).

In season two the least mean maize grain yield was recorded under control treatment using sawdust biochar at 0 kg P/Ha, that had 0.626 t/ha (Table 3). Yield was high under coffee husks biochar at 26 kg P/Ha treatment having maize grain yield of 2.685 t/ha, followed by biochar from sugarcane bagasse plus 26 kg P/Ha having 2.119 t/ha of maize grain that were significantly ($P\leq0.05$) high above the other treatments in Chwele (Table 3).

Table 3. Interactions between biochar sources and phosphorus rates on maize grain yield in Acrisols and Ferralsols sites

		Acrisols site			Ferralsols site		
		Season 1	Season 2		Season 1	Season 2	
		Yield (t/ha)	Yield (t/ha)	Mean	Yield (t/ha)	Yield (t/ha)	Mean
Coffee Husks	**0 kg/Ha P**	1.848a	1.496a	**1.672**	0.979a	0.626a	**0.803**
	13 Kg/Ha P	3.899c	3.519b	**3.709**	1.646b	1.266cd	**1.456**
	26 Kg/Ha P	6.293e	5.876d	**6.085**	3.067e	2.685f	**2.876**
Sugarcane Bagasse	**0 kg/Ha P**	2.051a	1.668a	**1.860**	1.703b	1.312cd	**1.508**
	13 Kg/Ha P	3.622bc	3.205b	**3.414**	2.022c	1.516d	**1.769**
	26 Kg/Ha P	6.272e	5.859d	**6.066**	1.647b	1.295cd	**1.471**
Sawdust	**0 kg/Ha P**	1.695a	1.317a	**1.506**	1.535b	0.809ab	**1.321**
	13 Kg/Ha P	2.985b	2.613b	**2.799**	2.528d	1.106bc	**2.324**
	26 Kg/Ha P	4.801d	4.409c	**4.605**	1.217a	1.119e	**1.013**
	Grand mean	**3.719**	**3.329**		**1.816**	**1.415**	
	e.s.e.	*0.264*	*0.2957*		*0.086*	*0.116*	
	s.e.d.	*0.3733*	*0.4182*		*0.1216*	*0.1641*	
	l.s.d.	*0.7914*	*0.8866*		*0.2578*	*0.3479*	
	%CV	*12.3*	*15.4*		*8.2*	*14.2*	
		Biochar	***P-Rate***	***BxPR***	***Biochar***	***P-Rate***	***BxPR***
	e.s.e.	2.312	1.350	2.999	0.31	0.24	0.46
	s.e.d.	3.269	1.910	4.241	0.43	0.34	0.65

Mean values with same letter in a column do not differ significantly (p≤0.05)

Maize grain yield in Kibabii and Chwele was high under coffee husks biochar (26 kg/Ha^{-1} Phosphorus) treatment. This enhancement in the grain and maize yield of maize may be due to the ability of the enriched biochar after addition of 26 kg P/Ha as a result of improved soil pH thereby making P available for plant uptake. The cell constituents are the products of several metabolic processes, and for such processes to take place a balanced supply of nutrients is required for the plants (Chauhan et al., 2020; Liu et al., 2021). In this context, the improvement of maize grains yield may be due to the potential of enriched biochar to form myccorrhizal association with maize roots.

3.3 Effect of Biochar and Phosphorus on Maize Stover Yields

In season one, maize stover yield was high under sugarcane bagasse (5.328 t/ha), followed by sawdust and coffee husks biochar (26kg/Ha^{-1} Phosphorus) treatments having 4.599 and 4.313 t/ha respectively in Acrisols site season one (Table 4). These two did not differ significantly (P≤0.05).

In season two the least mean maize stover yield was recorded under control treatment using sawdust biochar at 0 kg P/Ha, that had 1.021 t/ha (Table 3). Maize stover yield was high under sugarcane bagasse biochar at 26 kg/Ha^{-1} Phosphorus treatment having a yield of 4.328 t/ha, followed by biochar from sawdust plus 26 kg/Ha^{-1} Phosphorus having 3.699 t/ha of maize stover (Table 4).

Several reasons for increases in crop yield following biochar addition have been reported in the literature. These include liming effects, increased water-holding capacity, structural soil improvement, increased surface area for nutrient adsorption and others (Thomas et al.,2019). Indicators of biomass and/or yield have been shown to have a positive and substantial connection (r > 0.5) with root characteristics, which is assumed to be related to roots' enhanced synthesis of cytokinins, which are essential for partitioning biomass. This suggests that as Phosphorus is absorbed and used more effectively, grain yield will increase (Sharma PK et al., 2023).

3.4 Effect of Biochar and Phosphorus on Available Soil Phosphorus

Available P in Acrisol site was low at the initial sampling stage of 4WAP with a mean of 5.821. At 9WAP, the available P recorded was high at a rate of 26 kg/Ha^{-1} Phosphorus across all the tested biochar. This was highest under coffee husks biochar and 26 kg/Ha^{-1} Phosphorus. The trend was similar at 10 WAP and at harvest, in season one (Table 5). The interaction between biochar sources and P rates was not significantly different but the P rates alone was significantly different as evidenced in (Table 5).

In Ferralsols, the highest mean available phosphorus was recorded at 10 WAP and harvest, both having 6.840 mg kg^{-1} of soil. At harvest, coffee husks and 26 kg P/ha recorded mean of 7.806 mg kg^{-1} of soil, followed by sugarcane bagasse having 7.783mg kg^{-1} of soil (Table 6).

The interaction between biochar sources and P rates was highly as evidenced in (Table 6).

The analysis results also indicated that soil available P was significantly ($P < 0.01$) affected by the main treatments of coffee husks and sugarcane bagasse biochar and their interaction with fertilizer applied (Table 4 & Table 6). This result might be related to significantly increased soil pH due to the application of coffee husks biochar and released available P and other basic cations from the soil as a result of chelation between biochar and sesquioxides (Solomon et al., 2018) and also due to the beneficial effect of coffee husks biochar application preventing P fixation in the soil (Nduka., 2015). The result is in agreement with Takala (2020) who reported application of coffee husks biochar increase in available P contents of the soil. Dzung et al. (2013) and Solomon et al. (2018) also reported that coffee husks biochar release Phosphorus into soil when used alone or in combination with inorganic fertilizer and improve soil available P. The application of Phosphorus fertilizer at 26 kg/ha could have caused increased available phosphorus content in the soils. This explains the reduced levels of available P under 13kg/ha^{-1} Phosphorus rate of application, that realized a lower percentage increase of P in the soils. The nature of the soil also, could be the reason for the change slight change of available P content in the two sites. Acrisols exhibit poor chemical properties, including low levels of plant nutrients and limitations related to aluminum toxicity and phosphorus sorption. Ferralsols, characterized by high iron and aluminum oxide content, generally have low native phosphorus fertility and strong phosphorus retention (fixing), limiting crop production. The history of continuous use of acidified inorganic fertilizer over time, could have resulted to increased level of phosphorus fixation. Addition of different biochar to these soils resulted into a reduction of soil acidity, enabling availability of available phosphorus at different levels. This could be the cause of the difference in available phosphorus in Acrisols and Ferralsols.

Table 4. Interactions between biochar sources and phosphorus rates on maize stover yields in Acrisols and Ferralsols sites

		Acrisols site			**Ferralsols site**		
		Season 1	**Season 2**		**Season 1**	**Season 2**	
		Yield (t/ha)	**Yield (t/ha)**	**Mean**	**Yield (t/ha)**	**Yield (t/ha)**	**Mean**
Coffee Husks	**0 kg P/Ha**	2.106a	1.176a	**1.641**	1.521a	0.475a	**0.998**
	13 Kg P/Ha	3.379b	2.523b	**2.951**	1.697a	1.182a	**1.440**
	26 Kg P/Ha	4.313bc	3.311bc	**3.812**	1.69a	0.705a	**1.198**
Sugarcane Bagasse	**0 kg P/Ha**	2.163a	1.31a	**1.737**	1.368a	0.945a	**1.157**
	13 Kg P/Ha	3.74b	2.863b	**3.302**	2.681a	1.698a	**2.190**
	26 Kg P/Ha	5.328c	4.328c	**4.828**	2.242a	1.386a	**1.814**
Sawdust	**0 kg P/Ha**	1.854a	1.021a	**1.438**	1.275a	0.509a	**0.892**
	13 Kg P/Ha	3.685b	2.872b	**3.279**	2.230a	1.282a	**1.756**
	26 Kg P/Ha	4.599bc	3.699bc	**4.149**	2.640a	1.699a	**2.170**
	Grand mean	**3.463**	**2.567**		**1.93**	**1.098**	
	e.s.e.	*0.3796*	*0.3917*		*0.443*	*0.3799*	
	s.e.d.	*0.5369*	*0.5539*		*0.626*	*0.5372*	
	l.s.d.	*1.1381*	*1.1743*		*1.327*	*1.1388*	
	%CV	**19**	**26.4**		**39.8**	**59.9**	
		Biochar	***P-Rate***	***BxPR***	***Biochar***	***P-Rate***	***BxPR***
	e.s.e.	0.057	0.047	0.088	0.306	0.192	0.409
	s.e.d.	0.080	0.066	0.124	0.433	0.272	0.579

Table 5. Interaction between biochar sources and phosphorus rates on available P (mg/kg) in Acrisol site

		4WAP	5WAP	6WAP	7WAP	8WAP	9WAP	10WAP	HARVEST
Coffee Husks	**0k g/Ha P**	5.53b	5.75b	5.80a	5.90a	6.00a	6.69a	6.73a	6.915a
	13 Kg/Ha P	5.90d	5.96c	6.37d	6.74e	6.98d	7.41d	7.45d	7.635d
	26 Kg/Ha P	5.98g	6.67d	6.97f	7.50f	7.77f	8.07g	8.11g	8.295g
Sugarcane Bagasse	**0 kg/Ha P**	5.62c	5.71a	5.84c	5.93b	6.04c	6.73c	6.76c	6.952c
	13 Kg/Ha P	5.94f	5.97c	6.40e	6.73d	7.00e	7.60f	7.64f	7.822f
	26 Kg/Ha P	6.01h	6.72f	6.99g	7.54h	7.81h	8.07g	8.11g	8.292g
Sawdust	**0 kg/Ha P**	5.513a	5.71a	5.81b	5.93b	6.02b	6.70b	6.74b	6.928b
	13 Kg/Ha P	5.92e	5.96c	6.37d	6.63c	6.98d	7.52e	7.56e	7.748e
	26 Kg/Ha P	5.98g	6.68e	6.97f	7.51g	7.78g	8.06g	8.10g	8.288g
	Grand mean	**5.821**	**6.12**	**6.39**	**6.71**	**6.93**	**7.42**	**7.47**	**7.65**
	e.s.e.	0.0029	0.0028	0.0028	0.0028	0.0028	0.112	2.188	0.0028
	s.e.d.	0.0041	0.004	0.004	0.004	0.00408	0.224	4.082	0.004
	l.s.d.	0.0087	0.0086	0.0086	0.0086	0.0086	0.208	1.654	0.008
	%CV	20.1	10.7	13.1	17.2	9.1	12.05	20.6	16
		Biochar	***P-Rate***	***BxPR***					
	e.s.e.	2.545	1.421	3.242					
	s.e.d.	3.599	2.009	4.585					

Mean values with same letter in a column do not differ significantly (P≤0.05)
WAP- Weeks After Planting

Table 6. Interaction between biochar sources and phosphorus rates on available P (mg/kg) in Ferralsols site

		4WAP	5WAP	6WAP	7WAP	8WAP	9WAP	10WAP	HARVEST
Coffee Husks	**0 kg/Ha P**	5.05a	5.11a	5.13a	5.40a	5.68c	5.72a	5.75a	5.740a
	13 Kg/Ha P	5.95d	5.96d	6.07d	6.54d	6.84d	6.95e	6.98e	6.973d
	26 Kg/Ha P	6.02f	6.35g	6.67g	7.03f	7.30f	7.69f	7.71f	7.806f
Sugarcane Bagasse	**0 kg/Ha P**	5.11c	5.15c	5.22b	5.53c	5.62a	5.80c	5.79b	5.758ab
	13 Kg/Ha P	6.01f	6.02f	6.09e	6.65e	6.84e	6.92d	6.92c	6.901c
	26 Kg/Ha P	6.03f	6.57i	6.67g	7.06g	7.33g	7.87h	7.89h	7.873g
Sawdust	**0 kg/Ha P**	5.07b	5.12b	5.24c	5.44b	5.66b	5.77b	5.79b	5.784b
	13 Kg/Ha P	5.98e	5.99e	6.12f	6.55d	6.85e	6.94e	6.97d	6.957d
	26 Kg/Ha P	6.02f	6.46h	6.73h	7.04f	7.35h	7.79g	7.82g	7.704e
	Grand mean	**5.690**	**5.850**	**5.990**	**6.360**	**6.607**	**6.827**	**6.840**	**6.833**
	e.s.e.	0.006	0.0028	0.0029	0.00693	0.002836	0.0028	0.00353	0.01046
	s.e.d.	0.0085	0.004	0.0041	0.00981	0.00401	0.004	0.00499	0.01479
	l.s.d.	0.0181	0.0085	0.00877	0.02079	0.008501	0.0085	0.01057	0.03136
	%CV	11.5	8.56	19.6	12.01	9.4	11.1	10.07	18.12
		Biochar	***P-Rate***	***BxPR***					
	e.s.e.	0.307	0.242	0.460					
	s.e.d.	0.434	0.343	0.651					

Mean values with same letter in a column do not differ significantly (p≤0.05)
WAP- Weeks After Planting

4. CONCLUSION

The study concludes that the combination of coffee husks and P at 26kg/ha^{-1} Phosphorus in Acrisols and Ferralsols enhanced the crops root system significantly to enable uptake of nutrients that led to improved crop development. Interactions of Biochar and P had influence on the yield of maize in Ferralsols but not in Acrisols.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Table A1. Grain yield (t/ha)

Variate: Acrisols Yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.7012	0.8506	2.09	
Biochar	2	4.2115	2.1057	5.17	0.078^{ns}
Residual	4	1.6287	0.4072	2.85	
P_Fertilizer_Rate	2	69.9213	34.9606	244.48	<.001***
Biochar*P_Fertilizer_Rate	4	1.6892	0.4223	2.95	0.065^{ns}
Residual	12	1.7160	0.1430		
Total	26	80.8679			

*^{ns}-not significant, *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at (p≤0.001)*

Variate: Ferralsols Grain Yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.05382	0.02691	0.92	
Biochar	2	0.09369	0.04684	1.60	0.308^{ns}
Residual	4	0.11694	0.02924	1.47	
P_Fertilizer_Rate	2	2.30934	1.15467	58.21	<.001***
Biochar*P_Fertilizer_Rate	4	7.56942	1.89235	95.39	<.001***
Residual	12	0.23805	0.01984		
Total	26	10.38127			

*^{ns}-not significant, *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at (p≤0.001)*

Table A2. Available phosphorus

Variate: AVAILABLE_P_ACRISOLS 10WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATE stratum	2	0.03660	0.01830	183.00	
REPLICATE.Biochar stratum					
Biochar	2	0.02427	0.01213	121.33	<.001
Residual	4	0.00040	0.00010		
REPLICATE.Biochar.P-Rate stratum					
P-Rate	2	8.41447	4.20723		
Biochar.P-Rate	4	0.03093	0.00773		
Residual	12	0.00000	0.00000		
Total	26	8.50667			

*^{ns}-not significant, *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at (p≤0.001)*

Variate: AVAILABLE_P_FERRALSOLS 10WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATE stratum	2	0.0018761	0.0009380	5.16	
REPLICATE.Biochar stratum					
Biochar	2	0.0101712	0.0050856	27.98	0.004
Residual	4	0.0007270	0.0001818	0.48	
REPLICATE.Biochar.P-Rate stratum					

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
P-Rate	2	18.7829810	9.3914905	24906.22	<.001
Biochar.P-Rate	4	0.0447808	0.0111952	29.69	<.001
Residual	12	0.0045249	0.0003771		
Total	26	18.8450610			

*[ns]-not significant, [*]Significant at p≤0.05; **Significant at p≤0.01; ***Significant at (p≤0.001)*

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