

Effects of Biochar Feedstock Type and Rates on Growth, Yield and Grain Quality in Soybean (*Glycine max* L.)



Miriam Zeka, Keston Njira, Joseph Chimungu, Patson Nalivata, and Ivy S. Ligowe

Abstract Soil fertility decline pose a great threat to crop production in Malawi. Biochar application enhances crop yield and productivity; however, feedstock type and rates may influence its performance. The chapter illustrates how biochar application at different rates and feedstock types contribute to significant effects on plant height, stem diameter, leaf canopy and leaf area of soyabean causing a 13.8%, 20.6%, 50.6% and 19.1% increase, respectively. Biochar made from maize cores can cause an improvement in above ground biomass, below ground biomass, 100 seeds weight, and number of seeds per pod as compared to groundnut shell biochar. However, from this study reported in this chapter biochar did not affect grain weight and number of pods per plant. Data in the current chapter also reveals significant effects of biochar on Fe and Ca concentration in soybean grain, with no effects observed on Na, Mg, P, and Zn concentration. Nutrient uptake of P, Zn and Mg can also be affected by biochar, as compared to Na, K, Ca, and Fe. In this chapter, we have provided a synthesis of the impact of feedstock types and rates on growth, grain nutritional quality and yield of soybean. The chapter recommends a long-term field trial to conclusively ascertain the extent of biochar effects on soybean growth and yield, in different soil types and agro-ecological zones.

Keywords Biochar · Growth parameters · Nutrient uptake · Feedstock types · Yield

1 Introduction

Biochar is a carbon rich and highly stable, charcoal material produced by a thermo-chemical process called pyrolysis, where biomass is heated in the absence of oxygen (Baronti et al. 2010). It is produced from organic wastes such as agricultural residues, sewage sludge, or wood chips (Głodowska et al. 2017), grass, cow manure, wood chips, rice husk, wheat straw, and cassava rhizome. The extent of its effect on growth

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and yield of food crops is determined by several factors including feedstock type, rate, as well as pyrolysis methods as these impact changes in soil features induced by the physical and chemical properties of biochar (Van Zwieten et al. 2010; Steiner 2009; Glaser et al. 2002; Zhu et al. 2015). On the other hand, Wang et al. (2016) in an on farm trial revealed that increasing biochar rate improved the plant growth parameters of soybean. Regarding feedstock types on biochar effects, Singh et al. (2010) observed that biochar had different properties and nutrient content depending on raw materials used. In addition, Filiberto and Gaunt (2013) found that biochar produced from wood, paper pulp, wood chips and poultry litter has positive impact on biomass yield. Zhang et al. (2012) also revealed that pyrolysis methods affected biochar properties such as biochar yield, soil pH, particle size, and surface area. Biochar is known to have several benefits including improved soil physical and chemical properties, improved biological nitrogen fixation (BNF), nodulation, growth and yield in different crops (Fig. 1).

Low yield is a major limiting factor in soybean production in Malawi as farmers obtain 800 kg ha⁻¹ on average in comparison to its potential yield of over 4000 kg ha⁻¹ (MoAFS 2012). This is due to a number of factors including poor soil fertility (Kananji et al. 2013), parasitic weeds, poor crop husbandry practices,

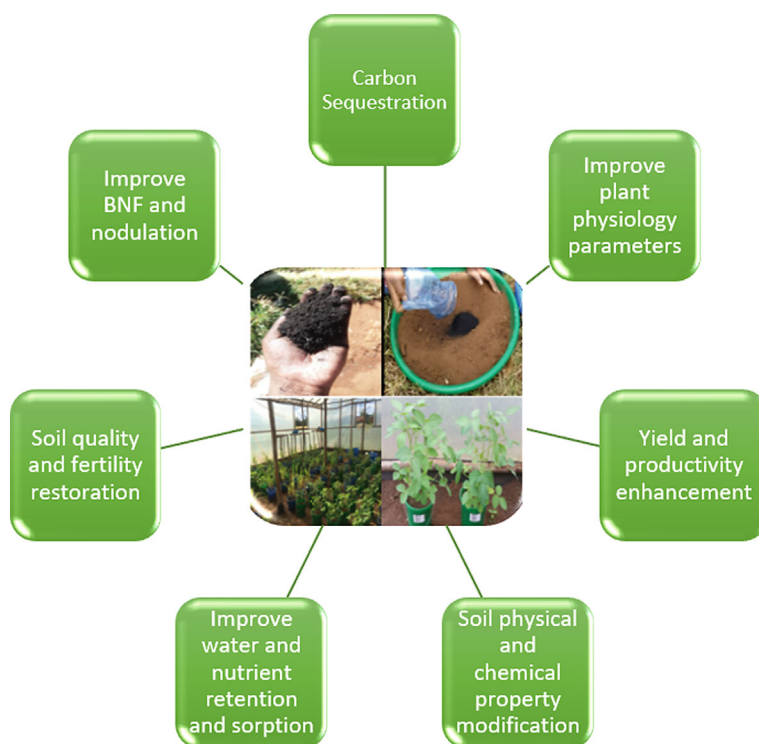


Fig. 1 Summary of the benefits of biochar to soil and plant health

drought, pests and diseases. Interestingly, biochar has the potential to improve plant growth (Ndor et al. 2016) and yield (Baronti et al. 2010) due to its ability in nutrient retention, encouraging nutrient availability for plant uptake which later can be utilized for plant growth and other metabolic processes hence improve yield. Various biochar feedstock types such as hydrochar and paper pulp at different rates, have been evaluated in other countries for their impact on yield and growth of various crops; however, data regarding use of maize cores and groundnut shell feedstock types at rates that could potentially improve growth and yield in soybean to improve food and nutrition security in Malawi is scanty. The objective of this chapter is to address specific biochar feedstock types and rates for locally available and economically feasible feedstock types for smallholder farmers in Malawi, with the aim of improving soybean growth, yield and grain nutritional quality at a minimal or no cost. The goal is to highlight the rates at which growth, yield and grain quality are enhanced in soybean in these feedstock types. Content in this chapter was derived from a study implemented to evaluate effects of biochar feedstock types and rates on growth, grain quality and yield of soybean in a green house at the crop and soil sciences students' research farm, LUNAR.

2 An Overview of Biochar

Biochar is amongst some of the many organic approaches in improving soil properties, plant yield and grain quality. Biochar is produced through a process known as pyrolysis from any organic material. It is a thermochemical process in which biomass is converted to biochar through heating with limited oxygen supply (Utomo 2014).

2.1 *Effects of Pyrolysis Conditions and Biochar Feedstock Types on Soil Amendment Quality*

Biochar has different properties depending on the raw materials and pyrolysis conditions used (Bonelli et al. 2010) which also affect the nutrients content of biochar (Singh et al. 2010). According to Nguyen et al. (2004), biochar produced from various organic materials under different conditions will have different effects on soils. The raw material and pyrolysis temperature used influence the quantity and dynamics of the release of nutrients and contaminants from the biochar (Tronto 2017). Furthermore, the biochar properties, such as elemental composition, structure, and chemical stability, depend on the raw material and the temperature of pyrolysis. Biochar from sewage sludge has the potential to improve the soil through release of P and micronutrients (Lu et al. 2013). It also reduces the volume of the solid residue, eliminates pathogens and organic compounds, and may also be used as a fertilizer or in remediation of contaminated soils. Demirbas (2004), Zhang et al. (2010), Hossain

et al. (2011), observed that the charcoals produced from residues of grain hulls, husk, straw, and manure generally produce biochar with high ash content, which may be a result of the silica and the mineral content of the raw material. The result is a gradual loss of C, H, and O during processing. This calls for the evaluation of the impact of different biochar feedstock types and rates, and their amelioration effects on soil physical and chemical properties, growth, BNF, yield and nutrient uptake in soybean. Increasing pyrolysis temperature results in decreased biochar yield and nitrogen content due to volatilisation in biochar, and increased CEC, carbon content, surface area, pH, and ash content in biochar (Gaskin et al. 2008; Novak et al. 2009). Pyrolysis conditions that increase biochar yield include lower maximum temperature, slower heating rates, higher pressure, and a high concentration of lignin in the feedstock (Antal and Grønli 2003; Amonette and Joseph 2009). The most influential pyrolysis parameter on biochar yield is temperature, followed by heating rate (Amonette and Joseph 2009). Biochar possesses a diverse range of surface functionality including various amounts of acidic, basic, hydrophilic, and hydrophobic properties depending on the composition of the feedstock biomass and the pyrolysis conditions (Amonette and Joseph 2009). The CEC of biochar increases with increasing pyrolysis temperatures (Gaskin et al. 2008) due to the increased negative charges on its surface at high temperature as compared to low temperatures.

2.2 Biochar Stability

Biochar chemical and physical properties, as well as environmental factors such as temperature and rainfall, influence the decomposition rate of biochar (Major et al. 2010; Lehmann 2009). The stability of biochar is due to the transformation of the native carbon structure of the biomass to aromatic ring structures that takes place during the thermal treatment of organic matter (Tang and Bacon 1964). Glaser et al. (2001) reported that biochar is very stable due to its polycyclic aromatic carbon structures and can resist physical and microbial breakdown, allowing it to persist in soil. A study in Columbia demonstrated that biochar produced from mango trees via a simple earthen kiln mineralises very slowly in the soil (savanna Oxisol, sandy clay loam) with only 2.2% (when applied at 23.2 tonnes ha⁻¹) being lost by respiration over two years (Major et al. 2010). Surface area and particle size may also influence the decomposition rate by allowing more surface area for microbial and chemical reactions to occur (Lehmann et al. 2009).

2.3 Biochar Effects on Soil Physical and Chemical Properties

Malawi soils are dominated by Alfisols, Oxisols and Ultisols where their texture is generally sands and sandy loam (Snapp 2016). Application of biochar is known to have great impact on soil physical and chemical properties; however, this depends

on the soil type, biochar rate, as well as biochar type. Recent studies have shown that the effects of biochar on the physical and chemical properties of soil are significantly influenced by both the type of soil and the specific characteristics of the biochar used. Application of biochar with a high acid neutralizing capacity (ANC) to acidic soils can effectively increase soil pH, while biochar with low ANC may not produce this effect. Furthermore, biochar can improve plant-available water in sandy soils by enhancing water retention; conversely, in heavy clay soils, it may reduce water content due to increased drainage. Biochar properties are also known to have been influenced by several factors including pyrolysis method among many. In another study, it was also observed that biochar from biomass pyrolysis has been proposed as an effective way of producing bioenergy, while at the same time improving some soil properties and sequestering carbon (Lehmann et al. 2006). Biochar addition to soil can produce changes in the soil's chemical and physical properties, including nutrient availability, CEC, pH, soil strength, and water holding capacity. Chan et al. (2008) reported that changes occur in the chemical properties of soil after biochar application. Studies have found that biochar addition to soil increases total Carbon (Van Zwieten et al. 2010), total N, pH, CEC, available P, and exchangeable cations (for example Ca, Mg, Na, and K) in soil (Chan et al. 2008). Similarly, Major et al. (2010) found that biochar addition increases available Ca, Mg, and pH in soil, but this may vary depending on the biochar rate and type used. Chan et al. (2007) also reported that addition of biochar produced from green waste (a mixture of grass clippings, cotton trash, and plant prunings) to soil resulted in increased organic carbon, available Na, K, and Ca, extractable P, and decreased available Al in the soil. Generally, these changes to soil characteristics are also proportional to the amount of biochar applied (Chan et al. 2007). One explanation of some biochar's ability to increase plant nutrient uptake is the formation of carboxylic groups on the edges of the aromatic carbon backbone that results from oxidation, leading to a greater ability to hold nutrients as the biochar weathers (Glaser et al. 2001). Among the many benefits associated with the use of biochar are the improvement of soil physical properties, including structure, density and pore size distribution, with implications for water holding capacity, aeration, soil workability as well as plant growth (Coumaravel et al. 2015).

2.4 Effects of Biochar on Nodulation and Biological Nitrogen Fixation

Nodule formation is a multi-step process involving movement of rhizobia by chemotaxis to the root hair. The attachment of rhizobia to the root hair induces deformation of growth in the root hair (Oke and Long 1999). This stimulates the division of the host cortical cells, culminating in infection and nodule development (Long 1990). Legumes are known to have a significant role in fixing nitrogen in the soil through a process called biological nitrogen fixation, estimated to contribute approximately

17.2×10^7 tons of nitrogen to soils globally each year (Azeem et al. 2019). In general, leguminous crops are estimated to contribute approximately half of the global symbiotic BNF at an estimated 21.5×10^6 tonnes (Azeem et al. 2019). Furthermore, Herridge et al. (2008) calculated soybean to fix 16.4 Tg N annually, representing 77% of the N fixed by the crop legumes. On the other hand, Güereña et al. (2015) discovered that addition of biochar could also improve the annual N fixed in the soil and improve nodulation and BNF. Regarding nodulation in soybean, Tagoe et al. (2008) and Ogawa and Okimori (2010) reported increased nodulation in response to short-term biochar addition due to increased population of soil microorganisms, including rhizobia bacteria which affect nodulation in legumes. The findings were contrary to a study by Quilliam et al. (2013) which showed no significant difference in the total number of root nodules of clover plants grown in soil having contained biochar for three growing seasons, regardless of the application rate. This raises a need to further explore various locally available feedstock types at rates that will enhance BNF in soybean.

3 Impact of Different Biochar Feedstock Type and Rates on Selected Soybean Growth Parameters

In assessing effects of biochar on yield and plant growth data on plant height (cm), leaf length (cm), leaf width (cm), leaf canopy (cm) and stem diameter (mm) was collected. These variables were measured using a 100 cm ruler. For leaf area, leaf length and width were measured consecutively which was then used to calculate the leaf area for the soybean leaves. Stem diameter was measured using a caliper, which was placed at the bottom of the stem and the diameter was recorded. Leaf area was estimated from non-destructive sample by using direct method to measure lamina length and width of all leaves in the pot of each treatment using a ruler.

3.1 Plant Height and Stem Diameter as Influenced by Different Biochar Rate and Feedstock Types

Results show significant effects of biochar rate on plant height and stem diameter. Biochar at the rate of 15 tonnes ha^{-1} increased stem diameter and plant height values significantly compared to the control treatment as more nutrients for growth and development were available. A similar trend was observed by Wang et al. (2016), where biochar increased stem diameter and plant height at the increasing rate of biochar applied to rice in tropical riparian wetlands, Indonesia. The study indicated that biochar incorporated in the soil improved growth parameters, including stem diameter and plant height. This could have been attributed to the fact that biochar improves soil properties, including CEC which have a nutrient retention ability that

improves processes like photosynthesis, hence improving plant height and stem diameter. The findings corresponded with Tian et al. (2018) where increased biochar rate improved soil pH, reduced nutrients leaching especially of N, and improved CEC (Yooyen et al. 2015). Nitrogen is vital in forming part of chlorophyll component which plays a role in photosynthesis, thereby improving plant growth through photo-assimilates. This nutrient is usually available to plants in the form of nitrate and nitrate nitrogen. Ammonium nitrogen can be adsorbed on to soil colloids in the soil, and is readily exchangeable, as it easily dissolves in the soil solution, and can be directly absorbed by the plant (Wang et al. 2016). Increasing rates of biochar helps to improve availability of essential nutrients in the soil, which in turn aids in improving soybean growth parameters. The ability of biochar to improve nutrient retention and availability for plant use is evidenced by the significant differences in plant height and stem diameter of soybean growth parameter, which act as a morphological trait showing the availability of growth resource (Khan et al. 2008).

3.2 Leaf Canopy and Leaf Area in Soybean, as Affected by Biochar

Adding biochar shows significant increase in leaf canopy and leaf area. As the rate of biochar increases from 0 to 15 tonnes ha⁻¹, leaf canopy and leaf area showed the highest values in pots with 15 tonnes ha⁻¹ (Table 1). A similar trend to this one is reflected in a study by Profile (2019) where rice husk biochar improved the leaf area of maize. Wang et al. (2016) also conducted a similar study of soybean in tropical riparian wetlands in Indonesia and found that every addition to the biochar rate increased leaf area in soybean. This might be attributed to the ability of biochar to retain nutrients. These nutrients play a big role in vital metabolic processes like cell division and photosynthesis, directly affecting plant growth in soybean. The result is improved growth and leaf expansion, which in turn enhances leaf canopy. Similarly, leaf area values were also positively influenced by biochar rate, where every addition of biochar depicted an increase in leaf area, resulting from improved photosynthesis and other vital processes in the plant. The increase in leaf area in soybean can also be attributed to the availability of nutrients and moisture, which allows sufficient N uptake and synthesis of nucleic acids, amides and amino acids (Mahboob et al. 2023), resulting in cell multiplication and increase of leaf area. Increased leaf area and canopy by biochar is a very vital development as it helps to improve growth and nutrient production in soybean, hence improved yield.

Table 1 Biochar feedstock types and rates in enhancing plant growth parameters in soybean

Biochar rate	Stem Diameter (mm)			Plant height (cm)			Leaf area (cm ²)			Leaf Canopy (cm)		
	G/nut Shell biochar	Maize cores biochar	Mean rate	G/nut Shell biochar	Maize cores biochar	Mean rate	G/nut Shell biochar	Maize cores biochar	Mean rate	G/nut Shell biochar	Maize cores biochar	Mean rate
0 tonnes ha ⁻¹	2.65	2.51	2.57 ^a	38.35	36.29	37.32 ^a	40.40	36.60	38.47 ^a	30.80	29.67	30.24 ^a
5 tonnes ha ⁻¹	2.85	2.71	2.78 ^b	39.68	37.55	87.62 ^a	41.90	38.70	40.31 ^b	32.09	31.53	31.35 ^b
10 tonnes ha ⁻¹	2.91	2.86	2.88 ^c	41.34	39.80	40.57 ^b	44.70	40.70	42.70 ^c	31.56	31.15	31.81 ^b
15 tonnes ha ⁻¹	3.23	3.09	3.16 ^d	42.80	43.13	42.97 ^c	49.00	45.50	47.22 ^d	32.46	31.31	31.89 ^b
Mean type	2.90	2.79		40.54	39.19		44.0	40.40				
F pr. type	0.59			0.367			0.07			0.082		
F pr. rate	< 0.01			< 0.001			< 0.001			0.015		
Fpr.(Type*Rate)	0.696			0.371			0.874			0.803		

Key: *LSD least significant difference, CV is coefficient of variation, T biochar type, R Biochar rate, G/nut groundnut. Within row means followed by the same letter are not significantly different

4 Biochar and Soybean Yield

Biochar rate showed significant effects on 100 seeds weight, which is a trait of yield components of soybean, and positively related with grain yield (Table 2). The increase in 100 seeds weight were attributed to the ability of biochar to improve nutrient retention, hence allowing for sufficient nutrients and water, which aid seed development. This in turn helps produce large and healthy seeds, hence increasing its weight. Results in this study stipulate that increasing rates of biochar will increase seeds weight significantly, which is in agreement with studies done by Yooyen et al. (2015) and Rab et al. (2016). Data regarding seeds/pod in the study also showed significant interactive effects of biochar type and rate ($p = 0.046$). This could be caused by the ability of biochar in improving C:N ratio in the soil (Rab et al. 2016), and hence improving the availability of nitrogen which in turn helps in seed pod formation. Biochar rate or feedstock type did not affect grain weight and pods/plant, but the increase in seeds per pod could be attributed to the ability of biochar to retain water as this improves soil porosity and helps in moisture retention (Li et al. 2021). Additionally, maize cores biochar contributed to higher yield as compared to groundnut shell biochar. Results also revealed higher variation in pods per plant as compared to seeds per pod. This was very likely because of the role of biochar in improving nutrients and water availability, causing an increase in vegetative growth, dry matter accumulation and longer linear growth rate, which directly influences higher number of pods per plant. This is in agreement with Berihun et al. (2017) who found that the number of pods was significantly affected by biochar. Above and below ground biomass of soybean was significantly affected by biochar rate and type, respectively as shown in Table 2. Plant biomass was measured at 50% flowering and harvesting, where destructive sampling was conducted and one plant in a pot was removed for biomass analysis. The total fresh plant weight was observed, which was composed of below and above ground biomass. After this, the stalks were oven dried at 60 °C for 56 h in order to observe the dry biomass on the selected plants. The biomass increase could be related to an early increase in leaf canopy which allowed enough area for photosynthesis, thereby improving accumulation of dry matter in the crop. This agrees with the results presented by Seadh and Abido (2013), where early leaf canopy closure enhanced maximum leaf area index, consequently increasing dry matter accumulation. In the current study, biochar rate affected leaf canopy from as early as week two, which allowed enough surface area for photosynthesis, and thus led to improved yield and growth. Similarly, Baronti et al. (2010) found that a minimum biochar rate of 10 tonnes ha⁻¹ increased the above ground biomass by 23% compared to the control. Biochar caused significant effects for rate ($p = 0.07$) and interaction between biochar rate and type ($p = 0.037$) in total biomass of soybean crop. These findings are in agreement with the results by Barus (2017) where mixed rice husk biochar and compost manure significantly increased dry grain weight and biomass of soybean compared to the control. Biochar improves part of chlorophyll content in the leaf tissue, which enhances biomass production thereby increasing grain yield (Mete et al. 2015).

Table 2 Biochar rates and feedstock types in influencing soybean yield and seed parameters

Yield component	Biochar rate	Maize Cores biochar	G/nut shell biochar	Mean (Rate)	Yield component	Biochar Rate	Maize Cores Biochar	G/nutShell Biochar	Mean (Rate)
100 seeds dry(g)	0 tonnes ha ⁻¹	12.08	11.16	11.62 ^a	Pods/plant	0 tonnes ha ⁻¹	30	11	20.5
	5 tonnes ha ⁻¹	13.97	11.94	12.96 ^a		5 tonnes ha ⁻¹	17	22	19.5
	10 tonnes ha ⁻¹	16.53	15.45	15.99 ^b		10 tonnes ha ⁻¹	19	17	18
	15 tonnes ha ⁻¹	17.58	15.61	16.60 ^b		15 tonnes ha ⁻¹	19	28	23.5
	Mean (Type)	13.54	15.04			Mean (Type)	21.25	19.5	
	F pr. Rate		0.010			F pr. Rate		0.741	
	F pr. Type		0.533			F pr. Type		0.735	
	F pr.(T* ^a R)		0.964			F pr.(T* ^a R)		0.066	
	LSD (0.05)		6.616			LSD (0.05)		18.4	
	CV%		26.2			CV%		41.5	
Seedspod ⁻¹	0 tonnes ha ⁻¹	1.85 ^{abc}	1.77 ^{ab}	1.81	BG biomass(g/pot)	0 tonnes ha ⁻¹	6.34	2.40	4.37
	5 tonnes ha ⁻¹	1.70 ^a	1.93 ^{bc}	1.82		5 tonnes ha ⁻¹	6.45	3.76	5.11
	10 tonnes ha ⁻¹	1.85 ^{abc}	1.85 ^{abc}	1.85		10 tonnes ha ⁻¹	4.41	4.13	4.27

(continued)

Table 2 (continued)

Yield component	Biochar rate	Maize Cores biochar	G/nut shell biochar	Mean (Rate)	Yield component	Biochar Rate	Maize Cores Biochar	G/nutShell Biochar	Mean (Rate)
	15 tonnes ha ⁻¹	1.87 ^{abc}	2.02 ^c	1.95		15 tonnes ha ⁻¹	6.18	4.31	5.24
	Mean (Type)	1.82	1.90			Mean (Type)	3.65	5.85	
	F pr. Rate		0.655			F pr. Rate		0.484	
	F pr. Type		0.230			F pr. Type		0.001	
	F pr.(T*R)		0.046			F pr.(T*R)		0.157	
	LSD (0.05)		0.197			LSD (0.05)		0.314	
	CV%		13.4			CV%		27.5	
Grain weight (g)	0 tonnes ha ⁻¹	13.90	13.65	13.78	AG biomass(g/pot)	0 tonnes ha ⁻¹	5.43	6.23	5.83 ^a
	5 tonnes ha ⁻¹	12.52	13.90	13.21		5 tonnes ha ⁻¹	6.80	7.10	6.95 ^a
	10 tonnes ha ⁻¹	13.39	16.40	14.90		10 tonnes ha ⁻¹	7.02	7.84	7.43 ^a
	15 tonnes ha ⁻¹	17.18	17.03	17.11		15 tonnes ha ⁻¹	11.72	9.96	10.84 ^b
	Mean (Type)	14.25	15.25			Mean (Type)	7.74	7.78	
	F pr. Rate		0.152			F pr. Rate		0.004	
	F pr. Type		0.630			F pr. Type		0.646	
	F pr.(T*R)		0.743			F pr.(T*R)		0.238	

(continued)

Table 2 (continued)

Yield component	Biochar rate	Maize Cores biochar	G/nut shell biochar	Mean (Rate)	Yield component	Biochar Rate	Maize Cores Biochar	G/nutShell Biochar	Mean (Rate)
	LSD (0.05)		6.200			LSD (0.05)		4.477	
	CV%		32.3			CV%		37.4	

5 Effects of Biochar on Grain Quality

Grain quality includes a range of properties that can be defined in terms of physical (moisture content, kernel size), sanitary (fungi and mycotoxin count), and intrinsic (fat content, protein content, hardness, starch content) quality characteristics (Ratnavathi et al. 2016). In this study we have focused on quality characteristics as a component in defining grain quality. Results from the grain analysis showed significant effects of biochar type, rate and their interactions on the nutrient uptake and concentration (Table 3). These effects were attributed to the nutrients present in biochar as well as their major role in improving CEC and nutrient retention (Sriburi 2016). Furthermore, Horel et al. (2019) found that biochar improves soil nutrients availability, making them available to the plant hence improving uptake, and creates a conducive environment for nutrient uptake. Significant interactive effects of biochar type and rate improved Mg uptake, with biochar type affecting Ca uptake. This was as a result of improved cation exchange capacity as caused by biochar, in line with Martinsen et al. (2017). The improved CEC results in enhanced cation availability at ion exchange sites, allowing availability of more cations including Ca and Mg to be made available for plant uptake, hence its availability in the grain. Additionally, biochar rate, type and interaction and their interactions significantly, ($p < 0.05$) affected phosphorus uptake in grain. This could be attributed to the ability of biochar to influence plant access to soil P (Zwetsloot et al. 2016) making it available for plant uptake. Fe concentration and Zn uptake were also significantly ($p < 0.05$) affected by biochar interactions between biochar rate and type as well as biochar rate, respectively.

6 Conclusion and Recommendations

The study found that biochar significantly enhanced soybean growth, yield, grain quality, and biomass accumulation, particularly at an application rate of 15 tonnes per hectare. The effectiveness of biochar varied based on the application rate and the type of feedstock used. Groundnut shell biochar notably improved growth parameters, while maize cores biochar influenced yield. Increased biochar application also positively affected seed weight, a key yield component. Grain analysis revealed that biochar type and rate significantly impacted nutrient uptake. As biochar rates increased from 0 to 15 tonnes ha^{-1} , leaf canopy and area improved the most at the highest rate. Although all biochar types at 5 tonnes ha^{-1} benefited soybean growth, the most significant improvements were seen at 15 tonnes ha^{-1} . The study recommends using groundnut shell and maize cores biochar at this rate, while suggesting further research on varying rates and conditions to maximize benefits across different soils and agro-ecological zones.

Table 3 Soybean grain nutrient concentrations and uptake as influenced by biochar

Nutrient	Conc./uptake	Biochar type	Biochar rate (tonnes ha ⁻¹)					F pr. R		Fpr.T*R	LDS	CV%
			0	5	10	15	Fpr. T					
Na	Conc. (mg/kg)	G/nut shell	254	253	255	259	0.543	0.78	0.62	243.2	38.7	
		Maize cores	271	320	347	395						
	Uptake (g)	G/nut shell	3.79	3.85	4.96	5.88	0.801	0.843	0.278	0.0038	32.9	
		Maize cores	3.55	3.72	3.03	3.86						
Mg	Conc. (mg/kg)	G/nut shell	4529	4776	5328	5533	0.788	0.443	0.238	938.1	10.6	
		Maize cores	4645	4729	4795	5282						
	Uptake (g)	G/nut shell	57.3	63.9	94.3	95.5	0.617	0.063	0.015	0.03431	14.9	
		Maize cores	73	63.9	62.5	73.2						
P	Conc. (mg/kg)	G/nut shell	4666	4827	4455	5231	0.476	0.417	0.390	734.3	7.6	
		Maize cores	4517	4639	4737	4666						
	Uptake (g)	G/nut shell	41.5	63.5	60.9	91.6	0.004	0.001	0.030	0.016	15.5	
		Maize cores	73.9	59.1	67	85.9						
K	Conc. (mg/kg)	G/nut shell	20,673	20,731	21,409	21,527	0.429	0.903	0.597	2871.1	7.6	
		Maize cores	20,535	21,627	21,730	21,878						
	Uptake (g)	G/nut shell	259	283	349	367	0.731	0.093	0.096	0.122	15.4	

(continued)

(continued)

Table 3 (continued)

			Biochar rate (tonnes ha ⁻¹)									
			331	265	273	333						
Ca		Maize cores										
	Conc. (mg/kg)	G/nut shell	6687	7767	8035	8286	0.036	0.381	0.782	506.7		14.8
		Maize cores	6685	7375	7278	7021						
	Uptake (g)	G/nut shell	102	112	149	243	0.215	0.444	0.466	0.0604		27.7
		Maize cores	103	88	92	106						
Fe	Conc. (mg/kg)	G/nut shell	1633	2191	1074	1297	0.485	0.492	0.019	1312.2		32.5
		Maize cores	2169	1061	1845	2445						
	Uptake (g)	G/nut shell	28.1	32.7	20.5	21.9	0.931	0.666	0.173	0.023		47.6
		Maize cores	29	13.1	23.3	35.6						
Zn	Conc. (mg/kg)	G/nut shell	47.8	52.3	50.3	57.6	0.679	0.407	0.579	10.68		11.3
		Maize cores	48.9	50.3	52.7	51.1						
	Uptake (g)	G/nut shell	5.27	7.22	7.62	10.22	0.763	0.003	0.198	0.002		20.9
		Maize cores	7.69	63.6	7.21	8.7						

Key: *SD* standard deviation, *CV* coefficient of variation, *LSD* Least significant difference, *F* *pr* F probability, *T* biochar type, *R* Biochar rate, *Conc.* concentration, Uptake values were converted to kg pot⁻¹, all nutrient concentration were rated at mg kg⁻¹. Bold F probability values represent points of Significance

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