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INFLUENCE OF BIOCHAR AND INORGANIC FERTILIZER ON UPLAND RICE-COWPEA INTERCROP COMPETITIVE INDICES

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Abstract: A trial was conducted to evaluate the competitive indices of upland rice-cowpea intercrop. Sole cropping of the two crops was also done. The experiment was a randomized complete block with 4 replications. The treatment included a control (no input), fertilizer, rice and cowpea intercrop either applied alone or in combination with three different sources of biochar (poultry manure, corn cobs and groundnut shell). At the same time 5 t ha^{-1} of biochar level each were incorporated into the soil. Inorganic fertilizer was applied at the rate of 90, 60, 60, and 45 kg ha^{-1} NPK, as straight fertilizer, and then top-dressed with nitrogen levels in the form of urea at 30 kg ha^{-1} N eight (8) weeks after transplanting. The crops were arranged in a 3:1 rice-cowpea ratio. In this study, intercropping system gave higher land equivalent ratio (LER). Biochar of poultry manure+45N30P30K exhibited higher rice aggressivity (2.43), relative crowding coefficient (1.74) and competitive ratio (4.11). Rice performed better in terms of competitive ratio when grown in combination with cowpea. In terms of nutrient use efficiency nitrogen was high with intercrops, but was very low in sole crop. Intercropping of rice with cowpea gave higher economic advantage (9544.5), income equivalent ratio (403.1), production and cost benefit ratio for biochar poultry manure+45N30P30K (2.68) than 90N60P60K (2.52) respectively. For economic crop yield in upland rice-based ecosystems, small-holder farmers, therefore, should intercrop rice and cowpea and apply biochar +45N30P30K and nitrogen (30 kg N ha^{-1}).

Keywords: Land equivalent ratio, intercropping, nutrient use efficiency, biochar, inorganic fertilizer

Introduction

The main benefit of intercropping is an increase in yield per unit area of land. Several research studies have been reported on intercropping. According to (Lizarazo et al., 2020) concluded that in most of the experiments on mixed cropping in the tropics, more than one acre of sole stand was required to produce the yield of one acre of mixed crop, and concluded that for the tropical small-scale farmer, there was no advantage to be gained by replacing the traditional practice of mixed cropping. Research by (Iderawumi and Friday, 2013) reported that intercropping maize is one of the most popular mixed cropping combinations in rain-fed agriculture in the tropics. Cultivation of maize in combination with other crops is, therefore, a widespread practice in northern Ghana, especially in the Northern Region. It is not uncommon to see crops like legumes, okra, melon, peppers, and cassava being intercropped with maize. Systems that intercrop maize with cowpea are able to reduce the amount of nutrients taken from the soil as compared to maize as a sole crop (Ananthi et al., 2017; Zhang and Li, 2003). Production increased due to reduced competition between species compared with competition within species. Eskandari, 2011; Maitra et al., 2021; Maitra et al., 2019 also considers intercropping as an economic method for higher production with lower levels of external inputs. This improved resource use efficiency is critical, particularly for small-scale farmers and in areas where the growing season is short (Altieri, 2002; Daryanto et al., 2020). More production in intercropping can be attributed to the

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higher growth rate, reduction of weeds, reducing pests and diseases, and more effective use of resources due to differences in resource consumption (Eskandari, 2011; Maitra et al., 2020; Stomph et al., 2020). In addition, if there are "complementary effects" between the components of intercropping, production increases due to reducing the competition between them (Dwivedi et al., 2015; Maitra et al., 2019; Mousavi and Eskandari, 2011).

Increased diversity of the physical structure such as leaves and roots of plants in an intercropping system also produces many benefits. Increased leaf cover in intercropping systems helps to reduce weed populations once the crops are established (Belel et al., 2014). Having a variety of root systems in the soil reduces water loss, increases water uptake and transpiration. The increased transpiration may make the micro-climate cooler, which, along with increased leaf cover, helps to cool the soil and reduce evaporation (Ai et al., 2021; Gebregergis, 2016; Workayehu, 2014). This is important during drought or water stress, as intercropped plants use a larger percentage of available water from the field than mono cropped plants. Seran and Brintha, 2010 also reported that, rows of maize in a field with a shorter crop will reduce the wind speed (above the shorter crops) and thus reduce desiccation. Increased plant diversity in intercropped fields may reduce the impact of pest and disease outbreaks by providing more habitats for predatory insects and increasing the distance between plants of the same crop (He et al., 2019; Smith and McSorley, 2000). Intercropping has environmental benefits such as requiring less land for crop production, reducing use of inorganic fertilizers, pesticides, and herbicides, and reducing soil erosion. Intercropping also has several benefits to the farmer, including a reduction in farm inputs, the addition of cash crops and diversification of diet, increased labor utilization efficiency, and a reduced risk of crop failure due to uncertainties in the weather. The quantity of time to plant the multiple varieties of seeds is reduced to increase labour utilization efficiency. Peak labour requirements during the harvest become easy when two or more crops are harvested at different times, allowing the smallholder to finish the harvest with family labour (Maitra et al., 2021). Intercropping presents a large level of risk reduction for smallholders in northern Ghana. If one crop is entirely lost to pest or drought damage, the farmer may still harvest the other crop in the field. Given the unpredictable rainy season and the different water requirements of each crop, planting many varieties of the same crop in an intercropped field gives the farmer a better chance that some crops will survive (Maitra et al., 2021). One important advantage of intercropping is its ability to reduce pest and disease damage. In general, strategies involved in reducing pest infestation and damage in intercropping can be divided into three groups (Mousavi and Eskandari, 2011). The first is the delimiter crop hypothesis, in which the second specie breaks down the ability of a pest to attack its host and is used more in proprietary pests. Second, for pests and pathogenic agents, the trap crop hypothesis, in which the second species attracts pests or pathogens that normally cause damage to the main species, is used more broadly. The natural enemy's hypothesis asserts that predators and parasites prefer intercropping to monocropping, which reduces parasitized and preyed populations.

Although intercropping does not always reduce pest or pathogen populations, most reports have pointed to reduced populations of pests and diseases in intercropping (Lopes et al., 2015). In a review by (Mousavi and Eskandari, 2011) on intercropping, in 53% of the experiments, intercropping reduced the pest, and in 18% it increased the pest more than pure cropping. Increasing pests can be due to several reasons, like the second crop may be a host for pests in intercropping, or increasing the shade in the canopy provides favourable conditions for pests and pathogen activity. In addition, plant residues are often used as a source for pathogens inoculated, as also reported by (Imathiu et al., 2014). More species diversity in agricultural ecosystems can limit the spread of plant pathogenic bacteria.

Intercropping systems increase biodiversity just like natural ecosystems. This increase in diversity reduces pest damage and diseases, (Imathiu et al., 2014). Recent advances in organic agriculture have reemphasized the use of conservation agricultural practices such as crop intercropping with leguminous species and green manuring as cost-effective mechanisms for improving and maintaining soil fertility (Sarkar et al., 2021). In addition to biological nitrogen fixation, biochar sources play an important role in plant nutrient recycling, soil temperature improvement, soil structure enhancement, and microbial activity promotion, as well as maintaining high soil nutrient status (Das and Ghosh, 2020; Palansooriya et al., 2019). Despite this, the long-term beneficial impacts of biochar and fertilizers on farmlands may be limited by weak soil structure and weathering, which makes them more vulnerable to erosion and nutrient leaching (Ding et al., 2016). According to reviews by (Guo et al., 2016; Mulabagal et al., 2017; Rawat et al., 2019), amending soils with biochar (a by-product of the pyrolysis of plant biomass in a low-oxygen environment) reduces nutrient leaching and improves soil cation exchange capacity, soil organic matter, microbial biomass, pH, and soil moisture retention. Smallholder farmers in Northern Ghana use legume–cereal intercrop systems with organic residue inputs, although yield responses are generally limited by the aforementioned soil issues. Biochar's incorporation into these cropping systems is thus predicted to enhance the long-term benefits of crop rotation systems by increasing nutrient availability, nitrogen recovery efficiency, and crop performance (Bashagaluke et al., 2020; Kalu et al., 2021; Oladele et al., 2019). Biochar's use could ensure a long-term advantage for soil fertility improvement and crop output because it can persist in soils for decades without degrading (Agegnehu et al., 2017; Kalu et al., 2021). Currently, only a few research studies in African agroecosystems have looked into the viability of applying biochar in legume–cereal intercropping systems. The effects of biochar on soil nutrient availability and the agronomic performance of upland rice within a legume–rice intercropping system in Northern Ghana were thus the focus of this study. It is expected that biochar application will increase upland rice agronomic performance in the legume–rice intercropping system by increasing soil nutrient availability, nutrient uptake. Also serving carbon sink and making them effective in the ecosystems for storing carbon in the soil. The aim of the study is to decrease yield losses and sustain a level of cropping competition indices that improves resource use as well as impacts on high crop yields within the rice-cowpea intercrop.

Material and methods

Study area

The research site was located at the Farming for the Future, University for Development Studies (UDS), Nyankpala near Tamale in the Northern Region of Ghana (latitude 09.246070N and longitude 000.589920W). The area has a unimodal rainfall pattern with an annual rainfall of 800-1100 mm (Abdul-Ganiyu et al., 2018); SARI, 2013). The dry season starts from November to March with day temperatures ranging from 33 °C to 39 °C, with night temperatures range from 20 °C to 26 °C (Abdul-Ganiyu et al., 2015; Dogbe et al., 2016). The mean annual daytime relative humidity is 54% with altitude of the area is 252 m above sea level. The site is underlain by Upper Voltaian sediments. The area is covered with red and orange-brown drifts partly eroded in places and exposing a layer of shallow ironstone and sandstone (Adjei-Gyapong and Asiamah, 2002; Adu, 1957; Imoro et al., 2012).

This layer is often separated from the underlying sandstone by a thin stone-lime (Imoro et al., 2012) (Adjei-Gyapong and Asiamah, 2002; Adu, 1957). The soil profile has been classified as Nyankpala series (Ferric Luvisols) (Adjei-Gyapong and Asiamah, 2002; Imoro et al., 2012); ISSS/ISRIC/ FAO, 1998; (FAO, 1988). They are shallow to very shallow soils overlying in situ developed iron pan within 55.9 cm. It is also moderately shallow to moderately deep concretionary and or gravelly, heavy to medium textured soils overlying mostly highly weathered granites shales (Asiamah and Dwomo, 2009). Characteristically the soils are acidic, with low nitrogen and phosphorus content. They are susceptible to moderate erosion and should not, therefore be left bare. They are inherently infertile and will need to be fertilized to obtain optimum yield (Adjei-Gyapong and Asiamah, 2002; Adu, 1957; Imoro et al., 2012).

Biochar preparation

Three different sources of feedstocks were produced from slow and high pyrolysis of groundnut shells, corn cobs, poultry manure at 400°C - 700°C with a dwelling time of 24 hours in oxygen-limited conditions in a reactor, followed by water and air cooling of charred feedstock to room temperature and grind the biochar. The synthesized biochar was ground and analyzed for a few selected parameters (Table 1). Organic carbon was determined by the wet combustion method according to (Walkley and Black, 1934). Total nitrogen was determined by the Kjeldahl method. Phosphorus and potassium were determined in plant ash using the Gallenkamp flame analyzer method (Bremner, 1965). Available phosphorus was determined by (Bray and Kurtz, 1945).

Biochar Types

Table 1: Basic biochar properties used for simulations

Feedstock	Pyrolysis	pH 1:5	CEC me100g^{-1}	N %	P %	K %	C/N ratio (-)	Fraction C (0 -1)
Biochar Corn cobs	High	6.67	118.26	0.95	0.21	0.45	11.0	0.129
Biochar Poultry manure	Low	9.29	125.63	2.19	0.50	0.47	10.5	0.324
Biochar Groundnut shells	Low	11.13	85.52	1.34	0.13	0.74	12.3	0.243

Source: Frimpong-Manso and Ganiyu (2021)

Table 2: Initial Chemical and Physical Properties of Soil

Soil Parameters	0-30 cm
pH (1:1 H_2O)	5.66
% Org Matter	2.80
Org C (%)	1.62
% N	0.08
P (mg kg^{-1})	3.30
Ca (cmol kg^{-1})	1.56
Mg (cmol kg^{-1})	1.00
K (cmol kg^{-1})	0.08
Exchangeable acidity (cmol kg^{-1})	0.45
ECEC (cmol kg^{-1})	2.79
% Base saturation	93

Sand (%)	62.7
Silt (%)	29.3
Clay (%)	8.0
Texture class	Sandy Loam

The data used in the current study cover the main crop and soil processes. Initial soil sampling was done at a depth of 0-30 cm for characterization of both chemical and physical properties (Table 2). Ten plants were randomly selected on each plot and plant height at maturity, number of panicles, number of tillers and number of grains per panicle were determined. Data was collected every week from 30 days after transplanting to heading. Data were collected on maturity indices, namely measurements of plant height for both cowpea and rice, number of panicles, and number of plants within 1m area.

Five panicles were randomly selected for number of spikelet's, panicle length, number of grains per spikelet on a panicle, weight of unfilled and filled grains, total grain weight and 1000 grain weight for both rice and cowpea and straw weight. The combination of the rice and cowpea was in a 3:1 ratio (half rice and half cowpea). Varieties of the crops were Nerica 14 (85 days) for the rice (*Oryza sativa* L.) and erect cowpea (padituya) type (*Vigna unguiculata* L. W), respectively. Data on yield components were collected at the field while data on yield was obtained from net plot area of 12 m2 (3 m × 4 m). Grain parts were analyzed for nutrient uptake and total nitrogen concentration using the micro Kjedahl method (Chukwuka and Omotayo, 2008). Nutrient use in the interplant competition was evaluated using the nitrogen, phosphorus and potassium utilization efficiency-NUE concept (Baligar et al., 2001; Baumann et al., 2001; Fixen et al., 2015).

$$NUE= YF -Yo/ Uf- Uo$$

where YF and YO = Yield in kg ha^{-1} at corresponding fertilizer rates; Uf and UO = Uptake of nitrogen, phosphorus and potassium in kg ha-1 at corresponding fertilizer rates. The intra- and interspecific competition in the rice – cowpea intercropping system was assessed using the land equivalent ratio-LER (Mead and Willey, 1980), the relative crowding coefficient-K (Willey and Rao, 1980) and the aggressivity index-A (Taha and El-Mahdy, 2014)

$$LER= Yij /Yii + Yij /Yjj$$

where, Y = Yield per unit area; Yii = Sole crop yield of crop i (rice); Yjj = Sole crop yield of crop j (cowpea); Yij and Yji = yield per unit area of i intercropped with j and j intercropped with i. When LER is 1, there is no advantage in intercropping as compared to sole cropping, whereas if LER > 1, a larger area of land is needed to produce the same yield of both sole crops of each component, in relation to intercropped mixture. A LER < 1.0 shows a disadvantage of intercropping. If a species i is in mixture with a species j in a 3:1 mixture of i and j, then an individual coefficient, termed the relative crowding coefficient k can be expressed as

$$Kij = Yij/Yii-Yjj$$

$$Kij =Yji/Yjj –Yii$$

where, Kij and Kji = relative crowding coefficients of crop i intercropped with crop j and crop j intercropped with i; Yij and Yji = yields per unit area of i intercropped with j and j intercropped with i; Yii and Yjj = yields per unit area of sole crop i and sole crop j. The crop component that had a higher coefficient was said to be dominant. If the coefficient of a particular crop species is less than, equal to or greater than 1, then that species has produced less yield, the same yield, or more than "expected", respectively ((Willey and Rao, 1980). Aggressivity (Taha and El-Mahdy, 2014) is a measure of how much the relative yield in a species i is greater than that for species j. This can be expressed as follows:

$$Aij = Yij/Yii * Zji – Yji/ Yjj * Zji$$

Aij = Aggressivity index of crop i intercropped with j; Yij = Yield per unit of crop i intercropped with j; Y-ii and Yjj = yield per unit area of sole crop i and j; Zji = Proportion of intercropped area initially allocated to crop i; Zji = Proportion of intercropped area initially allocated to crop j. If A = O, the component species are equally competitive, for situations where A ≠ O, both species will have the same numerical values, only that the value of the dominated species will be negative. If the numerical absolute value of A is large, there is a large difference in the competitive abilities of the two species and the larger is the difference between measured and expected yields. Values of yield, yield components and total nitrogen of both rice and cowpea were presented as average of two cropping seasons, and were subjected to the appropriate analysis of variance (ANOVA) for factorial and randomized complete block designs statistical using statistix10.0 (Analytical software, Tallahassee FL) techniques for analyzing intercropping trials (Akter Suhi et al., 2022; Pereira¹ et al., 2021) (Degaga and Angasu, 2017). Comparisons of means of the cropping systems were made by the Honest significant difference.

Results

Increasing nitrogen rates increased (P < 0.05) yield and yield components of rice in sole rice arrangement competition indices (Tables 3, 4 and 5), but in the mixtures, only the number of panicles significantly increased (Table 4). However, for cowpea, higher nitrogen rates did not increase yield and yield components in sole and mixed competition indices, respectively. The number of panicles per rice plant was reduced (P< 0.01) by higher arrangement competition indices in mixed populations (Table 5 and 6). Number of panicles per plant decreased with planting competition in sole and mixture stands of rice, although the sole rice crops had higher number of panicles per plant on average. Increasing planting row arrangement competition decreased panicle number by 26%, 38%, 47% and 59% at biochar poultry manure+45N30P30K+cowpea, biochar groundnut shells+45N30P30K+ cowpea, biochar corncobs+45N30P30K +cowpea, biochar saw dust+45N30P30K+cowpea, biochar rice husk+45N30P30K+cowpea, respectively, for rice mixtures. This trend did not occur in the sole rice stands. High density competition indices decreased (P < 0.05) the number of grains per panicle in mixed rice populations (Table 7). Weight of pods per plant and grain yield of cowpea in mixed populations did not result any increase with increasing plant density (Tables 5, 6.and 7). Grain yield of cowpea in sole crop increased (P < 0.05) with cropping density (Table 6). With exception to the number of grains per panicle of rice (Table 7) that decreased in biochar rice husk+45N30P30K by intercropping with cowpea, other yield and yield components of rice and cowpea had no effect when intercropped (cropping systems). Interactions (P < 0.05) were observed between Nutrient use efficiency on rice grain (NPK) × row arrangement density, treatment on Nutrient use efficiency ×

cropping system and row arrangement density× cropping system in yield and yield components of rice (Table 5). Weight of pods per plant showed no significant interactions with cowpea. Cowpea grain yield indicated ($P < 0.05$) row arrangement density x system interactions. However, the grain yield of rice presented significant interactions with N x row arrangement density ($P < 0.05$), P × cropping system and K x cropping system ($P < 0.01$) but percentage phosphorus in grain showed negative (Tables 5, 6 and 7). A yield advantage of intercropping was observed at all levels of nitrogen, phosphorus, potassium and row arrangement density on the treatments for the rice-cowpea intercrop. This is shown by the (LER) values in Table 9. The low biochar rice husk+45N30P30K and biochar corn cobs+45N30P30K in density recorded yield advantages ranging from LER 1.236 and LER 1.259, respectively. A lower LER of 1.236 was observed for the high in density at biochar rice husk+45N30P30K. Yield advantage due to NPK was more pronounced at biochar poultry manure+45N30P30K (LER 1.552) and biochar groundnut shell+45N30P30K (LER 1.324) at the lowest density. High nitrogen levels of biochar saw dust+45N30P30K and biochar rice husk +45N30P30K with high density gave lower intercrop yield advantage of LER 1.289 and 1.236, respectively. Values of the aggressivity indices (A) indicated that cowpea is the dominant crop (Table 5). The values of A are high at biochar poultry manure+45N30P30KNPK and high in density. At all levels of NPK with low row arrangement in density at biochar rice husk+45N30P30K, rice was more aggressive on the dominant crop. The relative crowding coefficient values also indicate that cowpea was dominant in the rice-cowpea intercropping system in the experiment (Table 5). The dominant attribute of the cowpea was expressed more at high densities. However, rice was more dominant at all levels of nitrogen with low density biochar rice husk+45N30P30K. Both rice and cowpea yield in the intercrop at all nitrogen in rice grain levels were high than expected in plots with low density. Compared to their sole crop absolute control, NUE was generally higher in all intercrops (Table 3). In rice, NUE was higher with sole crops 90N60P60K and high densities. Negative NUE values in phosphorus were obtained for most of the biochar+45N30P30K combination with cowpea as well as biochar sole rice plots, except 90N60P60K and absolute control. At the low NPK in absolute control, high values of NUE were obtained for biochar+45N30P30K combination with cowpea intercrop and sole rice crop 90N60P60K and biochar at medium and high densities. Therefore, the results of nutrient uptake (kg ha^{-1}) of rice straw grown at various treatment levels in the 2018 and 2019 cropping seasons previously perform on UDS-farming for the future experimental plots (Table 3) were integrated into the newly developed.

Table 3. Efficiency of utilization (kg ha^{-1}) of rice grain absorbed nutrients on biochar and inorganic fertilizer in the seasons 2018 and 2019

Treatment	Nutrient Use Efficiency (% N) 2018	Nutrient Use Efficiency (%N) 2019	Nutrient Use Efficiency (% P) 2018	Nutrient Use Efficiency (%P) 2019	Nutrient Use Efficiency (%K) 2018	Nutrient Use Efficiency (%K) 2019
Absolute Control	1.25	1.28	0.46	0.38	0.22	0.23
90N60P60K	16.63	20.96	16.65	21.10	16.65	23.60
CharGroundnutshell+45N30P30K+C	20.39	22.32	-71.46	22.44	20.42	27.92
CharPoultrymanure+45N30P30K+C	27.04	25.31	39.81	25.38	27.07	26.32
CharCorn cobs	15.11	18.63	-1.57	18.69	15.14	20.98

45N30P30K+C						
CharGroundnut shell+45N30P30K	4.55	16.35	0.49	16.48	4.55	17.38
Char Poultry Manure45N30P30K	1.81	16.93	-0.81	16.98	1.81	18.84
CharCorn cobs+45N30P30K	6.59	14.02	-2.69	14.07	6.59	12.76
Grand Mean	9.67	17.29	-0.83	17.21	9.61	17.16

(Source: Frimpong-Manso and Ganiyu, 2021)

Char-biochar, Nitrogen (N), Phosphorus (P), Potassium (K) and Cowpea (C)

Nutrient uptake of rice straw

Among the treatments, the highest N% uptake was logged under the biochar+45N30P30K combination with cowpea, followed by biochar compared to 90N60P60P for both the 2018 and 2019 seasons at maturity phase (Table 4). The least N uptake was recorded under absolute control, which did not incorporate biochar and inorganic nutrients as well as cowpea intercrop. At maturity, there was a similar trend in P, K, and S uptake. Nutrient uptake is a product of nutrient concentration and straw accumulation. The combination of biochar plus inorganic fertilizer with cowpea intercrop helped nutrient use by analyzing for healthier NPKS uptake and NPKS yield of rice. The improved uptake capacity owing to the higher availability of nutrients from the soil pool and also from the add-on sources of biochar resulted in a similarity to (Lehmann et al., 2006). The effect of biochar plus inorganic fertilizer combination with cowpea intercrop treatment on the macronutrient (N, P, S, and K) uptake of rice plants was analyzed in both seasons (Table 4). The results of nutrient concentrations in rice straw and grain from various treatments were recorded in terms of percentages. In both cropping seasons on sandy loam soils, biochar+45N30P30K combination with cowpea treatment aided higher N uptake in rice plants for both straw and grain. Both cropping seasons, 90N60P60K, caused higher N intake. However, the biochar+45N30P30K treatment had high N uptake in plants. (Dong et al., 2018) also testified to the higher retention of N in the paddy fields through successive growing seasons after biochar incorporation. The combined use of biochar plus inorganic fertilizers and cowpea intercrop performed significantly better than inorganic fertilizers alone for N uptake. Biochar+45N30P30K in combination with cowpea intercrop help to sustain higher absorption of soil nitrate (NO_3-N) and ammonium (NH_4^+) retention for a longer period of time, as well as restoring carbon in the soil environment to grasp its fertility and yield, thus grasping higher N uptake of rice.

Phosphorus moves very little in mineral soil, diffusing over a distance as small as one-quarter inch. While P uptake in plants was best in moist soils, substantial differences were seen in the sandy loam soils among the 32 plots. Among the eight treatments, the biochar+45N30P30K combination with cowpea intercrop was the best in well-drained soil, improved phosphorus uptake, and translated into the grain. Biochar treatments had a greater effect on total nitrogen balance than straw (Table 3). An experiment by (Liu et al., 2019), exhibited an increase in the availability of soil P after rice straw biochar application. In contrast, application of biochar+45N30P30K combination with cowpea intercrop improves the activity of microorganism that place phosphorus in solution and improves diffusion to roots for phosphorus uptake by plants in sandy loam soil, which might be due to the inherent P content of biochar+45N30P30K combination with cowpea intercrop. The absolute control treatment resulted in relatively low soil compaction or poorly drained soil, which reduced the percentage of P uptake in rice plants' straw and grain (0.15 and 0.30%) in both seasons.

Steiner et al., 2007 also uttered similar views. Improved P uptake with careful application of biochar+45N30P30K combination with cowpea intercrop blended factors that improve P availability in soils. These consist of production of organic acids through decomposition of organic matter and ensuing releases of phosphate ions, development of phospho-humic complexes, isomorphic restoration of phosphate ions by humate ions, and also synergistic results existing between N and P due to application of biochar as carbon. Such properties in soil P and rice straw uptake were also attested to by (Liang et al., 2006).

Potassium uptake in rice was high in plants to transpire less and make better use of water supplies in biochar+45N30P30K combination with cowpea intercrop treatment. Shin et al., 2020 testified to increased K in soil after rice straw biochar incorporation. The K uptake in rice plants increases hardiness or toughness. In general, plants well stocked with potassium have strong stems that are less prone to lodging both rice straws and grains of rice in sandy loam soils compared to absolute control. The outcomes of rice plant growth and nitrogen uptake in this study conform with those exhibited by (Kang et al., 2021), where they testified to improved rice yield and N retention after the incorporation of biochar with inorganic fertilizer. Percentage (%) N and potassium content act to balance the effects of nitrogen and a particular nitrogen-potassium ratio in rice plants. The percentage of P, K, and S uptake by rice-cowpea plants varied significantly across three different biochar incorporation sources. Higher uptake of K capacity may be owing to the readying result of biochar on decay linked release of organic acids that solubilize innate K. In addition, the advanced greatness of rises in K uptake by conjunctive use of biochar plus inorganic fertilizers in combination with cowpea intercrop exhibited that biochar takes advantage of biochar in improving the use efficiency of practical nourishment as well as inherent nutrient availability in the soil. (Gul and Whalen, 2016) also produced a similar report. Biochar as well as 90N60P60K treatment were significantly effective in improving rice % S content in both cropping season plants. In both cropping seasons, treatments triggered the lowest S uptake in rice (Table 4). The biochar+45N30P30K combination with cowpea intercrop was shown to aid in the highest sulfur uptake for straw (0.57 and 0.58%) in both the 2018 and 2019 seasons. Absolute control treatments had a relatively very low percentage of S uptake in straw during the cropping seasons.

Biochar+45N30P30K in combination with cowpea intercrop treatment of % sulphur aids rice plant in making chlorophyll and also aids cowpea nodulation and seed production of all plants more than the absolute control. Biochar+45N30P30K combination with cowpea intercrop treatment showed that sulphur uptake in rice and cowpea plants improves protein and chlorophyll content, stress tolerance, and also pungent flavors more than absolute control. Sulphur uptake by straw was significantly influenced by the application of three different sources of biochar in a combination of inorganic fertilizer with cowpea intercrop (Table 4). The S uptake by straw ranged from 0.58 to 0.41% biochar, poultry manure+45N30P30K to absolute control. The highest S uptake by straw (0.58%) was observed in the biochar poultry manure+45N30P30K treatment and the lowest S uptake by straw (0.41%) was observed in the absolute control treatment (Table 4). Bhuvaneswari and Sriramachandrasekharan, 2006 detected that incorporation of biochar and inorganic fertilizers improved the sulfur uptake significantly by rice. Azmi et al., 2004 stablished that increasing fertility levels significantly improved the upland rice yield and S uptake. In general, the combination of biochar + 45N30P30K with cowpea intercrop is recommended for the production of upland rice-cowpea intercrop.

Table 4. Effect of biochar (5 t ha^{-1}) and inorganic fertilizer (kg ha^{-1}) on the nutrient uptake in rice straw

	Rice Straw – 2018				Rice Straw – 2019			
Treatment	N	SO4-S	K	P	N	SO4-S	K	P
				%				
Absolute Control	0.69	0.45	1.30	0.14	0.08	0.50	1.96	0.15
90N60P60K	1.36	0.41	1.78	0.19	1.33	0.45	1.75	0.18
CharGroundnutshell+45N30P30K+C	1.25	0.55	1.80	0.20	1.19	0.57	2.24	0.17
CharPoultry manure+45N30P30K+C	1.44	0.57	1.65	0.25	1.41	0.58	2.94	0.29
CharCorn cobs+45N30P30K+C	1.27	0.55	1.85	0.20	1.09	0.51	2.00	0.22
CharGroundnut shell+45N30P30K	1.08	0.51	1.81	0.18	1.13	0.46	2.10	0.16
CharPoultry Manure+45N30P30K	1.02	0.52	1.29	0.23	1.08	0.44	2.43	0.35
CharCorn cobs+45N30P30K	1.02	0.48	1.80	0.25	0.94	0.46	2.04	0.21
Grand Mean	1.15	0.51	1.67	0.20	0.94	0.50	2.20	0.20

Source: Frimpong-Manso and Ganiyu (2021)

Char-biochar, Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur and Cowpea (C)

Competitive roles of rice and component crop

When different crops are put on an effective, similar basis by employing some relative metrics, the extensive effects of intercropping were often recognized by comparing intercropping with sole cropping. The competitive ratio (CR), relative crowding (K), and aggressivity (A) are roles that evaluate intercrop competition by correlating yield changes (Dhima et al., 2007). Rice appeared to be substantially overridden in this experiment's intercropping systems (Table 5), as it had greater relative crowding coefficient (K) values than the component crop in all row layouts. For both cropping seasons, the following treatments were used: biochar poultry manure+45N30P30K combination + cowpea, biochar groundnut shells+45N30P30K combination + cowpea, biochar corncobs+45N30P30K combination with cowpea intercrop. Biochar poultry manure+45N30P30K combination + cowpea gave the highest K value. According to the K Value, one rice plant was comparable to 15.5 percent of cowpea plants. In the biochar poultry manure+45N30P30K combo + cowpea (3:1) row arrangement of rice and cowpea, cowpea most likely had a competitive edge over the component crop, therefore receiving the bulk of growing resources for better grain output. The implication is that the intercropping systems had yield advantages because the product of the relatively high crowding coefficient (K) of component crops in the biochar poultry manure + 45N30P30K combination + cowpea (3:1 rice-cowpea) and biochar groundnut shells + 45N30P30K combination + cowpea (3:1 rice-cowpea) row arrangements were greater than one. During the 2018 and 2019 seasons (Table 5), K values for rice were consistently higher than K values for component crops in all intercrop row combinations, implying that rice had absolute dominance. Biochar poultry manure+45N30P30K combination + cowpea and biochar groundnut shells+45N30P30K combination + cowpea gave the K value (1.76 and 1.56) for rice in the two seasons. In both experiments, the rice crowding coefficient (K) was consistently greater than one. Rice, on the other hand, had total K values larger than one, with the exception of rice-cowpea row arrangements in the 2019 season, which had total K values less than one. In most cases, three different sources of biochar plus inorganic fertilizer combinations with cowpea under rice-cowpea intercrop where they captured more resources were possibly better than 90N60P60K and absolute control under sole crop (Table 5).

Aggressivity

Under all row arrangements, treatments for both cropping seasons were biochar poultry manure+45N30P30K combination+cowpea, biochar groundnut shells+45N30P30K combination with cowpea intercrop, biochar corncobs+45N30P30K combination+cowpea. An aggressivity value of zero shows that the component crop is in every way competitive. In any other circumstance, both crops will have the same value, but the sign of the dominant varieties will be positive and that of the dominated varieties negative. Chhetri and Sinha, 2019 stated similar outcomes for maize gaining positive aggressivity value when intercropped with legumes. The greater the value, the bigger the difference between actual and expected yields. The data exhibited in (Table 5) revealed that the component crops did not compete correspondingly. In the three different sources of biochar plus inorganic fertilizer combinations with cowpea under rice-cowpea intercrop systems, rice was dominated by cowpea in the biochar poultry manure+45N30P30K combination + cowpea under 3:1 row arrangement in both seasons. In the biochar groundnut shells+45N30P30K combination+ cowpea 3:1 row arrangement, on the other hand, the results showed that rice and cowpea were equally competitive. In both cropping seasons, cowpea seemed to be more dominant in their respective row arrangements, whereas rice dominated the cowpea significantly in the 3:1 row arrangement. Cowpea had the lowest aggressiveness value in the biochar corn cobs+45N30P30K combination + cowpea row arrangement, implying that cowpea was less competitive against rice. Khan and Khaliq, 2004 also reported similar results of positive aggressivity value in maize-cotton intercropping.

Competitive ratio (CR)

During the 2018 and 2019 cropping seasons, the competitive ratios were biochar poultry manure+45N30P30K combination+cowpea, biochar groundnut shells+45N30P30K combination +cowpea, biochar corncobs+45N30P30K combination+cowpea. It's a useful technique for determining how closely one crop competes with another. In all combinations, there were higher CR values for rice than for cowpea, except for the biochar rice husk+45N30P30K combination + cowpea row arrangements of rice and cowpea at both cropping seasons. The experiment exhibited that in rice-cowpea row arrangements, rice was more competitive than cowpea (Table 5). Rice was found to be a superior competitor than cowpea when cultivated in combination. According to (Dhima et al., 2007), competitive ratio (CR) is a better indication of a crop's competitive potential in a polyculture and can show a better index than relative crowding coefficient (K) and aggressively. Khan, 2009 has highlighted the benefits of rice-cowpea intercropping. Rice was the most dominant type in a crop combination, according to the relative crowding coefficient and competitive ratio in terms of aggressively. Rice has been shown to have a higher competitive ability in regard to resources when grown alongside cowpea (Ogola et al., 2013). The advantages gained from intercropping systems were attributable to better growth resources under the cowpea intercropping system, which were evident through competitive roles (Kermah et al., 2017). In these conditions, the major aim of intercropping is to get a full yield of the staple crop and an extra yield from the alternative crop, so that the combination gives the alternative crop the highest output without lowering the main crop production.

Land equivalent ratio (LER)

The land equivalent ration (LER) imitates the increased benefit of intercropping systems above single-cropping systems. For both cropping seasons, the LER values are listed in Table 5. Both cropping seasons of the intercropping advantage experiment are on biochar poultry manure+45N30P30K with cowpea intercrop, biochar groundnutshells+45N30P30K with cowpea intercrop, biocharcorncobs+45N30P30K with cowpea intercrop, which are under rice-cowpea intercrop in 3:1 row arrangement. Both time-based and spatial harmonization, according to (Negash and Mulualem, 2014), resulted in a yield benefit. When the LER value of the biochar poultry manure+45N30P30K combination +cowpea was more than one (1), it showed that intercropping outperformed sole cropping in terms of conservational resource consumption for plant growth. The LER values for rice were more than 0.5 in all intercropping row combinations, indicating a yield benefit for intercropping rice over biochar corn cobs+45N30P30K + cowpea intercrop, 90N60P60K, and absolute control in single cropping systems.

The LER value for biochar corn cobs+45N30P30K combination + cowpea (0.95) was less than (0.5) biochar poultry manure+45N30P30K combination +cowpea. When three different sources of biochar plus inorganic fertilizer were combined with cowpea under three rows of rice, one row of cowpea was to one row of rice, implying that the intercropping utilized resources more efficiently than 90N60P60K and absolute control. Workayehu (2014) found that under a maize-based intercropping system, the LERs for cowpea, soybean, and groundnut were less than half of one (LER<0.05). Rice is more competitive than cowpea in the intercrop context, as evidenced by the yield advantage of intercropping systems (total LERs). Studies showed that such competition led to decreased or survival, growth or reproduction of at least one species (Malézieux et al., 2009). Rice had LER values of 5.07 in both seasons, indicating yield advantages for rice intercrop over sole crop under 90N60P60K. In the rice-cowpea row arrangements, the biochar poultry manure+45N30P30K combination +cowpea 1.19 had the highest LER value. The overall LER achieved with biochar corn cobs+45N30P30K combination+cowpea 3:1 row arrangement was 0.95, indicating a yield disadvantage for intercropping systems compared to 90N60P60K and absolute control solo cropping.

Cowpea had a lower LER value than 0.5 in the 3:1 row arrangement, according to the report. The biochar poultry manure+45N30P30K combination+cowpea total LER (LER for rice+LER for cowpea) was 1.55 in comparison to 90N60P60K and absolute control of sole cropping, the system of intercropping rice with cowpea was highly productive in terms of conservational resource use between row arrangements, indicating that the system of intercropping rice with cowpea was highly productive in terms of conservational resource use. The LER values obtained in this experiment can be compared to those obtained in rice-cowpea intercropping systems by (Mbah and Ogidi, 2012). The higher LER values could be attributed to a higher combined intercropped yield as well as a time-based difference between the crops. Rice's short season and early maturity crop growth rate are expected to enable it to rebound from competitive consequences (Amanullah, Somasundaram, et al., 2007; Amanullah, Vanathi, et al., 2007).

Economic advantage index

Significant agronomic advantages from intercropping do not always ensure an economic advantage, and there is a need for some economic evolution and absolute yield comparisons of intercropping systems (Tana and Mulatu, 2000). Thus, a more satisfactory use of cost benefit ratio values would probably be to calculate the absolute value of the unaffected yield advantage (Hayder et al., 2003). Consequently, the cost benefit ratio was calculated by multiplying the respective yields of the component crops by their lowest market prices during the trial and dividing them by their respective LER. Intercropping advantage values shows the disadvantage of the system as the economic values were negative. On the other hand, cost benefit ratio values were positive, which presented a definite yield advantage in intercropping compared to sole cropping (Khan, 2009). It is an indicator of the economic viability of intercropping systems as compared to 90N60P60K and absolute control of sole cropping. The experimental data presented in Table 6 exhibited that economic advantage was significantly influenced by intercropping arrangements. The economic values in terms of net income were positive under five different sources of biochar in the 3:1 row arrangement in the experiment: biochar poultry manure+45N30P30Kcombination with cowpea intercrop (6699.5), biochar groundnut shells+45N30P30K combination with cowpea intercrop (5251.85) and biochar corncobs+45N30P30K combination with cowpea intercrop (4274.8) intercropping row arrangements (Table 6), which demonstrates a definite yield advantage compared with sole cropping systems and other intercrops tested in this experiment. Cost benefit ratio values in biochar poultry manure+45N30P30K intercropping arrangements with cowpea (2.92) and biochar corncobs+45N30P30K intercropping arrangements with cowpea (2.68) were found to be highly positive when compared to 90N60P60K and absolute control due to very low LER caused decrease in cowpea yield.

The outcome was in substantiation with (Dhima et al., 2007), who stated that vetch-barely intercropping in different seeding ratios gave a positive cost-benefit ratio as compared to sole cropping. In the same way, cost benefit cost benefit ratio values in rice barley combinations were found highly positive among the treatments due to the high LER-caused increase in rice yield. (Ghosh, 2004). The maximum positive value in the biochar adsorbs more moisture and cowpea for the intercropping arrangements, implying that the compatibility arrangement showed an economic advantage. The combined maximum positive cost benefit ratio values in both experimental intercropping arrangements showed that the 3:1 intercropping arrangement was high in terms of economic advantage and implies suitability of intercropping arrangements. A probable explanation for the moisture content and increased soil organic carbon content was the better use of resources between the rice-cowpea intercropping arrangements. In the same way, (Ghosh, 2004) found that when the LER is high, there is also a significant economic benefit expressed with a higher cost benefit.

Table 5. Enhance the resource use efficiency through intercropping for production efficiency and rice grain average nutrient efficiency for mixtures of rice and cowpea as influenced by row arrangements

Treatment	LER			Rice Grain N	Rice Grain P	Rice Grain K	RCC	K		A		CR	
	LER Rice	LER Cowpea	Total	%	%	%	K Rice	K Cowpea	Total	A Rice	A Cowpea	CR Rice	CR Cowpea
CharGs+45N30P30K+C	1.06	0.26	1.32	21.36	-24.51	24.17	1.56	-0.99	-1.55	2.33	0.41	3.25	0.24
CharPM+45N30P30K+C	1.19	0.37	1.55	26.17	32.61	26.69	1.74	-1.41	-2.44	2.43	0.43	4.14	0.31
CharCc+45N30P30K+C	0.95	0.31	1.26	16.87	8.56	18.06	1.39	-1.19	-1.65	2.26	0.46	3.22	0.34
Grand Total	5.07	1.59	6.66	95.99	40.16	104.43	7.42	-3.80	-9.08	11.46	1.74	16.48	1.21

Char-biochar, PM-poultry manure. Cc-corn cobs, cowpea Land equivalent ratio (LER), relative crowding coefficient (K) and Aggressivity index (A), Competitive Ratio (CR), Area Time equivalent (ATER) (A), Nitrogen (N), Phosphorus (P) and Potassium (K)

Table 6. Economic evaluation of three different sources of biochar and inorganic fertilizer Intercropping combinations.

Treatment	LER		Cowpea grain t ha^{-1}	Rice grain t ha^{-1}	Total variable cost GH₵ t ha^{-1}	Total variable cost GH₵ t ha^{-1}	RYE Revenue (rice yield equivalent) GH₵ t ha^{-1}	RYE Revenue (rice yield equivalent) GH₵ t ha^{-1}	Net income GH₵ t ha^{-1}	Net income GH₵ t ha^{-1}	Benefit cost ratio BCR	Benefit cost ratio BCR
	LER Rice	LER Cowpea			Rice	Cowpea	Rice	Cowpea	Rice	Cowpea	Rice	Cowpea
CharGs+45N30P30K+C	1.06	0.26	181.75	286.40	2895	200	8146.85	355.45	5251.85	155.45	2.20	1.78
CharPM+45N30P30K+C	1.19	0.37	256.08	403.05	2845	200	9544.5	299.85	6699.5	99.85	2.68	2.11
CharCc+45N30P30K+C	0.95	0.31	205.33	373.07	2945	200	11159.5	422.5	8214.5	222.5	2.92	1.94
control	-	-	-	139.11	1475	-	1866.6	-	391.6	-	1.435	-
90N60P60K	-	-	-	301.87	2530	-	8534.4	-	6004	-	2.52	-

Char-biochar, PM-poultry manure. Cc-corn cobs, cowpea, N-nitrogen, P-phosphorus, K-potassium

Table 7. Number of spikelets on a panicle of rice planted solely with cowpea and intercropped with it at different treatment levels and cropping densities

Treatment	No of Tillers (m^2) 2018	No of Tillers (m^2) 2019	No of spikelets per panicles (m^2) 2018	No of spikelet panicles (m^2) 2019	No of grains per panicles (m^2) 2018	No of grains per panicles (m^2) 2019	Weight of full grains (g) 2018	Weight of full grains (g) 2019	Weight Unfill grains (g) 2018	Weight of Unfill grains (g) 2019
CharCc+45N30P30K+C	57.50	72.00	28.50	37.75	508.75	534.75	11.57	12.41	3.29	4.13
CharGs+45N30P30K+C	46.69	81.88	31.50	39.50	561.50	553.25	12.76	13.60	2.61	3.45
Char Corncob	39.94	54.63	25.25	37.00	441.75	472.00	8.00	8.77	2.46	3.30
Char Groundnuts hells	42.94	59.00	21.00	33.00	418.00	476.25	9.72	10.56	2.73	3.57
Char PM	47.94	58.88	22.75	34.75	430.50	449.00	8.00	8.84	2.59	3.44
CharPM+45N30P30K+C	66.69	101.75	33.25	43.500	586.00	686.75	16.03	16.87	2.88	3.72
Control	32.69	34.38	10.00	23.500	219.25	325.25	6.10	6.94	0.89	1.73
90N60P60K	50.13	74.88	28.25	38.750	431.25	510.00	11.233	12.073	2.8375	3.68
Tukeys HSD	22.35	28.49	10.10	7.71	194.87	151.04	7.64	7.64	2.92	3.01
CV	19.33	17.32	16.19	9.35	17.77	12.44	28.84	26.75	2.01	39.30

Char-biochar, PM-poultry manure. Cc-corn cobs, cowpea, N-nitrogen, P-phosphorus, K-potassium

Discussion

The reduction in yield components of rice-cowpea intercrops with high densities, in spite of high NPK rates, may be ascribed to excessive density ensuing in intra and inter-competition for sunlight, moisture, volatilization, and mineralization of nutrients. Low availability in vegetative and reproductive development showed that there was a possible increase in soil organic carbon with respect to biochar accumulation, leading to soil N immobilization (Lehmann et al., 2011) and, consequently, reduced N uptake by the rice plants. However, the upsurge in grain yield of sole rice and cowpea with cumulative plant density was as an effect of the rise in yield components per unit area. This was buttressed by (Inthapanya et al., 2001), who testified to improved yields by 13–31% when the stand density improved from 16 stands per m^{-2} of plants (25x25 cm) to 25 and 44 stands per m-^{2} of plants, respectively, as an effect of improved panicle density. The non-significance of N on most yields and yield components of rice and cowpea may be due to the high rainfall that occurred during the period of the experiment, which may be linked to nitrogen mineralization and resulting leaching losses. Poor growth of rice and cowpea in Guinea savanna was due to the leached acid soils (ferric Luvisol soils found in low rainfall areas; the top soil tends to be droughty while the subsoil had moderate to poor moisture holding capacity because of many concretions and gravel. Results attained for the intercropping ratios gave land equivalent ratios above unity, demonstrating an intercrop benefit and hence an apparent upsurge in resource usage efficiency by the crop combination (Table 5 and 6). The yield benefit of the rice-cowpea combination may be an inherent characteristic of more effective use of sunlight in combination with tall rice and erect cowpea. The differences in growth cycles between rice and cowpea allowed for more efficient use of available water and nutrients (Table 5). Consequently, the crop combination enhanced the resource utilization through higher yield, which was ascribed to a density outcome, though lower LER was detected at high density. A similar investigation was conducted in a rice-cassava intercrop in Sierra Leone and was testified by (Dahniya et al., 1991), who distinguished the highest LER with low density (1.85 and 1.73) and high intercrop density, which gave lower LER (1.54 and 1.13).

Competition effects were observed on biochar corn cobs+45N30P30K densities were low, hence K values too were low. This might have triggered insufficient use of resources (Baumann et al., 2000). In terms of crowding coefficient values and aggressivity indices, cowpea seems to be the overriding crop, and rice the dominating crop. The dominance of cowpea in the intercrop could be owing to its phenological traits and branching during the growth period (Abayomi et al., 2001). This is buttressed by (Sullivan, 2001), who stated that in a cereal–legume intercropping system, an aggressive creeping bean could destroy rice, maize, or sorghum intercrop, which could decrease yield. The effect could be serious for smaller cereals such as rice. Due to the dominant nature of the cowpea, which results in its ability to trap light, interception, and integrate soil fertility, Cowpea, with its trifoliate leaves, has the ability to seizure lighter than rice, with its thin leaves. This study was also supported by (Baumann et al., 2000). Under nutrient use efficiency on rice grain, the biochar+45N30P30K combination with cowpea intercrop had high nitrogen usage (Table 3). The high interspecific competition of biochar rice husk+45N30P30K of the rice-cowpea intercrop led to low NUE, while absolute control resulted in very low NUE. The biochar+45N30P30K combination with cowpea N and water interrelates sturdily to control crop yield and water availability, and the strictness of drought can affect NUE. Drought tolerance hybrid (NERICA 14) results showed larger NUE since they increased biomass production over a lengthy range of soil moisture availability and meteorological conditions (Beringer et al., 2011; Harrigan et al., 2009). Plant P uptake was negative when the nutrient was dissolving. There is some proof that changing plant phenology influences nutrient attainment (Nord and Lynch, 2009).

Accelerated growth limits P uptake; plants that flower swiftly and have a short vegetative stage have small biomass production and P uptake. The disruption in growth that is characteristic of P deficiency is thought to be a changing condition for low P because it allowed for a longer period of P uptake (Postma and Lynch, 2012). High temperatures could speed growth and decrease uptake of P, leading to a decrease in PUE. However, this prediction saw the result of the intensification of soil temperatures on P uptake. This study found that high nitrogen rates can compensate for interspecies competition. Intercrops provided increased benefits, as did complementarity among component crops and decreased intercrop competition (Oroka and Omoregie, 2007). Biochar+45N30P30K cowpea combination could improve time-based and spatial complementarity, as well as the compatibility of hybrids used as combination components. For instance, time-based changes in resource use by the crops may involve planting at any of various alternating times of planting the crops. Other studies have revealed increased yield benefits as a result of the arrangement of various treatments to the component crops (Oroka and Omoregie, 2007). The interplanetary assigned to the component crops is correlated directly to the resources accessible for both crops. Nevertheless, (Hauggaard-Nielsen et al., 2001) observed that row arrangement trials within some particular range of plant densities yielded no decline. The biochar +45N30P30K combination with cowpea exhibited that there was a response in rice yield to intercrop density. It was vital that the biochar+45N30P30K combination with cowpea was vital that the population of the rice crop and the density of the cowpea ought not be so high as to significantly reduce grain yield.

Grain yield, nutrient uptake and efficiency utilization

The values for N and K were near maximum and that of P was near minimum on the biochar+45N30P30K combination with cowpea intercrop of both seasons, indicating that P was the least available of these four nutrients. Biochar releases nutrients which are absorbed by the crops cultivated. In Table 3 the results of nutrient use efficiency show a decrease in P total plants in and after harvest (85 days) and the effect has disappeared. Due to the improved P status, plant growth was stimulated, apparently to such an extent that the absorbed N was diluted. This explains the higher mass portions of N in plants on biochar+45N30P30K combination with cowpea intercrop than in plants on 90N60P60K combination with 85 days. In both seasons, the biochar+45N30P30K combination with cowpea intercrop increased K availability to the point where K mass fractions of straw remained higher on the biochar+45N30P30K combination with cowpea intercrop than on the absolute control.

In both seasons' biochar+45N30P30K combination with cowpea intercrop and 90N60K60P, some of the P were negative. This can be clarified by soil water tension stress through the panicle stage. At this stage, rice is extremely sensitive to water deficits (Ndjiondjop et al., 2012). If there was adequate moisture in the soil, the soil absorption of P would have been utilized more efficiently. Yields would have amounted to 301.87 t ha^{-1} for rice. On both the 90N60P60K and to over for rice, 403.05 t ha^{-1} and cowpea, 256.08 t ha^{-1} on the biochar+45N30P30K combination with cowpea intercrop for both seasons, if P value for 90N60P60K in 2018 (16.65%) and 2019 is 22.10%), biochar+45N30P30K combination with cowpea intercrop for 2018 (39.81%) and 2018, in 2019, the absolute amount of nutrients absorbed by rice had decreased, except for sole cowpea. In 2019, moisture sources were sufficient for a more efficient use of the absorbed nutrients, resulting in higher N, S, and K than in 2018. The biochar+45N30P30K combination with cowpea intercrop values of P for rice in 2018 and 2019 indicated that the absorbed nutrients were efficiently used, although yields were very high in both seasons. The biochar+45N30P30K combination with cowpea of K was probably not overrated. The Biochar+45N30P30K combination with cowpea intercrop considerably increased both seasons' yields of rice and cowpea.

Efficiency utilization for four nutrients for rice, but not for cowpea. This could be because cowpea was more sensitive to acidity than upland rice. Incorporating biochar into the soil resulted in a pH increase. Table 2 showed the relationship between pH 5.66 at the initial stage of the growing season and biochar+45N30P30K combination with cowpea of P, for cowpea in 2018 and for cowpea in 2019. For rice, the absolute control of P was not influenced by pH, but it was for cowpea. For rice, the positive effect of the biochar+45N30P30K combination with cowpea intercrop consisted of a pH effect and a P effect, and for rice of a P effect only. In (Table 4), the differences in uptake of nutrients from the Biochar+45N30P30K combination with cowpea intercrop and 90N60P60K studies were obtained in kg ha^{-1} as well as in percentages of the amounts of nutrients added. After harvest chemical analysis differences decreased in P from 2018 to 2019. In both seasons, the trends were regular. In both seasons, extra N was absorbed more than P. Apparently, biochar+45N30P30K combination with cowpea intercrop stimulated uptake of soil-N. The increase in pH due to biochar + 45N30P30K combination with cowpea intercrop improved the mineralization rate of organic matter. Another reason, more important, was the combination of biochar+45N30P30K with cowpea intercrop and cowpea intercrop that stimulated crop growth and increased the essential N. It is possible that with 90N60P60K, more N was available than perhaps used by the plant because of growth being limited by a P deficit. This was emulated in the high biochar+45N30P30K combination with cowpea of N and the low biochar+45N30P30K combination with cowpea of P in the plant.

Conclusion

From the standpoint of climate change, this study reveals the good impacts of biochar obtained from local resources as an organic soil additive. Biochar improved rice soil fertility by enhancing its chemical, physical, and biological qualities. Biological nitrogen fixation, cowpea play an important role in plant nutrient recycling. The studies also suggested that biochar can be used as a lime substitute in Nyankpala acidic soils, increasing the yield of acid-sensitive crops. Rice growth was improved by improving soil properties using organic soil amendment applications, as evidenced by increasing plant height, number of tillers, number of spikelets, grain per panicles and grain yield. In general, the experiment demonstrated that intercropping systems perform better than sole cropping. They specify better growth resources for rice under rice-cowpea intercropping systems, as evidenced by competitive functions. The intercropping systems exploited resources more competitively, as evidenced by the crowding coefficient, especially when three rows of rice to one row of cowpea were present. Rice, on the other hand, looked to be the dominating crop, as demonstrated by higher relative crowding coefficients, competitive ratios, and positive aggressivity indicators. Cowpeas utilized resources more aggressively in the 3:1 row arrangement, indicating their eligibility as prospective intercropping crops in a rice-based system. Carbon sequestration in soils and vegetation can extract carbon from the atmosphere, lowering carbon dioxide levels in the atmosphere. The use of biochar has an effect on the C sink capacity of upland rice soils, as evidenced by increasing CEC and soil organic carbon in biochar studies. Higher macroaggregate formation was reported in rice-cowpea intercrop soil with biochar, which encourages the storage of significant amounts of CEC and soil organic carbon in the soil. Importantly, a positive link between CEC and soil organic carbon and aggregate stability was discovered. The study demonstrates that adding biochar to the soil and biomass increases carbon level, indicating that it can act as a carbon sink. Biochar application to soil could be a significant step in reducing the detrimental impact of upland rice cultivation on global warming. Biochar has the extra benefit of reducing CO_2 emissions when used instead of lime in Nyankpala soils. Biochar additions can significantly reduce total direct N_2O emissions and indirect CO_2 emissions in rice production by reducing N fertilizer consumption and increasing agronomic NPK-use efficiency and nutrient uptake. As a result, biochar can significantly reduce the total global warming potential of rice soil, making it a viable tool for combating global warming without jeopardizing productivity or food security. Because nutrient losses and contamination of the soil and water systems of rice cultivation tract is a key managerial issue, the potential of biochar to hold applied fertilizer against leaching and also boost fertilizer use efficiency is very desirable for the soils of Nyankpala. Biochar addition into upland rice soils may help to minimize the toxicity and transport of common agro-based pollutants by increasing the overall sorption capacity of soils towards anthropogenic organic contaminants. Despite the fact that organic composts and chemical fertilizers provided positive outcomes in some areas, they were unable to have a significant impact on rice soil from the viewpoints of climate change and yield optimization. The research highlights the importance of transitioning from high-input agriculture to a low-cost, long-term system. Biochar application along with conversion to organic agriculture techniques can help restore system resilience without compromising crop yield. Hence it is vital to favour sustainable agriculture approaches in upland rice cultivation areas like Nyankpala, towards reaching maximum yield without harming our climate system.

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References

Abayomi, Y., Fadayomi, O., Babatola, J., & Tian, G. (2001). Evaluation of selected legume cover crops for biomass production, dry season survival and soil fertility improvement in a moist savanna location in Nigeria. *African Crop Science Journal, 9*(4), 615-627.

Abdul-Ganiyu, S., Agyare, W., Kyei-Baffour, N., & Dogbe, W. (2015). Effects of Irrigation Regimes on Irrigated Rice Production in the Northern Region of Ghana.

Abdul-Ganiyu, S., Kyei-Baffour, N., Agyare, W. A., & Dogbe, W. (2018). Evaluating the effect of irrigation on paddy rice yield by applying the AquaCrop model in Northern Ghana. In *Strategies for Building Resilience against Climate and Ecosystem Changes in Sub-Saharan Africa* (pp. 93-116). Springer.

Adjei-Gyapong, T., & Asiamah, R. (2002). The interim Ghana soil classification system and its relation with the World Reference Base for Soil Resources. *Rapport sur les Ressources en Sols du Monde (FAO).*

Adu, S. (1957). Report on the detailed soil survey of the Central Agricultural Station, Nyankpala. *Soil Research Institute, Kumasi, Ghana*.

Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. *Applied soil ecology, 119*, 156-170.

Ai, P., Ma, Y., & Hai, Y. (2021). Influence of jujube/cotton intercropping on soil temperature and crop evapotranspiration in an arid area. *Agricultural Water Management, 256*, 107118.

Akter Suhi, A., Mia, S., Khanam, S., Hasan Mithu, M., Uddin, M. K., Muktadir, M. A., Ahmed, S., & Jindo, K. (2022). How Does Maize-Cowpea Intercropping Maximize Land Use and Economic Return? A Field Trial in Bangladesh. *Land, 11*(4), 581.

Altieri, M. A. (2002). Agroecological principles for sustainable agriculture. *Agroecological innovations: Increasing food production with participatory development*, 40-46.

Amanullah, M. M., Somasundaram, E., Vaiyapuri, K., & Sathyamoorthi, K. (2007). Intercropping in cassava–a review. *Agricultural Reviews, 28*(3), 179-187.

Amanullah, M. M., Vanathi, D., Somasundaram, E., Sathyamoorthi, K., & Vaiyapuri, K. (2007). Direct seeded rainfed rice in coastal tract-A review. *Agricultural Reviews, 28*(3), 223-228.

Ananthi, T., Amanullah, M. M., & Al-Tawaha, A. R. M. S. (2017). A review on maize-legume intercropping for enhancing the productivity and soil fertility for sustainable agriculture in India. *Advances in environmental biology, 11*(5), 49-64.

Asiamah, R. D., & Dwomo, O. (2009). Ethno-management of plinthic and ironpan soils in the savanna regions of West Africa. *Ghana Journal of Agricultural Science*, *42*(1-2).

Azmi, N., Singh, A., Sakal, R., & Ismail, M. (2004). Long-term influence of intensive cropping and fertility levels on the build-up of sulphur and its influence on crop performance. *Journal of the Indian Society of Soil Science, 52*(1), 85-88.

Baligar, V., Fageria, N., & He, Z. (2001). Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis*, *32*(7-8), 921-950.

Bashagaluke, J. B., Logah, V., Sakordie-Addo, J., & Opoku, A. (2020). Nutrient uptake and productivity of four tropical cropping systems under biochar amendment. *Agronomy Journal*, *112*(4), 2664-2675.

Baumann, D., Kropff, M., & Bastiaans, L. (2000). Intercropping leeks to suppress weeds. *Weed Research (Oxford), 40*(4), 359-374.

Baumann, D. T., Bastiaans, L., & Kropff, M. J. (2001). Competition and crop performance in a leek–celery intercropping system. *Crop Science, 41*(3), 764-774.

Belel, M., Halim, R., Rafii, M., & Saud, H. (2014). Intercropping of corn with some selected legumes for improved forage production: A review. *Journal of Agricultural Science, 6*(3), 48.

Beringer, T., Lucht, W., & Schaphoff, S. (2011). Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. *Gcb Bioenergy, 3*(4), 299-312.

Bhuvaneswari, R., & Sriramachandrasekharan, M. (2006). Influence of organic manures in conjunction with sulphur on yield and nutrient uptake by rice. *ADVANCES IN PLANT SCIENCES, 19*(2), 543.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science, 59*(1), 39-46.

Bremner, J. (1965). Total nitrogen. *Methods of soil analysis: Part 2 chemical and microbiological properties, 9*, 1149-1178.

Chhetri, B., & Sinha, A. (2019). Competitive Indices and Production of Maize (Zea mays L.) and Cowpea (Vigna unguiculata) Intercropping System as Influence by Nutrient Management Practices. *International Journal of Bio-resource and Stress Management, 10*(2), 203-214.

Chukwuka, K., & Omotayo, O. (2008). Effects of Tithonia green manure and water hyacinth compost application on nutrient depleted soil in South-Western Nigeria. *International journal of soil science, 3*(2), 69-74.

Dahniya, M. T., Jalloh, A., & Ezumah, H. (1991). Intercrop yields of cassava and rice as influenced by cassava variety and population. Symposium on Tropical Root Crops in a Developping Economy 380,

Daryanto, S., Fu, B., Zhao, W., Wang, S., Jacinthe, P.-A., & Wang, L. (2020). Ecosystem service provision of grain legume and cereal intercropping in Africa. *Agricultural Systems*, *178*, 102761.

Das, S. K., & Ghosh, G. K. (2020). Soil health management through low cost biochar technology. In *Biochar applications in agriculture and environment management* (pp. 193-206). Springer.

Degaga, J., & Angasu, B. (2017). Assessment of indigenous knowledge of smallholder farmers on intercropping practices in west Hararghe Zone; Oromia National Regional State, Ethiopia. *Journal of Agricultural Economics and Rural Development, 3*(3), 270-278.

Dhima, K., Lithourgidis, A., Vasilakoglou, I., & Dordas, C. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crops Research, 100*(2-3), 249-256.

Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., Zeng, G., Zhou, L., & Zheng, B. (2016). Biochar to improve soil fertility. A review. *Agronomy for sustainable development, 36*(2), 1-18.

Dogbe, W., Abebrese, S., Owusu, R., Inusah, B., & Danaa, A. (2016). Performance of eleven introduced improved lowland rice varieties in the northern Savanna zones of Ghana. *African Journal of Agricultural Research, 11*(5), 324-329.

Dong, N., Tang, M.-M., Zhang, W.-P., Bao, X.-G., Wang, Y., Christie, P., & Li, L. (2018). Temporal differentiation of crop growth as one of the drivers of intercropping yield advantage. *Scientific Reports, 8*(1), 1-11.

Dwivedi, A., Dev, I., Kumar, V., Yadav, R. S., Yadav, M., Gupta, D., Singh, A., & Tomar, S. (2015). Potential role of maize-legume intercropping systems to improve soil fertility status under smallholder farming systems for sustainable agriculture in India. *International Journal of Life Sciences Biotechnology and Pharma Research, 4*(3), 145.

Eskandari, H. (2011). Intercropping of wheat (Triticum aestivum) and bean (Vicia faba): Effects of complementarity and competition of intercrop components in resource consumption on dry matter production and weed growth. *African Journal of Biotechnology, 10*(77), 17755-17762.

FAO. 1988. FAO/UNESCO Soil Map of the World Revised legend, with corrections. World Soil Resources Report 60. Rome. (Reprinted as Technical Paper 20, ISRIC, Wageningen, 1994).

FAO, F. (1988). Unesco Soil Map of the World, Revised Legend, with corrections and updates. *World Soil Resources Report, 60,* 140.

Fixen, P., Brentrup, F., Bruulsema, T., Garcia, F., Norton, R., & Zingore, S. (2015). Nutrient/fertilizer use efficiency: measurement, current situation and trends. *Managing water and fertilizer for sustainable agricultural intensification, 270*.

Gebregergis, Z. (2016). Cropping systems of East Africa: A review. *Developing Country Studies, 6*, 2225-0565.

Ghosh, P. (2004). Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. *Field Crops Research, 88*(2-3), 227-237.

Gul, S., & Whalen, J. K. (2016). Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biology and Biochemistry, 103*, 1-15.

Guo, M., He, Z., & Uchimiya, S. M. (2016). Introduction to biochar as an agricultural and environmental amendment. *Agricultural and environmental applications of biochar: Advances and barriers, 63*, 1-14.

Harrigan, G. G., Ridley, W. P., Miller, K. D., Sorbet, R., Riordan, S. G., Nemeth, M. A., Reeves, W., & Pester, T. A. (2009). The forage and grain of MON 87460, a drought-tolerant corn hybrid, are compositionally equivalent to that of conventional corn. *Journal of agricultural and food chemistry, 57*(20), 9754-9763.

Hauggaard-Nielsen, H., Ambus, P., & Jensen, E. S. (2001). Interspecific competition, N use and interference with weeds in pea–barley intercropping. *Field Crops Research, 70*(2), 101-109.

Hayder, G., Mumtaz, S. S., Khan, A., & Khan, S. (2003). Maize and soybean intercropping under various levels of soybean seed rates. *Asian Journal of Plant Sciences*.

HE, H.-m., LIU, L.-n., Munir, S., Bashir, N. H., Yi, W., Jing, Y., & LI, C.-y. (2019). Crop diversity and pest management in sustainable agriculture. *Journal of Integrative Agriculture, 18*(9), 1945-1952.

Iderawumi, A., & Friday, C. (2013). Effects of geometric row arrangement on growth and yield of cowpea in a maize-cowpea intercrop. *Indian Journal of Innovation Development, 2*, 816-820.

Imathiu, S., Edwards, S., Ray, R., & Back, M. (2014). Artificial inoculum and inoculation techniques commonly used in the investigation of Fusarium head blight in cereals. *Acta Phytopathologica et Entomologica Hungarica, 49*(2), 129-139.

Imoro, A. Z., Okai-Anti, D., & Asmah, E. A. (2012). Productivity index rating of some soils in the Tolon/Kumbungu district of the Northern region of Ghana.

Inthapanya, P., Siyavong, P., Sihathep, V., Chanphengsay, M., Schiller, J., Linquist, B., & Fukai, S. (2001). Agronomic practices for improving yields of rainfed lowland rice in Laos. Increased lowland rice production in the Mekong Region: Proceedings of an International Workshop held in Vientiane, Laos, 30 October-2 November 2000,

Kalu, S., Simojoki, A., Karhu, K., & Tammeorg, P. (2021). Long-term effects of softwood biochar on soil physical properties, greenhouse gas emissions and crop nutrient uptake in two contrasting boreal soils. *Agriculture, Ecosystems & Environment, 316*, 107454.

Kang, S.-W., Cheong, Y. H., Yun, J.-J., Park, J.-H., Park, J.-H., Seo, D.-C., & Cho, J.-S. (2021). Effect of biochar application on nitrogen use efficiency for sustainable and productive agriculture under different field crops. *Journal of Plant Nutrition, 44*(19), 2849-2862.

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D., Abaidoo, R. C., & Giller, K. E. (2017). Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crops Research, 213*, 38-50.

Khan, M. B., & Khaliq, A. (2004). Studies on intercropping summer fodders in cotton. *J. Res. Sci, 15*(3), 325-331.

Khan, M. M. (2009). Assessment of yield advantages, competitiveness and economic benefits of diversified direct-seeded upland rice-based intercropping systems under strip geometry of planting. *Pak. J. Agri. Sci, 46*, 2.

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems–a review. *Mitigation and Adaptation Strategies for Global Change, 11*(2), 403-427.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota–a review. *Soil Biology and Biochemistry, 43*(9), 1812-1836.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J. O., Thies, J., Luizão, F. J., & Petersen, J. (2006). Black carbon increases cation exchange capacity in soils. *Soil science society of America journal, 70*(5), 1719-1730.

Liu, M., Che, Y., Wang, L., Zhao, Z., Zhang, Y., Wei, L., & Xiao, Y. (2019). Rice straw biochar and phosphorus inputs have more positive effects on the yield and nutrient uptake of Lolium multiflorum than arbuscular mycorrhizal fungi in acidic Cd-contaminated soils. *Chemosphere, 235*, 32-39.

Lizarazo, C. I., Tuulos, A., Jokela, V., & Mäkelä, P. S. (2020). Sustainable mixed cropping systems for the boreal-nemoral region. *Frontiers in sustainable food systems, 4*, 103.

Lopes, T., Bodson, B., & Francis, F. (2015). Associations of wheat with pea can reduce aphid infestations. *Neotropical entomology, 44*(3), 286-293.

Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., & Palai, J. B. (2021). Intercropping—A low input agricultural strategy for food and environmental security. *Agronomy, 11*(2), 343.

Maitra, S., Palai, J. B., Manasa, P., & Kumar, D. P. (2019). Potential of intercropping system in sustaining crop productivity. *International Journal of Agriculture, Environment and Biotechnology, 12*(1), 39-45.

Maitra, S., Shankar, T., & Banerjee, P. (2020). Potential and advantages of maize-legume intercropping system. *Maize-Production and Use*, 1-14.

Malézieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., Tourdonnet, S. d., & Valantin-Morison, M. (2009). Mixing plant species in cropping systems: concepts, tools and models: a review. *Sustainable agriculture*, 329-353.

Mbah, E. U., & Ogidi, E. (2012). Effect of soybean plant populations on yield and productivity of cassava and soybean grown in a cassava-based intercropping system. *Tropical and Subtropical Agroecosystems, 15*(2), 241-248.

Mousavi, S. R., & Eskandari, H. (2011). A general overview on intercropping and its advantages in sustainable agriculture. *Journal of Applied Environmental and Biological Sciences, 1*(11), 482-486.

Mulabagal, V., Baah, D. A., Egiebor, N. O., & Chen, W.-Y. (2017). Biochar from biomass: a strategy for carbon dioxide sequestration, soil amendment, power generation, and CO utilization. In *Handbook of climate change mitigation and adaptation* (pp. 1937-1974). Springer.

Ndjiondjop, M. N., Futakuchi, K., Cisse, F., Baimey, H., & Bocco, R. (2012). Field evaluation of rice genotypes from the two cultivated species (Oryza sativa L. and Oryza glaberrima Steud.) and their interspecifics for tolerance to drought. *Crop Science, 52*(2), 524-538.

Negash, F., & Mulualem, T. (2014). Enhanced land use system through cassava/maize intercropping in south region of Ethiopia. *Sky Journal of Agricultural Research, 3*(10), 196-200.

Nord, E. A., & Lynch, J. P. (2009). Plant phenology: a critical controller of soil resource acquisition. *Journal of experimental botany, 60*(7), 1927-1937.

Ogola, J., Mathews, C., & Magongwa, S. (2013). The productivity of cassava-legume intercropping system in a dry environment in Nelspruit, South Africa. African Crop Science Conference Proceedings,

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A., & Fasina, A. (2019). Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (Oryza sativa) yield grown on an Alfisol in Southwestern Nigeria. *International Journal of Recycling of Organic Waste in Agriculture, 8*(3), 295-308.

Oroka, F. O., & Omoregie, A. U. (2007). Competition in a rice-cowpea intercrop as affected by nitrogen fertilizer and plant population. *Scientia Agricola, 64*, 621-629.

Palansooriya, K. N., Wong, J. T. F., Hashimoto, Y., Huang, L., Rinklebe, J., Chang, S. X., Bolan, N., Wang, H., & Ok, Y. S. (2019). Response of microbial communities to biochar-amended soils: a critical review. *Biochar, 1*(1), 3-22.

Pereira¹, P., Barata, A. M., Pereira, G., Gaspar, C., Martinho¹, P., Groenewegen¹, M., Costa¹, J., Vaz, M., Mexe, J., & Meneses, M. (2021). Intercropping Maize and Cowpea as a Sustainable Technique to Adapt the Production to Climate Change in Portugal. *Breeding and Seed Sector Innovations for Organic Food Systems*, 16.

Postma, J. A., & Lynch, J. P. (2012). Complementarity in root architecture for nutrient uptake in ancient maize/bean and maize/bean/squash polycultures. *Annals of botany*, *110*(2), 521-534.

Rawat, J., Saxena, J., & Sanwal, P. (2019). Biochar: a sustainable approach for improving plant growth and soil properties. *Biochar-an imperative amendment for soil and the environment*, 1-17.

Sarkar, D., Singh, S., Parihar, M., & Rakshit, A. (2021). Seed bio-priming with microbial inoculants: A tailored approach towards improved crop performance, nutritional security, and agricultural sustainability for smallholder farmers. *Current Research in Environmental Sustainability, 3*, 100093.

Seran, T. H., & Brintha, I. (2010). Review on maize based intercropping. *Journal of agronomy, 9*(3), 135-145.

Shin, J., Park, S., & Jeong, C. (2020). Assessment of Agro-Environmental Impacts for Supplemented Methods to Biochar Manure Pellets during Rice (Oryza sativa L.) Cultivation. *Energies*, *13*(8), 2070.

Smith, H. A., & McSorley, R. (2000). Intercropping and pest management: a review of major concepts. *American Entomologist, 46*(3), 154-161.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E., & Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and soil, 291*(1), 275-290.

Stomph, T., Dordas, C., Baranger, A., de Rijk, J., Dong, B., Evers, J., Gu, C., Li, L., Simon, J., & Jensen, E. S. (2020). Designing intercrops for high yield, yield stability and efficient use of resources: Are there principles? *Advances in agronomy, 160*(1), 1-50.

Sullivan, P. (2001). Intercropping principles and production practices: Appropriate technology transfer for rural areas (ATTRA). *Fayetteville (AR): USDA Rural Business*.

Taha, E., & El-Mahdy, A. (2014). Land Equivalent Ratio as a reference for relative crowding coefficient and aggressivity of intercropped plant species. *Middle East Journal of Agriculture Research*, *3*(3), 576-585.

Tana, T., & Mulatu, E. (2000). Evaluation of Sorghum, Maize and Common Bean Cropping Systems in East Hararghe, eastern Ethiopia. *Ethiopian Journal of Agricultural Sciences*.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science, 37*(1), 29-38.

Willey, R., & Rao, M. (1980). A competitive ratio for quantifying competition between intercrops. *Experimental Agriculture, 16*(2), 117-125.

Workayehu, T. (2014). Legume-based cropping for sustainable production, economic benefit and reducing climate change impacts in southern Ethiopia. *Journal of Agricultural and Crop Research*, *2*(1), 11-21.

Zhang, F., & Li, L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and soil*, *248*(1), 305-312.