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The Use of Biochar to Increase Productivity of Indigenous Upland Rice (*Oryza sativa L.*) and Improve Soil Properties.

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ABSTRACT

A study of the Increase in Productivity of Indigenous Upland Rice and the Improved Soil Properties with Soft Wood Biochar was conducted on an experimental plot in the Pa-deng Biochar Research Center, Pa Deng Sub-district, Petchaburi Province, Thailand. The study investigated the effect of soil incorporation of biochar on crop yield in the area. The experiments were carried out in a randomized complete block design in four treatments with three replicates; untreated soil (control), soil with organic fertilizer, soil with biochar, and soil with organic fertilizer and biochar. Both soil samples and biochar samples were collected before and during the six growth stages of rice: seedling, tillering, panicle initiation, booting, flowering and grain maturation. The results showed that biochar amendment improved the soil properties. The results of yield and growth of native yellow rice such as panicle per area, seeds per panicles, thousand grain weight and percentage of filled grain increased significantly at 95% confidence level when applied the soil incorporation of biochar treatment. The results indicated that the soil properties, yield and growth of rice increased even more the soil incorporation of biochar and organic fertilizer was applied.
Keywords: Biochar, rice production, upland rice, biochar amendment, soil properties

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INTRODUCTION

Biochar is most commonly produced by pyrolysis, or the heating organic materials such as crop stubble, wood chips, manure and municipal waste in the complete or near absence of oxygen [1]. Soil incorporation of biochar has been advocated as a potential approach to address critical environmental problems such as soil degradation, food security, water pollution from agrichemicals and climate change, with claimed benefits ranging from soil improvement to ecosystem functioning and climate change mitigation [2,3,4]. A considerable body of research reports that adding biochar to soil increased yields of field crops [5,6], and rice [7,8,9]. In Asia, biochar has long been used in agriculture in many countries. In Thailand, on the other hand, biochar has only recently been used in agriculture.

Thailand's agriculture is highly dependent on, and vulnerable to, specific climate conditions as the primary determinant of agricultural productivity. Adams et al [10] reported that changes in climatic factors such as temperature and precipitation and the frequency and severity of extreme events such as droughts, floods, and windstorms directly impacts upon agricultural productivity as well as the economic well-being of resource-poor farmers. In view of Thailand's dependence on agriculture both for subsistence and export earnings, it is important to understand the characteristics and potential of biochar to contribute to the country's sustainable agricultural development.

The study area was located in Pa Deng Sub-district, adjacent to Kaeng Krachan National Park, Southern Thailand. Agricultural productivity in the area is hampered by low soil fertility, soil erosion, a growing population leading to expansion of agriculture into forest and foothill areas as well as severe annual water shortages. Moreover, Wijitkosum's study [11] indicated that the area is at a moderate to high risk of desertification. Most farmers in the area were using fertilizers, unaware of the risk of soil degradation. Over time, soil fertility declined due to continuous cultivation, and productivity of staple crops, such as upland rice, was correspondingly low [12]. Such agricultural practices were not sustainable and led to chemical residues in crops, soils, and the surrounding environment; crop yields and farmers' health both suffered. Degraded soils required special treatment and extra fertilizer, further increasing costs and driving farmers closer to indebtedness and poverty.

MATERIALS AND METHODS

Experimental site

The 542.50 sq m experimental site is located in the Pa-deng Biochar Research Center (PdBRC), Pa Deng Sub-district, Petchaburi Province. The area was divided into twelve experimental plots with dimensions of 4x10 m.

This study site was selected because of the serious soil degradation problems and frequent droughts prevailing in the area. The central plain (9.14% of the total area), which can be utilized for agriculture or housing, represents only 12% of the total area while the population growth is 2.80% [13].

Field experiment

Yellow rice (*Oryza sativa L.*), a drought-tolerant local rice, was used in this experiment. The experiments were carried out in a randomized completely block design (RCBD) in four treatments with three replicates; untreated soil (control), soil with organic fertilizer (SO), soil with biochar (SB), and soil with organic fertilizer and biochar (SOB).

The SO treatment; applied 1 kg/sq m of the organic fertilizer (cow manure) per plot. This amount was split among two applications, with 0.625 kg/sq m per plot, applied two weeks before rice planting, and the remaining 0.375 kg/sq m plot applied at the booting stage. The SB treatment; applied at 1 kg/sq m of the biochar per plot. This amount was split among two applications of 0.625 kg/sq m per plot, applied two weeks before rice planting and 0.375 kg/sq m plot applied at the booting stage. For the latter treatment, the mixture of biochar and manner was in the ratio of 1:1. The combination was applied among two applications like the SB and SO treatment. The rice plants were watered every three days.

Preparation of biochar

Biochar for this study was produced by slow pyrolysis of soft woods forest residues commonly found in the study area; *Blachiasiamensis*, *Getonia floribunda Roxb, Albizziamyriophylla* and *Hymenppyramis brachiate Wall.* A low-cost locally-designed retort was designed and constructed locally following the FAO guidelines [14]. The retort itself was designed for slow pyrolysis which operating temperature was controllable within the range of 500-600.

The soft woods were machine-cut to roughly equal lengths. Physical properties of the soft woods were measured before pyrolysis began; the data analyzed were temperature using Multi Logger Thermometer HH506RA, moisture using moisture meter (CEM DT-129) and weight. The ratio of biomass volume for making biochar and biomass volume for fuel is 1.0:0.6. The weight of the fuel used for the production of biochar must be at 60% of the biomass weight in order to control temperature of the heating at 500-600 ^{o}C [15].

Biochar analysis

Physical and chemical properties of biochar were measured both before and after the experiments by analyzing key parameters. The properties included surface and interface analysis [16]. The specific surface area of biochar was tasted with Brunauer-Emmett-Teller (BET) method [17], pH, EC, OM [18], CEC [19], CHN, total N [18], available P [18,20] and exchangeable K [18].

Analysis of soil properties

Soil samples were collected before the experiment and during six growth stages of the upland rice: seedling, tillering, panicle initiation, booting, flowering and grain maturation; at a depth of 15 cm below the soil surface [21]. The samples were then dried, crushed and sieved through a 2-mm mesh and the parameters of interest were analyzed**.**

Soil treatment were destructively sampled and the entire amount of soil was analyzed for CEC (Soil Survey Staff, 1996), pH**,** EC**,** available K and exchangeable P [20], OM was tasted with Walkley and Black method [18], total C was tasted with CHNOS analyzer, total N was tasted with Kjeldahl method [18].

Analysis of rice yield

Rice samples from three 0.5x0.5m quadrats from each treatment were collected to assess rice growth and yield from the number of panicles of paddy per sq m., mean number of seeds per panicle, percentage of good seeds, calculated of weight of 1,000 seeds from finding the mean of 100 seeds in the harvesting stage, counted the number of panicles of paddy per sq m and evaluated dry unit weight by putting stems and roots in various stages in an oven at 75^{o}C for 48 hours.

Samples were collected at six different periods; 15 days old (seedlings), 45 days old (tillering), 60 days old (panicle initiation), 70 days old (booting), 90 days old (flowering) and 120 days old (harvesting).

Data analysis

The ANOVA and Duncan's New Multiple Range Test (DMRT) were used for statistical analysis. Laboratory analysis of samples was conducted at the PdBRC and Chulalongkorn University.

RESULTS AND DISCUSSION

Properties of physical and chemical composition of biochar

The physical and chemical properties and composition of biochar are important predictors of their utility to soils and crops. Applying the statistical analysis to compare traditionally-produced biochar with laboratory-produced biochar, no statistically significant differences were found between the two materials for key parameters at the 95 percent confidence level (T-Test, $P < 0.05$).

Surface and Interface Analysis

The analysis of Multipoint BET of softwood showed that softwood biochar had a surface area ranging from 3.67-2.92 sq m/g. Total pore size of softwood was in the range of 0.0104-0.0163 ccm/g, depending on type of softwood. Analysis showed average pore diameter ranging from 164.60-211.4 Å.

A wide range of pore sizes within the biochar results in a large surface area and a low bulk density. Biochar incorporation can alter soil physical properties such as structure, pore size distribution and density, with implications for soil aeration, water holding capacity, plant growth, and soil workability [22]. Sohi et al. [3] reported that the surfaces of low temperature biochar can be hydrophobic, and this may limit the capacity to store water in soil. Application of biochar with soil to cultivation can increased surface area [23], consequently, may improve soil water and nutrient retention [22] and decrease soil erosion [24], particularly in fine-textured soils.

Biochar pH

The analytical results presented in Table 1 show that the biochar pH result from experiment showed the pH was decreased. The decrease of biochar pH was due to its high aromatic chemical characteristics [25] which may cause high oxidation reaction and generate a large amount of carboxylate anions. The acid soil (H^+) allows ion exchange which causes the decreases of both the biochar pH and the soil acidity. Comparing the pH results, it showed that the pH result of the SOB treatment was higher than that of the SB treatment owning to the high pH level of the organic fertilizer mixed in the former treatment which was 7.3.

Biochar EC

After the experiment, the biochar EC of the both treatment showed a statistically significant reduction (Table 1). The reduction in EC caused by a large number of anions on the surface of the biochar allows biochar to attract cations which are useful to plants. When biochar is in contact with water, the cations then dissolve and become conductive. Plants roots can then take up the dissolved cations, which results in a reduction in the EC over time. The data indicated that EC of the SOB treatment was higher than that of the SB soil treatment due to the high conductivity of the organic fertilizer in the former treatment (0.35 dS/m).

Biochar OM

The amount of OM in the SB treatment showed a statistically significant reduction to 19.28^{a}-15.67^{e} % (Table 1). In the SOB treatment, OM levels also decreased significantly to 20.10^{a}-16.68^{e} %. Biochar has a higher surface area and greater porosity relative to other types of SOM, and can therefore improve soil texture and aggregation, which improves water retention in soil. Retained OM would be released gradually into the soil over time [22].

The result showed that the SOB treatment contained a higher amount of OM than the SB treatment in every growth stage. This was because the organic fertilizer contained in the SOB treatment, itself contained 20.70% of OM which boosted total OM content in these treatments.

Biochar CEC

Before the experiment, the CEC of biochar was 26.97 cmol/kg. After the experiment, the CEC for the SB and SOB treatment showed a significant reduction (Table 1). Biochar has a greater ability to adsorb and retain cations exchangeable form than other forms of SOM due to its greater surface area, and negative surface charge according to Liang et al. [26]. The large surface area of biochar allows adsorption of a large number; its porosity enables the soil to adsorb a much greater amount of macronutrients–or cations–following biochar incorporation into the soil. However, the surface areas of biochar decreased over time, reducing the biochar's cation exchange capacity. Biochar has a high CEC, and with its high recalcitrance, it is reasonable that soil applied with biochar has highest CEC [8,23]. The results indicate higher CEC in SOB treatment than for all other treatments at every growth stage.

Moreover, addition of organic fertilizer accelerates microbial decomposition of the mixture of organic fertilizer in SOB treatment, which releases minerals and produces humus, which is highly effective in cation adsorption.

Table 1: The pH, EC, OM and CEC of biochar in different treatments

Growth stage	pH in treatment			EC in treatment			OM in treatment			CEC in treatment		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post	
		SB	SOB		SB	SOB		SB	SOB		SB	SOB
Seedling	8.50±0.02	7.86±0.02^{a}	7.92±0.03^{a}	0.49 ± 0.15	0.44±0.02^{a}	0.47±0.01^{a}	20.25 ±0.5	19.28±0.18^{a}	20.10±0.21^{a}	26.97 ±0.56	12.86±2.63^{a}	14.74±1.63^{a}
Tillering		7.85±0.01^{ab}	7.90±0.02^{ab}		0.43±0.03^{a}	0.45±0.03^{ab}		18.62±0.45^{b}	19.65±0.13^{a}		10.60±1.02^{a}	10.35±0.94^{b}
Panicle Initiation		7.82±0.01^{b}	7.88±0.01^{abc}		0.40±0.02^{ab}	0.43±0.01^{abc}		17.87±0.24^{c}	18.35±0.42^{b}		8.06±1.34^{b}	8.47±2.22^{bc}
Booting		7.77±0.02^{c}	7.87±0.02^{bc}		0.39±0.02^{ab}	0.40±0.04^{bcd}		17.52±0.25^{c}	18.89±0.19^{c}		7.93±0.62^{b}	8.05±1.07^{bc}
Flowering		7.76±0.03^{c}	7.86±0.01^{bc}		0.37±0.03^{ab}	0.39±0.02^{cd}		16.89±0.10^{d}	17.66±0.08^{d}		6.54±0.27^{bc}	7.89±1.36^{bc}
Harvesting		7.74±0.03^{c}	7.85±0.04^{c}		0.33±0.04^{b}	0.37±0.03^{d}		15.67±0.35^{e}	16.68±0.34^{e}		5.27±0.18^{c}	7.53±0.15^{c}

Percentages of Carbon, Hydrogen and Nitrogen of Biochar

The result showed that the amount of carbon, hydrogen and nitrogen in biochar was decreased from pre-experiment. The percentages of nutrients in the SB treatment changed as follows: carbon 59.40^{c}-68.25^{ab} %, hydrogen 2.25^{c}-2.86^{a} % and nitrogen 0.44^{c}-0.55^{bc} % (Table 2). The corresponding levels for the SOB treatment were 61.02^{e}-67.23^{b} %, 2.09^{c}-2.87^{b} % and 0.50^{b}-0.76^{a}%, respectively.

The results indicated that levels of carbon and hydrogen increased and stabilized when the crop reached the flowering period, while nitrogen levels increased and stabilized when the crop reached the booting period. Carbon, hydrogen and nitrogen are important for soil microorganism nutrition [27]. Moreover, rice roots take up nitrogen in the form of nitrates from biochar, reducing final nitrogen levels. The findings are consistent with the field research of many researches [27,28,29].

Table 2: The percentage of Carbon, Hydrogen and Nitrogen of biochar in different treatments

Growth stage	% C in treatment			% H in treatment			% N in treatment		
	Pre	Post-experiment		Pre	Post		Pre	Post	
		SB	SOB		SB	SOB		SB	SOB
Seedling	70.51 ±1.24	59.40±0.21^{c}	61.02±0.21^{e}	2.92±0.06	2.25±0.05^{c}	2.09±0.09^{c}	1.21±1.24	0.55±0.10^{bc}	0.76±0.06^{a}
Tillering		64.67±1.61^{b}	63.75±0.33^{c}		2.49±0.18^{bc}	3.01±0.14^{ab}		0.72±0.08^{ab}	0.74±0.03^{a}
Panicle Initiation		64.50±3.35^{b}	61.59±0.23^{d}		2.42±0.12^{bc}	2.97±0.22^{ab}		0.75±0.14^{a}	0.68±0.03^{ab}
Booting		68.25±0.15^{a}	68.12±0.13^{a}		2.86±0.32^{a}	3.20±0.10^{a}		0.55±0.07^{bc}	0.59±0.27^{ab}
Flowering		66.45±0.13^{ab}	67.59±0.42^{b}		2.78±0.22^{ab}	2.94±0.08^{b}		0.50±0.02^{c}	0.55±0.08^{ab}
Harvesting		66.05±0.06^{ab}	67.23±0.26^{b}		2.72±0.09^{a}	2.87±0.13^{b}		0.44±0.10^{c}	0.50±0.03^{b}

Macronutrient of Biochar

Comparing macronutrient levels among pre-and post-treatments, pre-treatment total N was 0.68%, available P was 0.25% and exchangeable K was 0.77%. Post-treatment total N was 0.36^{d} %, available P was 0.09^{c} % and exchangeable K was 0.50 % for the SB treatment, and total N was 0.42^{c} %, available P was 0.10^{c} % and exchangeable K was 0.55 % for the SOB treatment. The results of macronutrient levels of the treatment showed a significant reduction (Table 3).

Table 3: Primary nutrients in different treatments of yellow rice

Growth stage	Biochar macronutrient levels at various growth stages of upland rice								
	Total N in treatment (%)			Available P treatment (mg/Kg)			Exchangeable K treatment(mg/Kg)		
	Pre	Post-experiment		Pre	Post		Pre	Post	
		SB	SOB		SB	SOB		SB	SOB
Seedling	0.68± 0.03	0.59± 0.02^{a}	0.63± 0.15^{a}	0.25± 0.04	0.23± 0.04^{a}	0.25± 0.05^{a}	0.77± 0.03	0.69± 0.10^{a}	0.71± 0.12^{a}
Tillering		0.54± 0.03^{ab}	0.59± 0.06^{ab}		0.19± 0.04^{ab}	0.20± 0.06^{ab}		0.65± 0.08	0.68± 0.10
Panicle Initiation		0.49± 0.08^{abc}	0.55± 0.16^{ab}		0.15± 0.06^{bc}	0.16± 0.05^{ab}		0.60± 0.09	0.63± 0.07
Booting		0.44± 0.04^{bcd}	0.53± 0.07^{ab}		0.13± 0.03^{bc}	0.14± 0.05^{bc}		0.57± 0.14	0.62± 0.13
Flowering		0.40± 0.11^{cd}	0.48± 0.06^{bc}		0.11± 0.03^{c}	0.12± 0.05^{bc}		0.54± 0.14	0.59± 0.17
Harvesting		0.36± 0.17^{d}	0.42± 0.05^{c}		0.09± 0.03^{c}	0.10± 0.04^{c}		0.50± 0.18	0.55± 0.04

Higher total N levels were found in the SOB treatment (0.63^{a}-0.42^{c} %). This result shows that biochar can sorb nitrogen fertilizers and inhibit their nitrification and thus the concentrations of nitrate in the fields with biochar addition were largely decreased [30]. Levels of available P also showed significant treatment differences. While available P in the SB treatment was 0.23^{a}-0.09^{c} %, levels in the SOB treatment were much higher (0.25^{a}-0.10^{c} %). In contrast, exchangeable K in the SB treatment was 0.69-0.50%, while the SOB treatment showed significant decline in levels of exchangeable K (0.71-0.55%).

Effect of biochar as a soil amendment on soil properties

The effects of biochar on the quality of sandy clay soils used to cultivate yellow rice were evaluated by comparing soil properties pre-and post-experiment. The findings are summarized as follows.

Soil pH and EC

The soil pH results from the pre-experiment, all plot had pH range of 6.70^{b}-6.77^{a}, which this values appropriate for rice growing. Post experiment, all treatments except SO treatment raised soil pH, with the SOB treatment resulting in the largest increase (pH 7.51^{a}). Before the experiment, the Soil EC of all treatment showed the range of 0.18^{c}-0.20^{a} dS/m. After the experiment, the soil EC values were increased for all treatments (Table 4).

The results indicated that biochar increase soil pH and EC was statistically significant. The higher EC in the soil sample was indicated a larger amount of ions in the soil. Since biochar typically has higher pH than soil it can act as a liming agent resulting in an overall increase in soil pH [31]. The capacity of biochar can neutralize the acidic soil [32]. Biochar retains nutrients in soil directly through the negative charge that develops on its surfaces, and this negative charge can buffer acidity in the soil, as does organic matter in general [28].

Soil OM

Comparing OM levels among pre-and post-treatments, pre-treatment OM was 0.66[d] % for untreated soil, 0.91[c] % for SO treatment, 0.98[b] % for SB treatment and 1.07[a] % for SOB treatment. Post-treatment, the SOB treatment was highest value of SOM (1.74[a] %). These values were significantly different from the SO treatment (1.49[b] %) and control (0.58[c] %) (Table 4). The structure of the soil was also visibly altered, and, anecdotally, uprooting plants in the SB treatment was much easier than in the other treatments.

Many studies found that application of biochar effected soils have an increase of soil pore volume caused by the organic amendments was mainly attributed to the dilution effect of a low bulk density amendment to the soil [3,30,33]. The increase in soil OM showed that fairly large amounts of carbon and exchangeable cations were introduced by biochar application [30]. Low bulk density of soil increases soil porosity and soil aeration, and may have a positive effect on microbial respiration [34,35]. In addition, soil analysis after harvest revealed that soil organic matter and soil pH were both generally higher after application of biochar and fertilizer than after application of fertilizer only [30].

Table 4: The pH, EC, OM and CEC of soil in different treatments

Treat ments	pH in treatment		EC in treatment		OM in treatment		CEC in treatment	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Untreated soil	6.7±0.14[b]	6.78±0.45[b]	0.18±0.05[c]	0.13±0.05[b]	0.66±0.10[d]	0.58±0.06[c]	11.62±0.08[d]	8.95±0.18[c]
SO	6.71±0.25[b]	6.60±0.18[b]	0.19±0.06[bc]	0.25±0.04[a]	0.91±0.15[c]	1.49±0.11[b]	12.04±0.06[c]	16.68±0.63[b]
SB	6.73±0.36[ab]	7.49±0.29[a]	0.19±0.10[ab]	0.29±0.07[a]	0.98±0.15[b]	1.66±0.06[a]	12.25±0.05[b]	17.58±0.21[a]
SOB	6.77±0.34[a]	7.51±0.16[a]	0.20±0.15[a]	0.31±0.04[a]	1.07±0.21[a]	1.74±0.08[a]	13.63±0.11[a]	17.75±0.27[a]

Soil CEC

Before planting, all plot had CEC range of 11.62[d]-13.63[a] cmol/Kg. After harvesting, the SOB treatment showed the highest in CEC (17.75[a] cmol/Kg), followed by SB treatment (17.58[a] cmol/Kg). These CECs were statistically significant different from the after harvesting CEC of 16.68[b] cmol/Kg for SO treatment, and 8.95[c] cmol/Kg for untreated soil (Table 4).

Biochar amended soil was due to increase in CEC. Since biochar is highly porous and has a large surface area, its impact on the soil's CEC over time can be important [5]. The surfaces of biochar particles oxide and interact with soil constituents, resulting in function groups and greater surface negative charge [26], which ultimately leads to increase in CEC. The increase in CEC of the soil with organic fertilizer would probably be due to the negative charge arising from the carboxyl groups of the organic matter [8]. Thus, incorporation of biochar and organic fertilizer increase the highest in CEC.

Total C, Total N, Available P and Exchangeable K

Application of biochar on soil increased significantly the mean values of total C from its pre-experiment values (Table 5). Before planting, all plot had total C range of 0.06[c]-0.19[a] %. After harvesting, the SOB treatment showed the highest in total C (0.37[a] %). The difference was statistically significant from the control. Total C content in biochar was higher than the cow manure, had as a result of increasing the total C in SB treatment was higher than SO treatment.

Comparing pre- and post-experiment total N, available P and exchangeable K in soil, it was found that post-experiment total N, available P and exchangeable K of SO, SB and SOB treatments was increasing, and it found that total N (0.26[a] %), available P (21.08[a] %) and exchangeable K (110.44[a] %) were highest at SOB treatment. The difference was statistically significant from the control (total N=0.05[c] %, available P=7.22[d] %, exchangeable K=70.33^{c} %). However, the increase of total N and exchangeable K were not statistically different from the total N (0.22^{ab} %), and exchangeable K (103.01^{ab} %) for SB treatment, but were significant different at the 95% confidence level of total N (0.19^{b} %) and exchangeable K (98.38^{b} %) for SO treatment and the total N for control (0.05^{c} %) (Table 5).

Many researchers found that increased cation exchange capacity in soils with biochar application improved nutrient retention [8,34,36]. Soil nutrient levels would be expected to decline over the growing season due to crop uptake. In the SOB treatment, the cow manure, containing the primary macronutrients (N, P, K), was mixed with the biochar and the nutrients from the manure were then adsorbed and retained in the biochar [37]. The comparison between the treatments revealed that the SOB treatment had a higher amount of N, P and K than the SB treatment.

Table 5: Total C, Total N, Available P and Exchangeable K of soil in different treatments

Treatments	Total C		Total N		Available P		Exchangeable K	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Untreated soil	0.06±0.01^{c}	0.08±0.07^{d}	0.13±0.02^{c}	0.05±0.02^{c}	10.88±0.35^{c}	7.22±0.44^{d}	86.84±0.15^{d}	70.33±5.99^{c}
SO	0.07±0.05^{c}	0.17±0.17^{c}	0.14±0.07^{bc}	0.19±0.02^{b}	11.08±0.06^{c}	14.30±0.31^{c}	90.26±0.17^{c}	98.38±2.21^{b}
SB	0.14±0.27^{b}	0.31±0.31^{b}	0.15±0.02^{b}	0.22±0.09^{ab}	12.73±0.21^{b}	17.70±0.30^{b}	93.58±0.17^{b}	103.01±7.55^{ab}
SOB	0.19±0.10^{a}	0.37±0.30^{a}	0.17±0.03^{a}	0.26±0.03^{a}	14.73±0.24^{a}	21.08±0.18^{a}	101.14±0.19^{a}	110.44±2.57^{a}

Effects of Biochar on Rice Productivity

The improvement of the soil's physical and chemical properties due to soft wood biochar applications was followed by the improvement of the growth of rice planted in soil. Panicles of paddy per area, number of seeds per panicle, percentage of good seeds, weight of 1,000 seeds, rice tillering and dry unit weight of rice growth in SB treated soils were significantly ($p<0.05$) higher compared to that of SO treatment and control, respectively. The yield and growth of rice increased even more when the soil incorporation of biochar and organic fertilizer was applied (Table 6).

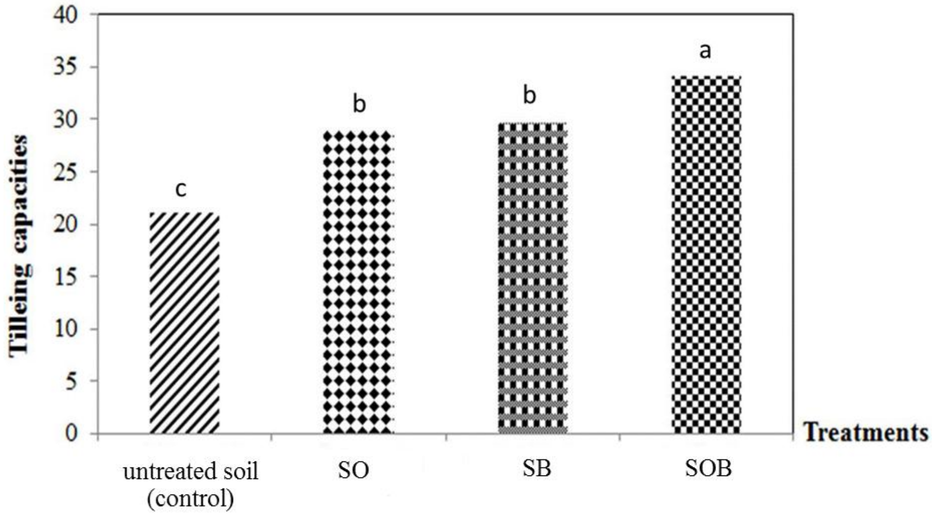
The SOB treatment showed the highest number of panicles per area (25^{a}), but treatment differences were non-significant. Number of seeds per panicle showed statistically significant differences between treatments. The SOB treatment showed the highest number of seeds per panicle (175.50^{a}). Statistically significant differences were found between treatments, with the SOB treatment resulting in the highest percentage of good seeds (94.16^{a} %) and the weight of 1,000 seeds (25.80^{a} g) compared with the other treatments.

Table 6: Composition of yellow rice yield

Treatments	Composition of yellow rice yield			
	Panicles per area (panicles/area)	Seeds per panicle (seeds/panicle)	Weight of 1,000 seeds (gram)	Percentage of good seeds (%)
Untreated soil	19.67^{a}	101.55^{d}	22.5^{b}	81.00^{c}
SO	22.33^{a}	136.13^{c}	23.47^{b}	81.60^{c}
SB	24.33^{a}	149.80^{b}	24.58^{ab}	89.03^{b}
SOB	25.00^{a}	175.50^{a}	25.80^{a}	94.16^{a}

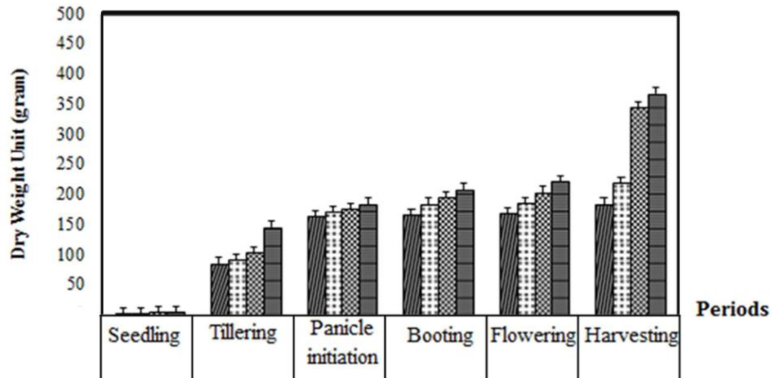
The highest numbers of rice tillers was obtained under the SOB treatment (34[a]), with the experimental data indicating that both biochar and organic fertilizer treatments resulted in increased tillering compared with control (21[c]). The differences were statistically significant; however, for the SB (29.67[b]) and SO treatments (28.67[b]) differences were non-significant (Fig. 1).

Figure 1: Tillering capacities during rice tillering stage (45 days) of yellow rice



Dry unit weight increased as time progressed. The result showed that rice grown with the SOB treatment achieved the highest dry weight (268.71 g.) compared with the other treatments (Fig. 2). According to Kannuch [38] this would be expected from the growth stimulus provided by NPK contained in the biochar amendments.

Figure 2: Dry weight unit of rice from different treatments during each stage of growth



	Seedling	Tillering	Panicle initiation	Booting	Flowering	Harvesting
untreated soil (control)	3.23	62.36	80.90	88.91	105.40	118.71
SO	3.95	113.77	133.07	135.87	138.93	172.64
SB	5.72	121.43	147.82	153.74	162.19	230.54
SOB	7.71	140.49	178.32	187.51	189.474	268.71

The results of this study showed that biochar soil amendments significantly increased productivity of yellow rice. While pure biochar did not directly enrich the soil with nutrients [39], when combined with fertilizer, biochar had the greatest ability to enhance plant growth and nutrient content [7]. This effect may be explained by the porosity and high surface areas of biochar, which increases its capacity to adsorb or retain essential plant nutrients, allowing greater soil availability of primary macronutrients [31,40]. A fraction of primary nutrients was retained in biochar in potentially extractable form. Compared to other forms of soil organic matter, biochar had a greater surface area and negative surface charge which allowed it to adsorb and retain exchangeable cations more efficiently [26]. An increase in CEC, soil pH alteration and direct nutrients from biochar could all influence nutrient availability in soil [2]. Moreover, biochar's porosity and high internal surface area increased its ability to adsorb organic matter and provide a suitable habitat for soil microbiota. The soil microbiota catalyzed mineralization processes, reduce nitrogen loss and increase nutrient availability for plants.

CONCLUSIONS

The study findings revealed that biochar produced by pyrolysis of soft woods in a locally constructed retort contributed to statistical significant increases in rice growth and yields. The study found that application of biochar increased SOM, soil pH, EC, CEC, total C, total N, available P and exchangeable K of soil, and all values were generally highest after application of biochar plus organic fertilizer, than after application of either fertilizer or biochar alone. The SOB treatment resulted in the highest yields. The increase in productivity is attributed to the high porosity and surface area of biochar, allowing it to effectively adsorb and retain organic matter, water and macronutrients and increase their availability to the crop over the growth period.

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