Asian Journal of Crop Science

ISSN 1994-7879

science alert
http://www.scialert.net

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS
Asian Journal of Crop Science
ISSN 1994-7879
DOI: 10.3923/ajcs.2017.159.166

Research Article
Effects of Rice Straw Biochar and Nitrogen Fertilizer on Rice Growth and Yield

[1]Lai Lai, [1,2]Mohd Razi Ismail, [3]Farrah Melissa Muharam, [2]Martini Mohammad Yusof, [4]Roslan Ismail and [4]Noraini Md Jaafar

[1]Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3]Department of Agriculture Technology, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[4]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Abstract
Background and Objectives: Nitrogen (N) fertilizer management with other soil amendments is crucial for optimal growth and productivity of grain crops. There has been increasing interest on converting rice straw to biochar and examining its use as a soil amendment. This study was conducted to evaluate the effects of different nitrogen fertilizer managements combined with rice straw derived biochar on rice growth and yield attributes. **Materials and Methods:** This greenhouse pot study was performed in a randomized complete block design with 4 replications. Treatments comprised of 150 kg ha^{-1} N fertilizer as a control (T1), 9 t ha^{-1} rice straw biochar added to 30, 60, 90, 120 and 150 kg N ha $^{-1}$ (T2, T3,T4, T5 and T6, respectively). Growth measurement was carried out at week 2, 6 and 10 after transplanting, while yield attributes were obtained upon harvesting at 110 days. The effects of N and biochar treatments data were analysed using two-way analysis of variance (ANOVA) in PROC ANOVA in SAS Ver. 9.4 while treatments means differences were compared using least significant difference (LSD), both at $p<0.05$. **Results:** Treatment 5 (120 kg N ha^{-1} with biochar) was able to promote more plant growth and yield attributes than the other treatments, especially in plant height, leaf area, relative chlorophyll content and tiller number. Increased yield over the control treatment was found similar to 90 and 120 kg N ha^{-1} with biochar, reducing fertilization up to 40% and resulted in 20% grain yield improvement compared to the control. Therefore, rice straw biochar addition at 9 t ha^{-1} with 90-120 kg N ha^{-1} can be recommended for sustainable rice productivity and improvement of rice yield and farmers' profits. **Conclusion:** The use of biochar in addition to the chemical fertilizers in rice production systems is an economically feasible and practical nutrient management practice.

Key words: Biochar, nitrogen fertilizer management, growth and yield, rice straw, rice productivity

Citation: Lai Lai, Mohd Razi Ismail, Farrah Melissa Muharam, Martini Mohammad Yusof, Roslan Ismail and Noraini Md Jaafa, 2017. Effects of rice straw biochar and nitrogen fertilizer on rice growth and yield. Asian J. Crop Sci., 9: 159-166.

Corresponding Author: Noraini Md Jaafar, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Over 90% of rice production globally is harvested and consumed in Asian countries[1]. In these countries, rice is the staple food and is typically consumed two or three times a day, making it an essential source of carbohydrates in medium and low-income countries. In Asia, there is still a gap between the farmer's field and potential yield. In Malaysia, for instance, the rice yield gap accounts for 1.2 t ha^{-1}, which is the difference between a potential yield of 7.2 t ha^{-1} and the actual yield that is 6 t ha^{-1}. By 2020, one among many government aspirations on food security is to achieve self-sufficiency level, which is currently around 71.6%[2]. Additionally, it was estimated that by 2025, rice production must increase about 60% more than current productivity in order to fulfil the needs of an ever growing global population[3]. Nevertheless, producing more food from fixed agricultural lands signifies the need for sustainably optimising agricultural inputs, including ones from natural resources.

Nitrogen (N) which is an important macro nutrient element in cropping systems, is required by rice in abundance quantities and is more needed than any other nutrients [4]. The optimization of N application for rice production is justified through high grain yield and profitable farming, whereas excessive N application is not only costly but could detrimentally affects our environment (Rice Production, BMPs)[5]. Therefore, for sustainable agriculture, the use of chemical fertilizer should be assessed not only for the food but also for climate change mitigation[6]. The use of rice residue along with chemical fertilizer in rice production to improve physico-chemical properties of soil and consequently contribute towards sustainable productivity of local rice production is yet an alternative that should be weighed.

Kedah is an area located in the Muda Irrigation Scheme and possesses Malaysia's main rice producing fields, with approximately 96,558 ha under cultivation[7]. At these cultivation areas, most of straw from the harvested rice plants are burnt in the fields, causing air pollution problems and loss of carbon from improved fertile soil. Through the burning of the straw, portions of rice residues are indirectly being applied back to soil by means of composting or direct, raw application. However, in order to maintain sustainable soil productivity, these straw needs yearly supplication yet the applications should be through a more sustainable approach that possibly can improve air quality and be cost effective. In weighing alternatives, straw should be turned into black carbon (biochar). The conversion of the straws into biochar is well supported by the priorities of the local government to improve fertilizer efficiency and promote the use of cost effective, recycled agricultural waste such as rice straw[8].

After pyrolysis of rice material at high temperature (600°C), the combination of inorganic and organic substances form Si-C bonds and enclosed C as distinct chemical properties due to the high silica content of rice plants that can prevent degradation of carbon[9-11]. Among benefits of biochar are improving soil biology, physical and chemical properties, suppressing soil-borne pathogens and acting as soil amendments[12,13]. The application of rice straw biochar with inorganic N fertilizer has been reported to increase soil aeration in a short term incubation study of microcosm[14], reduced N_2O emission by increasing the pH of soil and enhanced soil aeration and bacterial immobilization[15,16].

Regarding the rice straw biochar, Liu *et al.*[17] reported that its use resulted in increasing soil pH values and decreased methane producing bacterial activity. Zhao *et al.*[18] found that 9 t ha^{-1} rice straw biochar had a synergetic effect with standard NPK fertilizer on soil properties, increased rice yield and reduced methane gas emission, while Kamara *et al.*[19] demonstrated that rice straw biochar had the capacity to improve yield through early seedlings growth increment. Nevertheless, Kyaw[20] illustrated insignificant differences in rice yield by the application of rice husk biochar (20 Mg ha^{-1}+NPK) and rice straw biochar (20 Mg ha^{-1}+NPK).

Until now, researchers have studied the application of organic residue with chemical fertilizer on seed production and soil properties in tropical countries such as demonstrated by Mutezo[21]. The author, for instance, recommended the utilization of certain amounts of good quality organic fertilizer in tropical soil to improve mineral fertilizer use efficiency. Filiberto and Gaunt[22], on the other hand, suggested that a single application of 25 t ha^{-1} biochar should not be substituted for usual fertilizer applications without adding certain amounts of NPK fertilizer for maintaining crop yield. In general, the interaction between different nitrogen fertilizer managements and rice straw derived biochar on rice growth and yield have been not well documented. In this light, the objective of the current study was to examine the synergistic effects of different N fertilizer rates combined with biochar derived from rice straw on rice growth and yield.

MATERIALS AND METHODS

Experimental sites and design: This experiment was conducted at a glasshouse (Ladang 2) in Universiti Putra Malaysia, Serdang, Selangor, Malaysia in March, 2016. The experimental design was a randomized complete block design with six rates of nitrogen (N) and a fixed rate of rice straw biochar, replicated four times. The treatments were 150 kg N ha^{-1} (T1) as the control rate following the MADA recommended rate, 30 kg N t ha^{-1} and 9 t ha^{-1} rice straw biochar (T2), 60 kg N t ha^{-1} and 9 t ha^{-1} rice straw biochar (T3), 90 kg N t ha^{-1} and 9 t ha^{-1} rice straw biochar (T4), 120 kg N t ha^{-1} and 9 t ha^{-1} rice straw biochar (T5) and 150 kg N t ha^{-1} and 9 t ha^{-1} rice straw biochar (T6). The T2 to T6 treatments were designed based on the N recommended rate that was reduced 20% per treatment while maintaining the same amount of biochar.

Dried rice straw was first chopped and screened through a 2.0 cm sieve and pyrolyzed in a pyrolysis stove for 10 min at limited oxygen conditions at 300°C. Immediately, the hot biochar was spread on the floor by using a rolling device and cooled to room temperature for about an hour. Prior to analysis, the rice straw biochar was ground into fine particles and screened through a 2 mm diameter sieve. Biochar pH 1:10 (biochar:H_2O) was tested with a pH meter (Accument 910, Fisher Scientific Ltd., Pittsburg, PA, USA). The TRU MAC CNS Analyzer (LECO Corp., MI, USA) was used to measure total C, N and S of the biochar using the combustion method. The biochar was characterized by a pH of 10.08 and total C (%), N (%) and S (%) of 24.09, 0.60 and 0.08, respectively.

The rice was grown in flooded pots containing of topsoil (0-15 cm) collected from the Muda Agricultural Development Area (MADA) rice field in Kedah. Prior to the experiment, the soil physico-chemical properties were analyzed and depicted in Table 1.

The rice variety used in this study was MR288 (110 days old), which is a common variety planted by Malaysian rice growers in Kedah, with a yield record for this variety of 6 t ha^{-1} using farmer's practice. The MR228 seeds were soaked in a beaker for 24 h and germinated in a plastic box filled with quartz sand. Twenty litres plastic buckets were filled with 15 kg air-dried soil and mixed well with the recommended rate of rice straw biochar (9 t ha^{-1} rice straw biochar), which was based on the surface area (1 ha = 10,000 m^2) with inner surface area of 0.078 m^2, for respective treatments T2 through T6. Watering was done to maintain approximately 70% of the water holding capacity. After 14 days of germination, three seedlings were transplanted to each bucket.

Actual N applications were adjusted following the designated T1 to T6 treatments based upon the fertilization schedule as provided by MADA (Table 2). In addition to the treatments, 98 P_2O_5 kg ha^{-1}, 96 K_2O kg ha^{-1} and 7 MgO kg ha^{-1} were applied to the plants. The N were applied as urea, P_2O_5 as triple superphosphate (TSP), K_2O as muriate of potash (MOP) and MgO as itself. Regular management and plant protection measures were carried out by following standard procedures.

Table 1: Physical and chemical properties of soil used for the experiment

Characteristics	Value
Textural class	Silt loam
Sand (>50 µm)	18.70
Silt (2-50 µm)	60.43
Clay (<2 µm)	20.85
Soil pH	5.90
CEC (cmol kg^{-1})	8.00
Total carbon (%)	1.69
Total nitrogen (%)	0.13
Carbon nitrogen ratio (C/N)	13.00
Extractable (µg g^{-1})	
Phosphorus	31.57
Potassium	135.90
Calcium	797.30
Magnesium	76.30
Copper	0.61
Iron	521.50
Manganese	7.97
Zinc	0.98

CEC: Cation exchange capacity

Data collection: Plant growth measurement, such as leaf area (cm^2), plant height (cm), tiller numbers, relative chlorophyll content (SPAD unit) and stomatal conductance (mmol m^{-2} sec^{-1}) were carried out on each plant at week 2, 6 and 10 after transplanting. The CI-203 Leaf Area Meter was used to measure the leaf area of the three uppermost, fully expanded leaves of each plant. These values were later averaged. Plant heights were acquired by using a 3.5 m metal measuring tape by taking the average plant height from the base to the tip of the longest rice leaf. Prior to the panicle initiation, the relative chlorophyll contents were obtained by using the SPAD chlorophyll meter taken on the uppermost, fully expanded leaf of each plant and averaged for each pot. After the panicle initiation, the measurements were obtained from the flag leaf. To estimate the stomatal conductance, the uppermost expanded leaf from each plant was measured using by a hand-held Leaf Porometer model SC-1 from Decagon Devices.

Grain yield and yield attributes such as panicle per hill, panicle length, number of grain per panicle and thousand grains weight produced by the one hill of each bucket were also recorded. The panicles were hand-threshed and separated into filled and unfilled grain groupings to obtain number of grains per panicle. Length of panicle was measured by using a 30-cm stick and filled grains were weighed.

Table 2: Applications of treatments following MADA recommended timing which was at 15, 35, 55 and 75 days after sowing (DAS)

			Actual fertilization in pot (gm 0.078 m^{-2})			
Treatments	DAS	Fertilizer type	Urea	P_2O_5	K_2O	MgO
T1 (150 kg N ha^{-1})	15	Fertilizer mixture 17.5:15.5:10	1.070	0.967	0.468	NA
	35	Urea	0.359	NA		
	55	Fertilizer mixture 12:12:17:2	0.356	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.356	0.364	0.390	0.027
T2 (30 kg N ha^{-1}+BC)	15	Fertilizer mixture 17.5:15.5:10	0.209	0.967	0.468	NA
	35	Urea	0.072	NA		
	55	Fertilizer mixture 12:12:17:2	0.071	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.071	0.364	0.390	0.027
T3 (60 kg N ha^{-1}+BC)	15	Fertilizer mixture 17.5:15.5:10	0.418	0.967	0.468	NA
	35	Urea	0.144	NA		
	55	Fertilizer mixture 12:12:17:2	0.142	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.142	0.364	0.390	0.027
T4 (90 kg N ha^{-1}+BC)	15	Fertilizer mixture 17.5:15.5:10	0.627	0.9672	0.468	NA
	35	Urea	0.215	NA		
	55	Fertilizer mixture 12:12:17:2	0.214	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.214	0.364	0.390	0.027
T5 (120 kg N ha^{-1}+BC)	15	Fertilizer mixture 17.5:15.5:10	0.836	0.9672	0.468	NA
	35	Urea	0.287	NA		
	55	Fertilizer mixture 12:12:17:2	0.285	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.285	0.364	0.390	0.027
T6 (150 kg N ha^{-1}+BC)	15	Fertilizer mixture 17.5:15.5:10	1.07	0.9672	0.468	NA
	35	Urea	0.359	NA		
	55	Fertilizer mixture 12:12:17:2	0.356	0.364	0.390	0.027
	75	Fertilizer mixture 12:12:17:2	0.356	0.364	0.390	0.027

NA: Not applicable

Statistical analysis: The growth parameters and yield attributes data were tested for the N and biochar treatment effects ($p<0.05$) using the two-way ANOVA in PROC ANOVA in SAS Ver. 9.4 (SAS Institute, 2013). Differences in treatments means were compared by using least significant difference (LSD) at $p<0.05$.

RESULTS

Leaf area: All biochar treated plants had significantly the same leaf area as the control plants in week 2 and 6 after transplanting. Only at week 10 after transplanting, all biochar treated plants had significantly higher leaf area than the control (150 kg N ha^{-1}), with the exception of T2 (30 kg N ha^{-1}+BC) which was significantly comparable to the control (Table 3).

Plant height: In week 2 after transplanting, the plant height of T3 (30 kg N ha^{-1}+BC) and T6 (150 kg N ha^{-1}+BC) had significantly higher plant height compared to the control. However, at week 6 and 10, the trend completely changed; the N and biochar combined treatments failed to induce plants with statistically higher plant heights in comparison to the control (Table 3).

Relative chlorophyll content: Treatment 4 (90 kg N ha^{-1}+BC) and T5 (120 kg N ha^{-1}+BC) had significantly higher relative chlorophyll content values at week 2 after transplanting. At week 6 after transplanting, all of the biochar combined treatments successfully produced plants with higher relative chlorophyll content values than the control specimens. At 10 weeks after transplanting, only the T5 had significantly higher relative chlorophyll content values than the control (Table 3).

Tiller number: All biochar combined treatments produced statistically insignificant tiller number compared to the control at week 2 after transplanting. Only at week 6 and 10 were significant differences observed between the N and biochar treatments and control: T6 (150 kg N ha^{-1}+BC) at week 6 and T3 to T6 week 10 after transplanting (60-150 kg N ha^{-1}+BC), respectively (Table 3).

Stomatal conductance: Similar to the leaf area and tiller number at week 2, stomatal conductance measured during this period were also insignificantly different from each other. The trend continued at week 6 and 10, where stomatal conductance readings of different treatments were statistically comparable (Table 3).

Table 3: Treatments effects on leaf area, plant height, relative chlorophyll content and stomatal conductance on week 2, 6, 10 after transplanting

Treatments	Leaf area (cm^2)	Plant height (cm)	Relative chlorophyll content (SPAD unit)	Tiller number	Stomatal conductance (mmol m^{-2} sec^{-1})
Week 2					
T1 (150 kg N ha^{-1})	24.8^{a}	41.6^{cd}	34.3^{b}	3.3^{a}	295.4^{a}
T2 (30 kg N ha^{-1}+BC)	23.7^{a}	41.7^{cd}	32.9^{c}	3.0^{a}	294.9^{a}
T3 (60 kg N ha^{-1}+BC)	25.7^{a}	44.7^{ab}	34.0^{b}	3.5^{a}	275.9^{ab}
T4 (90 kg N ha^{-1}+BC)	24.7^{a}	40.0^{d}	36.2^{a}	3.5^{a}	279.9^{ab}
T5 (120 kg N ha^{-1}+BC)	25.0^{a}	43.5^{bc}	35.5^{a}	3.0^{a}	227.6^{b}
T6 (150 kg N ha^{-1}+BC)	24. 7^{a}	46.9^{a}	34.5^{b}	3.3^{a}	268.2^{ab}
LSD at 5%	2.90	2.29	0.72	0.64	55.01
Week 6					
T1 (150 kg N ha^{-1})	64.0^{ab}	83.3^{ab}	40.6^{c}	8.5^{b}	430.3^{a}
T2 (30 kg N ha^{-1}+BC)	63.2^{b}	78.8^{c}	43.0^{ab}	7.5^{c}	437.3^{a}
T3 (60 kg N ha^{-1}+BC)	62.8^{b}	80.4^{bc}	42.6^{b}	8.0^{bc}	379.5^{ab}
T4 (90 kg N ha^{-1}+BC)	64.5^{ab}	81.3^{abc}	43.7^{a}	8.5^{b}	419.5^{a}
T5 (120 kg N ha^{-1}+BC)	66. 5^{ab}	84.1^{ab}	44.0^{a}	8.5^{b}	347.7^{b}
T6 (150 kg N ha^{-1}+BC)	67.5^{a}	85.0^{a}	43.2^{ab}	9.5^{a}	423.6^{a}
LSD at 5%	3.76	4.30	1.07	0.91	60.06
Week 10					
T1 (150 kg N ha^{-1})	68.7^{c}	99.6^{ab}	48.1^{b}	10.8^{cd}	392.5^{a}
T2 (30 kg N ha^{-1}+BC)	70.9^{bc}	97.3^{b}	48.6^{ab}	9.5^{d}	386.0^{a}
T3 (60 kg N ha^{-1}+BC)	75.1^{a}	105.0^{a}	48.1^{b}	12.3^{b}	372.4^{a}
T4 (90 kg N ha^{-1}+BC)	76.8^{a}	97.3^{b}	48.7^{b}	12.0^{b}	376.7^{a}
T5 (120 kg N ha^{-1}+BC)	77.4^{a}	104.8^{a}	49.7^{a}	12.0^{b}	359.5^{a}
T6 (150 kg N ha^{-1}+BC)	74.2^{ab}	106.3^{a}	49.3^{ab}	14.0^{a}	391.2^{a}
LSD at 5%	4.06	7.33	1.24	1.47	78.04

Means followed by the same letter within the same column are not significantly-different (p>0.05) using LSD

Table 4: Treatments effects on yield attributes of rice plant at harvesting (110 days)

Treatments	Panicle per hill	Panicle length (cm)	Grain per panicle	Thousand grain weight (g)	Straw yield per hill (g)	Grain yield per hill (g)	Increased grain yield over control (%)
T1 (150 kg N ha^{-1})	10.0^{c}	22.5^{bc}	66^{ab}	23.1^{c}	23.4^{bc}	15.9^{c}	0^{c}
T2 (30 kg N ha^{-1} + BC)	9.0^{d}	21.8^{c}	64.8^{b}	23.9^{b}	21.1^{c}	14.0^{d}	-11.6^{d}
T3 (60 kg N ha^{-1} + BC)	12.0^{a}	22.7^{bc}	66.6^{a}	24.3^{b}	25.0^{ab}	19.1^{a}	20.7^{a}
T4 (90 kg N ha^{-1} + BC)	11.3^{b}	23.5^{ab}	66.9^{a}	25.4^{a}	24.5^{ab}	19.2^{a}	21.2^{a}
T5 (120 kg N ha^{-1} + BC)	11.5^{ab}	24.5^{a}	67.2^{a}	25.9^{a}	25.0^{ab}	19.2^{a}	21.1^{a}
T6 (150 kg N ha^{-1} + BC)	10.3^{c}	22.6^{bc}	66.5^{a}	23.2^{c}	26.3^{a}	16.4^{b}	3.3^{b}
LSD at 5%	0.57	1.11	1.58	0.56	2.32	0.36	2.29

Means followed by the same letter within same column are not significantly-different (p>0.05) using LSD

Yield attributes: The combination of N and biochar treatments significantly affected grain yield and other yield attributes (Table 4). The N fertilizer rates ranged from 60-150 kg N ha^{-1} with biochar (T3 to T6) successfully induced higher yield attributes such as panicle per hill, panicle length, thousand grain weight and grain yield compared to the control. Treatment 3 (60 kg N ha^{-1}+BC) had the highest panicle per hill among all treatments. In contrast, panicle length was highest in T5 (120 kg N ha^{-1}+BC). Grain per panicle and straw yield per hill shared a similar trend in which all biochar treated soil with increasing N fertilizer rate had significantly higher grain per panicle and straw yield per hill compared to the 30 kg N ha^{-1}+BC. Increasing N fertilizer rate from 60-120 kg N ha^{-1}+BC produced significantly higher and similar grain yields per hill. The increment found in 60-120 kg N ha^{-1} + BC treatments was almost 20% more than the over control. In general, T2 remained the lowest amongst other treatments for most yield attributes.

DISCUSSION

In this experiment, rice plants treated with N fertilizer and biochar treatments except for T2 (30 kg N ha^{-1}+BC) performed better in terms of leaf area, plant height, SPAD value and tiller number in comparison to the control. Previously, Kamara *et al.*[19] reported that rice plant height, tiller number, dry biomass and yield were improved by sole rice straw biochar applications after eight weeks of planting. The positive effects of biochar on the plant growth parameters could be explained through the supplementary nutrients available from the biochar per se[23], for instance, Peng *et al*.[24] and Wu *et al*. [25] demonstrated that rice straw biochar contains nutrients beneficial for plants such as N, C and Si. The other possible mechanism for these positive effects of biochar is via the increased availability of soil nutrient whereby biochar addition into the soil was found to improve soil properties[26,27]. Zhao *et al*.[28] stated that the addition of biochar could neutralize soil pH and increase CEC, which consequently promotes soil nutrient availability. In addition, Peng *et al*.[24] demonstrated that the amendment of 1% biochar increased pH and CEC as well as soil fertility for short terms. This study finding, however, was in contrast with Xie *et al*.[29], who found non-significant effects of wheat straw biochar on rice biomass and yield in both fertile and infertile soils. This contrary finding is perhaps due to the high application of P fertilizer, which might influence the chemical properties of the applied biochar.

The application of rice straw biochar with different N fertilizer rates was found to illustrate positive effects rice plant growth parameters and yield attributes over the control treatment or farmers' practice. Biochar addition to the reduced N rates of 60, 90 and 120 kg N ha^{-1} resulted in a 20% improvement of grain yield plus strong responses from yield attributes such as panicle per hill, panicle length, grain per panicle and thousand grain weight. This finding was similar to the previous study by Gathorne-Hardy *et al*.[30] on the combined application of 50% biochar and 80% N ha^{-1} fertilizer that increased barley yield up to 30%. This finding was consistent with Peng *et al*.[24], who showed that the application of rice straw biochar could increase rice yield by 64% and up to 146% with the addition of NPK fertilizer, despite yield improvements being lower. Similarly, Zheng *et al*.[31] observed biochar from wood chips and corn cobs combined with a 50% N fertilizer treatment increased corn yield up to 54 and 39%, respectively. Zhang *et al*.[32] also reported that wheat straw biochar combined with 300 kg N fertilizer ha^{-1} resulted in rice yield increments from 9-28 % in two subsequent seasons. The increased grain yield over the control group in these treatments again was attributed to the improved soil qualities and increased nutrient uptake for rice growth and yield, as above mentioned. Nonetheless, Vinh *et al*.[33] demonstrated that while the combination of 2.5 t ha^{-1} biochar produced from rice straw, bamboo and tree branches with NPK fertilizer increased rice yield, the application of biochar alone had a negative yield reduction effect. Sui *et al*.[34] also noted the absence of positive effects of rice straw biochar on rice yield, regardless of N fertilization rate, which is a result possibly due to low temperature region where grain productivity was suppressed.

At week 10 after transplanting, T5 (120 kg N ha^{-1}+BC) resulted in better plant growth performance than the other treatments, especially in terms of plant height, relative chlorophyll content and stomatal conductance. Based on the current study, rice straw biochar conserved N fertilizer compared to the control (farmer's practice) at the rate of 150 kg N ha^{-1}. It was also found that the increased yield over the control was statistically insignificant between the 60, 90 and 120 kg N ha^{-1} plus biochar treatments. Essentially, this finding implies that biochar applications with reduced N rate are an economically feasible and practical alternative to current farmers' practice. Steiner *et al*.[35] earlier recommended that in the interest of increasing crop yield, generally, charcoal should be applied supplementary to inorganic fertilizer. While only 3% grain yield increased was found over the control treatment for the 150 kg N ha^{-1}+BC, this treatment resulted in the highest straw yield per hill. This finding supports those of Zhao *et al*.[18], who demonstrated that the seasonal addition of 9 t ha^{-1} rice straw biochar with the standard fertilizer rate resulted in increased straw yield in both seasons but only increased grain yield in the subsequent season. Excessive N supply has been found to stimulate vegetative growth such as over tillering[36,37] and thus promoted carbohydrates storage in vegetative organs instead of harvesting organs. This also could be also explained by de Melo Carvalho *et al*.[38], who reported that the surplus N fertilization could limit the capacity of rice to relocate carbohydrate to fill developing grains. Furthermore, Shukla *et al*.[39] stated that tall N plants had open architectures panicles that consequently lead to lower grain yield.

CONCLUSION

This study demonstrated that rice straw could be transformed into a sustainable supplementary fertilizer in the form of biochar for enhancing rice plant growth and seed yield for farmers who had limited sources of inorganic fertilizer. We recommended the application of a 120 kg N ha^{-1}rate of fertilization with the addition of 9 t ha^{-1} rice straw biochar. This practice will reduce the N application rate currently being practiced by farmers by up to 20%. At this rate, significant yield improvement up to 20% over farmer practice could be obtained, mostly through improved characteristics of plant growth such as plant height, leaf area, relative chlorophyll content and tiller number. The rate of 90 kg N ha^{-1} can also be considered due to insignificantly different yield performance compared to the 120 kg N ha^{-1}, despite at this rate, lower growth performance was observed. Further studies should be conducted under field conditions to quantify the long-term benefits of rice straw biochar as a soil ameliorant. Moreover, the residual effects of rice straw biochar and different N fertilizer rates on sustainable rice productivity should be considered.

SIGNIFICANCE STATEMENTS

This study discovered the possibility of utilizing organic soil amendments, that is rice straw derived biochar, in saving nitrogen (N) fertilization while promoting better growth and yield attributes of rice. This study reveals the combined effects of varying N fertilizer rate along with rice straw biochar on plant growth and yield productivity. The findings can be beneficial for agronomists as well as farmers in managing N fertilization for grain crops. Thus, this study provided new knowledge on the utilization of biochar in addition to the chemical N fertilizer in rice production systems for promoting economically feasible and practical nutrient management practice.

ACKNOWLEDGMENTS

The authors thank the Ministry of Higher Education Malaysia for providing financial support through the Long-Term Research Grant Scheme (LRGS 2011-2016) for Food Security-Enhancing Sustainable Rice Production. Authors also thank the Ministry of Higher Education Malaysia for the Higher Institution Centre of Excellence (HICoE) initiative on Tropical AgriFood to the Institute of Tropical Agriculture and Food Security, University Putra Malaysia to support this study. Ms Lai thanks the Organization for Women in Science for the Developing World (OWSD) and the Swedish International Development Cooperation Agency (SIDA) for providing scholarship support.

REFERENCES

1. Hayashi, K., 2013. The role of biochar and prospects for its use in rice production in Southeast Asia. Proceedings of the National Workshop on Biochar for Future Food Security: Learning from Experiences and Identifying Research Priorities, February 4-5, 2013, Bogor, West Java, Indonesia, pp: 1-4.
2. Department of Agriculture, 2015. Crop statistic booklet (Food crop sub-sector). Department of Agriculture, Putrajaya, Malaysia. http://pertanian.kedah.gov.my/images/pdf/Booklet_Statistik_Tanaman_Sub-sektor_Tanaman_Makanan_2015.pdf
3. Fageria, N.K., N.A. Slaton and V.C. Baligar, 2003. Nutrient management for improving lowland rice productivity and sustainability. Adv. Agron., 88: 63-152.
4. Samonte, S.O.P.B., L.T. Wilson, J.C. Medley, S.R.M. Pinson, A.M. McClung and J.S. Lales, 2006. Nitrogen utilization efficiency: Relationships with grain yield, grain protein, and yield-related traits in rice. Agron. J., 98: 168-176.
5. Anonymous, 2000. Nutrient management. In Rice production, best management practices, 2000. https://www.slideshare.net/SatriaSakata/rice-production-best-management-practices
6. Brentrup, F. and C. Palliere, 2008. Energy efficiency and greenhouse gas emissions in European nitrogen fertilizer production and use. Proceedings of the International Fertiliser Society Conference, December 11, 2008, Cambridge, UK., pp: 1-25.
7. Afroz, R. and A.B. Ba, 2015. Environmental efficiency of rice production: A case study in Kedah Malaysia. Department of Economics, Faculty of Economics and Management Science, International Islamic University, Malaysia. http://www.wbiconpro.com/205-Rafia.pdf
8. FAO., 2004. Fertilizer use by crop in Malaysia. Land and Plant Nutrition Management Service, Land and Water Development Division, FAO, Rome. ftp://ftp.fao.org/agl/agll/docs/fertusemalaysia.pdf
9. Parr, J.F., 2006. Effect of fire on phytolith coloration. Geoarchaeology, 21: 171-185.
10. Guo, J. and B. Chen, 2014. Insights on the molecular mechanism for the recalcitrance of biochars: Interactive effects of carbon and silicon components. Environ. Sci. Technol., 48: 9103-9112.
11. Jindo, K., H. Mizumoto, Y. Sawada, M.A. Sanchez-Monodero and T. Sonoki, 2014. Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences, 11: 6613-6621.
12. Jaafar, N.M., 2014. Biochar as a Habitat for Arbuscular Mycorrhizal Fungi. In: Mycorrhizal Fungi: Use in Sustainable Agriculture and Land Restoration, Solaiman, Z.M., L.K. Abbott and A. Varma (Eds.). Springer, Berlin, Heidelberg, ISBN: 9783662453704, pp: 297-311.
13. Lone, A.H., G.R. Najar, M.A. Ganie, J.A. Sofi and T. Ali, 2015. Biochar for sustainable soil health: A review of prospects and concerns. Pedosphere, 25: 639-653.
14. He, L., X. Zhao, S. Wang and G. Xing, 2016. The effects of rice-straw biochar addition on nitrification activity and nitrous oxide emissions in two Oxisols. Soil Tillage Res., 164: 52-62.
15. Cavigelli, M.A. and G.P. Robertson, 2001. Role of denitrifier diversity in rates of nitrous oxide consumption in a terrestrial ecosystem. Soil Biol. Biochem., 33: 297-310.
16. Zhang, A., Y. Liu, G. Pan, Q. Hussain, L. Li, J. Zheng and X. Zhang, 2012. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant Soil, 351: 263-275.

17. Liu, Y., M. Yang, Y. Wu, H. Wang, Y. Chen and W. Wu, 2011. Reducing CH_4 and CO_2 emissions from waterlogged paddy soil with biochar. J. Soils Sediments, 11: 930-939.
18. Zhao, X., J. Wang, S. Wang and G. Xing, 2014. Successive straw biochar application as a strategy to sequester carbon and improve fertility: A pot experiment with two rice/wheat rotations in paddy soil. Plant Soil, 378: 279-294.
19. Kamara, A., H.S. Kamara and M.S. Kamara, 2015. Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties. Agric. Sci., 6: 798-806.
20. Kyaw, K.Z., 2016. Testing the effects of biochars on crop yields and soil properties in a rice-based cropping system of Myanmar: Field experiment and modeling. Ph.D. Thesis, Faculty of Sustainability, Leuphana University, Luneburg, Germany.
21. Mutezo, W.T., 2013. Early crop growth and yield responses of maize (*Zea mays*) to biochar applied on soil. International Working Paper Series No. 13/03, Natural Resources, Agricultural Development and Food Security, International Research Network.
22. Filiberto, D.M. and J.L. Gaunt, 2013. Practicality of biochar additions to enhance soil and crop productivity. Agriculture, 3: 715-725.
23. Lehmann, J., J.P. da Silva Jr., C. Steiner, T. Nehls, W. Zech and B. Glaser, 2003. Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central amazon basin: Fertilizer, manure and charcoal amendments. Plant Soil, 249: 343-357.
24. Peng, X., L.L. Ye, C.H. Wang, H. Zhou and B. Sun, 2011. Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. Soil Tillage Res., 112: 159-166.
25. Wu, W., M. Yang, Q. Feng, K. McGrouther, H. Wang, H. Lu and Y. Chen, 2012. Chemical characterization of rice straw-derived biochar for soil amendment. Biomass Bioenergy, 47: 268-276.
26. Ghoneim, A.M. and A.I. Ebid, 2013. Impact of rice-straw biochar on some selected soil properties and rice (*Oryza sativa* L.) grain yield. Int. J. Agron. Agric. Res., 3: 14-22.
27. Zhu, Q., X. Peng and T. Huang, 2015. Contrasted effects of biochar on maize growth and N use efficiency depending on soil conditions. Int. Agrophys., 29: 257-266.
28. Zhao, X., J.W. Wang, H.J. Xu, C.J. Zhou, S.Q. Wang and G.X. Xing, 2014. Effects of crop-straw biochar on crop growth and soil fertility over a wheat-millet rotation in soils of China. Soil Use Manage., 30: 311-319.
29. Xie, Z., Y. Xu, G. Liu, Q. Liu and J. Zhu *et al*., 2013. Impact of biochar application on nitrogen nutrition of rice, greenhouse-gas emissions and soil organic carbon dynamics in two paddy soils of China. Plant Soil, 370: 527-540.
30. Gathorne-Hardy, A., J. Knight and J. Woods, 2009. Biochar as a soil amendment positively interacts with nitrogen fertiliser to improve barley yields in the UK. IOP Conf. Ser.: Earth Environ. Sci., Vol. 6.
31. Zheng, W., B.K. Sharma and N. Rajagopalan, 2010. Using biochar as a soil amendment for sustainable agriculture. Final Project Report, Sustainable Agriculture Grant Program SA 09-37, Illinois Department of Agriculture, USA. http://hdl.handle.net/2142/25503
32. Zhang, A., R. Bian, G. Pan, L. Cui and Q. Hussain *et al*., 2012. Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Res., 127: 153-160.
33. Vinh, N.C., N.V. Hien, M.T.L. Anh, J. Lehmann and S. Joseph, 2014. Biochar treatment and its effects on rice and vegetable yields in mountainous areas of Northern Vietnam. Int. J. Agric. Soil Sci., 2: 5-13.
34. Sui, Y., J. Gao, C. Liu, W. Zhang and Y. Lan *et al*., 2016. Interactive effects of straw-derived biochar and N fertilization on soil C storage and rice productivity in rice paddies of Northeast China. Sci Total Environ., 544: 203-210.
35. Steiner, C., W.G. Teixeira, J. Lehmann, T. Nehls, J.L.V. de Macedo, W.E. H. Blum and W. Zech, 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil, 291: 275-290.
36. Kischel, E., R.R. Fidelis, M.M. dos Santos, D.R. Brandao, E.L. Cancellier and I.R. do Nascimento, 2011. Nitrogen in lowland rice genotypes in Tocantins State, Brazil. Rev. Ceres, 58: 84-89.
37. Hawkesford, M.J., 2014. Reducing the reliance on nitrogen fertilizer for wheat production. J. Cereal Sci., 59: 276-283.
38. De Melo Carvalho, M.T., B.E. Madari, L. Bastiaans, P.A.J. van Oort and A.B. Heinemann *et al*., 2014. Biochar improves fertility of a clay soil in the Brazilian Savannah: Short term effects and impact on rice yield. J. Agric. Rural Dev. Trop. Subtrop., 114: 101-107.
39. Shukla, S., T.J. Felderhoff, A. Saballos and W. Vermerris, 2017. The relationship between plant height and sugar accumulation in the stems of sweet sorghum (*Sorghum bicolor* (L.) Moench). Field Crop Res., 203: 181-191.