



Research article

Rice husk biochar effects on improving soil properties and root development in rice (*Oryza glaberrima* Steud.) exposed to drought stress during early reproductive stage

Kartika Kartika^{1,2}, Jun-Ichi Sakagami³, Benyamin Lakitan^{2,4,*}, Shin Yabuta³, Isao Akagi³, Laily Ilman Widuri⁵, Erna Siaga⁶, Hibiki Iwanaga⁷ and Arinal Haq Izzawati Nurrahma⁷

¹ Research Center for Biology, Indonesian Institute of Science, Cibinong 16911, Indonesia

² College of Agriculture, Universitas Sriwijaya, Inderalaya 30662, Indonesia

³ Faculty of Agriculture, Kagoshima University, 1-21-24 Korimoto, Kagoshima 890-0065, Japan

⁴ Research Center for Sub-optimal Lands (PUR-PLSO), Sriwijaya University, Palembang 30139, Indonesia

⁵ College of Agriculture, Universitas Jember, Jember 68121, Indonesia

⁶ College of Agriculture, Universitas Bina Insan, Lubuklinggau 31626, Indonesia

⁷ The United Graduate School of Agricultural Science, Kagoshima University, 1-21-24 Korimoto, Kagoshima 890-0065, Japan

* **Correspondence:** Email: blakitan60@unsri.ac.id; Tel: +62812 98115560.

Abstract: Benefits of biochar application on environment conservation and agricultural production have been widely studied. However, few studies were focused on root development. The objective of this study covered root and shoot development, yield, and soil properties associated with exposure of *Oryza glaberrima* rice during the early reproductive stage to drought stress in rice-husk amended soil. The biochar was amended at a rate of 10.5 g pot⁻¹, equivalent to 3 ton ha⁻¹. Biochar-amended and non-amended plants were exposed to drought stress after the panicles had visibly emerged in all plant populations. Biochar application caused less restriction on root elongation, volume, and surface area during water stress conditions. Enhanced root development was primarily associated with improvement in water status and chemical properties in biochar-amended soil. Soil chemical properties improved, including increased soil pH, available P, cation exchange capacity, and exchangeable Mg. Under drought stress conditions, shoot growth was more sensitive than root growth, as indicated by the significant reduction of stem dry weight (SDW) and leaf dry weight (LDW). Fine roots in biochar-amended soil were

longer than those in non-amended soil. In general, Biochar application enable the *O. glaberrima* rice to maintain yield under drought stress condition.

Keywords: rice husk biochar; root morphology; *Oryza glaberrima*; soil moisture; root volume; total surface area

1. Introduction

Despite uncontrollable flooding during the rainy season, Indonesia's riparian wetland ecosystem is also regularly exposed to drought problems during the dry season [1,2]. Drought occurrence can seriously reduce rice yield. In the worst scenario, prolonged drought can cause total harvest failure. Drought stress usually occurs during the reproductive stage of the first rice growing season and the early vegetative stage of the second rice-growing season in riparian wetlands in Indonesia [2–4]. During the reproductive stage, drought inhibits the grain filling process, accumulates reserve nutrients during grain development and maturation, and strongly affects quantitative and qualitative yield [5].

An increase in soil water holding capacity could salvage crop productivity under drought stress conditions [6]. Recently, biochar used as soil ameliorant has been considered an alternative solution for improving soil properties, including soil water holding capacity. Biochar is a solid carbon-rich product made from plant biomass via the pyrolysis process in an oxygen-limited environment. Biochar has been reported to improve soil chemical, physical, and biological properties [7].

Rice husk is a vastly available agricultural byproduct in rice producer countries. Approximately 822 million tons were produced annually worldwide and were currently underutilized due to limited recycling options [8]. Conversion of rice husk into biochar can be beneficial for energy production, sustainable waste recycling, carbon sequestration, soil quality improvement, and better plant growth [9]. The previous study proved that rice husk biochar's soil application improved rice growth and yield in riparian wetland soil [10]. The porous structure of biochar improves nutrient and water retention. Biochar application also bring variable effects on plant qualitative and quantitative growth [11].

Numerous studies had reported the significant positive effects of biochar application on root traits. Application of biochar improved root biomass, root morphology, root nutrient concentration, and root-associated microbes [12–14]. However, there were limited information about the effect of biochar application on the growth of fine and coarse root. Coarse roots provide anchorage and determine depth of penetration into the soil layers. Fine roots increase the surface area in contact with soil moisture and increase the soil volume that can be explored for water under drought condition [15].

This study's objectives were to evaluate rice husk biochar's effects on soil properties, root and shoot development, and yield in *O. glaberrima* rice. Regarding root development, this study focused on fine and coarse root growth under drought stress condition during early reproductive stage of rice.

2. Materials and methods

2.1. Plant material and research location

Rice seeds used in this experiment were RAM 101 accession of *O. glaberrima* has been reported to have the ability to grow in a wide range of harsh environment [16]. According to Kartika

et al [17], RAM 101 has drought tolerance mechanisms associated with leaf morpho-physiological responses, root traits and dry biomass accumulation. The investigation was conducted at Tropical Crop Science Laboratory, Kagoshima University, Japan (31°34'0.01" N, 130°33'0.00" E). The altitude was 6 m above sea level.

2.2. Experimental setup

The experiment was a completely randomized design with three replications per treatment. This research was set up in three phases, i.e., seed germination in an incubator, seedling preparation in a growth chamber, and rice cultivation in a greenhouse. The germination procedure was commenced by soaking the seeds in water for 48 hours. Then, the seeds were placed on wetted paper in the incubator at 28°C. After radicle emergence, germinated seeds were planted in boxes (25 cm × 37 cm × 14 cm) filled with prepared nursery substrate. The growing seedlings were kept in a growth chamber for 14 days. The internal air temperature was maintained at 28 °C with a 12 h photoperiod and 200–300 $\mu\text{mol m}^{-2} \text{s}^{-1}$ light intensity.

The 14-day old seedlings were transferred from the growth chamber to the greenhouse and transplanted to a 10 L pot filled with 7 kg of sandy loam soil. Microclimate within the greenhouse was recorded. Average day and night air temperature were 32 ± 3 °C (day) and 18 ± 5 °C (night), respectively. The relative humidity was ranged from 70% to 90%. The soil used contained 2.37 g kg^{-1} organic carbon; 0.029 g kg^{-1} total N; 11.64 mg kg^{-1} available P; 0.085 mg kg^{-1} exchangeable K; 0.36 mg kg^{-1} exchangeable Ca; 0.0367 mg kg^{-1} exchangeable Mg; 1.44% water content; soil pH was 6.38; and cation exchange capacity (CEC) of 3.43 cmol kg^{-1} . The soil was thoroughly mixed with 1 g N pot^{-1} , 0.22 g P pot^{-1} , 0.41 g K pot^{-1} as basal fertilizers.

2.3. Biochar application and drought treatment

Combination treatments of drought stress and biochar application on *O. glaberrima* were evaluated in the greenhouse. Plants were treated with sufficient water or exposed to drought conditions during the reproductive stage and combined with untreated or treated biochar application at rates of 10.5 g bucket^{-1} , equivalent to 3 tons ha^{-1} , following recommendation based on a previous experiment [10]. Thus, there were 4 combination of treatments including: drought stress with biochar application (DB), drought stress with no biochar application (DN), well-watered with biochar application (WB), and well-watered with no biochar application (WN).

Rice husk biochar was applied by thoroughly mixing it with the sandy loam soil a week before transplanting. Physical and chemical characteristics rice husk biochar used in this study were: particle size ≤ 1 mm; pH 6.38; contained 290 g kg^{-1} organic carbon; 0.686 g kg^{-1} total N; 0.295 g kg^{-1} available P; 6.519 mg kg^{-1} exchangeable K; 0.83 mg kg^{-1} exchangeable Ca; 0.60 mg kg^{-1} exchangeable Mg; and 32.99 cmol kg^{-1} cation exchange capacity (CEC).

All plants were watered to maintain saturated water content during the vegetative rice stage. Drought stress treatment started when 100 percent of the panicles have visibly emerged in all plant populations, corresponding to 110 days after transplanting. Watering was stopped until the soil moisture content reached between 5 and 8% (Figure 1). Soil moisture below 10% causes leaf of rice plant starts to roll. Leaf rolling index is used by the International Rice Research Institute as indicator for drought stress in rice plant [17]. It took four days to induce drought stress on rice plants.

Afterward, the drought-treated plants were re-watered to allow the plants to recover.

2.4. Analysis of growing substrate

Soil moisture was monitored hourly using Data Logger (Decagon Devices Inc., Em50 Series). The sensor was installed in the center of the pots at a 15 cm depth. The pH of soil-biochar mixtures was measured by mixing 20 g of sample with 50 mL distilled water, while pure biochar was mixed at a ratio of 10 g biochar to 50 mL. The samples were then stirred for an hour, then measured with a pH meter (F-51, Horiba Ltd., Kyoto, Japan). The CEC was determined by the semi-micro Schollenberger method using 1 mol/L of neutral ammonium acetate. Available P was determined using the Truog method, extracted by H₂SO₄ [0.002 mol L⁻¹, pH 3.0] and measured using spectrophotometer (JASCO V-530 UV-Vis, Artisan Technology Group, Champaign IL, USA) at 710 nm. Soil total N and total C contents were analyzed using a CN analyzer (JM1000CN, J-Science Lab Co, Ltd., Kyoto, Japan).

2.5. Biomass and root analysis

Three plants were destructively sampled from each treatment and were separated into the root, stem, leaf, panicle, and dead biomass. Shoot dry weight was obtained by adding leaf, stem, and panicle dry weight. The roots were carefully washed for characteristic analysis. The roots were arranged in a transparent tray and scanned using Photo Scanner (GT-X830, Seiko Epson Corp., Tokyo, Japan). Root length, root surface area, and root volume were measured using plant root measurement and analysis systems (WinRHIZO, Regent Instruments Inc., Quebec, Canada). Root dry weight was determined after the biomass was oven-dried at 80 °C for 72 h.

2.6. Statistical analysis

Effects of drought treatment and biochar application were tested by employing the analysis of variance using statistical analysis software (SAS[®] University Edition, SAS Institute Inc., Cary NC, USA). Differences among treatment combinations were determined with the Least Significant Difference (LSD) test at $P < 0.05$. Significant differences in soil chemical characteristics between biochar-treated and non-treated were analyzed using Student's t-test at $P < 0.05$.

3. Results

3.1. Soil properties

Soil moisture content indicates the amount of water available in the soil. Well-watered soil steadily maintained moisture content at 30 to 35 percent. Soil water content declined significantly after 2 to 4 days of drought treatment both with and without biochar application; however, soil moisture returned to pre-treated value between 30 to 35 percent after two days of the recovery period, except for drought without biochar treatment. Rapid depletion of water content was observed in soil without biochar application than the biochar applied soil (Figure 1).

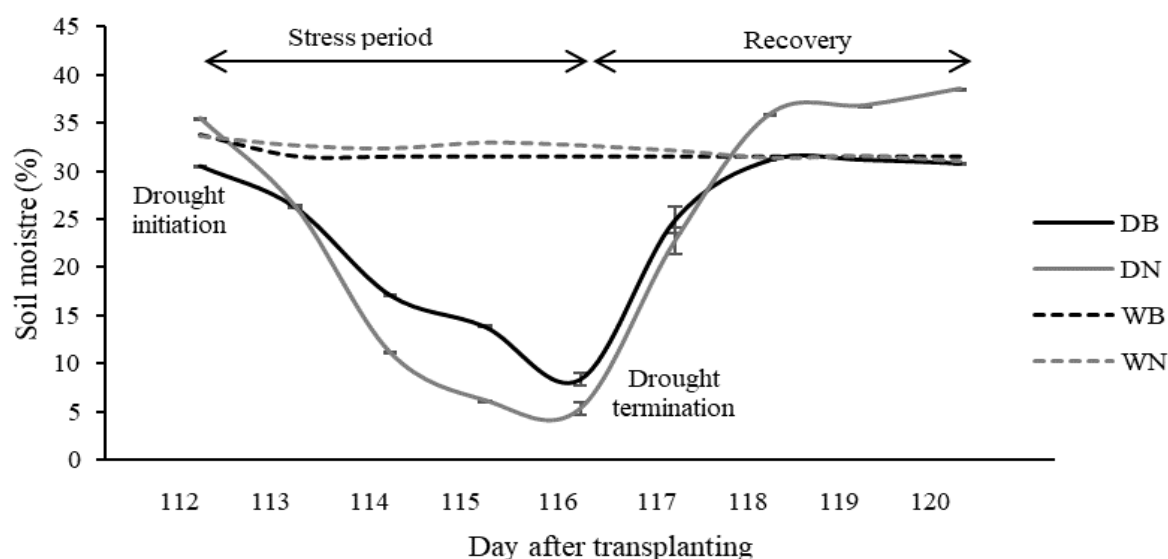


Figure 1. Soil moisture content during drought stress treatment and recovery period in soil amended or not amended with biochar. DB, DN, WB, and WN were drought with biochar, drought without biochar, watered with biochar, and watered without biochar, respectively. Vertical bars indicate the standard deviation of the mean ($n = 3$).

Biochar amendment before rice transplanting affected some soil chemical properties. Application of biochar at a rate of $10.5 \text{ g bucket}^{-1}$ (3 tons ha^{-1}) increased soil pH by 1.09, CEC value from $3.93 \text{ cmol kg}^{-1}$ to $4.94 \text{ cmol kg}^{-1}$, doubled available P, and exchangeable Mg; however, it did not significantly affect concentrations of total C, total N, exchangeable K and exchangeable Ca (Table 1).

Table 1. Influence of biochar application on soil chemical properties before rice transplanting.

Soil properties	Soil		Ratio (B/N)
	No Biochar (N)	Biochar (B)	
pH	$5.03^1 \pm 0.01$	5.48 ± 0.03	1.09 **
CEC ($\text{cmol}_c \text{ kg}^{-1}$)	3.93 ± 0.27	4.94 ± 0.63	1.26 **
Total C (g kg^{-1})	2.24 ± 0.10	3.03 ± 0.41	1.35 ns
Total N (g kg^{-1})	0.04 ± 0.00	0.05 ± 0.00	1.31 ns
Available P (mg kg^{-1})	26.6 ± 0.31	57.4 ± 1.79	2.15 **
Exchangeable K (mg kg^{-1})	217 ± 32.0	307 ± 43.0	1.41 ns
Exchangeable Ca (mg kg^{-1})	406 ± 22.0	326 ± 108	0.80 ns
Exchangeable Mg (mg kg^{-1})	48.0 ± 2.00	63.0 ± 3.00	1.31 **

¹Values are the mean of three replications \pm standard deviation. Means were compared using Student's t-test (* = $P < 0.05$; ** = $P < 0.01$; and ns = not significant).

Based on soil chemical properties measured after rice plants were harvested, soil water conditions altered biochar application effects (Table 2). CEC and exchangeable Ca were significantly increased in soil amended with biochar after drought stress, but they were not significantly affected under well-watered soil. On the contrary, biochar application significantly decreased available P and

exchangeable K under well-watered soil, while after drought treatment, these chemical properties were not greatly affected. The two different water regimes did not alter soil pH, total C, total N, and exchangeable Mg.

Table 2. Effect of biochar application and drought stress on soil chemical properties after rice harvested.

Soil properties	Drought			Well-watered		
	No Biochar (N)	Biochar (B)	Ratio B/N	No biochar (N)	Biochar (B)	Ratio B/N
pH	5.83 ¹ ± 0.03	5.99 ± 0.02	1.03 **	5.91 ± 0.00	5.99 ± 0.01	1.01 *
CEC (cmol _c kg ⁻¹)	4.66 ± 0.23	5.95 ± 0.23	1.28 *	4.79 ± 0.42	5.31 ± 0.20	1.11 ns
Total C (g kg ⁻¹)	1.86 ± 0.17	0.98 ± 0.19	0.53 **	1.59 ± 0.03	0.92 ± 0.04	0.58 *
Total N (g kg ⁻¹)	0.03 ± 0.00	0.02 ± 0.00	0.66 *	0.02 ± 0.00	0.02 ± 0.00	0.70 *
Available P ₂ O ₅ (mg kg ⁻¹)	45.90 ± 5.85	45.47 ± 2.80	0.99 ns	56.85 ± 1.89	50.14 ± 1.29	0.88 *
Exchangeable K (mg kg ⁻¹)	50.58 ± 4.12	58.42 ± 4.57	1.16 ns	72.29 ± 6.15	58.64 ± 3.48	0.81 *
Exchangeable Ca (mg kg ⁻¹)	413.12 ± 6.65	582.18 ± 9.98	1.41 **	430.71 ± 18.31	448.43 ± 10.14	1.04 ns
Exchangeable Mg (mg kg ⁻¹)	66.19 ± 1.56	112.45 ± 1.36	1.70 **	59.12 ± 2.00	71.52 ± 1.75	1.21 **

Drought stress in rice occurs at soil moisture between 5% to 8%. Well-watered is indicated by water saturated soil condition. ¹Values are the mean of three replications ± standard deviation. Means were compared using Student's t-test (* = $P < 0.05$, ** = $P < 0.01$, ns = not significant).

3.2. Root morphology

There was a correlation between soil water content and root development. The correlations revealed that the length of fine roots correlated stronger ($r = 0.9046$) than coarse roots ($r = 0.8292$) with a soil water content within the range of 5 to 40 percent (Figure 2). Before drought stress treatment, there was no significant difference observed in fine and coarse root length, total surface area, and total root volume (Figure 3). Regardless of soil water condition and biochar application, fine roots were longer than coarse roots. Root morphology, including length, surface area, and volume, was more regulated by soil water status as indicated by significant decline under drought stress. Root length of both fine and coarse was sharply decreased as soil water content was depleted, presumably due to the gradual death of root cells starting from the roots' tip.

Fine roots in biochar-amended soil were longer than those in non-amended soil; however, these differences in root length were diminished after rice plants were allowed to recover for four days (Figure 3A). The length of fine and coarse roots was significantly higher in well-watered conditions than those treated with drought stress. This water-related effect was more noticeable at the termination of 4-day drought treatment in biochar-amended soil (Figure 3B). Root surface area had a similar pattern to coarse root length (Figure 3C). An increase in root volume occurred under drought conditions but decreased during recovery (Figure 3D).

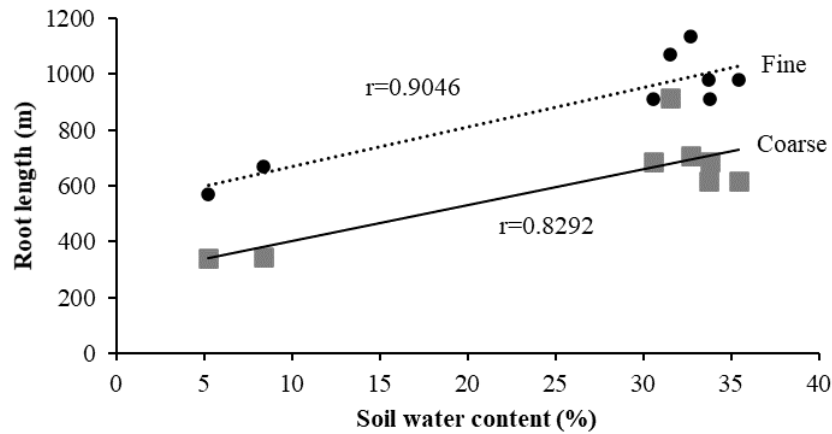


Figure 2. Correlation between soil water content and length of fine and coarse roots.

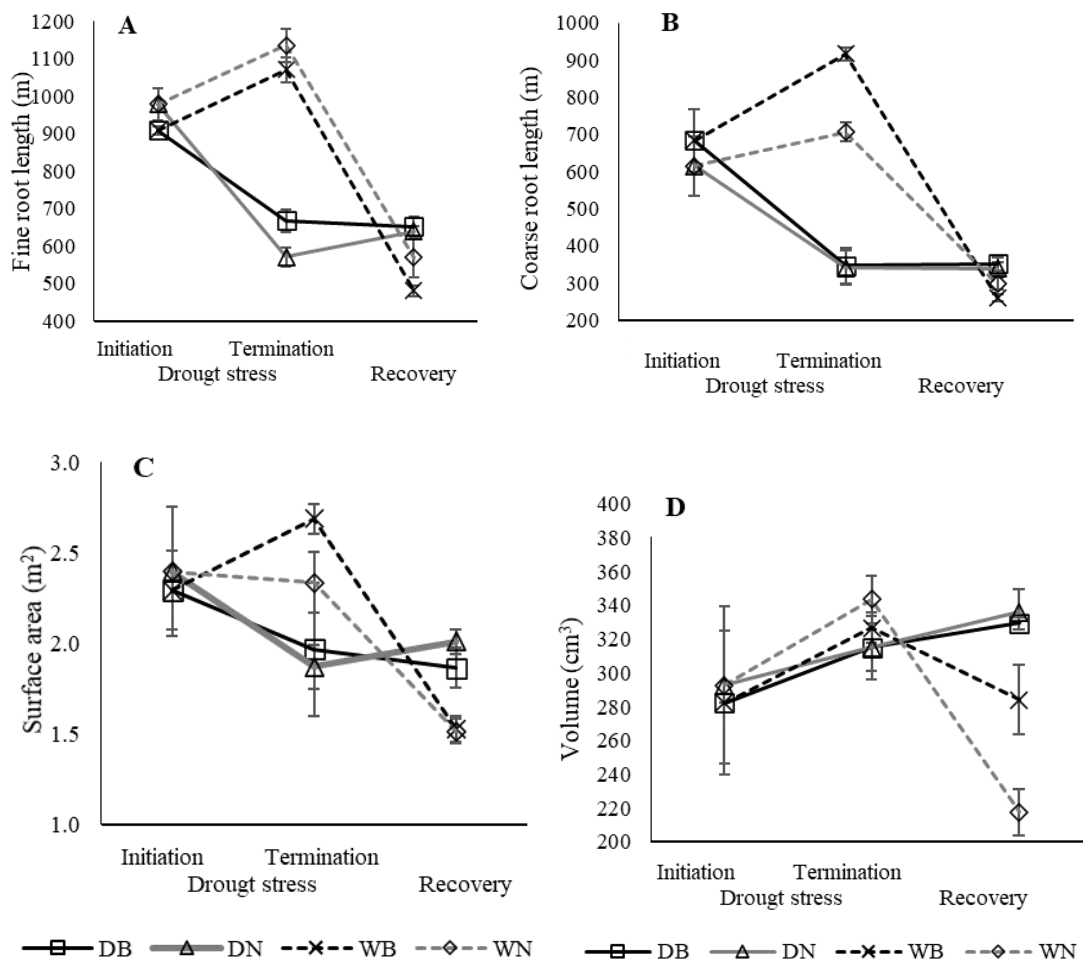


Figure 3. Fine root length (A), coarse root length (B), root surface area (C), and root volume (D) in *O. glaberrima* rice plant grown on biochar-amended or not-amended combined with or without drought-treated soil. DB, DN, WB, and WN were drought with biochar, drought without biochar, watered with biochar, and watered without biochar, respectively. Vertical bars indicate standard deviation.

Biochar application promoted the highest values for total root length/shoot dry weight ratio (TRL/ShDM) under drought stress, demonstrating most of the plant photo-assimilates allocated for root elongation (Figure 4A). An increase in root length is expected to increase plant ability in acquiring nutrients and water. Root to shoot ratio increased under drought conditions for rice plants grown on biochar-amended and non-amended soils and continued to increase during the recovery period (Figure 4B). It is also interesting to note that biochar application exhibited the highest root to shoot ratio in well-watered soil.

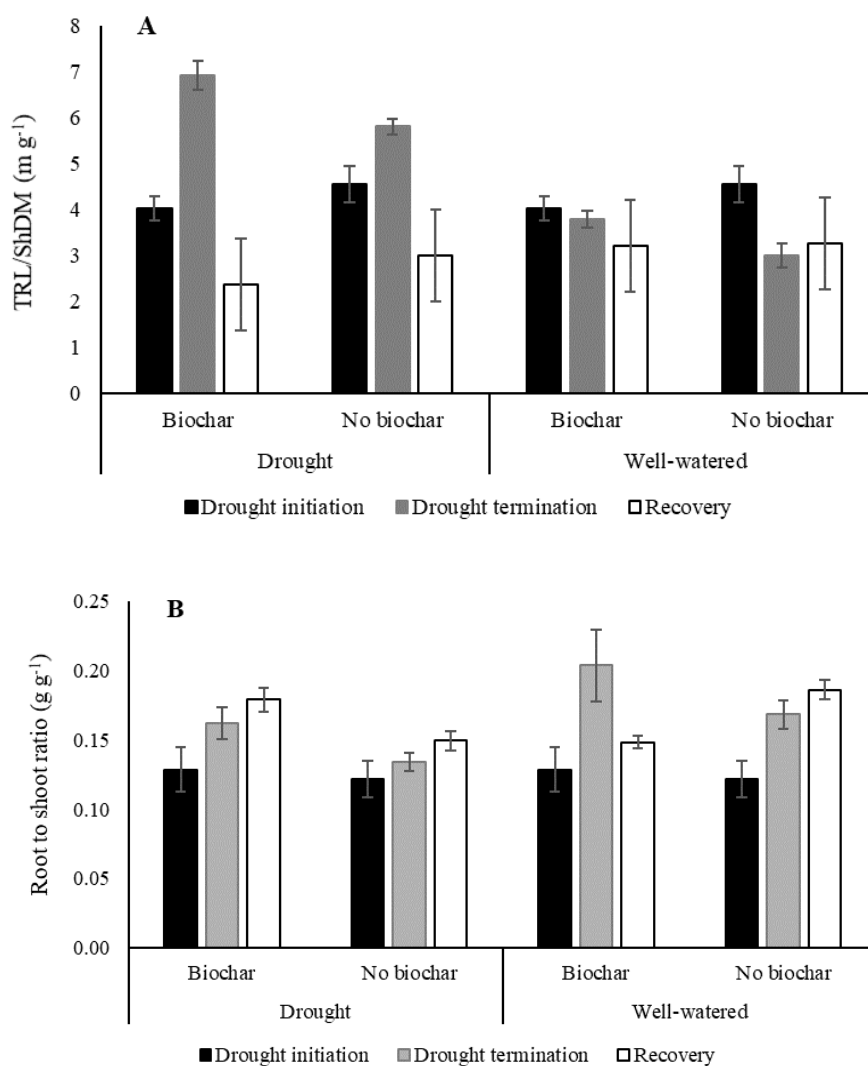


Figure 4. Total root length/shoot dry weight ratio (A) and root to shoot ratio (B). Drought indicated soil moisture was between 5% and 8% while well-watered indicated saturated water content. Vertical bars indicate standard deviation.

3.3. Dry matter accumulation and yield

Production of dry plant weight was significantly different between soil water condition and biochar application (Table 3). Nevertheless, stem dry weight (SDW), leaf dry weight (LDW), panicle

dry weight (PDW), and dead shoot presented no significant differences between treatments before drought stress occurred. On average, drought stress sharply decreased SDW, and significant differences were observed for SDW among treatments. Plants treated with biochar showed significantly higher SDW than those untreated at the recovery period in plants exposed to drought conditions.

Table 3. Dry weight production under drought condition and biochar application.

Treatment		Drought initiation	Drought termination	Recovery
<i>Root dry weight (RDW) (g)</i>				
Drought	Biochar	50.77 ± 4.74 a	46.33 ± 1.39 ab	55.87 ± 3.68 a
	No Biochar	42.53 ± 4.15 b	42.57 ± 1.99 b	43.13 ± 2.86 b
Well-watered	Biochar	50.77 ± 4.74 a	54.03 ± 4.64 a	46.23 ± 1.03 b
	No Biochar	42.53 ± 4.15 b	51.03 ± 1.95 ab	56.03 ± 1.93 a
LSD		6.1	9.91	7.67
<i>Stem dry weight (SDW) (g)</i>				
Drought	Biochar	252.60 ± 19.20	122.87 ± 7.62	129.43 ± 4.53 a
	No Biochar	218.50 ± 26.93	130.80 ± 4.71	112.10 ± 7.35 b
Well-watered	Biochar	252.60 ± 19.20	126.97 ± 18.81	126.83 ± 1.40 ab
	No Biochar	218.50 ± 26.93	132.43 ± 3.57	130.87 ± 6.40 a
LSD		-	-	16.89
<i>Leaf dry weight (LDW) (g)</i>				
Drought	Biochar	48.27 ± 0.52	28.27 ± 1.77 b	22.87 ± 2.19 b
	No Biochar	42.53 ± 4.77	26.90 ± 1.21 b	21.77 ± 1.18 b
Well-watered	Biochar	48.27 ± 0.52	37.60 ± 3.30 a	33.83 ± 1.21 a
	No Biochar	42.53 ± 4.77	39.63 ± 0.99 a	35.07 ± 1.08 a
LSD		-	7.09	5.44
<i>Panicle dry weight (PDW) (g)</i>				
Drought	Biochar	29.83 ± 0.85	39.70 ± 2.22	51.57 ± 1.05 b
	No Biochar	31.63 ± 2.54	39.63 ± 0.09	54.00 ± 1.00 b
Well-watered	Biochar	29.83 ± 0.85	37.27 ± 1.25	68.40 ± 3.61 a
	No Biochar	31.63 ± 2.54	44.33 ± 6.45	52.80 ± 1.16 b
LSD		-	-	8.17
<i>Dead Shoot (g)</i>				
Drought	Biochar	66.67 ± 3.65	97.53 ± 5.92 b	108.07 ± 7.74 a
	No Biochar	62.47 ± 6.21	120.63 ± 4.19 a	100.27 ± 0.97 a
Well-watered	Biochar	66.67 ± 3.65	68.70 ± 5.44 c	82.83 ± 1.53 b
	No Biochar	62.47 ± 6.21	88.00 ± 1.76 b	82.50 ± 1.82 b
LSD		-	17.21	13.91

Values are the mean of 3 replications ± standard deviation. Means followed by a different letter for each measured parameter within each column indicate significant differences among treatments at $P \leq 0.05$ using the LSD test.

Regarding LDW, significant differences were observed between drought-treated and non-treated plants; however, there was no difference between plants grown on biochar-amended and non-amended soil within each water regime. Furthermore, plants were unable to increase the LDW in

the recovery stage. The dry panicle mass increased even under drought stress. Biochar application under well-watered conditions produced significantly higher PDW during the recovery period.

Drought stress had caused the death of stem and leaves, which were classified in dead shoot dry weight. Dead shoot dry weight was significantly higher in plants exposed to drought stress and grown on soil without biochar application. We found that dry root weight was less affected in this experiment than stem and leaf dry weight under drought conditions. Interestingly, although reduced under drought stress, biochar application showed higher root dry weight at recovery.

Drought stress reduced rice yield. Reduction in the percentage of filled spikelet is accompanied with an increased in the percentage of empty spikelet due to drought stress conditions. Biochar application could maintain the percentage of filled spikelet under drought stress compared to those without biochar (Figure 5A). The reduction of filled spikelet resulted in the decreased in yield per hill. Biochar applications enable the plants to maintain yield under drought stress. Meanwhile, a significant decrease in yield was seen in plants without the provision of biochar under drought conditions (Figure 5B).

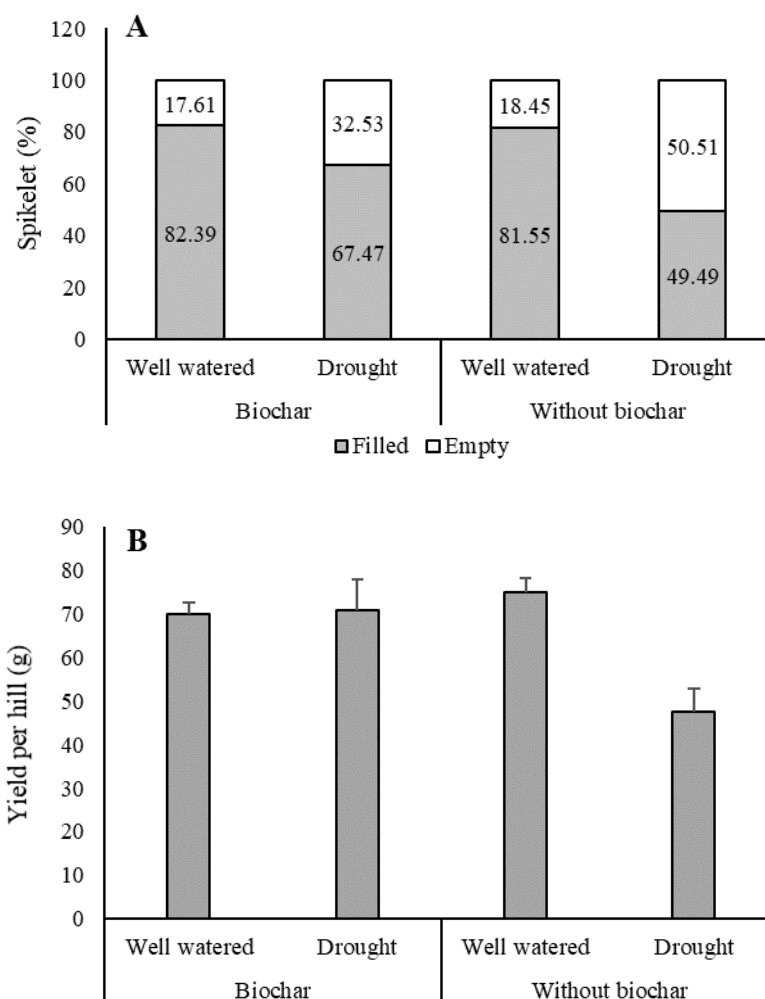


Figure 5. Percentage of filled and empty spikelet (A) and rice yield per hill (B). Drought indicated soil moisture was between 5% and 8% while well-watered indicated saturated water content. Vertical bars indicate standard deviation.

4. Discussion

The soil drying process was slower in biochar-amended soil (Figure 1). Many studies showed that biochar's application increases soil water holding capacity [18–20]. The decelerated drying process contributed to higher soil water content during drought stress treatment in biochar-amended soil. Characteristic of biochar with porous structure facilitates water infiltration from the ground surface to topsoil through the large pores after heavy rain and retains the water in small pores, thus increase soil water holding capacity [21–23]. Biochar retains moisture in the soil by modifying the soil pore size distribution associated with aggregation improvements and water storage in pores [24]. Lu et al. [18] reported that rice husk biochar application could increase soil pore structure by 20 percent.

The increases of soil pH after biochar application are mentioned in many works [25–27]. Due to ash content, most biochars are alkaline and release base cations and alkaline properties of organic functional groups. Thus, biochar's addition neutralizes soil acidity and base saturation, depending on soil and biochar's intrinsic properties [28]. A rise in pH improves the availability of plant nutrients and decreases the availability of harmful elements such as Al and other heavy metals [25].

A significant increase in soil CEC was detected after biochar application (Table 1) and showed a higher value under drought conditions (Table 2). An increase in CEC is strongly related to oxidation of the aromatic C, formation of hydroxyl and carboxyl groups, high surface area, and variable charges of biochar [27,29]. Our results confirmed that biochar application could improve the status of soil exchangeable cation capacity, especially for Ca and Mg, which was in accordance with the results of Jien and Wang [30], who assumed that original nutrients in biochar supplied the exchangeable cations in soils. The improvement of CEC is beneficial for plant growth, wherein fertilizers applied can be adsorbed to the surface area of biochar, and in turn, it will be easier to rice plants to absorb.

The biochar used in this study had a high amount of available P_2O_5 (1352 mg kg^{-1}). Therefore, a much greater increase of soil P was induced by incorporating the biochar into the soil (Table 1). This finding is consistent with studies whereby biochar addition can improve P availability in soil [11,31]. Improvement of soil available P is due to an additional P element in biomass used as raw material for biochar production and due to P mobilization, which immobilized by Al^{3+} , Fe^{2+}/Fe^{3+} under acidic condition [32]. Soil analysis after *O. glaberrima* rice harvested showed the number of available P was sharply decreased as it was used for rice growth and development.

It is recognized that plants modify their growth with changes in environmental conditions. In the present study, drought stress reduced dry weight accumulation in the leaves, stems, and roots (Table 3). In addition to reduction of plant dry weight, a notable observation was the increase in root to shoot ratio under drought stress (Figure 4B). This condition resulted from a greater reduction in aboveground biomass rather than due to an increase in root biomass. Specifically, leaf growth is more sensitive to drought stresses than root [3,17,33,34]. This finding was contrary to the effect of complete submergence in *O. glaberrima*, where growth in shoot biomass significantly greater [35].

Root plays an essential role in water and nutrient uptake in plants. Deep root penetration, a high number of fine roots, and the root's ability to penetrate smaller soil pores can be considered a survival strategy under drought stress [36]. In the present study, the root length correlates with soil water content. Fine and coarse root length and total surface area were decreased by reducing soil moisture (Figure 3).

Coarse roots determine plants' ability to provide anchorage, establish root system architecture, and control root system depth. Simultaneously, fine roots are more active in water and nutrients

uptake [37]. Under drought conditions, fine and coarse root length, root surface area, and root volume were considerably reduced. Our experiment results are consistent with those of the previous study [38]. Reduction in root growth occurs due to reduced carbon partitioning to below ground which may reduce root number, diameter, and length at the reproductive stage. However, root development may be promoted hormonal activities and biochemical processes to increase carbon assimilates sent to the roots [1,39]. This study confirmed that fine roots length was significantly higher under drought stress in biochar-treated soil. This finding was in accordance with other studies' results, which also indicated more extensive root systems with higher branching and fine roots in the presence of biochar [30,40].

The decline in yields occurred in plants under drought stress without the provision of biochar. Keshavarz et al. [6] stated that the ability of biochar to store water is a key factor to maintain crop yields under drought condition. The ability of biochar to increase crop yields is also due to improvements in soil physical, chemical, and biological characteristics [41].

5. Conclusions

Rice husk biochar application led to positive effects on soil properties as a growing substrate in *O. glaberrima* rice cultivation exposed to drought stress conditions during the early generative stage. Biochar beneficially altered soil chemical properties such as soil moisture, pH, CEC, and nutrients availability. Biochar-amended soil exhibited better performance than non-amended soil on growth and yield in *O. glaberrima* rice as indicated by shoot, roots, panicle dry weight, and percentage of filled spikelet. The highest ratio of fine or coarse root length to shoot dry weight was during the drought stress, indicating that the *O. glaberrima* rice plant enhanced its root elongation during the drought period. However, the highest value of root to shoot ratio occurred during the recovery period, indicating that root development shifted from root elongation to branching activity as soil moisture re-increased.

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Conflict of interest

The authors declare that there is no conflict of interest.

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