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The Effects of Silicon Content in Rice Husk Biochar of Southern Taiwan on the Germination of Corn Seeds (*Zea mays* L.)

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Abstract

To our knowledge, not many investigations about this topic were done in Southern Taiwan where the potential of rice residues from agriculture fields is abundant. Our purpose for those rice residues is to transform them into biochar. Our experiment was conducted in Southern Taiwan, where we studied the characteristics of biochar made from rice husks, applying different types of combustion and temperatures as well their effects on corn (*Zea mays* L.) seed germination. The experimental trial was composed of seven (7) different treatments including the application of rice husk, rice husk biochar, chemical fertilizer, and soil. The biochar treatments used a mixture of 50% biochar and 50% soil to balance the quantities of rice husk biochar that could be incorporated into clayey soils. The effect of biochar application on corn growth was evaluated. Results showed that silicon content in rice husk biochar can inhibit seed germination linearly. Silicon in this study was found to be harmful significantly to corn seed germination when Si content in rice husk biochar was higher than 25 to 30 wt% indicating that increased levels of silicic acid and quantities of the amendment above 8-10 ton per hectare reduce the germination rate.

Keywords: Biochar; Corn; Plant Growth; Rice Husk; Seed Germination; Silica Content; Clayey Soils

Introduction

There are few investigations related to rice husk transformation into biochar in the Southern Taiwan area where the potential of rice residues from agriculture fields is abundant. Biochar is the result of a pyrolysis process that occurs spontaneously at high temperatures, usually at or above 300°C. The high temperatures used in pyrolysis induce polymerization of the molecules within the feedstocks, producing larger molecules and thermal decomposition of some feedstock components into smaller molecules [1]. The remaining solid component following pyrolysis is charcoal, referred to as biochar, when produced to use it for soil improvement [2-5]. Biochar is known as a pyrolyzed carbon from waste biomass used in agriculture.

Rice-husk biochar has high silica (SiO_2) contents and silicon (Si) which is a beneficial element for plant growth. Silicon plays an important role in increasing plant resistance to pathogens such as blast on rice [6,7] and powdery mildew on cucumbers [8]. Silicon is effective in preventing rice lodging by increasing culm wall thickness and vascular bundle size [9], thereby enhancing stem strength. Silicon alleviates the effects of biotic and abiotic stresses including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature, and freezing [10,11] and has various beneficial effects on plant growth and productivity [12]. Maize takes up Si actively from the roots [13]. The benefits of silicon in crop production are, therefore, healthier plants and higher yield with fewer applications of pesticides and other chemical products [7].

The use of untreated rice straw and rice husk in rice growing has been practiced for a long time [14-17]. Williams, et al. [18] discussed the advantages and drawbacks of burning versus incorporating straw in rice growing. Karmakar, et al. and Mahvi, et al. [19,20] reported the mixed effects of fly ash and rice husk ash to decrease soil bulk density, and to increase soil pH, soil organic carbon, available nutrients, and crop yield. An increase in crop yield with biochar application has also been reported for crops such as cowpeas [21] and maize [21,22]. Thus, there might be a huge potential to use rice residues as soil organic amendments in Taiwan and beyond. According to Haefele, et al. [23], the total crop residues produced each year in rice-based systems of Asia are estimated at 560 million tons of rice straw and 112 million tons of rice husks (based on 2005 production, a harvest index of 0.5, and a husk/paddy ratio of 0.2). Depending on the biochar stability against microbial breakdown, this could help to reduce greenhouse gas emissions and sequester carbon in soils. However, it was reported that biochar stability in the soil depends on the temperature used in the pyrolysis process [24], which is, therefore, an important factor determining biochar quality.

Nonetheless, agronomists and farmers are not always aware that they could be able to improve crop production and increase stress and disease resistance by adding a source of available silicon to the soil. Still, reports on the Si effect of rice husk biochar on plant seed germination are scant. Therefore, in line with the above, the objective of this study is to assess the potential effects of biochar from pyrolyzed rice husks on corn (*Zea mays* L.) seed germination and its effect on the plant growth in Southern Taiwan.

Materials and Methods

Biochar Preparation and Characterization

Four different rice husk biochars were used in this study; biochar from the International Rice Research Institute (B1), Industrial Technology Research Institute biochar (B2), National Pingtung University of Science and Technology (B3), and Shui-Known Company (B4). Table 1 shows the preparation conditions of the tested biochars. Analyses, including scanning electron microscopy (SEM) equipped with an energy dispersion X-ray spectroscopy (EDX), Fourier transform infrared spectroscopy (FT-IR), volatile matter (VM), electrical conductivity (EC), water holding capacity (WHC), were used to characterize the four biochars and their properties.

Biochar	Origin	Method	Time	Temperature
B1	International Rice Research Institute in the Philippines	Drum	4 – 8 hours	400ºC
B2	Industrial Technology Research Institute	Artisanal reactor	3 – 4 hours	500 ºC
B3	National Pingtung University of Science and Technology	Laboratory scale reactor	1 hour	350 ºC
B4	Shui-Known Company	Specialized biochar reactor	2 – 3 hours	700 ºC

Table 1: Preparation conditions of the tested biochars.

Soil Characteristics

A clayey Ultisol soil from the NPUST campus field was used in this investigation. Ultisols are strongly leached acid (forest) soils with relatively low native fertility. They are found primarily in humid temperate and tropical areas of the world, typically on older, stable topographies. Intense weathering of primary minerals has occurred, and most Ca, Mg, and K have been leached from these soils. Ultisols have a sub-surface horizon in which clays have accumulated, often with strong yellowish or reddish colors resulting from the presence of Fe oxides [25].

Soils samples were dried in a precision oven at 35 ºC, mixed into a homogeneous sample, ground, and passed through a 2 mm sieve (10 mesh), then we used 20 grams of soil in a relation of 20:20 with distilled water. Soil texture and characteristics were obtained using the hydrometer method [26]. To measure water holding capacity of biochar and biochar/soil mixtures, samples were tested before oven drying (after drying at 35 ºC but before drying for 24 hours at 105 ºC). For this test, we followed the procedure of the soil analysis manual [27]. To determine the pH of the different treatments a Fisher Scientific Accruement was used. Salt content (ppt), total dissolved solutes (TDS), and electrical conductivity (EC) were measured with a portable Conductivity/Resistivity Meter S-110 (Suntex®).

Experimental Design

Seven treatments (B1, B2, B3, B4, RH, S1, and S2) were arranged in a fully randomized design, 10 pots were grouped to make one plot, and the total setup consisted of 7 pots with 4 replications each. The amount of biochar applied (45g) was calculated based on the surface area of the plastic pot used (4.5 x 5.0 cm), and the amendments were mixed to a 5 cm depth. After preparation, they were placed in a net house and watered every two days. The germination of corn plants was conducted for 15 days; the plants were harvested and kept refrigerated for further analysis. We set a serious experimental pot, when the settled time was up, we sample the experimental pot for analysis.

Rice Husk Biochar Analysis

A HITACHI S-3000N scanning electron microscope equipped with an energy dispersion X-ray (EDX) was used to examine the morphology and silicon content of dried rice husk and biochar rice husk samples. The sample powder was sprinkled as a thin layer on an adhesive tape placed on the brass sample holder. An excess amount of the sample was removed using a small manual air blower. The adhered sample was then coated with gold powder using the sputtering device with the Ion Sputter E-1010 HITACHI, and then transferred into the JEOL sample chamber for the analysis. The accelerating voltage was set at 15-40 kV and 200, 300, and 600-time magnification were selected. A Bruker Vector-22 FT-IR spectrometer was used for the identification of the organic functional groups present for each biomass, especially carbons and -OH- groups.

Statistical Analysis

Differences between biochar treatments were analyzed by one-way ANOVA using Duncan and LSD tests for mean comparisons where ANOVA showed significant differences between treatments. Biochar treatments were compared using the least significant differences for the main effect of biochar on plant growth properties. Significant levels used were $p \leq 0.05$ level, $p \leq 0.01$ level, and $p \leq 0.001$ level. All statistical analyses were carried out using SPSS statistical software.

Results and Discussion

Soil and Biochar Analysis

Table 2 shows a comparison between the pH of biochars before and after the incorporation of soil. All the biochars investigated had a higher pH than their corresponding crop husks, indicating the higher alkalinity of biochar compared with the husks and suggesting the formation of alkaline substances in crop residues during pyrolysis. Ultisols are acidic in nature and quite productive under good management [28]. However, high acidity and low availability of calcium, magnesium, and potassium render these soils poorly suited for continuous agriculture without the use of chemical fertilizers, showing with this the need of finding new additives for this type of soils that could give to the farmers an environmentally friendly option to improve them and increase crop production.

Treatment	pH of biochar	pH of biochar + soil, rice husk and soil and soil + fertilizer
B1	5.98	7.38
B2	6.4	8.02
B3	6.62	8.53
B4	6.92	10.04
RH	-	5.76
S1	-	5.02
S2	-	6

Table 2: pH of Materials used for Corn Germination.
*RH: Rice Husk. *S1: soil. *S2: soil with fertilizer.

Table 3 shows the results of the analysis of the different rice husk biochars as well as dried rice husk and soil characteristics. Besides, the soil used for the experiments had a percentage of 0.77% of organic carbon (equivalent to 1.33% of organic matter), and a silt loam texture (7% clay, 72% silt, 21% sand). The soil reaction was medium acidic. Volatile matter content (VM) of biochars is the portion lost after a moisture-free sample has been heated at 950°C for six minutes.

The volatile matter content of biochars has been shown to affect plant growth by immobilizing nitrogen otherwise used by plants and providing available carbon to microorganisms in the soil [29]. Because of this, the volatile matter content of different biochars needs to be determined as a method to ensure that biochar does not lower plant growth when added to soils.

Treatment	WHC	EC	Salt content	Total Dissolved Solids	VM
	(%)	(µs/cm; °C)	(ppt)	(ppm)	(%)
B1	56.8	1678 ; 23.1	0.3	663	2.75
B2	54.3	1294 ; 23.0	0.2	517	2.94
B3	55.9	946 ; 22.8	0.1	379	2.19
B4	56.1	1013 ; 22.7	0.1	405	2.05
RH	51.8	954 ; 22.8	0.1	371	8.59
S1	45.5	903 ; 22.9	0.1	301	-
S2	40.8	1241 ; 22.7	0.2	421	-

Table 3: Results from the analysis of different rice husk biochars, raw husk, and soil samples with and without fertilizer. *RH: Rice Husk. *S1: soil. *S2: soil with fertilizer.

Functional Group Analysis

The functional groups of rice husk biochar were examined by FT-IR spectroscopy (Figure 1). This analysis tool has frequently been used in investigations of surface chemistry of chars and activated carbons [30], as it provides valuable information on the chemical nature and the concentration of surface functional groups.

Various bonds in the spectra were detected in Figure 1: OH stretching vibrations corresponding to acid and/or alcohol groups (at 3398 - 3489 cm^{-1}), to CH$_2$ methylene group (2293 - 2885 cm^{-1}), CO$_2$ carboxyl group (2285 - 2379 cm^{-1}), C=O group (1602 - 1648 cm^{-1}) indicating ester and carboxylic acid structures, COOH carboxylic acid group (1064 - 1101 cm^{-1}), C-O carbon monoxide group (1056 - 1101 cm^{-1}), Si (789 cm$^{-1)}$, and amine compounds (497 cm^{-1}) in rice husk biochar. The FT-IR analyses showed similar results for all biochars analyzed except for the IRRI biochar which had lower intensity readings for –OH, -CO, and Si compounds.

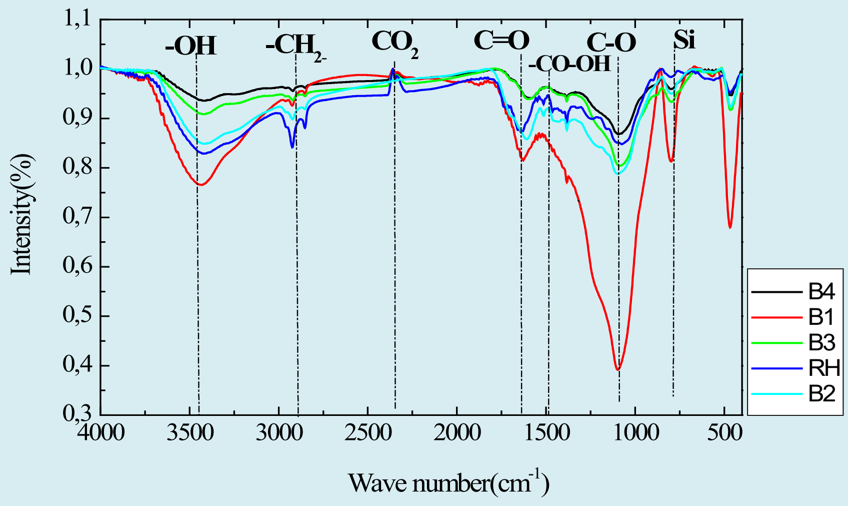

Figure 1: FTIR Spectra of tested samples.

Information taken from various studies [31] points out that the relative concentration of each of the functional groups depends on the biomass initial composition, final reaction temperature, the composition of the gas surrounding the charring particle (final reaction temperature), heating rate and post-treatment. The C functional group chemistry and molecular form of biochar may be expected to significantly differ between biochars, given the differences in feedstock types and production conditions. Lehmann [32] found that charge properties and, consequently, oxidized functional groups such as carboxyl groups differed significantly depending upon the production temperature. The importance of these differences from a soil fertility point of view is that surface area and porosity of the biochar alters significantly its role in soil fertility. In contrast to the optimum conditions for the formation of the acid functional groups, more intense charring conditions (higher temperatures and longer charring times) are required for the formation of porosity and high surface area in the biochar [33].

Electron Microscopy Analysis

Five scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) images of rice husk biochar produced at a final reactor temperature of 240°C, 300°C, 600°C, and 700°C and dry rice husk are evaluated (data showed here). Bamboo biochar developed high porosity, presenting longitudinal pores with sizes ranging from micro to macropores (10-100 μm). Vascular bundles of the raw biomass originate the bigger pores in the biochar. They are essential for the improvement of soil-improving quality as they can provide habitats for symbiotic microorganisms. The structure of rice husk and rice husk biochar was found to be highly heterogeneous. Our SEM-EDX analysis (non published data) also indicated that rice husk and rice husk biochar particles consisted of high silica mineral agglomerates on low carbon content fibers with structures typical of its biomass origin. Biochar produced from rice husks may well sequester carbon in soils whilst releasing plant nutrients to soil solution as ions disperse into and out of this vastly porous material [34]. The rate at which this process occurs will depend on several factors including the pore structure of both biochar and soil, the solubility of minerals in biochar, and chemical properties including the pH of soil and soil solution [34].

Corn seeds Germination and Plant Morphology

Figure 2, shows the root development data, it was found to be significantly affected by the use of rice husk biochars in comparison with the treatments soil and soil with fertilizer. According to the ANOVA mean comparison data in Figure 1, seedlings growing in the rice husks biochar treatments of B3 and B2 showed significantly higher weight than the rest of the treatments. This shows that increased levels of silicic acid can reduce the germination rate. High silicon levels are shown for B1 and B4 biochar.

Germination started on the 3rd day after seeds were planted. Corn seeds treated with biochar and soil showed significant development. The germination percentage for corn from the 7 different treatments can be observed in Figure 1. The treatment that showed the best growth rate was B2, followed by B3 and S2. B2 has a pH of 8.02, a VM of 2.94% (the highest among biochars), a high EC that could be compared with S2. B2 was obtained after applying a pyrolyzation temperature of 500°C. Treatments with the addition of biochar from B1 and B4 showed inhibition in seed germination. B4 was the treatment with higher pH (10.0) and produced at a higher pyrolyzation temperature (700°**C**).

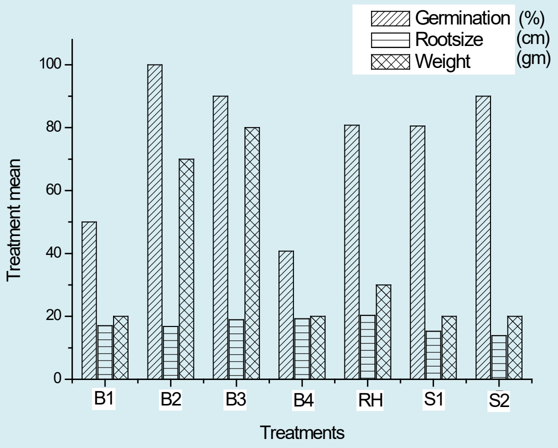

Figure 2: Effect of Biochar on the mean of germination, root length, and weight.

Figure 3 have found that rice husk biochar inhibits seed germination linearly, when the Si content is higher than 90 wt% in the biochar, it would have no germination. Si content was shown to increase when higher temperatures of pyrolyzation were used to produce biochar. Thus, germination was much lower in all samples with high silicon weight as compared with treatment B2 which had a low Si content and higher germination mean. Results of Studies realized around the world, have shown that applying supplemental silicon can inhibit plant disease, decrease insect injuries, and improve crop tolerance to environmental stress. Abro, et al. [7,35] assessed the effects of different levels of silicic acid on the germination of wheat seeds, where 7.2g of silicic acid kg^{-1} were applied to treatments and decreased considerably the germination of wheat seeds. Corn stem tissue Si concentration increased from 0.16 to 0.25 % as a result of the calcium silicate slag amendment. Increased silicon uptake was related to reduce damage to the corn stem tissue. In a similar study by Sundahri, et al. [36], the positive effects of gypsum and sodium silicate on wheat grown under waterlogged soils were observed.

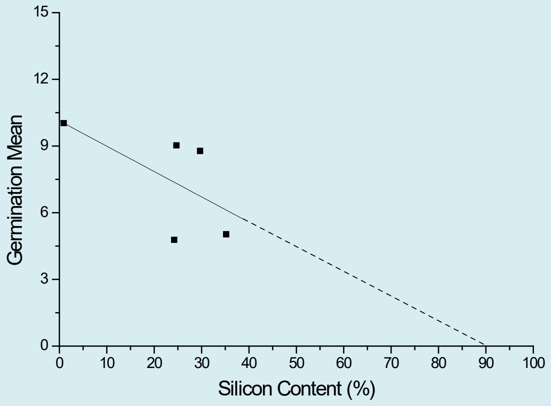

Figure 3: Relationship between germination mean versus Si weight % for the tested rice husk biochars.

In previous field trials by the authors, we observed the positive effects of rice husk biochar (RHB) on the growth rate of water spinach [37]. The results showed that the application of rice husk biochar improved biomass production, and increased plant weight by increasing the stem size and leaf length of the water spinach. Also, the stem size of the water spinach was proportional to the WHC/silt ratio, whereas the root size of the water spinach was proportional to the OM/OC ratio of the soil. We proposed that the mechanism of RHB in soil could be that the decomposition of OC in biochar-added soil to OM resulted in increased WHC and decreased silt in biochar-added soil [38]. In similar research [38-40], used municipal solid waste incineration bottom ash in combination with rice husk biochar pyrolyzed at different temperatures (400ºC and 500ºC), and concluded that the biochar pyrolyzed at 400ºC may have positive effects on the development and growth of maize (*Zea maize* L.). Nevertheless, the most promising effect is the apparent reduction in the total availability contents of heavy metals in bottom ash, suggesting that the use of binary mixtures in vegetation production is safe. These results are confirmed by the germination results, which show that Si inhibition in germination will occur at high Si content.

Conclusion

In this study rice husk biochar was shown to benefit corn growth because of its high silicon content; while it was inhibited linearly. Silicon in this study was found to be harmful significantly to corn seed germination when Si content in rice husk biochar was higher than 25 - 30 wt% indicating that increased levels of silicic acid and quantities of the amendment above 8 - 10 ton per hectare reduce the germination rate.

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