Biochar: effects on crop growth

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Abstract. Excessive tonnage of agricultural wastes from annual and field crops are generated yearly in Malaysia. The improper treatment such as open burning of residual biomass after the harvesting of rice plant can affect global warming. The processing of agricultural wastes into biochar through pyrolysis has gained tremendous interest globally. A field trial to compare effectiveness on rice growth of variety MR 263 using rice husk and paddy straw biochar was determined by application of four different rates of biochar 300 g, 600 g, 900 g and control (without biochar). Plant growth analysis based on average plant height was optimum with addition of 900 g rice husk biochar. A greenhouse trial using oil palm and rubber seedlings as indicators with application of 0, 10, 20, 30, and 40 g rice husk biochar and paddy straw biochar to the soil showed the highest plant height for treatment with 10 g biochar, ranging from 64.7 to 68.9 cm. Plant heights were slightly lower at higher levels of biochar added. From this study, application of biochar to the growth medium increased soil fertility as indicated by growth enhancement in soils enriched with rice husk biochar and paddy straw biochar.

1. Introduction
The agricultural wastes without proper treatments will create a lot of problems in future such as in open burning or slash-and-burn agriculture that is still practiced by local farmers. For field preparation, burning seem to be one of the ways to dispose of the straw left after harvest. Burning straw is considered a low-cost alternative to ploughing back the straw into soil especially as the only viable choice left for small farmers. The burning of rice straw is generally not recommended as it causes nutrient loss, air pollution and damage to human health [1, 2]. The bare soil left by burning events will be exposed to rainfall and the wind, thus, causing erosion and rapid loss of nutrients. The soil then quickly loses its fertility, especially the soil organic carbon needed for sustainable production. Therefore, biomass from agricultural wastes in the form of biochar can be used as an energy renewable source for biosustainability.

Biochar is an organic carbon rich material produced via pyrolysis of agricultural bio-waste such as wood chip or crop straw under an oxygen-limited environment [3]. Biochar is one of the three products resulting from the carbonization process other than bio-oil and syngas. Pyrolysis process convert biomass to solid (biochar), liquid (bio-oil) and gas [4]. The conversion of agriculture wastes into value added products such as biofuel and biochar has attracted tremendous interest attributed to the high energy demand and concerns over greenhouse gas emission as well as worldwide soil degradation [5]. Evidence has indicated that biochar amendment to soil is an efficient way to achieve agronomic benefits including reducing crop disease [6], improving soil fertility [7], elevating nutrient availability [8, 9], decreasing CH$_4$ emission [10], enhancing soil microbial activity [11], and remediating contaminated soils [12]. Thus, the aim of this study was to evaluate growth of annual and
perennial crops such as paddy, rubber and oil palm seedlings respectively, in application of biochar derived from biomass of agricultural wastes.

2. Materials and Methods

2.1. Preparation of raw material
Raw materials used in the production of biochar were rice husk and paddy straw. The paddy straw and rice husk used was prepared at the School of Bioprocess Engineering in Jejawi, UniMAP. The both samples were ground using grinder (Chyun Tseh Industrial Co., Taiwan). The paddy straw should be cut smoothly using a grasscutter to ease the raw materials for grinding. Both samples were sieved using an aperture sieve to obtain particle size in the range <2mm. In order to remove surface moisture, the samples were dried at 105 °C in an oven (Binder, Germany) for 24 hours. The prepared sample was used for the biochar production.

2.2. Production of biochar
Using an analytical balance, raw materials was weighed two grams from each sample. The prepared raw materials were pyrolyzed inside a furnace (Carbolite, UK) at temperature of 400 °C to 500 °C for 40 minutes with reaction rate at 10 °C min⁻¹.

2.3. Analysis of biochar
Biochar sample was determined for physical and chemical properties with different methods and techniques as follows:

2.3.1. Determination of pH. Biochar was added to the distilled water with ratio of 1: 20 to measure the pH of biochar. 100 ml water in the conical flask was added with 10 g of biochar. The mixture was shaken and left for five minutes before evaluating the value of pH using pH meter.

2.3.2. Fourier transform infrared spectroscopy (FTIR). Fourier Transform Infrared Spectroscopy (FTIR) was used to determined chemical composition and functional groups of biochar samples. A small amount of ground biochar sample was mixed with KBr to form a disk for analysis of functional groups. FTIR also can be used to confirm the identity of a pure compound in biochar and to detect the presence of carbon nitrogen.

2.3.3. Scanning electron microscopy analysis (SEM). This technique of analysis uses a focused beam of high energy electrons to generate a variety of signal at a surface of solid specimens. The sample of biochar was coated with thin layer of carbon before inserting into the SEM chamber. The interaction between the electrons in the sample will give a signal that will identify properties of the sample such as texture, chemical composition and crystal structure and orientation of the materials that make up the biochar.

2.4. Experiment design
There were two designs of application of biochar such as field trial of rice variety MR263 and pot trial of palm oil and rubber seedlings. Both were applied with the same types of biochar, rice husk biochar and paddy straw biochar.

2.4.1. Field experiment. Land preparation were started after a week field was harvested. There are activities involving clearing of field, building and repairing the irrigation or trench, poisoning of repetition weeds, and land rotation. The duration for land preparation took almost 50 days before the day of transplanting of seedlings. These activities were important as good preparation give positive effects on crop growth.
This experiment was in factorial format based on randomized complete block design with four replications on a paddy field in Institute of Sustainable Agrotechnology (INSAT), Sg.Chuchuh, Universiti Malaysia Perlis (UNIMAP). The factors of experiment included four treatments of biochar application, 0 g (control) (T1), 300 g (T2), 600 g (T3), and 900 g (T4). There were two plots of field trial, Plot 1 (rice husk biochar) and Plot 2 (paddy straw biochar) which had the same size (23 m x 14 m). The area of each individual treatment plot was (5.5 m x 3.3 m).

2.4.2. Greenhouse experiment. This study was conducted in greenhouse located at INSAT Sg. Chuchuh, UNIMAP. Oil palm seedlings and rubber seedlings were purchased from AEON Nursery located in Changlun, Perlis. The clone of rubber seedlings that were used in this experiment is PB 350, while the clone of palm oil seedlings is Yang Gambi. Throughout the experiment, temperature conditions in greenhouse were maintained between 32 to 34 °C during the day.

For this study, the soils collected from in the area of agriculture site in INSAT Sg. Chuchuh. The amount of soil that was used for oil palm planting is 15 kg per polybag, while for rubber seedling 8 kg of soil was used for each pot. After planting rubber seedlings and oil palm seedling, rice husk biochar and paddy straw biochar were applied respectively, to the soil. Root zone for rubber seedlings was 15 cm while the root zone for oil palm seedlings was 20 cm. Biochar applied for the treatment ranged from 0 g(control), 10 g, 20 g, 30 g, and 40g for both oil palm and rubber seedlings.

In this experiment, twelve pots of oil palm seedlings and twelve pots of rubber seedlings were planted in pots with addition of different amounts of 0 g(control), 10 g, 20 g, 30 g and 40 g of rice husk biochar and rice straw biochar respectively. The experimental design was randomized block design with three replications. Three pot of oil palm seedlings and three pot of rubber seedlings were conducted in controlled environment in glasshouse.

2.5. Growth analysis

2.5.1. Rice variety of MR263. Plant height was measured at 30 days after transplanting (DAT). The plant was cut aboveground at 20day intervals from 30 days DAT up to 90 DAT. The growth analysis was determined on ten random samples per individual treatment plot. Harvesting was done by hand at 110 DAT. The data was analyzed using t-test statistical analysis (Excel).

2.5.2. Palm oil and rubber seedlings. The growth development of both oil palm seedlings and rubber seedling was observed daily. Growth of oil palm and rubber plant was measured and recorded. The data was analyzed using the t-test statistical analysis (Excel).

3. Result and Discussions

3.1. pH value of biochar with different amount of rice husk and paddy straw

![Figure 1. pH Value of biochar with different amount of rice husk and paddy straw.](image-url)
The effect of pH on different amount of rice husk and paddy straw biochar (figure 1) showed that pH increased when the higher amount of rice husk and paddy straw biochar was used. The effect of biochar especially in acidic soil like Malaysia with low pH will enhance nutrient uptake without liming. The biochar can increase pH ranging from 4 to 12 [3]. Thus, this explains the variability in pH of the biochar as observed from this study.

The alkalinity is inherited by biochar through the pyrolytic process which also converts biomass acids into the bio-oil component during the process [13, 14]. Biochar contains alkaline components such as organic anions and inorganic carbonates [15]. This effect explained the result of increasing pH value obtained with increasing amount of biochar application. Thus, higher amount of organic matter increases the anions and inorganic carbonates content in biochar. Furthermore, with increasing biochar application rates could increase the ameliorating effects of biochar on soil pH [16]. The altered soil generally became less acidic when biochar with a higher pH value was applied to the soil [15]. This will lead to the fertility of the soil and the availability of nutrients in the soil.

3.2. Fourier transform infrared spectroscopy (FTIR)

The Fourier Transform Infrared Spectroscopy (FTIR) is one of the most important methods in identifying the chemical structure and the characteristics functional groups of biochar. Rice husk and paddy straw mainly composed of organic compound such as lignin, cellulose and hemicelluloses with different oxygen-containing functional groups. From the spectra, the OH (3600–3100 cm\(^{-1}\)) and C=O stretching (1750–1625 cm\(^{-1}\)) shows presence of hemicelluloses [17]. Moreover, the FTIR reading showed the presence of aromatic rings (1600–1580 cm\(^{-1}\)) which indicates the presence of lignin [18]. The peaks ranging between 750 to 900 cm\(^{-1}\) indicates the presence of silicates in rice husk biochar(792.86) and rice straw biochar(802.12) (table 1). Silica is one of the most important organic compounds essential to crop growth.

| Wave Numbers (cm\(^{-1}\)) | Functional Groups                      |
|----------------------------|----------------------------------------|
| **Rice Husk Biochar**      |                                        |
| 3391.48                    | Stretching of carboxylic acid O-H      |
| 2966.70                    | Stretching of alkanes asymmetric & symmetric H-C-H |
| 2922.00                    | Stretching of alkanes C-H             |
| 1604.02                    | Stretching of amides C=O              |
| 1427.20                    | Stretching of alkyl halides C-F       |
| 1098.62                    | Stretching of ester or eters C-O      |
| 792.86                     | 2 adjacent H deformation               |
| **Paddy Straw Biochar**    |                                        |
| 3411.96                    | Phenols & alcohols O-H or Si-OH       |
| 2960.80                    | Stretching of alkanes asymmetric & symmetric H-C-H |
| 2923.46                    | Stretching of alkanes C-H             |
| 1610.40                    | N-H bend of amides primary            |
| 1436.85                    | Stretching of alkyl halides C-F       |
| 1320.00                    | Nitro groups N=O bend                 |
| 802.12                     | 2 adjacent H deformation               |
3.3. Scanning electron microscopy (SEM)
SEM images as in figure 2 showed that the sample of rice straw biochar has a lot of macropores than rice husk. In rice straw, the widening pores and particle geometry could be observed compared to rice husk. This has occurred during pyrolysis process due to the immediate release of volatiles from inside of the particles. Furthermore, the structure of rice husk is more compacted compared to paddy straw biochar due to their nature.

The SEM images also showed that the rice husk and paddy straw raw samples have almost identical appearance, as we could see a smooth surface with some distributed pores on the images. This is because during the pyrolysis process, the volatile compounds released have created pores in the pyrolysis product. Nevertheless, each sample exhibit qualitatively different char morphologies after the heating and decomposition process. The presence of macropores structure in the char which is essential because it has a higher potential to water adsorption and water holding capacity [19].

![Figure 2. SEM image of paddy straw (a), rice husk (b), paddy straw biochar (c), and rice husk biochar (d).](image)

3.4. Growth analysis
The average height of paddy from Plot 1 (figure 3 (a)) had tallest plants within the individual treatment plot that treated with 900 g (T4) of rice husk biochar (RHB) on 90 DAT. The large amount of biochar had effect on height of the paddy throughout the growth from 70 DAT with average mean 71.17 cm. The application of rice husk biochar affects the growth of paddy to increase linearly from 50 DAT until 90 DAT. The Plot 2 (Figure 3 (b)) shows maximum increased of average height at 70 DAT. The highest plant was treated with 600 g of paddy straw biochar (PSB), 79.20 cm while individual treatment plot with 900 g of PSB give out slightly less which was 78.59 cm. This shows the increased of application of PSB had increased the height of paddy plant in Plot 2.
However, the average height of paddy from Plot 2 (PSB) shorter compared to Plot 1 (RHB). This was due to the uncontrollable disruption of pest such as rodents or birds. There was also presence of senescence of paddy leaves within Plot 2. Furthermore, as compared to the control plots, there was no significant effect with individual treatment plot that treated with RHB or PSB. There was a high probability of biochar from treatment plot had flowed into control plot. This occurrence has happened because of technical faulty during growth season.

Figure 3(c) shows the average height for different treatments of biochar on oil palm seedlings. Generally, the rate of growth in terms of heights increased for all treatments while the controlled treatment recorded the lowest rate of crop height ranging from 58.83 to 60.00 cm. There was only a slight increase in growth of oil palm seedling for the control. The highest height rate was recorded in treatment with 10 g biochar, resulting the heights between ranges of 64.73–68.90 cm, followed by 20 g of biochar (55.53–59.30 cm), treatment with 40 g of biochar (54.43–57.97 cm) and by treatment with 30 g of biochar (49.93–52.77 cm). The highest increase rate of oil palm height for the treatment with biochar was recorded between weeks 3 to weeks 4.

The slow increase rate between Week 1 to Week 3 due to the increase in pH and nutrient imbalances associated with fresh biochar [20]. From this study, biochar enhanced growth of oil palm seedlings and the highest growth was observed with the application of only 10 g of biochar. Therefore, only a small amount of biochar application enhanced the growth of oil palm seedlings. Figure3 (d) showed the average height for different treatment of biochar on rubber seedlings. Overall, the rate of crop heights increased for all treatments while the controlled treatment recorded the lowest rate of crop height with ranging between 51.70–52.80. It was observed that the average height of controlled
had fluctuation measurement between Week 3 to Week 4. This was caused by nutrient deficiency in the soil.

The highest height was recorded in treatment with 10 g biochar, resulting the heights between ranges of 49.30–51.10 cm, followed by treatment with 20 g of biochar (53.53–55.07 cm), treatment with 30 g of biochar (48.33–49.70 cm) and treatment with 40 g of biochar (54.37–55.67 cm). The treatment with 40 g biochar has the lowest average height rate among all of the treatment with biochar. The large amount of treatment which increases the pH value was led to high alkalinity in the soil. When the alkalinity is high, nutrient deficiency also occurred and affects the growth rate and development of the rubber seedling. The best treatment for rubber seedling was the treatment with 10 g of biochar.

The increased rate of application of biochar to the soil with oil palm and rubber seedlings reduced the nutrient uptake due to higher pH of the soil which reduced the nutrient availability to the crop growth. Therefore, waste after harvesting of rice could be utilized as added nutrient sources especially organic matter which is required for plant growth and yield. Utilization of paddy waste will reduce environmental pollution, global warming and enhanced fertility of soil. This study is a green technology utilizing waste and converting to wealth. It will also reduce environmental pollution and reduced the dependency of using chemical fertilizer. It is also cost effective.

4. Conclusion
Small addition of biochar to the oil palm and rubber seedlings enhanced the growth of the perennial crops. A tree crop will take between 4–5 years before it comes into production. The effect of biochar on the growth of the oil palm and rubber seedlings could help in enhancing growth during replanting in the field. The organic matter helps in added nutrients availability and increased pH of soil and reduced waste and environmental pollution. However, the annual crop which is paddy needed the higher amounts of biochar to enhanced growth. This may due to different soil conditions between annual and perennial crops that determined the significant played an important role of biochar application as a soil amendment.

Acknowledgement
We wish to acknowledge Ministry of Education (MOE), Malaysia for Long Term Research Grant Scheme– LRG5 (Food Security)– Enhancing sustainable rice production (9012 00004) for funding this research project and Universiti Malaysia Perlis for technical support.

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