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Effect of wood vinegar and rice husk biochar on soil properties and growth performances of immature kenaf (*Hibiscus cannabinus*) planted on BRIS soil

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Abstract

Beach ridges interspersed with swales (BRIS) soil is identified as one of Malaysia's problematic soil since this type of soil contains a plethora portion of sand texture that contributes to water and nutrient leaching causes infertile soil. A polybag trial was conducted to evaluate the effects of wood vinegar and rice husk biochar on soil properties and growth performances of immature kenaf. The plant was arranged in a completely randomised design with four treatments and three replications. The factors taken for the experiment were four different media compositions, i.e., T1(control), T2(BRIS soil amended with wood vinegar, WV), T3(BRIS soil amended with rice husk biochar, RHB) and T4(BRIS soil amended with wood vinegar and rice husk biochar, WV+RHB). Rice husk biochar and a combination of wood vinegar with rice husk biochar significantly improved soil properties in terms of soil moisture content, organic matter, water retention and soil porosity, as well as significantly increased the kenaf stem diameter. However, there was no significant difference in plant height, number of leaves, leaves area and chlorophyll content on different treatments medium. In conclusion, the application of rice husk biochar and wood vinegar in this study enhanced BRIS soil properties and showed a positive effect on the growth of immature kenaf.

1. INTRODUCTION

Beach ridges interspersed with swales soil or commonly known as BRIS soil, is one of the problematic soils group in Malaysia. BRIS soil covers about 150,000 hectares of Malaysian soil and mainly available in the east coastal area of Kelantan, Terengganu and Pahang (Roslan et al., 2011). Early scientific investigation on BRIS soil has begun around the year the 1980s (Nafis, 1984; Wells, 1986; Othman & Carlisle, 1987). This free-draining soil causes water and minerals to lost by leaching resulting in low fertility level. BRIS soil has a high percentage of sand and thus obstructs the growth of the plant. Most of the crops planted on BRIS soils do not perform well due to the high surface temperature, high infiltration rate, low water retention, low organic content and low nutrients retention (Hanafi et al., 2010; Hanafi et al. 2020). As noted by Wells (1986), tobacco is the only viable and profitable crop cultivated over the years on BRIS soils in Malaysia.

For water saving of irrigation on BRIS soil, a drip irrigation system is suggested by Baker et al. (2002), where this system can save about 40% water as compared to a sprinkler irrigation system. Typically, BRIS soil has acidic soil property less than pH five, as analysed by Toriman et al. (2009). Although BRIS soil properties have many drawbacks, the research on BRIS soil fertility status in Malaysia on chilli and tomato (Zaharah et al. 1992), acacia (Shariff et al. 1993; Shariff & Kadir 1994), vegetable crops (Jahan et al. 2014), paddy (Lah et al. 2011), kenaf (Abdul-Hamid et al. 2009; Hossain et al. 2011; Malisa et al. 2011; Yusoff et al. 2011; Basri et al. 2016; Halimatul et al. 2017), pineapple (Arshad et al. 2011; Arshad & Armanto 2012), sweet potato (Ishaq et al. 2014b), corn (Ishaq et al. 2014a; Arshad et al. 2015b), okra (Khandaker et al. 2017), watermelon (Tahir et al. 2018), roselle (Arshad et al. 2015a; Norhayati et al. 2019; Zakaria et al. 2019), and fig (Azmi et al., 2020) has been conducted since it has vast potential for agriculture and forestry use. Interestingly, it has many beneficial bacteria (Mustapha et al., 2017) for instance, entomopathogenic fungi (Elham et al., 2018) are reported in BRIS soil, thus improving soil fertility and plant growth. The National Kenaf and Tobacco Board (LKTN) of Malaysia had identified kenaf as one of the vital commodities for Malaysia to replace tobacco crop. Kenaf (*Hibiscus cannabinus*) is planted on BRIS soil in Malaysia since it has high commercial value and high adaptability to a wide range of soil fertility. Kenaf is cultivated mainly for fibre production, which can be used for composite materials, paper and furniture. Not only for fibre, but researchers also focus on forage (Zulkifli et al., 2014; Ammar et al., 2020), edible oil from seed (Cheng et al., 2016; Hue & Nyam, 2018) and bioenergy production (Saba et al., 2015) as alternative usage of kenaf. Kenaf is classified as immature when harvested between 30-42 days after planting for forage production. During this harvesting period, kenaf leave has optimum crude protein between 15 and 30%, where high-quality forage can be produced (Daud et al., 2014). Delaying harvesting time exceeding 50 days after planting will reduce the quality of the forage produced (Ammar et al., 2020).

There are a massive number of agricultural wastes produced every year, which lead to environmental problems. Asia contributes a hundred million tons of rice husks every year. It is considered a waste residue that farmers disposed of and burned. Residue burning is widely practised and causes air pollution and human health problems (Haefele et al., 2009). Rice husk can be converted into biochar by pyrolysis and applied as a soil amendment. Pyrolysis is a process of producing biochar from plant biomass due to thermochemical breakdown with optimum temperature between 350 ºC and 500 ºC under anaerobic conditions or limited supply of oxygen (Grewal et al., 2018). Slow pyrolysis of biomass is exposed to approximately 300 ºC temperature and produced proportion of charcoal, liquid and gas around 35%, 30 % and 35 %, respectively (Bridgwater 2004). In contrast, fast pyrolysis of biomass using around 500 ºC temperature and produced proportion of charcoal, liquid and gas around 20%, 65% and 15%, respectively (Mohan et al., 2006).

Wood vinegar, also known as pyroligneous acid, is a by-product produced from the condensation of smoke during charcoal and biochar production (Mathew & Zakaria 2015; Grewal et al. 2018). The collected liquid further will be fermented and later gone through the separation process. Generally, the charcoal factory released the smoke into the air and could contribute to air pollution. Wood vinegar has recently been widely applied to several applications such as medicine, smoky scent, food aggregation, pharmaceutical products (Theapparat et al. 2015), fight against plant diseases and pesticides (Rahmat et al., 2014; Theapparat et al. 2018), boosting plant growth, improving fruit quality, speeding up plant seed germination and serve as herbicides. Plant growth is directly dependent on soil properties and soil fertility. Li and Wang (2014) claimed that the application of diluted wood vinegar more than 50 times helped promote plant growth and yield. Previous researches focus on the improvement of morphological characteristics to exploit more potential of kenaf fibre (Hadi et al., 2014). However, scarce literature reported the suitability of planting medium to enhance the kenaf production, especially on BRIS soil, one of the problematic soil types in Malaysia. The land of BRIS soil requires the application of soil amendment to maximise the production of kenaf. Therefore, the present study attempts to investigate the effect of wood vinegar and rice husk biochar on selected soil properties and kenaf growth response planted on BRIS soil, specifically at the immature stage.

2. MATERIALS AND METHODS

2.1. Experimental site

The study was conducted at Plant Nursery Centre, Universiti Malaysia Kelantan, Jeli Campus, Malaysia. The research site is located at 5°44'44.5" N and 101°51'57.2" E with an elevation of 55 m above mean sea level (Figure 1). This experiment was carried out from August to September 2016 under a black netting shelter with 50% light penetration to prevent direct sunlight and heavy rainfall. The selected site was cleaned by removing the weeds surrounding it. The floor covered with a layer of black plastic silver shine to prevent weed growth. The average maximum and minimum temperature during the planting period were 33 ºC and 24 ºC, respectively. Average rainfall during the kenaf plantation was 257 mm, and the average daily relative humidity was around 81%.

2.2. Planting medium preparation

BRIS soil samples were taken from the Malaysian Agricultural Research and Development Institute (MARDI) located at Bachok, Kelantan. Rice husk biochar and kenaf seed (cultivar v36) were obtained from Universiti Putra Malaysia (UPM) and National Kenaf and Tobacco Board, respectively. The wood vinegar was gained from the Papan Bumi company located in Jeli, Kelantan. BRIS soil and rice husk biochar were first ground with mortar and pestle. Later, it was sieved through 2 mm sieve size manually to obtain the uniform size of biochar and soil composition. Rice husk biochar was applied at 150 g kg^{-1} soil, as suggested by Carter et al. (2013). Wood vinegar was diluted in water by the ratio of 1: 100 based on producer recommendation. Wood vinegar solution was applied at a rate of 6 litres of solution for 1 m^2 of land to enrich the soil before planting crops (Burnette, 2010). The mixture was incorporated with soil 15 days before filling into the polybag sized 230 mm x 85 mm to

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allow carbon monoxide releasing from the prepared soil media (Sadakichi et al., 2015). Watering was done in the morning and evening daily as commonly practised by farmers. Twelve mm of water per day was required for germination of seed and early plant establishment. The volume of irrigation per day was calculated as advocated by Hadi et al. (2014).

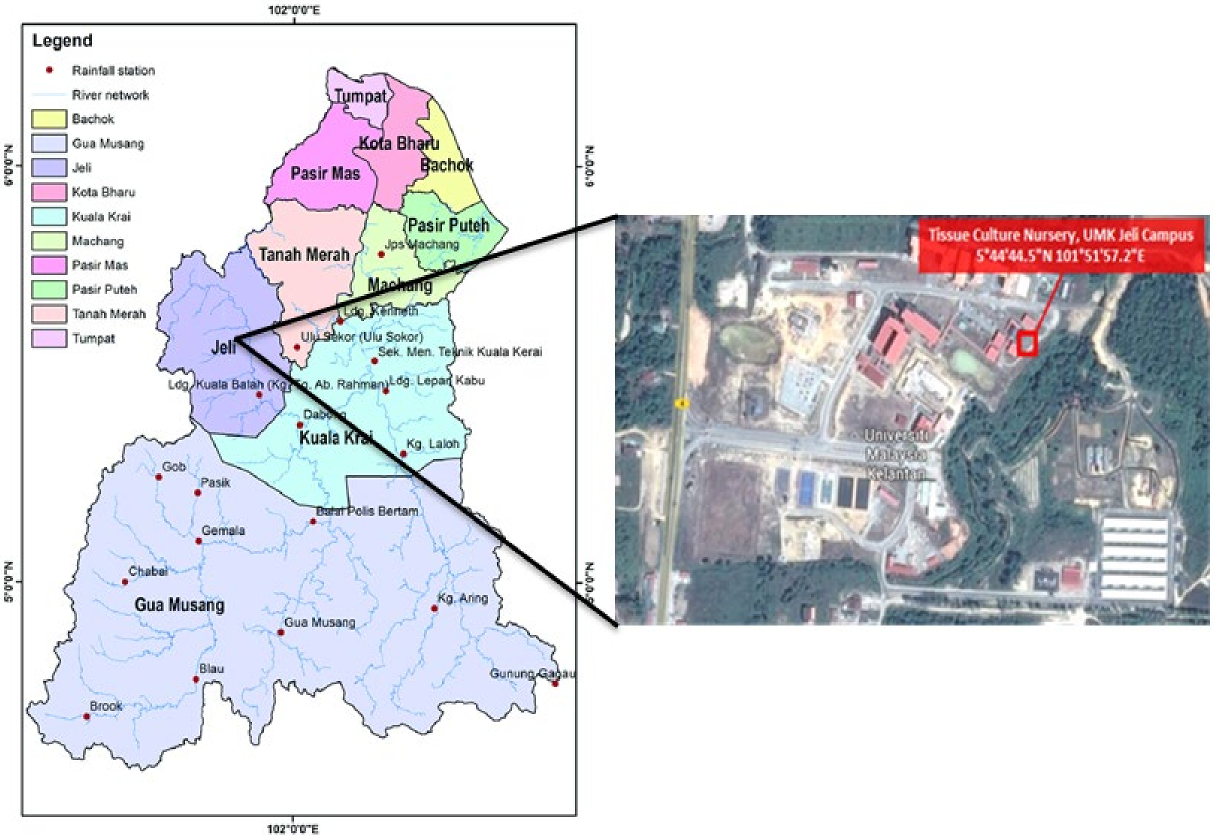

Figure 1: Location of the experimental site at Universiti Malaysia Kelantan, Jeli Campus, Malaysia.

2.3. Soil properties and plant growth determination

Soil properties measured were soil pH by using soil pH meter (Hanna HI99121, USA), moisture content using a gravimetric method (Susha et al., 2014), organic matter content, water retention capacity and soil porosity (Thien & Graveel, 2002). The soil samples were taken to the laboratory for further analysis at the beginning and the end of the research. This study involved a cultivation period of 5 weeks (35 days).

Growth parameters were observed during the planting period of kenaf, which was plant height, stem diameter, number of leaves, leaf area and chlorophyll content (Konica Minolta SPAD-502 Plus, Japan). The growth parameters were measured and recorded weekly. Root length and plant biomass was determined at the end of the experiment. The root was carefully separated and clean from the growing media using tap water. The fresh weight of kenaf was weighed and recorded. Stem, root and leaves were separated and oven-dried at 70±5 ºC for 48 hours. Biomass was recorded as plant components that achieved constant weight, as described in Hossain et al. (2010).

2.4. Experimental design

The experiment was laid out in a completely randomised design with four treatments and three replications, resulting in 12 polybags in this study. The treatments of planting media in this study were denoted as T1 (BRIS soil without amendment) which served as control, T2 (BRIS soil amended with wood vinegar, WV), T3 (BRIS soil amended with rice husk biochar, RHB) and T4 (BRIS soil amended with wood vinegar and rice husk biochar, WV+RHB). Kenaf seeds were grown in sowing trays filled with peat moss and transplanted to the polybags after three days. Only germinated seeds were selected to prevent the use of dormant and unhealthy seed. Seedlings selected for transplant were in almost similar height (8.00±0.5 cm).

The polybags were arranged at 7 cm between the plant and 12 cm between the rows.

2.5. Statistical analysis

The data collected was analysed using IBM SPSS Statistic V21 software of one-way ANOVA for significant different at 95% confidence level. If significant differences detected, Fisher's Least Significant Difference (LSD) posthoc test was executed to compare the mean between treatments. The graphs presented in this study were constructed by using Microsoft Excel. All data were expressed as mean ± standard error.

3. RESULT AND DISCUSSION

3.1 Effect of wood vinegar and rice husk biochar on selected soil properties

Figure 2 illustrates the effect of different soil amendments of BRIS soil on soil pH, moisture content, organic matter, water retention and porosity. At the end of the experiment, a significant difference ($p < 0.05$) was detected in soil pH between the four treatment groups (Figure 2a). Post hoc test analysis showed that there are significant differences in the soil pH between WV (T2), RHB (T3) and WV+RHB (T4) treatment compared to control. In general, BRIS soil from all treatments became slightly acidic at the end of the experiment with pH reduction in the range of 9 to 11%. Contradictory results have been noticed in literature, where some studies reported a significant increase (Zhang et al. 2019; Chintala et al. 2014) and others noted no significant increment in soil pH with biochar application (Liu et al. 2012; Li et al. 2020). The range of changes in pH and acidity depends on soil type, soil texture, fertiliser management and type of biochar used (Juriga & Šimanský, 2019). The application of biochar plays both roles, which can decrease and increase soil pH.

The pH reduction was expected due to leaching and plant root activity. As mentioned by McCauley et al. (2009), irrigation activity increased leaching of the base cation. Plants often take up nutrients in the form of cations than anions. The root will release hydrogen ion and replace cation absorbed to maintain a neutral charge around the root zone (Brady & Weil, 2002). As a result, soil pH was slightly reduced at the end of kenaf cultivations. As postulated by Rondon et al. (2007), soil pH was decreased by about 0.5, with the addition of vinegar. However, for an extended period of biochar application, for instance, 6 to 12 weeks (Chan et al., 2007; Milla et al., 2013), biochar could increase soil pH. Excess use or unfollow the proposed dosage of wood vinegar by the producer may reduce the performance of crop planted since most of the plant grows better between pH of 5.5 and 7.0 (Brejda et al., 2000). The soil moisture content from each treatment at the beginning and the end of the experiment were shown in Figure 2b. There were significant differences between treatments on initial and final soil moisture content. RHB treatment and WV+RHB treatment were significantly higher than control and WV treatment at the beginning and the end of the experiment. Soil moisture content in soil treated with rice husk biochar was recorded more than 22% compared to the control at the end of the experiment. Abukari (2014) proved that rice husk biochar was able to enhance soil moisture content. However, there was no significant difference in soil moisture between control and wood vinegar treated soil itself. From this finding, wood vinegar should be used with rice rusk biochar to improve soil properties in term of soil moisture capacity. Diluted wood vinegar moistens the soil and slightly increased soil moisture content.

In Figure 2c, RHB and WV+RHB treatment had significantly higher soil organic matter content at the beginning and the end of the experiment. Untreated soil (control) and soil treated with wood vinegar only have the most negligible organic matter content might contribute to low microbial activity in both treatments. Wood vinegar stimulated microbial activity (Steiner et al., 2007; Burnette, 2010), where microbes consume and decompose soil organic matter as food sources. Lehmann et al. (2003) and Rondon et al. (2007) indicated that rice husk biochar is a carbon organic source and soil amended by rice husk biochar showed a higher level of soil organic matter. From this finding, the addition of rice huck biochar on BRIS soil increased 6% of organic matter higher than the control as shown in RHB and WV+RHB treated soil.

Figure 2d shows a significant difference ($p < 0.05$) between treatments on initial and final water retention capacity. Water retention capacity of RHB and WV+RHB treatment were significantly higher than control and WV treatment. As highlighted by Steiner et al. (2007) and Chan et al. (2007), incorporating biochar in the soil can improve the water holding capacity of growing media. The high surface area of biochar helped increase water retention capacity (Glaser et al., 2002). The increase in soil organic matter content in RHB and WV+RHB treated soil also contributed to higher water retention capacity. The use of WV together with RHB could stabilise and prevent the drastic reduction of the water holding capacity of BRIS soil. As reported by Persaud et al. (2018) and Abukari (2019), RHB substantially improved the water holding capacity of sandy soil and become an effective method to increase water use efficiency for agriculture purpose.

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There was a significant difference ($p < 0.05$) in soil porosity before and after treatment (Figure 2e). Application of rice husk biochar increased soil porosity considerably in the study, as shown in treatment 3 and 4. The addition of organic amendment on BRIS soil increased organic matter content and lower the bulk density. Consequently, soil porosity has improved in RHB and WV+RHB treatment, providing better soil aeration for root development. The application of rice husk biochar on BRIS soil reduced around 35% to 38% of soil bulk density than the untreated soil. The result was parallel to the findings of Ghorbani et al. (2019), Carter et al. (2013) and Jien and Wang (2013), where biochar application can decrease soil bulk density and hence reduce soil compaction. However, we found a higher reduction of bulk density in sandy soil due to biochar amendments compared to Razzaghi et al. (2020), where they claimed that biochar could reduce around 9% bulk density regardless of soil texture class.

3.2 Effect of wood vinegar and rice husk biochar on growth performances of immature kenaf

Plant growth parameters of immature kenaf were tabulated in Table 1. From the finding, the application of rice husk biochar together with wood vinegar significantly increase the stem diameter of kenaf. Conversely, no significant difference ($p > 0.05$) was detected for plant height, the number of leaves, leaf area and chlorophyll content. Although the mentioned plant growth parameters have no significant difference against different treatments, they showed better growth performance compared to the control treatment. The soil fertility level of BRIS soil amended with rice husk biochar and wood vinegar has increased and shown better growth performance of kenaf. One reason is that amended BRIS has a better cation exchange capacity (Ghorbani et al. 2019) than the BRIS soil without biochar amendments. In this study, amendment of BRIS soil with rice husk biochar increased plant height, the number of leaves, leaf area and chlorophyll content by 32.10%, 12.18%, 14.84% and 12.95%, respectively.

No significant differences ($p > 0.05$) on the root length of kenaf were observed among treatments, as depicted in Figure 3. However, statistical analysis showed that there was a significant difference ($p < 0.05$) between treatments on stem biomass of WV treatment, RHB treatment and WV+RHB treatment as compared to control (Figure 4). Stem biomass in this study was found higher than leaves and root, as observed by Hossain et al. (2011). The application of diluted wood vinegar more than 50 times helped to promote plant growth and yield (Li & Wang, 2014). The root biomass obtained was around the same amount compared to WV, RHB, and WV+RHB treatments, although the mean root length of WV treatment was approximately 3.5 to 4.0 cm shorter than control. The comparison with other findings showed that the application of wood vinegar had no effects on shoot length, plant height, leaf area, and biomass on the common beans plant (Rondon et al., 2007).

Different effects of wood vinegar on plant growth could be observed from reported finding since the effectiveness of wood vinegar in terms of its properties is positively affected by the refining process, pyrolysis mechanism, and chemical composition of biomass (Theapparat et al. 2018). Application of biochar alone on BRIS soil might not have resulted in the best growth performance of kenaf. However, biochar must be combined with NPK fertiliser and zeolite to obtain the highest plant growth performance (Basri et al., 2013; Shi et al., 2019). Incorporation of biochar derived from burn rice husk into soil media improved available nutrient since rice husk biochar contain a high nutrient concentration of P, Na, Ca, and Mg (Cho et al., 2017). Besides that, the application of biochar provides a suitable microhabitat for mycorrhizal fungi (Huang & Gu, 2019). These two possible reasons increased soil fertility and thus promoting plant growth. The effect of biochar is more evident on a more extended planting period, as suggested by Carter et al. (2013).

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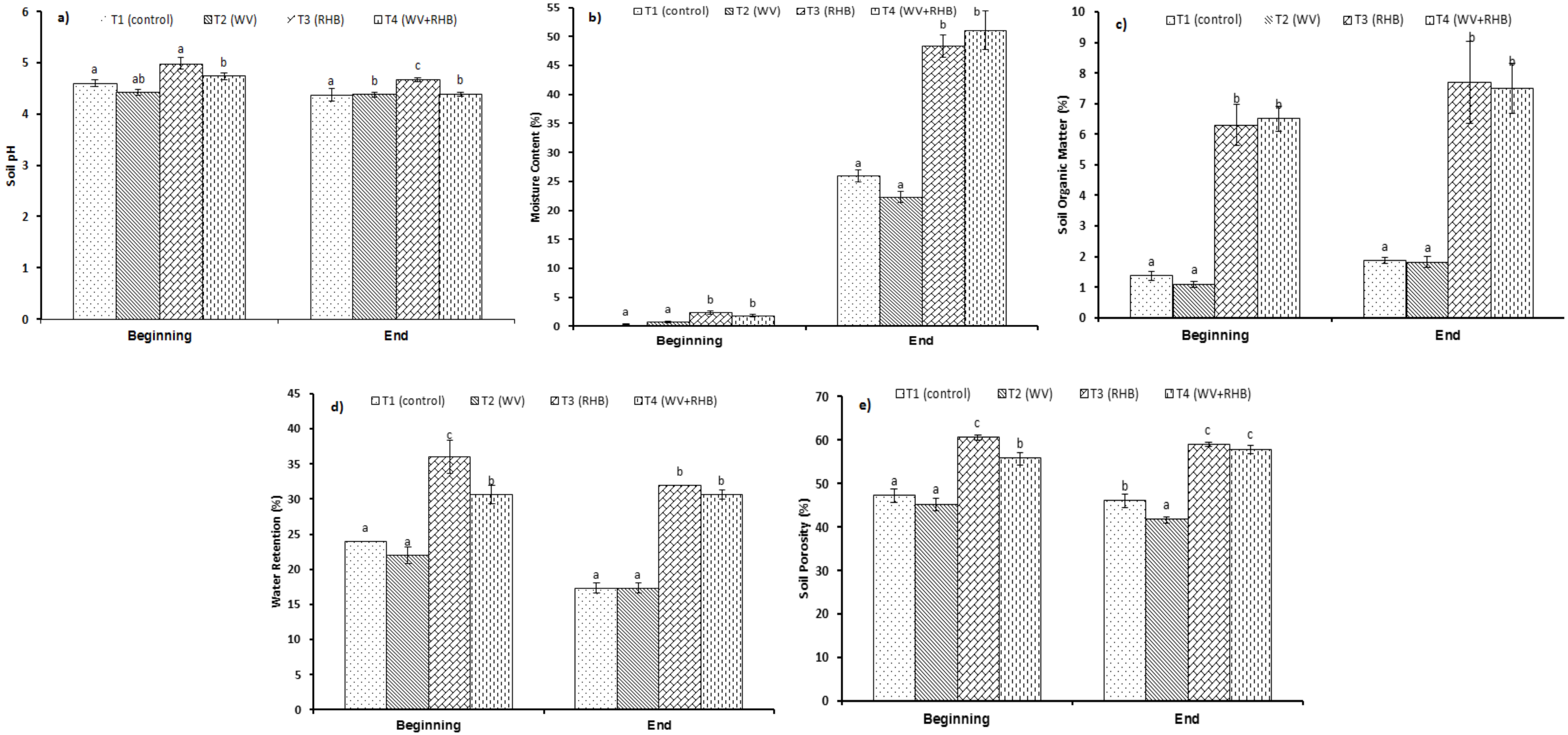

Figure 2: The effect of treatments on a) soil pH, b) soil moisture content, c) soil organic matter, d) soil water retention, and e) soil porosity at the beginning and the end of the experiment. Means followed by the same letters above the vertical bar were not significantly different ($p > 0.05$). Error bars represent the standard error of the mean ($n = 3$).

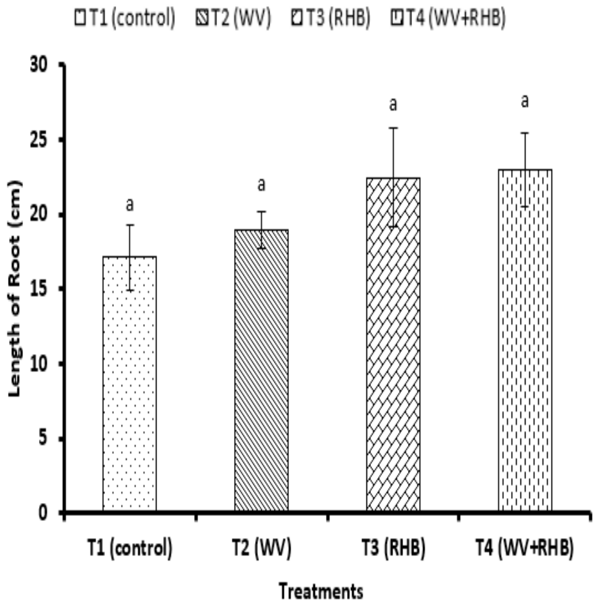

Figure 3: Mean of root length after harvesting. Means followed by the same letters above the vertical bar were not significantly different (p > 0.05). Error bars represent the standard error of the mean (n = 3).

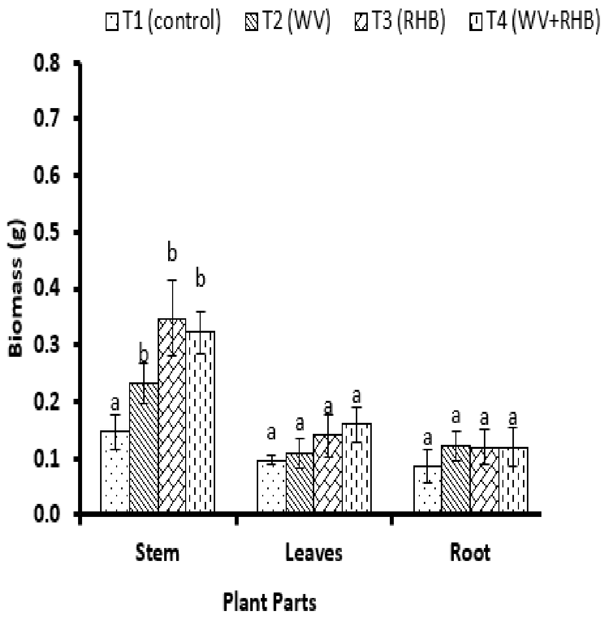

Figure 4: Mean of plant parts biomass after harvesting. Means followed by the same letters above the vertical bar were not significantly different (p > 0.05). Error bars represent the standard error of the mean (n = 3).

Table 1: Plant growth parameters on different treatments medium.

Parameter	Treatment (Mean ± Standard Error)				Sig. Level	Highest Percentage of Increment (Compared to T1)
	T1	T2	T3	T4		
Plant Height (cm)	19.16±9.26[a]	21.79±10.89[a]	25.31±13.86[a]	21.79±12.16[a]	NS	32.10% (T3 Vs T1)
Stem Diameter(cm)	0.22±0.05[a]	0.23±0.05[ab]	0.26±0.05[b]	0.27±0.07[b]	*	22.73% (T4 Vs T1)
Number of Leaves	5.50±2.14[a]	5.33±2.06[a]	6.17±2.66[a]	5.72±2.35[a]	NS	12.18% (T3 Vs T1)
Leaf Area (cm^2)	8.96±2.97[a]	9.51±3.99[a]	10.29±4.44[a]	9.83±5.16[a]	NS	14.84% (T3 Vs T1)
Chlorophyll Content	28.18±7.85[a]	30.62±8.36[a]	31.83±6.90[a]	30.16±6.45[a]	NS	12.95% (T3 Vs T1)

Notes where T1, kenaf with BRIS soil only (control); T2, kenaf and the media treated with wood vinegar; T3, kenaf and the media treated with rice husk biochar; T4, kenaf and the media treated with rice husk biochar and wood vinegar. Mean values within a row with the different superscript show significant different ($p < 0.05$). Sig., significance; NS, not significant ($p>0.05$); *, $p<0.05$.

4. CONCLUSION

An investigation of the effect of wood vinegar and rice husk biochar on immature kenaf growth and selected soil properties of BRIS soil has been explored. The amendment of BRIS soil is a must since this type of soil is classified as one of the problematic soils in Malaysia, which required special modification for agricultural land use. In a nutshell, the combination of wood vinegar with rice husk biochar improved soil moisture content, organic matter content, water retention capacity and soil porosity of BRIS soil. Rice husk biochar treatments and combination treatment between rice husk biochar and wood vinegar improved stem diameter, stem biomass, and growth performance of immature kenaf. The utilisation of wood vinegar and biochar in agriculture practice in Malaysia optimised agriculture waste towards sustainable agricultural practices. The usage of BRIS soil for agriculture purpose could be fully utilised to generate national income. For further research, it is suggested to study the effect of different wood vinegar and biochar sources from Malaysian agriculture waste such as corn and vegetables on the soil properties and crop performance, especially in container substrates.

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