International Journal of Agricultural Technology 2023 Vol. 19(3):983-996
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Effect of pineapple leaf biochar and chemical fertilizer incorporation on the agronomic and nutritional contents of MD2 pineapple on alluvial soil

Jos, S.[1,2,3], Mohidin, H.[2,3*], Ahmed, O. H.[4], Kassim, N. Q. B.[2], Hasni, R.[3] and Jack, R.[5]

[1]Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Jasin, 77300 Merlimau, Melaka, Malaysia; [2]Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia; [3]Natural Product Research Development Centre, Universiti Teknologi MARA Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia; [4]Faculty of Agriculture, Universiti Islam Sultan Sharif Ali, Sinaut Campus, Brunei; [5]Soil Management Division, Department of Agriculture, Sarawak, Jalan Badaruddin, 93050 Kuching, Sarawak, Malaysia.

Jos, S., Mohidin, H., Ahmed, O. H., Kassim, N. Q. B., Hasni, R. and Jack, R. (2023). Effect of pineapple leaf biochar and chemical fertilizer incorporation on the agronomic and nutritional contents of MD2 pineapple on alluvial soil. International Journal of Agricultural Technology 19(3):983-996.

Abstract Pineapple leaf biochar (PLB) could improve the agronomic and nutritional content of MD2 pineapple while reducing the use of compound fertilizer. Results indicated that treatment T4 with a 1:1 combination of PLB and compound fertilizer was the most successful treatment for MD2 pineapple cultivation on alluvial soil. It increased plant dry biomass and fruit yield to 718.22 g and 80%, respectively. This study highlighted the viability of utilizing and recycling pineapple leaf residues as a soil amendment, which increased nutrient content in alluvial soil and MD2 pineapple crop.

Keywords: Biochar, MD2 pineapple, Pineapple leaf biochar, Soil amendment

Introduction

Pineapple (*Ananas comosus* L.) is currently one of the nation's important agricultural commodities, with Malaysia ranking as the fifth largest exporter in the world (Safari *et al.*, 2020). Pineapple can be cultivated on most types of soil with good drainage, ranging from alluvial and acid sulfate to peat. Due to the robust demand and significant increase in consumption, Malaysia has increased its projection of premium pineapple production of MD2 variety (*A. comosus* var. MD2) by 50,000 MT between 2020 and 2023 (Mahmud *et al.*, 2018; MPIB, 2019). MD2 pineapple gains high demand due to its high-quality

[*]**Corresponding Author**: Mohidin, H.; **Email:** hasmah@uitm.edu.my

characteristics including sweeter fruit, very pleasant aroma, lower acidity content, and longer shelf life (Sanewski *et al*., 2018). Recent MD2 pineapple cultivation is mainly focused on mineral soil, which is believed to produce a high-quality yield (Zubir *et al*., 2020).

The annual increase in pineapple production in Malaysia also corresponds with waste production. Without proper waste management, more waste can be expected from increasing MD2 cultivation. According to Haruna *et al.* (2013), 13 tonnes of pineapple waste per hectare is produced each growing season. Approximately, 55% of the solid waste from post-harvest fruit processing is biodegradable, consisting of the stem, leaf, crown, peel, core, and other parts of the fruit (Upadhyay *et al*., 2010; Baidhe *et al.*, 2021).

In Sarawak, MD2 pineapple leaf waste is commonly left in situ and is occasionally disposed of by open burning. Both practices lead to nutrient loss, soil health damage, and environmental pollution. The use of pineapple by-products such as pineapple leaf biochar (PLB) can potentially improve sustainable usage of pineapple waste as well as provide additional economic value to the farmers (Rabiu *et al*., 2018). The conversion of PLB into biochar is a way to promote zero burning since biochar is produced using the pyrolysis method. The use of PLB as a soil amendment can improve soil quality and fertility while retaining soil nutrients, reducing pineapple residue disposal and usage of chemical fertilizer (Bonanomi *et al*., 2017; Ajema, 2018). Studies by Zainuddin *et al*. (2014), Leng *et al*. (2017), and Bohari *et al*. (2020) revealed that PLB contains high N and K.

This study systematically evaluated PLB suitability as soil amendment based on its physico-chemical characteristics and nutrient content analysis, thus, becoming a potential fertility index indicator. The biochar produced and raw biomass were subjected to elemental analysis and characterization. The subsequent combination of the mineral content from carbonized biochar (e.g., N, P, and K) from the feedstock and compound fertilizer were next assessed in terms of their effect on the growth, yield performance, nutritional and chemical status of MD2 pineapple cultivated in mineral soil. While the viability of PLB as an alternative to reduce dependency on compound fertilizer in MD2 pineapple cultivation is still in question, this study attempted to assess the viability of PLB–conventional fertilization practice combination on MD2 agronomic performance.

Materials and methods

The study was conducted in three randomized complete block design (RCBD) with 10 replications (plant) on alluvial soil at the Farm Management

Unit of UiTM Sarawak for 15 months, between 2020 and 2021. Five aerial suckers were planted on each planting bed to represent five different treatments. The rate and amount of PLB and compound fertilizer used are shown in Table 1. PLB was prepared according to the standard procedure following Bohari *et al*. (2020).

Table 1. Composition of treatment, rate of fertilizer and application

Treatment	Rate of Fertilizer	Quantity (g/plant)
T1	Absolute Control	-
T2	100% CF (Control)	20 g CF
T3	75% CF + 25% PLB	15 g CF + 5 g PLB
T4	50% CF + 50% PLB	10 g CF + 10 g PLB
T5	25% CF + 75% PLB	5 g CF + 15 g PLB

Note: CF = Compound Fertilizer as per the recommendation by MPIB (2020); PLB = Pineapple Leaf Biochar

Pineapple leaf residues were collected from smallholder farmers at Kampung Sungai Mata, Samarahan, Sarawak. Nutrient availability in PLB is listed in Table 2. Treatments were carried out according to the Malaysian Pineapple Industry Board (MPIB) standard (MPIB, 2019). Four data collections were carried out on the first, third, sixth, and ninth month after planting (MAP), at stages of pretreatment, vegetative (post-first and -second treatment applications), and reproductive (post-third treatment application), respectively.

Table 2. Elemental composition of pineapple leaf biochar

Element	Composition (%)
Total C	19.37 ± 2.03
Total N	8.33 ± 5.34
Total phosphorus (P)	0.39 ± 0.05
Total potassium (K)	48.32 ±9.92
Total magnesium (Mg)	1.27 ± 0.93
Total sulfur (S)	0.32 ± 0.14

Source: Bohari *et al*. (2020)

This study focused on three growth parameters: D-leaf length, D-leaf width, and leaf number per plant. Parameter data were manually obtained by counting and measuring the leaf using a measuring tape. D-leaf refers to the fourth leaf from the apex, the most recently matured leaf that contains the maximum physiological activity (Sinha *et al*., 2018). The destructive sampling of D-leaf for plant dry biomass was conducted at the 14^{th} MAP (harvesting period). The weight of plant dry biomass was recorded using an electronic digital balance (A&D GF-300 Precision Balance) after the plant was oven-dried at 65 ℃ for three days until a constant weight was achieved (Zubir *et al*., 2020). The relative chlorophyll (Chl) value in D-leaf, representing a relative estimation of N content in the leaf, was quantified using SPAD Chlorophyll Meter (SPAD-502 Konica Minolta, Japan). Next, six physical properties of MD2 pineapple fruit, specifically total fruit weight, fruit weight without crown, fruit length, fruit diameter, crown weight, and crown length, were determined. Fruit with crown, fruit without crown, and crown weight were weighed using EK-6000i digital balance (A&D, Tokyo, Japan). Fruit and crown lengths were measured with a metered ruler, while fruit diameter was measured with a metered tape.

Leaf samples for N, P, and K content analysis were oven-dried at 70 ℃ for 72 h, ground, and sifted through a 40-mesh screen before being stored in an airtight container (Gupta, 2007). Nutrient analysis of leaf samples was carried out according to the method of Mohidin *et al*. (2015). Statistical analysis for all growth parameters and physiological data was carried out using Statistical Analysis System version 9.4 software (SAS, 2013). The mean value for each treatment was derived using analysis of variance (ANOVA) and compared using Duncan's Multiple Range Test (DMRT) at $p< 0.05$ significant level (Mohidin *et al.*, 2019).

Results

Low chemical properties of alluvial soil were identified at the preplanting stage (N = 0.20%, exchangeable K = 0.13 +cmol/kg, available P = 7.5 ppm, Mg = 0.25 +cmol/kg, Ca = 0.37 +cmol/kg, and mean soil pH = 4.3); indicating adequate macro- and micronutrient content for MD2 growth. Dwevedi *et al.* (2017) established a similar finding where their study recorded low N and K in alluvial soil. Since MD2 plant could withstand adverse soil nutrient status, this study deemed the status sufficient to support crop growth.

The growth analysis of MD2 pineapple measured between the first and ninth MAP was shown in Figure 1. Growth parameter results indicated that D-leaf length, D-leaf width, leaf number per plant, and plant dry biomass were significantly different ($p < 0.05$) across all treatments.

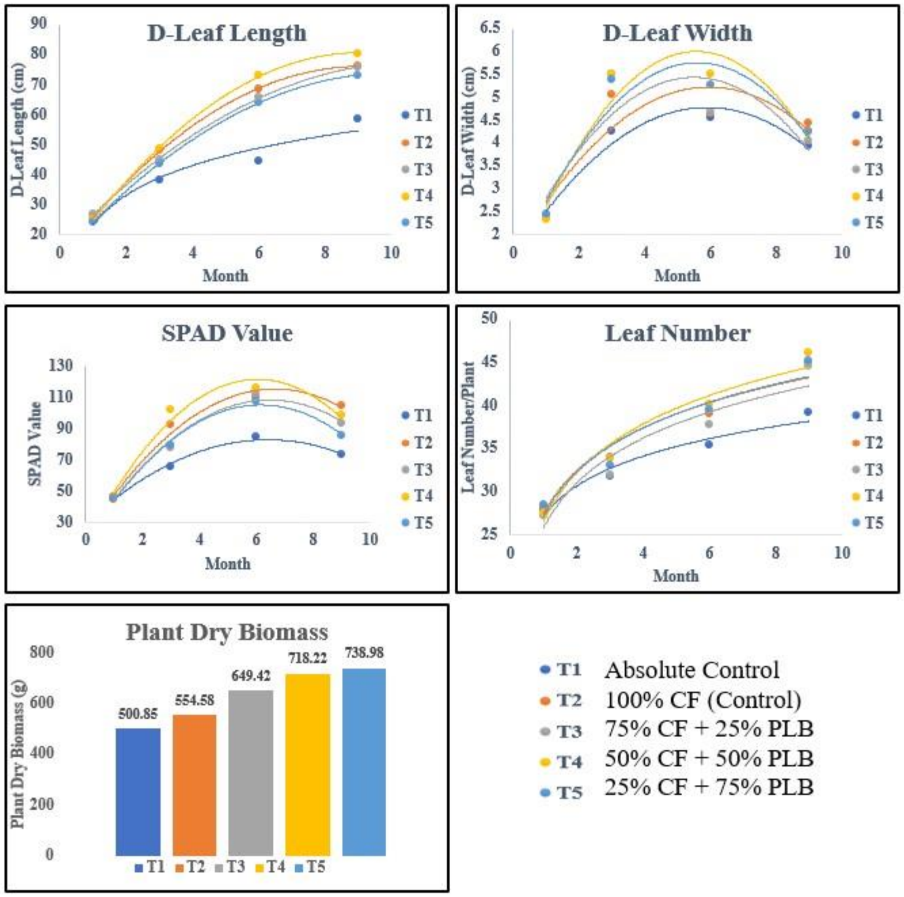

Figure 1. The effects of different experimental treatments on MD2 pineapple grown on alluvial soil on D-leaf length, D-leaf width, leaf number, SPAD value, and plant dry biomass

Among all treatments, T4 obtained the highest mean value of D-leaf length (80.54 cm), while no significant difference is shown between T2 and T3. The highest mean value of 4.45 cm for D-leaf width was recorded by T2, while no significant difference is shown between T4 and T5 at 4.23 and 4.25 cm, respectively. While no significant difference was detected between T4 and T5 for leaf number per plant, both are significantly different from the remaining treatments. Total plant dry biomass in descending order is as follows: T5, T4, T3, T1, and T2, ranging between 500.85 and 738.98 g. Overall, T4 recorded the highest mean value for most growth parameters and is therefore the recommended treatment to attain optimum growth for cultivation on alluvial soil.

SPAD Chl values of D-leaf were significantly different ($p < 0.05$) across all treatments (Fig.1). Treatment T4 obtained the highest mean Chl value of 102.09 SPAD Chl at the third MAP. All treatments recorded decreased SPAD Chl value at the ninth MAP, with no significant difference detected between T2 and T4.

The fruit yield analysis of MD2 pineapple at the harvesting period (14th MAP) was shown in Table 3. T1 (control treatment) did not bear any fruit throughout the study period. T4 obtained the highest number of fruits per treatment with a mean value of 0.50 and an estimated yield of 33.35 MT/ha. No significant difference in both parameters is shown by the remaining treatments. This study found that fruits produced from plants grown with the combination of PLB were shown to be better than fruits from soil applied with absolute compound fertilizer (T2), hence the former's smaller crown size and lower fruit weight and size.

Table 3. The effects of experimental treatments on MD2 fruit physical properties

Parameters	**T1**	**T2**	**T3**	**T4**	**T5**
Number of Fruits	0.00 ± 0.00^{b}	0.40 ± 1.06^{ab}	0.30 ± 0.15^{ab}	0.50 ± 0.17^{a}	0.20 ± 0.13^{ab}
Estimated Yield (MT/Ha)	0.00 ± 0.00^{b}	25.38 ± 1.07^{ab}	18.86 ± 0.96^{ab}	33.35 ± 1.17^{a}	11.67 ± 0.78^{ab}
Total Fruit Weight (kg)	0.00 ± 0.00^{c}	1.29 ± 0.07^{ab}	1.28 ± 0.04^{ab}	1.39 ± 0.08^{a}	1.22 ± 0.03^{b}
Fruit Weight without Crown (kg)	0.00 ± 0.00^{c}	1.12 ± 0.06^{ab}	1.09 ± 0.03^{b}	1.24 ± 0.07^{a}	1.09 ± 0.03^{b}
Fruit Length (cm)	0.00 ± 0.00^{d}	14.96 ± 0.88^{ab}	14.10 ± 0.95^{ab}	15.40 ± 0.98^{a}	12.80 ± 0.37^{c}
Fruit Diameter (cm)	0.00 ± 0.00^{c}	37.74 ± 1.32^{a}	36.19 ± 1.24^{ab}	38.88 ± 1.38^{a}	34.46 ± 0.88^{b}
Crown Weight (kg)	0.00 ± 0.00^{d}	0.17 ± 0.02^{ab}	0.19 ± 0.01^{a}	0.15 ± 0.01^{bc}	0.13 ± 0.00^{c}
Crown Length (cm)	0.00 ± 0.00^{c}	10.65 ± 0.52^{b}	15.00 ± 1.14^{a}	14.15 ± 0.94^{a}	11.30 ± 0.37^{b}

Note: Mean $\pm$ standard error of mean was analysed by ANOVA. The different letters within each row indicate significant differences at $p < 0.05$ based on DMRT. T1 = Absolute control, T2 = 100% CF (control), T3 = 75% CF + 25% PLB, T4 = 50% CF + 50% PLB, T5 = 25% CF + 75% PLB.

The yield traits in terms of total fruit weight, fruit weight without crown, fruit length, fruit diameter, crown weight, and crown length are significantly different ($p < 0.05$) across all treatments were shown in Table 3. T4 gave the highest mean value for total fruit weight of 1.39 kg, while no significant difference is shown between T2 and T3. T4 also recorded the highest mean value of fruit weight without the crown of 1.24 kg. Interestingly, T4 gave the highest value of fruit length of 15.4 cm while there is no significant difference in fruit diameter between T4 (38.88 cm) and T2 (37.74 cm). For crown weight, T3 obtained the highest mean value of 0.19 kg. Meanwhile, T3 and T4 crown lengths indicate no significant difference. An example of fruit yields is shown in Figure 2.

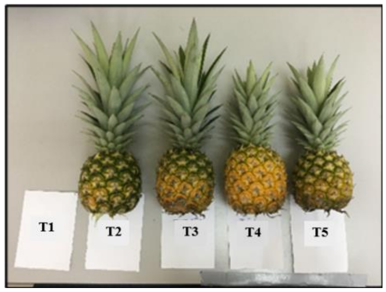

Figure 2. The different sizes of MD2 pineapple fruits grown on alluvial soil from different experimental treatments

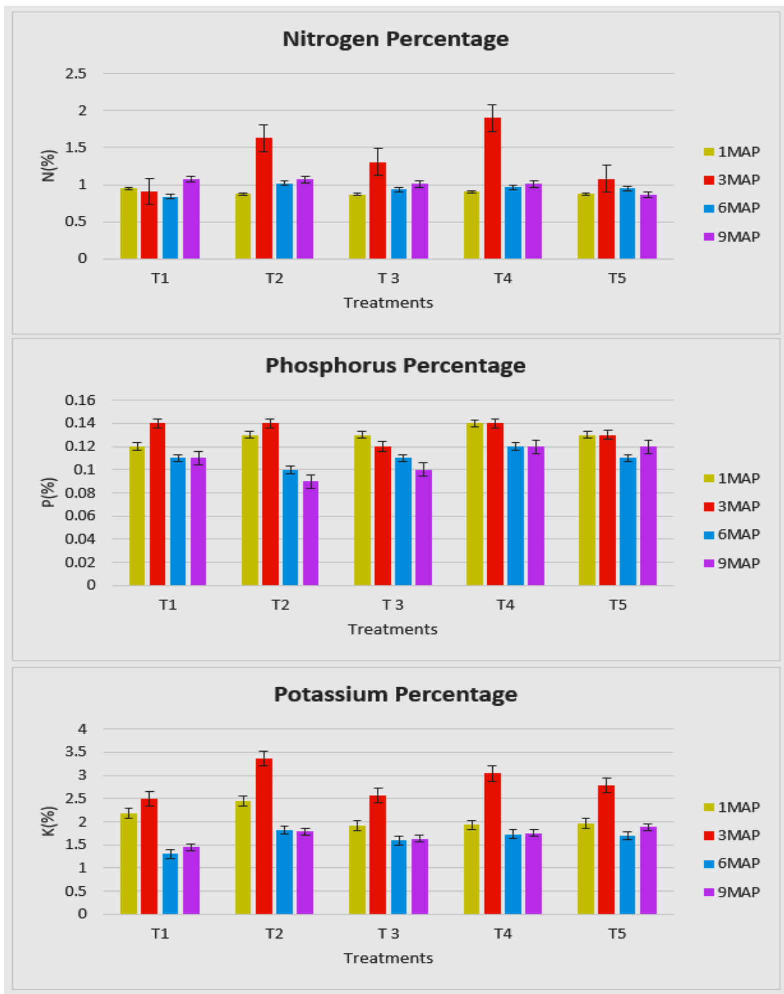

Figure 3. The effects of different experimental treatments on NPK content of MD2 pineapple D-leaf grown on alluvial soil

The macronutrient content in the D-leaf of MD2 pineapple plants. N, P, and K contents were found to be significantly different ($p < 0.05$) across all treatments is shown in Figure 3.

On the third MAP, all treatments showed an increased N and K contents but decreased on the ninth MAP. Results showed that on the ninth MAP, T2 obtained the highest mean value for N at 1.07%. Meanwhile, T4 and T5 obtained the highest mean values of D-leaf P content of 0.12% and were significantly different from the other treatments. Across all treatments, T5's mean K content of 1.88% was significantly different from other treatments.

The results also showed that T4 gave high mean value for N, P, and K concentrations in D-leaf at the third MAP, at 1.90%, 0.14% and 3.04%, respectively. Overall, T4 gave high mean value of D-leaf nutrient content for cultivation on alluvial soil.

Discussion

In this study, the field trials served as the uncontrolled environment where nutrient supply might undergo runoff or leach away to other plants. In general, pineapple plant requires more K than N (Vásquez-Jiménez and Bartholomew, 2018). The growth of MD2 pineapple plants supplied with a combination of PLB and compound fertilizer was compared to the growth of plants supplied solely with compound fertilizer. The comparison is crucial because according to Younis *et al.* (2014), biochar enhances soil organic matter stabilisation and improves nutrient uptake to promote plant growth. Rawat *et al.* (2019) added that the nature of biochar as slow-release fertilizer might result in different growth performances due to low N uptake by the plant. However, biochar which is alkaline in nature helps reduce soil acidity by providing the liming effect that improves nutrient and fertilizer retention in the soil (Oladele *et al.*, 2019; Yu *et al.*, 2019; Yuan *et al.*, 2011). Similarly, Khan *et al.* (2021), Akhtar *et al*. (2014), and Saarnio *et al*. (2013) reported crop growth improvement in response to the combination of biochar amendment and commercial fertilizer application. Higher D-leaf length values were obtained by MD2 pineapple plant which was supplied with a 1:1 combination of compound fertilizer and PLB. This proves that pineapple biochar could improve the N content in alluvial soil, and subsequently boost plant growth. While alluvial soil has low N content (Dwevedi *et al.*, 2017), this study reported a larger increment of leaf number per plant in alluvial soil. The finding is in line with that of Milla *et al.* (2013), who found that the application of rice husk biochar led to increased leaf number per plant and leaf width on water spinach. Our finding is also the same as that of Almaktsur *et al.* (2019), who found pineapples planted on alluvial soil had the longest leaf length and largest leaf number. Mendonça *et al.* (2017) also reported a significant increment in leaf number with the addition of organic matter to pineapple crops.

The dry plant biomass of MD2 pineapple planted with combined fertilizer is higher compared to sole compound fertilizer-associated biomass. According to Khan *et al*. (2021), lower dry biomass is attributed to a lower nutrient supply during a plant's vegetative growth. Another study by Safari *et al.* (2020) stated that differences in plant morphology are strongly influenced by the environment and soil type. Also, Mendonça *et al*. (2017) argued that the differences in growth environment and soil nutrient content influence plant leaf size, number of leaves, and plant dry weight per type of soil.

Physiological traits such as photosynthetic rates are the deciding factors for plant growth and yield development, as optimum photosynthesis contributes to higher crop productivity. The chlorophyll content is one of the main indexes reflecting leaf photosynthesis ability and plant health conditions (Jiang *et al*., 2017). Nitrogen is well known to be associated with the greenness of the leaf, where high N availability in the soil promotes leaf growth and development, especially in chloroplast formation and leaf chlorophyll accumulation (Shanmugapriya *et al*., 2012; Khaliq *et al*., 2017). A study by Asai *et al.* (2009) found that reduced leaf SPAD value is possibly related to the depletion of available N. Biochar enhances soil organic matter stabilization and improves the microbial activity in soil and nutrient uptake, which is directly involved in promoting pigment synthesis (Younis *et al*., 2014). Soil water holding capacity increases when biochar is mixed into the soil (Lorenz, 2007), thus improving N availability for root uptake in order to be consumed in photosynthesis for the production of pigments (Danish *et al*., 2014). From this study, SPAD Chl value of D-leaf supplied with 1:1 fertilizer combination is comparable with the value associated with sole compound fertilizer. This pattern indicates that MD2 pineapple supplied with combined fertilizer could provide a healthier MD2 pineapple growth condition.

This study found that fruits produced from plants grown with the combination of PLB were comparable to fruits applied with absolute compound fertilizer. However, fruits from the former combination had the smallest crown size. Field trial fruits' weight, size, and crown length were lower, potentially due to nutrient leaching under field conditions. A P-nutrient deficiency would reduce the fruit weight (Hawkesford *et al.*, 2012), while plants with N-nutrient deficiency will exhibit physical symptoms such as the production of smaller fruit, smaller crown, and the absence of plantlets (Mahmud *et al*., 2018). Cultivation under field conditions on alluvial soil needs more supplementary N as the soil contains low existing N (Dwevedi *et al*., 2017).

In this field study, the application of compound fertilizer treatment resulted in higher total N concentration in D-leaf. This might be due to the combined nature of fast-acting N and slow-acting P sources from the compound fertilizer (Behn Meyer, 2020). This result concurs with the study of Mahmud *et al*. (2018), where plants supplied with compound fertilizer contained higher total N concentration. On the other hand, N concentration in D-leaf decreased while K concentration increased at the reproductive stage, a trend that echoed the findings of Teixeira *et al.* (2011). This might be due to the increased rate of K application at the reproductive stage.

Another study by Nigussie *et al*. (2012) found that maize stalk biochar application improved nutrient uptake in lettuce through reported higher N, P, and K uptake. Nevertheless, the concentration of P in D-leaf was adequate but of no significant difference for both types of soil, likely due to the insignificance of P nutrient in pineapple growth (Zubir *et al*., 2020). Plants are generally known to respond positively to a certain level of nutrient application. Once exceeded, nutrient over application will become toxic to plants, where the plants began to be negatively affected.

The viability of PLB as the growth enhancer or soil amendment on alluvial soil was established in this study. Increased development of pineapple growth and yield parameters were observed after the application of various combinations of PLB. T4 which comprised 1:1 combination of compound fertilizer and PLB (10 g each) that was applied at three-month intervals was the most successful treatment for MD2 pineapple cultivation on alluvial soil in terms of agronomic properties and nutritional characteristics. Overall, T4 gave the highest mean value for most fruit yield parameters thus increased plant dry biomass and fruit yield to 718.22 g and 80%, respectively. Therefore it is the recommended treatment to attain optimum growth for cultivation on alluvial soil. The findings support the development of a practical and cost-effective approach to promote recycled nutrition to reduce the reliance on compound fertilizer, especially among pineapple smallholders in Sarawak.

Acknowledgements

The authors are grateful to Sarawak Digital Economy Corporation Berhad (SDEC) for the financial support through Grant no. SMA/R&D/600.1.03 JLD1(6), Universiti Teknologi MARA, Sarawak Branch, Samarahan Campus, Universiti Teknologi MARA, Jasin Branch and Soil Management Division, Department of Agriculture, Sarawak for the technical support in this study.

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(Received: 7 July 2022, accepted: 30 April 2023)