

# UNLOCKING THE POTENTIAL OF POME AS SOIL AMENDMENT TO ENHANCE GROWTH AND YIELD PERFORMANCE OF MAIZE CULTIVATED ON BRIS SOIL

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## ABSTRACT

*Beach Ridges Interspersed with Swales (BRIS) soil is a problematic soil for agriculture due to nutrient deficiencies. However, palm oil mill effluent (POME), agricultural by-products can be utilised as a soil amendment. This study was carried out to evaluate the potential of POME to enhance the growth characteristics and yield performance of maize. The experiment was conducted in a randomised complete block design with five treatments and four replications. The treatments consisted of: NPK fertiliser (T1), POME (5 t ha<sup>-1</sup>) + NPK fertiliser (T2), POME (10 t ha<sup>-1</sup>) + NPK fertiliser (T3), POME (15 t ha<sup>-1</sup>) + NPK fertiliser (T4) and GML + NPK fertiliser (T5). This finding demonstrated that the application of POME significantly enhances soil fertility by increasing CEC. The highest POME application rate in T4 produced greater average cob weight, length, and diameter than T1 and T5. The T4 recorded the highest yield at 191 kg ha<sup>-1</sup>, showing a 39% increase compared to T5. This study highlights the potential of POME, an agricultural by-product, as a soil amendment for BRIS soils demonstrating its positive effects on maize's growth and yield productivity and may offer a sustainable option in managing this waste product.*

**Keywords:** maize, POME, sandy BRIS soil, yield.

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## INTRODUCTION

The Beach Ridges Interspersed with Swales (BRIS) soil is a problematic soil in Malaysia, dominated by soils having more than 90% of sand texture

(Roslan et al., 2010). According to Reconnaissance Soil Map of Peninsular Malaysia (Department of Agriculture [DOA], 2002), BRIS soil covers approximately 160,090 ha, mostly found along the East Coast of Terengganu, Pahang, Kelantan and some areas in West Coast of Johor. BRIS soil originates from the undulating process which made up the ridges and swales by the seas during the monsoon seasons (Mohd Ekhwan et al., 2009). It is unsuitable for agriculture production due to their inherent poor fertility. The key limitation of these soils is their texture, followed by poor nutrient retention (Nossin, 1964). Furthermore, the high sand content exceeding 95% also leads to low water holding capacity (Roslan et al., 2011). This weak structure allows nutrients to leach easily into the groundwater. The availability of nutrients becomes scarce on BRIS soil for any crops grown and will impact growth performance. BRIS soils are unable to retain nutrients under normal

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circumstances due to their low cation exchange capacity and to supply sufficient nutrients for crop production (Usman et al., 2014). Some areas of BRIS soils have mostly been converted to other land use as it is classified as unproductive agriculture soil. It is also often perceived as degraded or wasted land (Jamilah et al., 2013). Highly likely crop production may decline in term of agronomic yield due to the low pH and poor organic matter of BRIS soil. The pH value of the soil plays a vital role in enabling plants to uptake available nutrients from BRIS soil. According to Guo et al. (2020), high pH value can reduce root activity, thereby limiting the absorption of water and nutrients. Conversely, low pH value can lead to poor crop growth and yield, primarily due to the lack of macronutrient and micronutrients such as phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K) and molybdenum (Mo) (Long et al., 2017), as well as reduced uptake of water (Bian et al., 2013). Therefore, producing food crops in BRIS soil requires significantly high input of fertiliser to conserve the soil so that the plants can produce maximum yields. Specific soil management is needed in order to increase crop production in these soils.

Although, BRIS soil is known as a problematic soil for agriculture, it is assumed that liming application helps to improve BRIS soil. One way to improve the fertility of BRIS soil is by applying soil amendments such as lime. Lime consists predominantly of calcium and magnesium compounds, including hydroxides, oxides, carbonates and silicates (Anderson et al., 2013). These compounds can alter a range of geochemical and biological characteristics of the soil, thereby improving soil fertility (Mahmud & Chong, 2022). The application of lime can increase the soil pH value and enhances the availability of essential plant nutrients (Enesi et al., 2023). However, the cost of liming materials becomes a constraint particularly for smallholders in Malaysia, since a large amount of lime is needed to increase soil pH value. The application of liming under field conditions is often time consuming and labour intensive (Jiang-Ming, 2022). This challenge is greater in BRIS soils where higher rates of lime are required to improve soil pH value. Approximately 3 to 6 t ha<sup>-1</sup> are required to increase soil pH value from pH 5.0 to 7.0 with the optimal liming effect typically lasting less than three years under field conditions (Li et al., 2019; Shamshuddin et al., 2021). In addition, high costs of liming ranging from USD100 to over USD1,000 (RM422–RM4,220) acre<sup>-1</sup>, including materials, transportation, application, and labour costs become a barrier for smallholders in Malaysia (Pow, 2025). In conjunction with this, some of the smallholders are reluctant to lime the soil due to their

unfavourable economic costs, especially in terms of time and labour (Zhou, 2022). Therefore, from a practical perspective, it is essential to look toward an alternative liming material from abundant and low-cost agricultural by-products.

Palm oil mill effluent (POME) is an agricultural by-product and often regarded as a 'waste product' generated from the manufacturing process in the palm oil industry. Reusing POME as a soil amendment is an environmentally friendly and sustainable way of managing this waste. This 'waste product' which is the focus of this article can be used as a cost-effective alternative to commercial soil amendments like limestone while benefiting from their abundant supply and ready availability. POME often regarded as waste material and may present pollution hazards in excessive quantities if not appropriately managed (Kanakaraju et al., 2016; Naibaho, 1998). Based on data from Ngatiman and Mohd Hamzah (2024), Malaysia produced around 68.06 million tonnes of POME in 2023. While limestone remains the most commonly used soil amendment to ameliorate the soil, there is an interest in identifying an alternative liming material due to its abundance and availability to improve BRIS soils.

An approach using this 'waste product' in agriculture as a soil amendment is considered as an effective waste management strategy for minimising this waste to the environment (Karim et al., 2022; Khairuddin et al., 2016). The 'waste product' from palm oil mill can be utilised as a soil amendment or ameliorant material and a suitable substitute for inorganic fertilisers (Embrandiri et al., 2013; Salihu & Alam, 2012; Usman et al., 2013). It easily biodegrades when incorporated into soil (Mohd Nizar, 2018; Nwoko & Ogunyemi, 2010) and contains high levels of carbon dioxide (CO<sub>2</sub>), organic compounds and major nutrients, such as nitrogen (N), P and carbon (C) (Ety et al., 2024; Mardiana, 2020). The raw and fresh POME contain NPK nutrients as the following N: 0.72%–0.95%; P: 0.12%–0.18% and K: 1.90%–2.30% (Loh et al., 2019). These elements were essential for improving crop productivity and show that POME can be potentially made into a soil amendment. In addition, this waste product also enhances soils aggregate on stability, porosity, and water infiltration rate (Jefferson et al., 2016). The increased growth and yield performance of several crops have already been reported worldwide by the application of POME into soil. Studies have been conducted to utilise POME to enhance soil productivity and the yield of Napier grass (Agamuthu, 1994). Additionally, a study by Teoh and Chew (1983) reported that cocoa seedlings exhibited vigorous growth when planted in a soil and POME mixture at 1:5 ratio. Furthermore, the heavy metal content

complied with WHO/FAO safety standards for human consumption (Dashti et al., 2020; Kanakaraju et al., 2016). Numerous studies have demonstrated that the application of POME to oil palm plantations has proven increased fresh fruit bunch (FFB) yield by 10%–20% (Hasanudin et al., 2015; Pujono et al., 2021; Salmiyati et al., 2017). However, limited study has been done on cereal crops, and the effect remains unclear. The test crop chosen in this study is maize (*Zea mays* L.), a widely cultivated cereal crop in Malaysia and is less prone to nutrient deficiencies under optimal conditions (Malaysian Agricultural Research and Development Institute [MARDI], 2005; Nor Hazlina et al., 2012). Therefore, this study was conducted to assess the suitability of POME as a soil amendment for maize under field condition on BRIS soil. Specifically, it aims to evaluate the potential of POME in enhancing maize growth and yield productivity.

## MATERIALS AND METHODS

### Experimental Design and Field Management

This study was conducted under open field conditions at the MARDI Research Station in Cherating, Pahang, Malaysia located at 3°77'014.4" N, 103°31'46.3" E. The soil at the site is classified as BRIS soils and the most dominant series in the study area was Baging Series (Aminuddin & Eswaran, 1973). According to soil taxonomy, Baging Series is classified as sandy, siliceous, isohyperthermic, typic, quartzipsamments (DoA, 2008; Paramanathan, 2000). The experimental area was 0.4 ha in size. The field was ploughed three weeks prior to planting. POME was applied to the respective plots one week before planting. Maize was planted at a seedling rate of 8 kg ha<sup>-1</sup> with planting distance of 75 cm between rows and 25 cm between individual plants. The experiment comprised five treatments including standard agricultural practice as outlined in *Table 1*. The experiment was arranged in a randomised complete block design (RCBD) with four replications for each treatment. The NPK fertiliser (15:15:15) was applied at a rate of 400 kg ha<sup>-1</sup> at the basal stage, followed by urea at a rate of 130 kg ha<sup>-1</sup> at 35 days after planting (DAP) across all treatments as following standard agricultural practice. Watering was applied twice daily, in the morning and evening, about 20 to 30 min to maintain soil moisture between 70% and 90% of field capacity (FC). Pest and disease control measures was applied whenever signs of disease or insect intensification were observed in field as following recommendation guidelines by MARDI (MARDI, 2005).

TABLE 1. TREATMENT DESCRIPTION

Treatment	Treatment details
T1	NPK fertiliser
T2	POME at rate 5 t ha <sup>-1</sup> + NPK fertiliser
T3	POME at rate 10 t ha <sup>-1</sup> + NPK fertiliser
T4	POME at rate 15 t ha <sup>-1</sup> + NPK fertiliser
T5	GML at rate 2 t ha <sup>-1</sup> + NPK fertiliser (standard practise)

Note: GML - ground magnesium limestone; NPK - nitrogen, phosphorus, potassium; POME - palm oil mill effluent.

### Chemical Characteristics of Soil and Physico-chemical Properties POME

POME was obtained from a palm oil mill in Gambang, Pahang, Malaysia. POME was stored under the shelter to prevent the changes on its characteristics and were kept not more than two weeks to avoid deterioration (Daud et al., 2013; Suzana & Abdul Aziz, 2016). Soil samples were collected from the study site at a depth of 0–10 cm two weeks prior to planting and at harvest. A total of 10 sub-sampling points were randomly selected from the experimental plot and soil was collected into clean plastic bags. The subsamples were thoroughly homogenised to form a composite sample. Approximately 1 kg of the composite soil was kept for laboratory analysis. POME and soil samples were air-dried, ground, and passed through 2 mm sieve for physico-chemical analysis. The parameters measured included pH value, total N, P, K, Ca and cation exchange capacity (CEC). Soil pH value was determined by using a glass electrode pH meter in a 1:2.5 (soil: water) suspension. Available P was analysed accordingly following the Bray and Kurtz No. 2 method (Bray & Kurtz, 1945) and measured by UV-Visible Spectrophotometer. Total N was determined by using the Kjeldahl procedure (Kjeldahl, 1883). Exchangeable bases and CEC were analysed through leaching with 1.0 M ammonium acetate (NH<sub>4</sub>OA) solution buffered at pH 7 as described by Lavkulich (1981). The concentration of exchangeable bases was determined by using an atomic absorption spectrophotometer, while K was measured using a flame photometer.

### Data Collection and Measurements

Plants were randomly selected and tagged in each plot to measure the growth performance according to growth stages, vegetative, reproductive and matured stage at 6, 8 and 10 weeks after planting (WAP), respectively. Plant height was taken from the base to top at 6, 8 and 10 WAP by using a measuring tape. Plant girth was measured at the base of the maize at 6, 8 and 10 WAP using a digital vernier calliper. Leaf count per plant was

manually counted at 6, 8 and 10 WAP. The selected plants were destructively sampled by harvesting parts of the leaf and stem at these time points. The plant biomass was oven-dried at 70°C for three days and weighed using a weighing balance. Photosynthesis rate and stomatal conductance were measured on the mature, unshaded, and fully expanded leaves using a portable photosynthesis system (model LI-6200, LICOR, USA). The gas exchange measurements were made between 09:00 to 11.00 hr. The maize plants were harvested at the central of each plot by using 4 × 4 m square quadrat comprised 85 plants and yield data components were taken using 1 × 1 m square quadrat during harvest. The fresh weight of the maize was determined using a weighing machine. The length of the maize was taken using a measuring tape and a ruler. The diameter of the maize was measured using a digital vernier calliper. A sample of 1,000 seeds were oven-dried to moisture content of 13%–14% and weighed using an analytical balance. The total yield from the quadrat sample was calculated in kg per hectare.

### Data Analysis

A one-way analysis of variance (ANOVA) followed by the least significant difference (LSD) test was conducted to compare the treatment means. Statistical significance level was determined at  $p < 0.05$ . Data analysis was performed by using statistical analysis system software version 9.4 (SAS Institute Inc., 2007).

## RESULTS AND DISCUSSION

### Chemical Characteristics of Soil

The initial soil chemical characteristics were compared with the soil fertility ranking as

shown in *Table 2*. BRIS soil in this study was moderately acidic (pH 5.16), low total N (0.028%), exchangeable K (0.00001 cmol<sub>c</sub> kg<sup>-1</sup>), exchangeable Ca (0.0028 cmol<sub>c</sub> kg<sup>-1</sup>), exchangeable Mg (0.0028 cmol<sub>c</sub> kg<sup>-1</sup>) and CEC (7.3 cmol<sub>c</sub> kg<sup>-1</sup>) but high in the available P (29.78 mg kg<sup>-1</sup>). The imbalance of essential macronutrients (N, K, Ca and Mg) in the initial soil clearly indicates nutrient deficiencies that could limit the maize productivity. Based on this finding, it was affirmed that the overall fertility of BRIS soil in this study was undoubtedly poor to support optimum maize productivity without application of soil amendments. This highlights the necessity for soil amendments such as POME for nutrient retention and promote more favourable conditions for maize growth on BRIS soils.

### Physico-chemical Characteristics of POME

The physico-chemical characteristics of POME are presented in *Table 3*. These results indicated that POME is a neutral material with pH 7.1 and an acceptable moisture content of 13.79%, suggesting its effectiveness in improving soil pH as the soil in this study was of low fertility and poor suitability for most crops, including maize. A study by Basri et al. (2024) suggested that the most favourable pH for nutrient uptake is between the pH 6.0 and 7.0. Soil with low pH value below pH 5.5 will cause aluminium (Al) and manganese (Mn) toxicity thus reduces plant and root development (Mohd Nizar et al., 2018). Total N and total P levels were found to be low in POME. The lower content of N in POME may be due to the leaching of the N after undergoing several stages of oil extraction process from fibres (Kanakaraju, 2016). A study by Ryals et al. (2014) stated that N from POME was produced from the decomposition process and any excess nutrients (N and P) from the breakdown of organic matter were released into the

TABLE 2. CHEMICAL CHARACTERISTICS OF SOIL BEFORE EXPERIMENT AND SOIL FERTILITY RANKING

Parameters	Fertility status					Soil before experiment
	Very low	Low	Optimum	High	Very high	
pH	<3.50	4.00	4.20	5.50	>5.50	5.16
Total N (%)	0.08	0.12	0.15	0.25	>0.25	0.028
Av. P (mg kg <sup>-1</sup> )	<8.00	15.00	20.00	25.00	>25.00	29.78
Ex. K (cmol <sub>c</sub> kg <sup>-1</sup> )	<0.008	0.200	0.250	0.300	>0.300	0.0001
Ex. Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	<1.000	2.000	3.000	>3.000	n.a	0.0028
Ex. Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	<0.008	0.200	0.250	0.300	>0.300	0.0015
CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	<6.000	12.000	15.000	18.000	>18.000	7.3

Note: Av. - available; Ex. - exchangeable; n.a - not available; N - nitrogen ; P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium; CEC - cation exchange capacity.

Source: Paramanathan (2015) and Laboski and Peters (2012).

soil. However, it demonstrated a high value of K ( $14.82 \text{ cmol}_c \text{ kg}^{-1}$ ), Ca content ( $65.60 \text{ cmol}_c \text{ kg}^{-1}$ ) and Mg content ( $51.04 \text{ cmol}_c \text{ kg}^{-1}$ ). Such conditions may be attributed to the presence and accumulations of various charged ions in POME. The high amounts of ions in POME might be attributed to dissolved solids generated during palm oil processing, which contain a high level of degradable organic matter (Haryani et al., 2019; Hiragi, 2015). However, the presence of Ca and Mg can help to promote favourable soil structure and chlorophyll formation in the leaf (Shafar et al., 2013; Silva et al., 2010). In particular, adequate Mg nutrition is essential for enhancing nitrogen use efficiency (NUE) and grain N accumulation (Olego et al., 2021), thereby supporting the overall plant growth and productivity of maize. Some of the nutrient such as K is relatively immobile in the soil due to its adsorption to colloids, however, high CEC would enhance its availability for plant uptake. A high CEC value ( $24.31 \text{ cmol}_c \text{ kg}^{-1}$ ) indicates that POME have a greater capacity to hold cations that allow some essential nutrients to be retained and available for crop production. This suggests that this waste can be applied as a soil amendment for BRIS soil.

TABLE 3. SELECTED PHYSICO-CHEMICAL PROPERTIES OF POME

Parameters	POME
pH	$7.16 \pm 0.01$
Total N (%)	$1.29 \pm 0.03$
Total P (%)	$2.62 \pm 0.14$
Ex. K ( $\text{cmol}_c \text{ kg}^{-1}$ )	$14.82 \pm 1.21$
Ex. Ca ( $\text{cmol}_c \text{ kg}^{-1}$ )	$65.60 \pm 5.21$
Ex. Mg ( $\text{cmol}_c \text{ kg}^{-1}$ )	$51.04 \pm 5.07$
CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	$24.31 \pm 0.26$
MC (%)	$13.79 \pm 0.05$

Note: Ex. - exchangeable; N - nitrogen ; P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium; CEC - cation exchange capacity; MC - moisture content.

The physico-chemical properties of soil are summarised in Table 4. The results showed changes in soil physico-chemical properties as compared to the initial soil properties. The initial soil pH value was acidic at pH 5.16, which is typical of many tropical soils in Malaysia prone to acidity-related nutrient limitations. All treatments increased soil pH to values between pH 5.60 and 5.74 with no significant differences observed amongst the treatments. The soil pH for all treatments meets the requirement for maize cultivation. The pH values fall within the optimum soil pH range of 5.5 to 6.6 for corn cultivation (Tisdale et al., 1993). However, the liming effect of POME treatments (T2, T3 and T4) contributes to increased soil pH after amendment application in the field by releasing base cations such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . Exchangeable Ca and Mg were higher in POME treatments (T2, T3 and T4) compared to standard practice (T5) with no difference observed amongst the treatments. A study conducted by Mahmud and Chong (2022) stated that increased levels of Ca and Mg along with sufficient P availability, are essential factors for enhancing plant growth and development. Total N content showed a significant difference amongst the treatments. T5 showed the highest total N at 0.034% and the lowest total N was from T1. However, no significant difference was observed between POME treatments (T2, T3 and T4) and commercial limestone (T5). This suggests that POME at rate  $\geq 10 \text{ t ha}^{-1}$  has been shown to ameliorate soil and enhance mineralisation by increasing the amount of N in BRIS soil. Available P increased significantly across treatments, with the highest concentration in T4. The increase in available P with higher POME rates is likely due to high organic acids that enhance P availability in BRIS soil. Exchangeable K, Ca and Mg increased in all treatments as compared to the initial soil, with no significant difference amongst the treatments. These increases in POME treatments (T2, T3 and T4) due to the high cations content from POME which contribute to better plant growth and metabolism

TABLE 4. PHYSICO-CHEMICAL PROPERTIES OF SOIL

Parameters	T1	T2	T3	T4	T5
pH	5.60 <sup>a</sup>	5.65 <sup>a</sup>	5.70 <sup>a</sup>	5.72 <sup>a</sup>	5.74 <sup>a</sup>
Total N (%)	0.011 <sup>b</sup>	0.011 <sup>b</sup>	0.018 <sup>ab</sup>	0.027 <sup>ab</sup>	0.034 <sup>a</sup>
Av. P ( $\text{mg kg}^{-1}$ )	21.10 <sup>b</sup>	26.37 <sup>b</sup>	38.37 <sup>ab</sup>	51.62 <sup>a</sup>	48.72 <sup>ab</sup>
Ex. K ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.22 <sup>a</sup>	0.24 <sup>a</sup>	0.27 <sup>a</sup>	0.28 <sup>a</sup>	0.29 <sup>a</sup>
Ex. Ca ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.48 <sup>a</sup>	0.68 <sup>a</sup>	0.70 <sup>a</sup>	0.83 <sup>a</sup>	0.60 <sup>a</sup>
Ex. Mg ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.36 <sup>a</sup>	0.44 <sup>a</sup>	0.54 <sup>a</sup>	0.58 <sup>a</sup>	0.43 <sup>a</sup>
CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	16.2 <sup>b</sup>	23.4 <sup>ab</sup>	23.6 <sup>ab</sup>	26.6 <sup>a</sup>	22.6 <sup>ab</sup>

Note: Means with the same letters in the same row were not significant at  $p \geq 0.05$ . Av. - available; Ex. - exchangeable; CEC - cation exchange capacity; N - nitrogen ; P - phosphorus; K - potassium; Ca - calcium; Mg - magnesium.

as these macronutrients promote enzyme activity for physiological processes. Consequently, the presence of these nutrients in the soil is expected to positively give effect on plant growth. CEC increased from 7.3 in the initial soil to between 22.6  $\text{cmol}_c \text{ kg}^{-1}$  and 23.6  $\text{cmol}_c \text{ kg}^{-1}$  after application of POME treatments (T2, T3 and T4) and commercial limestone (T5). The maximum CEC was from T4, reflecting POME can enhance soil nutrient holding capacity. This demonstrates that applying POME as soil amendment has the potential to ameliorate soils by enhancing nutrient availability in BRIS soil.

### Growth Characteristics

The vegetative growth parameters of maize showed a significant decrease in plant height, girth circumference and leaf count per plant 6 WAP as the application rate of the waste product increased from 0 to 10  $\text{t ha}^{-1}$ , as observed in T1 to T3 (Table 5). This may be attributed to insufficient levels of soil amendment to effectively promote the vegetative growth of maize. A study by Noorsuhaila et al. (2024) claimed that plant growth will improve once the soil fertility meets the optimal conditions for crop development. T5 recorded significantly greater growth as compared to T1 at 6, 8 and 10 WAP. A similar trend was observed for stem girth at 6 and 8 WAP, where T5 recorded significantly bigger plant girth than T1. However, no significant difference was observed between POME treatments and commercial limestone treatment in T5, indicating that application of POME is equally effective in promoting maize growth as the commercial liming material. Leaf count per plant was significantly higher in T5 across all stages. However, no significant difference was observed between POME treatments (T2, T3 and T4) and commercial limestone (T5) demonstrating that application of

POME similarly enhances physiological function and photosynthetic capacity, thereby supporting improved biomass accumulation in maize plants comparable to conventional liming material.

T5 produced significantly higher leaf dry weight as compared to T1 at 6 and 10 WAP (Table 6). However, no significant difference was observed on leaf dry weight between POME treatments (T2, T3 and T4) and commercial limestone (T5) at 6 and 10 WAP. The leaf dry weight increased across all treatments in the order of  $T1 < T2 < T3 < T4 < T5$  for both weeks. Similarly, T5 recorded significantly higher stem dry weight (2.51 g) than T1 (1.61 g) at 6 WAP. However, no significant difference was observed between POME treatments (T2, T3 and T4) and commercial limestone (T5) indicating that application of POME similarly contributes to plant biomass production in maize comparable to commercial limestone (T5).

At 6 WAP, leaf biomass constituted most of the total dry matter across all treatments, representing approximately 65%–70% of total plant dry weight (Figure 1). It showed that the accumulation of dry matter partitioning was greater in leaves as compared to stems across all treatments at this stage. By 8 WAP, all treatments exhibited increases in total dry mass, with a slightly greater allocation to leaf tissue. The trend suggested that at this early stage, the plants prioritise leaf development for photosynthetic rate (Pedram & Ghizan, 2019; Zhang et al., 2008). At 10 WAP, a shift in dry matter partitioning increased in stem biomass. This trend suggested that the plant allocation was more balanced between growth (leaf) and structural support (stem). T5 produced highest biomass in all stages. However, POME treatments also enhanced overall biomass production comparable to commercial liming material. This supports the hypothesis that POME can sustain leaf to stem ratio, which is

TABLE 5. IMPACT OF WASTE PRODUCTS ON MAIZE'S GROWTH PARAMETERS

Parameter	Weeks after planting (WAP)	Treatment				
		T1	T2	T3	T4	T5
Plant height (cm)	6	77.01 ± 3.86 <sup>b</sup>	84.19 ± 5.83 <sup>ab</sup>	84.22 ± 6.16 <sup>ab</sup>	84.75 ± 11.59 <sup>ab</sup>	96.38 ± 6.28 <sup>a</sup>
	8	111.00 ± 9.79 <sup>b</sup>	117.09 ± 6.69 <sup>ab</sup>	119.25 ± 10.47 <sup>ab</sup>	125.50 ± 7.82 <sup>ab</sup>	132.92 ± 10.80 <sup>a</sup>
	10	119.58 ± 3.81 <sup>b</sup>	124.25 ± 8.09 <sup>ab</sup>	126.08 ± 5.74 <sup>ab</sup>	126.42 ± 4.24 <sup>ab</sup>	136.25 ± 3.91 <sup>a</sup>
Plant girth (mm)	6	12.54 ± 0.52 <sup>b</sup>	12.94 ± 1.97 <sup>ab</sup>	13.44 ± 1.20 <sup>ab</sup>	13.6 ± 1.15 <sup>ab</sup>	15.65 ± 1.16 <sup>a</sup>
	8	14.14 ± 0.23 <sup>b</sup>	14.52 ± 0.44 <sup>ab</sup>	14.80 ± 0.95 <sup>ab</sup>	15.10 ± 0.67 <sup>ab</sup>	16.19 ± 0.34 <sup>a</sup>
	10	15.42 ± 0.51 <sup>a</sup>	15.64 ± 0.10 <sup>a</sup>	15.98 ± 0.70 <sup>a</sup>	16.13 ± 0.80 <sup>a</sup>	17.12 ± 0.32 <sup>a</sup>
Leaf count per plant	6	6.75 ± 1.65 <sup>b</sup>	7.50 ± 0.29 <sup>ab</sup>	7.50 ± 0.50 <sup>ab</sup>	8.00 ± 0.41 <sup>ab</sup>	9.00 ± 0.41 <sup>a</sup>
	8	10.25 ± 0.25 <sup>b</sup>	10.75 ± 0.48 <sup>b</sup>	11.00 ± 0.41 <sup>b</sup>	11.50 ± 0.65 <sup>ab</sup>	12.75 ± 0.48 <sup>a</sup>
	10	10.09 ± 0.25 <sup>b</sup>	10.58 ± 0.37 <sup>b</sup>	10.84 ± 0.42 <sup>b</sup>	11.00 ± 0.41 <sup>b</sup>	12.00 ± 0.27 <sup>a</sup>

Note: Means with the same letters in the same row were not significant at  $p \geq 0.05$ .

TABLE 6. EFFECT OF WASTE PRODUCT ON MAIZE'S DRY MATTER ACCUMULATION

Parameter	Weeks after planting (WAP)	Treatment				
		T1	T2	T3	T4	T5
Leaf dry weight per plant	6	3.67 ± 0.59 <sup>b</sup>	4.02 ± 0.81 <sup>ab</sup>	4.10 ± 0.92 <sup>ab</sup>	4.42 ± 0.51 <sup>ab</sup>	5.34 ± 0.78 <sup>a</sup>
	8	10.98 ± 0.70 <sup>a</sup>	12.50 ± 1.27 <sup>a</sup>	13.45 ± 2.50 <sup>a</sup>	13.58 ± 2.11 <sup>a</sup>	14.86 ± 2.97 <sup>a</sup>
	10	19.16 ± 1.37 <sup>b</sup>	20.08 ± 4.83 <sup>ab</sup>	20.29 ± 1.90 <sup>ab</sup>	21.48 ± 2.27 <sup>ab</sup>	34.65 ± 5.31 <sup>a</sup>
Stem dry weight per plant	6	1.61 ± 0.32 <sup>b</sup>	1.87 ± 0.43 <sup>ab</sup>	1.92 ± 0.22 <sup>ab</sup>	2.05 ± 0.28 <sup>ab</sup>	2.51 ± 0.44 <sup>a</sup>
	8	7.66 ± 0.38 <sup>a</sup>	8.02 ± 1.11 <sup>a</sup>	8.80 ± 1.06 <sup>a</sup>	10.67 ± 2.83 <sup>a</sup>	12.24 ± 3.23 <sup>a</sup>
	10	15.75 ± 1.39 <sup>a</sup>	16.03 ± 1.34 <sup>a</sup>	17.40 ± 1.86 <sup>a</sup>	20.74 ± 7.49 <sup>a</sup>	22.75 ± 2.60 <sup>a</sup>

Note: Means with the same letters in the same row were not significant at  $p \geq 0.05$ .

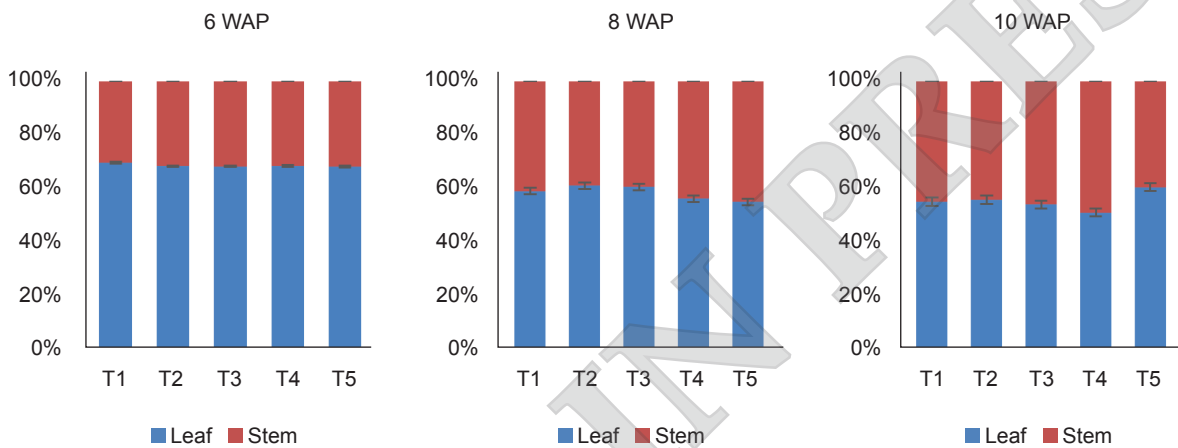


Figure 1. Dry matter accumulation at 6, 8 and 10 weeks after planting (WAP).

essential for optimising photosynthetic efficiency. This comparable growth performance between POME treatments and commercial limestone supports the potential of POME as an effective soil amendment for improving maize productivity on BRIS soils.

### Gas Exchange Properties

The result of the gas exchange variable on photosynthesis rate and stomatal conductance showed no significant difference amongst all treatments at 6 WAP (Table 7). Photosynthesis rate ranged from 27.41 to 30.44  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . This indicates that the incorporation of soil amendments into soil had no significant effect on photosynthetic efficiency at this early growth stage. T4 recorded the highest photosynthesis rate which was significantly higher than T1 at 8 and 10 WAP. This suggests that application of POME may have enhanced photosynthetic activity particularly during mid to late growth stages. The photosynthesis rate increased from 6 to 8 WAP across all treatments before declining at 10 WAP. This increase in photosynthetic activity at mid

growth suggest that the plants were reaching an active physiological state potentially due to better nutrient uptake leading to more efficient gas exchange. Nwoko and Ogunyemi (2010) reported that maize showed a positive growth response following the application of organic amendments attributed to the decomposition process of POME sludge. This condition could help to improve photosynthetic activity in the maize growth. Additionally, high CEC in the soil influenced stomatal conductivity impacting gas exchange in the guard cells (Hazandy et al., 2011). However, the reduction in photosynthesis rate at 10 WAP could be attributed to plant senescence. A similar trend was observed in stomatal conductance, which was highest at 8 WAP before slightly declining at 10 WAP. However, no significant difference was observed among treatments at 6 and 10 WAP with stomatal conductance values ranging from 0.27 to 0.32  $\mu\text{mol m}^{-2} \text{s}^{-1}$  and 0.27 to 0.35  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , respectively. By 8 WAP, stomatal conductance increased amongst all treatments, with the highest values recorded in T4 (0.56  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) and T5 (0.54  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ). In contrast, T1 showed the lowest stomatal conductance (0.42  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ).

TABLE 7. EFFECT OF WASTE PRODUCT ON PHYSIOLOGICAL RESPONSE

Parameter	Weeks after planting (WAP)	Treatment				
		T1	T2	T3	T4	T5
Photosynthesis rate ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	6	27.41 ± 1.72 <sup>a</sup>	29.99 ± 2.02 <sup>a</sup>	30.39 ± 0.96 <sup>a</sup>	30.44 ± 1.225 <sup>a</sup>	29.49 ± 1.75 <sup>a</sup>
	8	32.98 ± 2.59 <sup>b</sup>	35.58 ± 0.54 <sup>ab</sup>	34.57 ± 0.84 <sup>ab</sup>	36.98 ± 0.83 <sup>a</sup>	35.58 ± 0.54 <sup>ab</sup>
	10	17.67 ± 2.41 <sup>b</sup>	21.49 ± 3.10 <sup>ab</sup>	22.86 ± 0.48 <sup>ab</sup>	24.08 ± 0.79 <sup>a</sup>	22.80 ± 1.39 <sup>ab</sup>
Stomatal conductance ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	6	0.27 ± 0.02 <sup>a</sup>	0.28 ± 0.02 <sup>a</sup>	0.30 ± 0.03 <sup>a</sup>	0.31 ± 0.03 <sup>a</sup>	0.32 ± 0.06 <sup>a</sup>
	8	0.42 ± 0.04 <sup>b</sup>	0.47 ± 0.06 <sup>ab</sup>	0.50 ± 0.07 <sup>ab</sup>	0.56 ± 0.07 <sup>a</sup>	0.54 ± 0.03 <sup>a</sup>
	10	0.27 ± 0.06 <sup>a</sup>	0.32 ± 0.04 <sup>a</sup>	0.33 ± 0.03 <sup>a</sup>	0.35 ± 0.01 <sup>a</sup>	0.26 ± 0.03 <sup>a</sup>

Note: Means with the same letters in the same row were not significant at  $p \geq 0.05$ .

The decline in stomatal conductance at 10 WAP is consistent with the reduction in photosynthesis rate, indicating physiological responses as the plants matured. Basically, plants regulate water loss through transpiration by opening and closing stomata (Volpe et al., 2011). The observed trends indicates that the application of waste products, may possibly improve photosynthetic activity and stomatal function over time. This aligns with the findings of Khairuddin et al. (2018), who reported a significant increase in stomatal conductance and transpiration rate in maize treated with POME sludge, indicating improved leaf gas exchange and photosynthetic activity.

### Yield and Yield Characteristics

From the yield data shown in Table 8, the results indicated that a significant difference was observed amongst treatments for yield characteristics parameters except cob diameter and cob length. POME treatments (T2, T3 and T4) produced significantly higher cob weight than both T1 (NPK fertiliser only) and T5 (commercial limestone). The highest cob weight was recorded in T4 (125.62 g), followed by T3 (121.25 g) and T2 (121.21 g), while T1 (93.10 g) and T5 (88.36 g) showed significantly lower cob weight. This demonstrates that the 'waste product' from POME in T2, T3 and T4 positively influenced

growth development, resulting in heavier cobs. A significant difference was observed for 1,000 seed weight, with POME treatments (T2, T3 and T4) recorded higher values than T1 however, no significant difference was observed between POME treatments and commercial limestone (T5). This suggests that the application of POME can enhance soil fertility by improving grain filling and kernel development as well as standard agricultural practise. Fresh yield per hectare was significantly higher under POME treatments with T4 producing the highest fresh yield (191.05 kg ha<sup>-1</sup>), followed by T3 (184.91 kg ha<sup>-1</sup>) and T2 (178.33 kg ha<sup>-1</sup>), while T1 (122.30 kg ha<sup>-1</sup>) showed the lowest yield. The higher yield observed in POME treatments may be attributed to increased cob weight and 1,000 seed weight. The results were consistent with a study done by Akinyele et al. (2013) that the yield increases by 50.20% from the application of POME at the rate 10–20 kg ha<sup>-1</sup>. Although no significant difference was observed in fresh yield between POME treatments and commercial limestone (T5). This comparable yield performance between POME treatments and commercial limestone highlights the potential of POME as a soil amendment for improving yield productivity on BRIS soil. By utilising POME, which is abundantly available as a by-product of palm oil manufacturing, dependency on non-renewable resources such as commercial limestone can be reduced.

TABLE 8. EFFECT OF WASTE PRODUCT ON MAIZE'S YIELD PARAMETERS

Parameter	Treatment				
	T1	T2	T3	T4	T5
Cob weight (g)	88.36 ± 9.51 <sup>b</sup>	121.21 ± 12.91 <sup>a</sup>	121.25 ± 17.12 <sup>a</sup>	125.62 ± 18.79 <sup>a</sup>	93.10 ± 12.21 <sup>b</sup>
Cob length (cm)	13.10 ± 1.16 <sup>a</sup>	13.60 ± 0.65 <sup>a</sup>	14.22 ± 1.07 <sup>a</sup>	14.88 ± 0.52 <sup>a</sup>	13.22 ± 0.53 <sup>a</sup>
Cob diameter (cm)	39.29 ± 5.03 <sup>a</sup>	38.67 ± 0.93 <sup>a</sup>	38.38 ± 1.08 <sup>a</sup>	39.46 ± 0.90 <sup>a</sup>	35.92 ± 1.52 <sup>a</sup>
1,000 seed weight (g)	64.57 ± 20.45 <sup>a</sup>	76.29 ± 6.25 <sup>a</sup>	71.01 ± 6.00 <sup>a</sup>	69.35 ± 7.38 <sup>a</sup>	72.55 ± 7.57 <sup>a</sup>
Fresh yield (kg ha <sup>-1</sup> )	122.30 ± 21.77 <sup>b</sup>	178.33 ± 27.62 <sup>a</sup>	184.91 ± 33.22 <sup>a</sup>	191.05 ± 36.87 <sup>a</sup>	137.81 ± 27.52 <sup>a</sup>

Note: Means with the same letters in the same row were not significant at  $p \geq 0.05$ .

The physico-chemical properties of POME demonstrate its potential as a soil amendment, particularly for BRIS soils. The neutral pH 7.1 and high Ca content ( $65.60 \text{ cmol}_c \text{ kg}^{-1}$ ) create favourable conditions for plant growth by buffering soil acidity and enhancing soil structure. Moreover, the high CEC of POME ( $24.31 \text{ cmol}_c \text{ kg}^{-1}$ ) enhances the soil nutrient retention capability, thereby directly supporting nutrient uptake by crops. The application of POME improves soil fertility by increasing pH value, nutrient availability, and CEC. Notably, higher POME rates in T4 exhibited improvements in nutrient availability such as available P, exchangeable cations, and CEC, highlighting its potential as a liming material for BRIS soils.

The application of POME at higher rates significantly enhanced the vegetative growth of maize, with optimal results observed at an application rate of  $15 \text{ t ha}^{-1}$  as in T4. This application rate resulted in greater plant height, girth circumference, and leaf count per plant, suggesting that POME supplies adequate nutrients to promote early vigorous crop growth for maize plants. Application of POME enhances physiological function and photosynthetic capacity, thereby supporting improved biomass accumulation in maize plants comparable to standard agricultural practise.

The comparable significance in cob weight and 1,000 seed weight across treatments suggest, that POME positively enhances yield components by improving the yield productivity of maize. The effectiveness of POME is proven by the yield results, with the highest yield of  $191.05 \text{ kg ha}^{-1}$  recorded at an application rate of  $15 \text{ t ha}^{-1}$  as in T4. This represents a 38.6% increase in yield as compared to the commercial limestone (T5), highlighting the potential of POME as an alternative liming material. By incorporating POME as a soil amendment, this can reduce reliance on conventional liming while converting this 'waste product' into a valuable agricultural input, offering a sustainable solution to the environment.

However, further research is needed to assess the long-term effects of POME application on soil fertility, long-term crop performance and potential environmental impacts across multiple cropping seasons. This would ensure the sustained efficiency and stability of POME as a sustainable soil amendment and enhance agricultural productivity.

## CONCLUSION

Based on aforementioned results, application of POME at rates between  $5$  and  $15 \text{ t ha}^{-1}$  increased

maize yield, with the highest rate ( $15 \text{ t ha}^{-1}$ ) providing better improvement in enhancing soil fertility, growth development, physiological response and yield performance, comparable to standard agricultural practices. This finding highlights the potential of POME as an alternative liming material for BRIS soils with positive effects on growth and yield productivity of maize. It is recommended to utilise POME, a readily available by product of palm oil manufacturing to reduce dependency on non-renewable resources such as commercial limestone.

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