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Influence of palm oil mills effluent (POME) sludge vermicomposting on soil physicochemical properties and Zea mays growth performances

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ABSTRACT

Discharging the palm oil mill effluents (POME) might result in environmental pollution, thus the POME wastes that had high total solids, abundant in oil palm mills, potential to be utilized as an organic amendment, vermicompost or treated POME sludge (TPS). The objectives of this study are to determine the best treatment effect of organic amendments and *Zea mays* growth performances, and to analyse the soil physicochemical properties after application of treatments after harvesting. This experiment was carried out in Randomized Completely Block Design (RCBD) with 4 treatments and 6 replications. The treatments consisted of; treatment 1: Control, treatment 2: 2 kg FVC, treatment 3: 2 kg TPS and treatment 4: 1 kg FVC and 1 kg TPS. Based on the result, 2 kg FVC (T2) treatment showed significant improvement in soil physical properties and soil shear strength. Cation exchange capacity (CEC), nutrients availability and and *Zea mays* growth performances were also improved in this experiment. For shear strength analysis, T4 treatment showed high normal stress at 319.4 kN/m^2. In conclusion, FVC organic fertilizer and mixed FVC and TPS indicated the best amendment in improving soil physicochemical and enhanced *Zea mays* growth performance and it is cost effective and environmentally friendly.

Keywords: POME sludge, Vermiculture, Physicochemical properties, Growth performances.

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1. INTRODUCTION

In 2017, Malaysia's agricultural sector generated RM96.0 billion to the nation's gross Domestic product. With a proportion of 46.6%, oil palm led all other agricultural sectors, followed by livestock (11.4%), fisheries (10.5%), rubber (7.3%), and forestry products (5.6%). (Department of Statistics Malaysia, 2018). There has been an increased usage of chemical fertilizer as it helps in growing crops on the economic scale. Modern agriculture makes extensive use of chemical (inorganic) fertilisers to alter nutritional deficiencies, to give sufficient nutrition that helps plants survive stress, to maintain optimum soil fertility, and to enhance crop quality.

Even though chemical fertilizer looks promising for crop growth, it is also contributing to decreasing soil quality and performance (Baghdadi et al., 2018). Frequent applications may generate harmful levels of toxic substances including arsenic, cadmium, and uranium to accumulate in the soil (Kumar et al., 2019). Over time, inorganic fertilisers, particularly chemical fertilisers that are not balanced, can deplete nutrients and acidify the soil. Crop growth will be thrown off as a result of this. Chemical fertiliser use will have a negative impact on soil conditions if it is widespread. This has promoted the use of organic fertiliser for enhancing soil nutrients. Organic fertilizers produced from animal and plant waste with high-quality content before applied for crop uptake with adequate nutrients availability. Organic fertilizer is safe for the agriculture ecosystem and efficient crop growth. A toxic buildup of chemicals and salts that could be fatal to plants is extremely unlikely It is very difficult to over fertilize with organic fertilizer and harm plants because it appears to be a slow-release fertilizes (Arthur et al., 2019). When organic fertilizers decompose, they release nutrients that strengthen the soil's structure and increase the soil's capacity to hold water and nutrients. (Bokhtiar et al., 2005; Hazra, 2016). The strength and health of soil and plants will be enhanced by organic fertilizers over time.

Treated POME sludge (TPS) is one of the organic fertilizers that originates from POME sludge, which is a waste extracted from crude palm oil in mills. The extraction of crude palm oil generates many by-products and liquid waste that severely affects the environment if not managed properly. Based on Najafpour et al. (2006) study, aq tonne of liquid waste containing 37.5 kg of biochemical oxygen demand (BOD), 75 kg of chemical oxygen demand (COD), 27 kg of suspended solids, and 8 kilogramme of oil and grease is generated by oil extraction from each tonne of fresh fruit bunch. Thus, it is necessary to find an alternative approach that is efficient to preserve the environment while maintaining the economic viability of the oil palm industry. A common treatment to treat POME is by using an open ponding system with a long hydraulic retention time of 150 days and maintained at 40% moisture content (Khairuddin et al., 2016).

TPS organic fertilizer formulated with some treatments and processed based on hydraulic retention time (HRT) and constant moisture content from water retention curve. TPS comprises N, P, K, Fe, Mg, Ca and S that are essential for the growth of plants while preserving soil health (Khairuddin et al., 2016). Other than that, vermicompost is also one of the organic fertilizers that has higher nutritional value characteristics compared to other organic fertilizers (Hussain & Abbasi., 2018). Vermicomposting, which involves the accumulation of organic material through the facilitative activity of earthworms and microorganisms, has the potential to become a substitute in the framework of integrated solid waste management (Wani et al., 2013).

Therefore, negative effects on agricultural practices reduced and improved using organic amendments together with the application of inorganic fertilizer to sustain soil health. At the same time, they provide enough nutrients for crops to grow economically. This not only conserves soil fertility but also reduces chemical or inorganic fertilizer cost up to 50%. This study aimed to determine the influence of TPS and vermicompost on soil physicochemical properties and yield of *Zea mays*. At the same time, to determine the best treatment effect of organic amendments application, to analyse the soil physicochemical properties after application of treatments, and to observe the yield performance of *Zea mays* after harvesting.

2. MATERIALS AND METHODS

2.1 Glasshouse Experiment

The experimental plot was located at 2°58'55.1"N 101°42'55.2"E, Biotechnology premise in Universiti Putra Malaysia. Polythene bags of a size 10’ x 12’ and the media contained a 20 kg of topsoil (0-30 cm) sandy clay loam texture obtained at 2°59'09.9"N 101°44'17.3"E, Ladang 15 Fakulti Pertanian UPM used for each polybag. The soil media mixed with fortified vermicompost (FVC) and TPS organic fertilizer (TPS) with rate: Treatment 1: No Treatment (Control) (C), Treatment 2: 2 kg FVC (FVC), Treatment 3: 2 kg TPS (TPS), and Treatment 4: 1 kg FVC + 1 kg TPS + 10 g (FVC+TPS). Treated POME Sludge (TPS) used in this experiment was obtain from the dumping pond at Oil Mill Jengka 8, Pahang. Treated POME Sludges (TPS) used as the organic amendment was processed and fortified to ensure that this material was stable and safe before used to the soil. The treated POME sludge needed to go through the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the African Night Crawler (*Eudrilus eugeniae*) consumed it as food media with additional paper shredded as their bedding. The vermicast was collected from the surface media and used as treatment after 14 days after harvested and achieved the optimum stage.

The experiment used *Zea mays* as a tested plant for one cycle, 90 days (Day after Transplant (DAT)) used as a test crop for growth and physiological characteristics. The maize seeds obtain from Malaysian Agricultural Research and Development Institute (MARDI). The maize seed was sow in sowing tray with 100% peatmoss media to get uniform growth. After 10 days, the plantlets were transplant into the polybag with the treatment. Watering the plant twice a day, in the early morning and evening until maturated stage. The chemical fertilizer (15:15:15 NPK) was introduce to plant after 14 DAT from the recommended practices. There were four treatments and 6 replications with a total of 24 experimental units was set up for a period of 100 days from June to September 2019. The polybags were arranged in a Randomized Completely Block Design (RCBD).

2.2 Soil Physicochemical Analysis

Soil samples for each polybag (0-10 cm) collected in three replications for soil physicochemical analysis. After air-drying, soil samples were grounded and passed through a 2 mm sieve. The soil physical properties were determined such as particle size distribution, bulk density, moisture content, porosity, aggregate stability, and hydraulic conductivity (Ks). Particle size distribution was determined using the pipette method with slight modification by Gee and Bauder (1986). Bulk density measured using the core method by (Blake and Hartage, 1986). Moisture content determination using the Pressure membrane method by Richards (1941). The porosity of the soil measured using the ratio of the bulk density to the particle density to describe the fraction of the total volume occupied in the solids (Blake and Hartage, 1986). Aggregate stability was determined using the dry sieving method by disturbing the size particle pass (Kemper and Rosenau, 1986). Hydraulic conductivity measurement using the falling head method described by Kirkby (1980). The soil shear strength is determined by

Direct Shear Test Apparatus, TKA-DDS-5C (Nanjing TKA Technology Co.,Ltd, Jiangsu, China) using the direct shear test method (Gan et al., 1988). The column boxes of 20 cm × 20 cm × 100 cm fixed the soil samples into it after cutting and trimming. The direct shear test device was set up at 25 cm intervals in each column box and carefully trimmed according to the size needed. A metal shear box inserted with the soil sample before starting the measurement (Abou-Chakra and Tüzün, 1999). The angle of internal friction was determined by plotting the graph of shear stress against the normal stress, which stated in the equation of soil shear strength.

Soil pH, total nitrogen, total of carbon, available phosphorus, exchangeable Potassium, Magnesium, and Calcium and Cation Exchange Capacity (CEC) were analyse for the chemical properties. Soil pH was analysed by using distilled water based on a 1:2.5 ratio of soil and water that measured by pH meter, HI-2211 (Hanna Instruments Inc., Woonsocket, United State) (Metson AJ, 1957). Kjeldahl method (Persson JÅ, 2008) used to determine the total Nitrogen while total organic carbon determine bv chromic acid titration method (Walkley and Black, 1934). Available Phosphorus measurement using the method of Bray and Kurtz (1945). Exchangeable base cations (Ca^{2+}, Mg^{2+}, and K^{+}) were determined by using NH_4OAc extraction, which then measured by atomic absorption spectrometry (AAS) instrument, PinAAcle 900T (PerkinElmer, Inc, Waltham, United States). Then, the cation exchange capacity (CEC) was determined by the addition of base and acid cations (McLean EO, 1965).

2.3 Plant Analysis

The dry weight of the plants were recorded to determine the total dry matter yield (leaves, stem, cobs and roots) at the maturity stage (90 day after transplant) for each the polybag. The plant samples were dried in the oven and left to dry at 60°C for 75 h or until the constant weight achieved. Root weight density (RWD) calculated by dividing the root weight (g) with the volume of the sampling block (cm^3) (Yang et al., 2010). Leaf area index was determined by leaf area divided by planted area. Leaf area was measured using Scanning Area Meter, LI-3100C (LI-COR Biosciences, Nebraska, United State). The chlorophyll content of maize was measure using chlorophyll content instrument, SPAD-502 (Konica Minolta, Tokyo, Japan). The measurement of the chlorophyll conducted between 8:00 to 11:00 am. To avoid the effects of leaf ages on SPAD readings, the new fully expanded leaves adjacent to a similar leaf that about to emerge was measured. Photosynthesis rate, transpiration rate, stomatal conductance was determined by using the LI-6400XT Portable Photosynthesis System- LI-COR (LI-COR®Biosciences, Nebraska, United State) during the period 8.00-11:00. From photosynthesis rate and transpiration rate data obtained, water use efficiency was calculated using Instantaneous water use efficiency (IWUE) equation (Guo et al., 2016).

2.4 Statistical Analysis

All the data were analysed using Statistical Analysis of System Software (SAS version 9.4). The effect of the treatments was analysed using ANOVA (Analysis of Variance) to determine the significant effect at $P < 0.05$ and Least Significant Different LSD test for the means of separation.

3. RESULTS AND DISCUSSION

3.1 Soil Physical

3.1.1 Particle Size Analysis (Texture)

Soil texture is one of the most fundamental properties of soil. The measured distribution of particle sizes and the proportions of the different size ranges of particles in a specific soil are represented quantitatively by soil texture. Soil texture was identified in this method. Different proportions of various sizes of particles will result in different types of soil texture. It indicates whether the soil is fertile or not. Based on the result obtained from soil texture analysis, soil used in the experiment identified as sandy clay loam texture and classified under Bungor series soil (Table 1). For sandy clay loam, a high percentage of sand was 65% and the content of silt was 9% and 26% of clay. The sand contributed good aeration to the soil but not in a high amount as it could cause high leaching of water. This is because the high content of silt and clay might result in soil compaction and creating an acidic soil condition. Bungor series soil was well drained and permeable. Rubber, oil palm, fruit trees, and cocoa were among the crops that did well in the Bungor series soil. Some of these areas are still under primary forest vegetation (Zannah et al., 2016).

3.1.2 Bulk Density

There are a significantly different at $p < 0.05$ of treatments from T1 (1.34 g/cm^3), T2 (1.05 g/cm^3), T3 (0.88 g/cm^3) and T4 (0.85 g/cm^3) (Table 2). The bulk density of

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Table 1. Result soil texture analysis

Soil Depth	Particle size distribution (micron)								Total			Soil texture class (USDA)
	Clay	Silt		Very fine sand	Fine sand	Medium sand	Coarse sand	Total	Clay	Silt	Sand	
	0-2	2-20	20-50	50-100	100-250	205-500	> 500		< 2	2-50	> 50	
C1	26.52	5.10	2.75	5.44	21.07	20.85	18.28	100.0	26.52	7.85	65.64	Sandy clay loam
C2	27.67	5.32	3.43	5.58	20.97	19.62	17.42	100.0	27.67	8.75	63.59	Sandy clay loam
C3	22.89	8.59	2.85	4.69	21.01	23.07	16.9	100.0	22.89	11.44	65.67	Sandy clay loam

Notes: C1 = 0-10 cm, C2 = 10-20 cm, and C3 = 20-30 cm.

Table 2. Soil physicochemical analysis

Parameter	Treatment			
	T1	T2	T3	T4
Soil Physical analysis				
Bulk density (g/cm^3)	1.34a	1.05c	0.88b	0.85bc
Soil Moisture Content (%)	13.70c	37.68a	25.27b	36.02a
Porosity (%)	50.00c	68.00a	60.33b	67.33a
Aggregate Stability (%)	56.58d	79.68a	66.63c	72.26b
Saturated Hydraulic Conductivity, Ks (cm/h)	3.22c	6.52b	3.42c	13.26a
Soil shear strength (kN/m^2)	277.98d	296.23b	293.06c	319.40a
Soil Chemical analysis				
pH	5.05b	5.80b	5.20a	6.20ab
Total of Carbon, TOC (%)	1.06c	2.72b	4.10a	2.62b
Available Phosphorus, P (mg/kg)	7.00b	63.50a	63.00a	63.00a
Exchangeable Potassium, K (cmolc/kg)	0.14c	1.90ab	2.69a	0.89bc
Exchangeable Calcium, Ca (cmolc/kg)	2.60c	11.60a	9.96b	12.26a
Exchangeable Magnesium, Mg (cmolc/kg)	0.39c	5.38a	3.02b	3.13b
Cation exchange capacity, CEC (cmolc/kg)	4.37b	19.65a	16.16a	16.32a

T2 was significantly higher than T3 while there was no significant difference between T4 with T3 and T4 with T2. T1 a control treatment showed significantly the highest among all the treatments. The bulk density measured using the core ring method. Generally, the bulk density parameter measures the compaction level of the soil. Bulk density tends to rise with depth and rises with compaction. It is also highly related to pore space or porosity. High traffic tends to increase the compaction level by altering soil structure in the soil. Soil bulk density is a necessary soil characteristic as an indicator before planting any type of crops.

Bulk density is highly relatable with soil compaction that might affect the soil texture, organic matter, minerals and porosity percentage (Ghestem et al., 2014). A higher proportion of small particles (clay), low content of organic matter and low porosity indicated less fertile soil. High bulk density value affects the availability of water capacity, root establishment, air and water movement through the soil. Thus, crops will be under stress as the soil is not efficient in storing water and restricts root growth. USDA (2008) states that soils with bulk densities more than 1.6 g/cm3 tend to limit root growth. Therefore, from the results obtained, soil media that mixed with organic matter; fortified vermicompost (FVC) and TPS organic fertilizer (TPS) were observed to have lower bulk density than the control treatment. Fortified vermicompost (FVC) treatments showed a reduction in soil bulk density than TPS treatment as expected.

3.1.3 Soil Moisture Content

The moisture content among the treatments which showed significant differences in T2 (37.68%), T3 (25.27%) and T4 (36.02%) compared to the control treatment (T1 13.70%) showed in Table 2. Libohova et al. (2018) claimed that organic matter could increase soil moisture content. In this experiment, the trend of soil moisture content increased as the treatment was used in the following order T1 < T3 < T4 < T2. However, there is no significant difference between treatment T2 and T4 where both treatments consist of FVC but with the different rates. As observed, the highest soil moisture content identified in T2 where 2 kg FVC applied (Table 2). This occurred as a result of its structure, high porosity, and effective water holding capacity (WHC) as soil amendments, soil conditioners, and plant growth media.

3.1.4 Porosity

Based on the results, there was a significant difference at $p < 0.05$ between T1 (50%), T2 (68%), T3 (60.33%) but no significant difference between T2 and T4 (67.33%) (Table 2). FVC treatment (T2) was significantly higher than TPS treatment (T3). The relationship of bulk density and porosity was reciprocal. Due to the inverse relationship between bulk density and porosity, the more pores a soil has, the lower its bulk density value will be. From the results, porosity in FVC treatment is the highest among the treatments. The main reason is the contribution of organic matter that is able to modify the structure by increasing the porosity. Vermicompost indicated a better result than TPS and contained adequate nutrients for plant uptake (Khairuddin et al., 2017). The presence of porosity will benefit the plant by providing spaces for the roots to establish. Furthermore, porosity was highly correlated with the movement and water retention of the soil. Thus, an adequate percentage of porosity that is also observed in this experiment might benefit the hydraulic conductivity, water holding capacity enhancement and nutrients holding (Vo and Wang, 2014).

3.1.5 Aggregate Stability

Aggregate stability was dependent on many factors, especially organic matter, soil texture and oxide contents (Duchicela et al., 2012). Based on the results observed, all treatments showed a highly significant difference at $p < 0.05$ in their aggregate stability as shown in Table 2 which was T1 (56.58%) < T3 (66.63%) < T4 (72.26%) < T2 (79.68%). Soil aggregate stability affected by the increasing organic matter content in the soil. As stated by USDA (1996), high organic matter content in the soil will have greater stability aggregate. Theoretically, good soil stability benefits the environment and crop growth as it retains soil structure by reducing erosion and improving infiltration rate. Hence, the application of organic materials such as manure or mulch is able to supply both organic matter and nutrients to the soil, thus improving aggregate stability (Hetrick et al., 2016). Therefore, similar results obtained in this experiment (Table 2) which showed treatment with organic matter having high aggregate stability compared to control. The same result discovered in Doan et al. (2015) which showed vermicompost treatment resulted in the lowest soil detachment among organic amendments as the soil has high stability. For long term or perennial plants, aggregate stability is a necessary characteristic to preserve soil structure and produce maximum yield for the long term with less maintenance.

3.1.6 Saturated Hydraulic Conductivity (Ks)

The hydraulic conductivity status after the treatments applied shows in Table 2. Hydraulic properties among treatments varied significantly between each other except, T1 and T3 where they had no significant difference between them. T4 contained 1 kg FVC and 1 kg TPS showed the highest value of Ks among the treatments while T1 (control) and T3 (2 kg TPS) showed the lowest Ks value. The high Ks value in treatment T4 was due to the contribution of FVC and TPS treatments. T1 (3.22 cm/h) and T3 (3.42 cm/h) were classified as having a moderate hydraulic conductivity, T2 (6.52 cm/h) moderately rapid hydraulic conductivity and T4 (13.26 cm/h) were at the rapid hydraulic conductivity class by referring Table 3. Therefore, hydraulic conductivity (Ks) increased due to the presence of high contents of organic matter. A similar finding in this experiment as Khairuddin et al. (2017) in his study stated That organic matter had a substantial impact on the development of the soil's pore size distribution, which also altered the soil's hydraulic conductivity. The modification of soil structure with the addition of organic matter such as TPS and FVC might reduce the pore sizes thus easing the conductivity or movement of water in the soil.

Table 3. Saturated hydraulic conductivity according to classes (O'Neal, 1949)

Class	Hydraulic conductivity, K (cm/h)
Very slow	< 0.125
Slow	0.125 – 0.500
Moderately slow	0.500 – 2.00
Moderate	2.00 – 6.25
Moderately rapid	6.25 – 12.5
Rapid	12.5 – 25.00
Very rapid	> 25.00

3.1.7 Soil Shear Strength

The results of shear strength from the supplication of different organic fertilizers shows Table 2. The analysed data indicated that there was a significant difference of shear strength ($p < 0.05$) among treatments in trend line T4 (319.40 kN/m^2) < T2 (296.23 kN/m^2) < T3 (293.06 kN/m^2) < T1 (277.98 kN/m^2). The control treatment (T1) shows the lowest shear strength while T2 with vermicompost treatment was the second highest. Shear strength correlated to soil moisture content and organic matter. Hence, these three factors correlated with each other because organic matter improved water-holding capacity that provided good moisture to the soil and good nutrient uptake for root distribution (Mahmud et al., 2018).

As we could observe from the result, T4 was the highest shear strength due to the organic matter content in the fortified vermicompost and TPS (Table 2). The soil shear strength would also correlated to the high densities of plant roots in T4 that enhanced better anchorage and provided better aggregate stability to the soil (Fig. 14(c)). These statements in agreement with Khairuddin et al. (2017) who claimed that crop roots enhanced soil shear strength thus; better root distribution due to adequate nutrients supply improved the shear strength of the soil.

3.2 Soil Chemical Analysis

When the soil was acidic or alkaline, macronutrients were not available in the soil. Thus, suitable soil pH was vital to ensure healthy plant growth. Table 2 shows that there was no significant difference in pH after application of T2 (5.8), T3 (5.2) and T4 (6.2) compared to the control T1 (5.05). Edmeades (2003) claimed that there was no consistent or significant influence of organic fertilizer on the change of the soil pH. However, in another study by Lin et al. (2019) claimed that organic fertilizer treatment had improved soil pH. Thus, to improve soil pH by organic amendment, applying appropriate rate might influence significant changes in soil pH. Table 2 also highlighted that all treatments showed the range of pH were within 5.5 to 6.5, which is conducive for roots water uptake.

3.2.1 Total Nitrogen

In Table 2, the Nitrogen content was observed significantly higher in all amended treatments; T2 (0.32%), T3 (0.49%) and T4 (0.34%) compared to control T1 (0.08%). This resulted from the inclusion of additional nutrient sources in the form of organic amendments, which through mineralization increased the amount of N pool that was available in the treated soil. The maximum availability of N in T3 treated soil was due to the TPS treatment with a low C/N ratio (6.35) (Table 4) and high N content (3.7%) (Table 4) that accelerated the N-mineralization process. Nitrogen is strongly correlated with soil organic carbon (SOC). For the production of biomass on cropland, nitrogen was the most pervasive constraint. On well-drained soils, SOC content and composition is a determining factor for soil productivity (Gaiser and Stahr, 2013).

Table 4. Physicochemical of Fortified Vermicompost (FVC) and TPS organic fertilizer (TPS)

Selected chemical characteristics	Fortified vermicompost	TPS organic fertilizer (Khairuddin et al., 2016)
pH value	8.9	6.2
Moisture content (%)	57.6	68.4
Carbon (%)	12.1	15
Total N (%)	5.0	3.7
Phosphorus (%)	0.4	0.4
Potassium (%)	10	7.6
Magnesium (%)	2.8	2.8
Calcium oxide (%)	5.06	4.5
C/N ratio	14.6	6.35

3.2.2 Total Carbon

Table 2 shows the content of organic soil carbon (SOC) which was significantly different among the treatments. SOC from T2 (2.72%), T3 (4.1%) and T4 (2.62%) were significantly higher compared to the control treatment, T1 (1.06%). T3 that is amended with TPS resulted in highest SOC content while T1 which was the control treatment showed the lowest content of SOC as expected based on Table 4 which showed TPS has a high content of SOC (15%) compared to FVC (12.1%). Soil organic matter is not only important for soil needs but also important for plant needs because of its contribution to soil nutrient pool other than improving soil structure. For soil microbes, soil organic carbon would replace other sources of energy (Dungait, 2012) and pH stabilisation, which is crucial for regulating the nutrients that are available for plant absorption (Halim et al., 2018).

3.2.3 Available Phosphorus

Table 2 shows that the available content of phosphorus (P) in T2 (63.5 mg/kg), T3 (63 mg/kg) and T4 (63 mg/kg) were significantly difference compared to the control treatment, T1 (7 mg/kg) but no significant difference among them. This may be due to the increased soil fertility level in the amended soil that made them significantly fertile than the control treatment. The initial value of available phosphorus before treatment was 7 mg/kg which was very low. Thus, as the organic amendments applied in every treatment respectively, the phosphorus availability was increased. According to Bhat et al. (2017), a concentration of phosphorus was greater in soil when incorporated with organic fertilizer.

3.2.4 Exchangeable Potassium

Table 2 shows that value of exchangeable potassium (K) was significantly difference in upward trend where T1 (0.14 cmolc/kg) < T4 (0.89 cmolc/kg) < T2 (1.9 cmolc/kg) < T3 (2.69 cmolc/kg). The lowest of total exchangeable K content observed in the control treatment, T1, and the highest was in T3 treatment. Potassium needed by crops in large quantities especially for an established crop to produce yield but easily leached by leaching. Therefore, to avoid leaching, the organic matter with high cation exchange capacity (CEC) could retain nutrients needed for crop growth (Han et al., 2016).

3.2.5 Exchangeable Calcium (Ca) and Total Magnesium (Mg)

Table 2 shows that exchangeable calcium (Ca) content was significantly difference referring to T2 (11.6 cmolc/kg), T3 (9.96 cmolc/kg) and T4 (12.26 cmolc/kg) compared to the control treatment, T1 (2.6 cmolc/kg). T2 with FVC treatment resulted as the highest content of exchangeable Ca while the lowest was the control treatment. Exchangeable magnesium (Mg) also significantly differenced among the treatments as shown in Table 2. T2 (5.38 cmolc/kg) was significantly higher than TPS treatment, T3(3.02 cmolc/kg). T3 shows no significant different with T4(3.13 cmolc/kg). While the lowest exchangeable Mg content was observed in the control treatment (0.39 cmolc/kg). The organic amendment was claimed not just acting as soil structure modification but also as nutrient sources for plant growth; besides N, P, K nutrient, Ca and Mg also supplied by organic fertilizer that was strongly associated with pH value. (Hlisnikovsky et al., 2015).

3.2.6 Cation Exchange Capacity

A measurement of the soil's capacity to hold positively charged ions is called the cation exchange capacity (CEC). It is a crucial soil characteristic that affects the stability of the soil structure, the availability of nutrients, the soil's pH, and how the soil responds to fertilisers and other ameliorants (Hazelton and Murphy, 2016). Table 2 shows that there was a significant difference on the value of cation exchange capacity from T2 (19.65 cmolc/kg), T3 (16.16 cmolc/kg), T4 (16.32 cmolc/kg) compared to the control treatment (T1 (4.37 cmolc/kg)). There was no significant difference between different organic amendments because all organic amended treatments tend to increase CEC. The organic amendment aids in enhancing the physical characteristics of the soil and raising its capacity to absorb cations and anions, which increases yield. Based on Mccauley et al. (2009) study, a typical of soils with higher levels of organic matter have a higher cation exchange capacity (CEC), which may bind more cations like calcium or potassium. A similar result indicated in this experiment.

3.3 Plant Analysis

Fig. 1 (a) shows that there was a significant difference of *Zea mays* dry weight after treated with different organic amendments; T2 (590.63 g), T3 (159.79 g) and T4 (520.47 g) compared to the control (33.03 g). T2 and T4 was a significant difference compared to T3 and T1, FVC influenced the plant growth and no significant difference among them. The application of organic amendment in the treatments was able to increase soil fertility and plant growth (Fig.1). However, the treatment with vermicompost had the most favourable effects on biomass accumulation, followed by treatment with compost (Roy et al., 2010) which also showed a similar result in this experiment. Chaulagain et al. (2017) reported, there were plant growth regulators observed in vermicompost and this might be one of the contributions to the healthy growth of a plant in FVC treatment.

3.3.1 Leaf Area Index (LAI)

Fig. 1 (b) shows that there was a significant difference in leaf area index (LAI) after treated from T2 (3780.1 m^2/m^2), T3 (2070.4 m^2/m^2) and T4 (3801.6 m^2/m^2), compared to control, T1 (515.0 m^2/m^2). The highest LAI was T2 and T4 that showed no significant difference among them that were treated with different rates of FVC. LAI was a leaf area per unit area and high LAI indicated a high plant growth rate. It proved that the growth of crops enhanced with the addition of FVC organic amendments as shown in this experiment. Additionally, according to a study by Guerrero (2010), vermicompost also includes elements that stimulate and control plant growth. Arora et al. (2011) discovered that vermicompost could increase soil microbial activity and growth, which would then result in the mineralization of plant nutrients and greater soil fertility. These advantages provided by vermicompost might be the reason for its high plant growth rate.

3.3.2 Root Weight Density

RWD is described as the root weight per unit of soil volume. Fig 1 (c) shows that there was a significant difference of RWD between all the treatments; T1 (534.4 g/m^3), T2 (1927.50 g/m^3), T3 (1042.30 g/m^3) and T4 (1514.40 g/m^3). T2 with 2 kg FVC treatment showed the highest RWD and highly significant difference compared to the other treatments. A study by Haitao et al. (2017a) showed that adding vermicompost and additional inorganic fertilizer to the soil considerably boosted plant growth and marketable yields. Mirza et al. (2010) and Khairuddin et al. (2017), reported similar findings where with organic amendments, the leaf might absorb enough nutrients and enhance good root development.

3.3.3 Chlorophyll Content

Fig. 1 (d) shows the chlorophyll content for different treatments which were difference significantly among them in the upward trend was T1 (15.3 $\mu mol/m^2$) < T3 (30.53 $\mu mol/m^2$) < T2 (45.97 $\mu mol/m^2$) < T4 (47.03 $\mu mol/m^2$). The highest chlorophyll content observed in FVC treatment followed by TPS and the lowest content observed in the control treatment. Chlorophyll is an essential photosynthetic pigment for the plant that largely determines the capacity of the photosynthetic process and hence the growth of plants (Li et al., 2018). Thus, chlorophyll content quantity is a directly proportional relationship with the photosynthesis process; the high chlorophyll content increases the photosynthesis rate process. So, based on the result in Fig. 1, a crop with FVC treatment indicated a better growth rate than the crop applied with TPS treatment because FVC showed significantly higher chlorophyll content than the TPS treatment. However, both organic amendments had improved the chlorophyll content compared to the control treatment. These results were in agreement with the data obtained by Ganeshnauth et al. (2018) that claimed the highest chlorophyll level in a plant with vermicompost treatment compared to other organic and inorganic fertilizer.

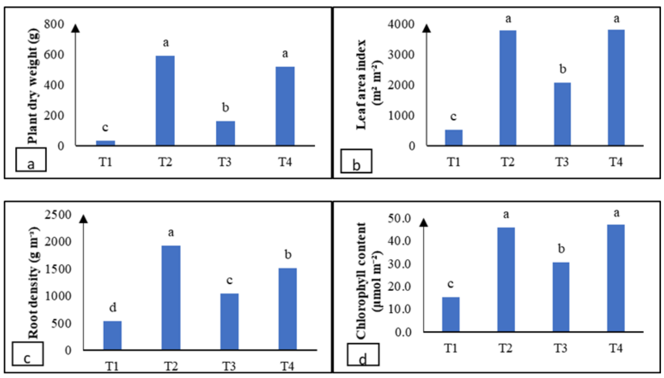

Fig. 1. Effect of different organic amendments on (a) Plant dry Weight, (b) Leaf area index, (c) root density, and (d) chlorophyll content after treated with a different organic amendment. (Mean with a difference letter are significantly difference at $p < 0.05$). (Notes: T1: Control, T2: FVC, T3: TPS, and T4: FVC+TPS).

3.3.4 Photosynthesis Rate

Fig. 2(a) shows the photosynthesis rate which significantly different compared to different organic amendment's application in the downward trend from T1

(19.91µmol/mg·h) < T3 (26.61 µmol/mg·h) < T4 (36.90 µmol/mg·h) < T2 (38.10 µmol/mg·h). Photosynthesis rate and plant chlorophyll content were directly proportional related; photosynthesis rate will get higher when chlorophyll content was high. Based on the result in Fig. 2(a), the photosynthesis rate in FVC treatment was significantly higher than TPS treatment. The same result obtained in plant chlorophyll content (Fig. 1 (d)). This indicated that a plant with FVC was grown healthily than the plant treated with TPS. The same result also obtained from Arancon et al. (2003) that revealed the use of vermicompost with appropriate dosage of inorganic fertilizer significantly increased the crop yield. This might happen due to the vermicompost contribution that promotes better soil microbial growth and behaviour, resulting in plant nutrients availability thus, increasing the soil fertility and quality (Varghese and Prabha, 2014).

3.3.5 Stomata Conductance

Fig. 2(b) shows that there was significant difference of the stomata conductance affected by different organic amendments application from T2 (1.28 mmol/m^2·s), T3 (0.83 mmol/m^2·s) and T4 (1.95 mmol/m^2·s) compared to control treatment, T1 (0.27 mmol/m^2·s). The stomata conductance in FVC treatment was significantly higher than stomatal conductance in TPS treatment. Stomata conductance was a measurement of stomata opening rate and leaf photosynthesis discovered highly correlated with stomatal conductance (Kusumi et al., 2012). Photosynthesis rate was high with the stomata conductance. The same result obtained in this experiment where stomatal conductance (Fig. 2(b)) from FVC was the highest. The same result observed in its photosynthesis rate (Fig. 2(b)). Thus, stomata conductance was a major determinant of the photosynthetic rate.

3.3.6 Transpiration Rate

Fig. 2(c) shows that there was a significant difference of transpiration rate after organic amendment application from T4 (1.44 mol/m^2·s), T2 (1.43 mol/m^2·s) and T3 (1.25 mol/m^2·s) compared to T1 (1.17 mol/m^2·s). As photosynthesis increases, more water is utilised or taken into the leaves, where the photosynthesis process takes place, increasing transpiration rates. Fig 2(c) highlighted that the plant transpiration rate in T2 (FVC treatment) showed significantly higher than TPS treatment indicating that plant growth rate in fortified VC was also higher than the TPS. Vermicompost often has a considerably finer structure than regular compost and a higher surface area, resulting in significant nutrient absorption and retention. (Imran, 2018), this was the reason why plants in FVC indicated better growth than the plant treated with TPS.

3.3.7 Water Use Efficiency (WUE)

Fig. 2(d) shows that there was a significant difference of water use efficiency effect after organic amendment application on soil in the upward trend from T1 (16.96/m^2·s) < T3 (21.30/m^2·s) < T4 (25.57/m^2·s) < T2 (26.67/m^2·s). Based on Fig. 2(d) shows that the treatments with organic amendments indicated significantly higher the transpiration rate than the control treatment. Based on the study conducted by Wang et al. (2017), the improvement in plant growth which contributed by organic amendments might also generate a high transpiration rate which in turn led to improvement of plant nutrients and water use efficiency. Water use efficiency (WUE) was highly related to the growth rate, which in this experiment the same result was obtained; vermicompost significantly affected the growth rate (Fig. 1 (a)) and water use efficiency (WUE) (Fig. 2(d)).

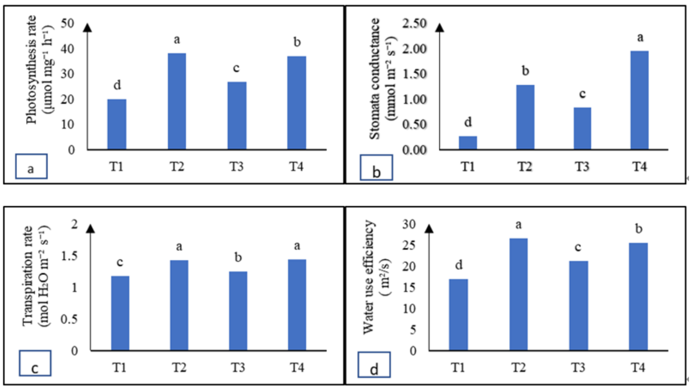

Fig. 2 indicates the (a) photosynthesis rate, (b) stomata conductance, (c) transpiration rate, and (d) water use efficiency on different treatment. Mean with a different letter are significantly difference at $p < 0.05$). (Notes: T1: Control, T2: FVC, T3: TPS, and T4: FVC+TPS).

3.3.8 Dry Weight vs. Water Use Efficiency

Fig. 3 shows the significant correlation between dry weight and water use efficiency (WUE). Based on the result, high plant dry weight contributed to a high water use efficiency. This was because a healthy plant has a better photosynthesis rate that led to better use of water efficiency by the plant. Wang et al. (2017) proved similar results in this experiment; a high photosynthesis rate indicated better plant growth rate and better water use efficiency by plants. The WUE effect observed physically on the plant appearances.

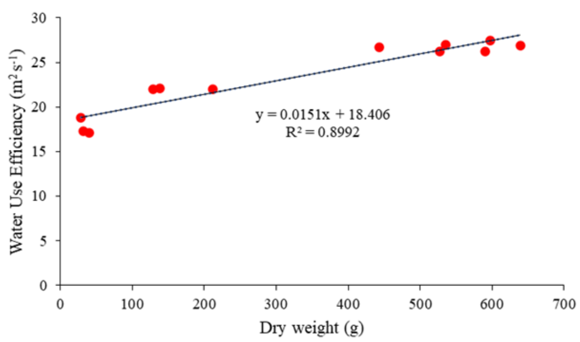

Fig. 3. Correlation between plant dry weight and water use efficiency

4. CONCLUSION

The application of FVC that produced from treated POME sludge (TPS) and the TPS as an organic amendment mixed with inorganic fertilizer to the soil had significantly shown the growth performances of the plant. FVC treatment showed significant improvement in *Zea mays*' performances in dry weight, root weight density, leaf area index, chlorophyll content, and photosynthesis process rate. There were also significant results obtained in soil physicochemical properties (bulk density, moisture content, porosity, aggregate stability, soil shear stress) and exchangeable cation capacity (CEC), and increase of macro and micronutrients contents in the soil after application of treatments in this experiment. Application of FVC exhibited the best treatment compared to TPS alone in this experiment. Future study is important to consider a combination of organic amendments and inorganic fertilizer with various rates of application for plant establishments such as maize or other potential crops. As a conclusion, the incorporation of organic and inorganic fertilizers is a good initiative of practising sustainable agriculture fertilization programs to produce high yield crops and improving farmer's income in the agricultural sector.

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