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

Khairul Najmuddin Abd Karim¹, Isharudin Md Isa¹,²*, Mohd Fauzi Ramlan², Azham Mohamad³, Mohd Nizar Khairuddin⁴, Mohd Rizal Ariffin¹

¹ Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
² Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
³ Pusat Asasi Sains Pertanian, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
⁴ Department of Statistics, FGV R&D Sdn. Bhd., Tun Razak Center of Agriculture Research, 26400 Bandar Tun Abdul Razak Jengka, Malaysia

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/m². 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.

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 fertilizers, particularly chemical fertilizers that are not balanced, can deplete nutrients and acidify the soil. Crop growth will be thrown off as a result of this. Chemical fertilizer use will have a negative impact on soil conditions if it is widespread. This has promoted the use of organic fertilizer 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 fertilizers (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 at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days. The Fortified Vermicompost (FVC) produced from the TPS where the hydraulic retention time of at least 90 days.

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 test 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 contribution 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. 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).

3.1.2Bulk Density

There are a significantly different at p < 0.05 of treatments from T1 (1.34 g/cm³), T2 (1.05 g/cm³), T3 (0.88 g/cm³) and T4 (0.85 g/cm³) (Table 2). The bulk density of...
showed a reduction in soil bulk density than TPS treatment. Fortified vermicompost (FVC) treatments observed to have lower bulk density than the control vermicompost (FVC) and TPS organic fertilizer (TPS) were media that mixed with organic matter; fortified limit root growth. Therefore, from the results obtained, soil that soils with bulk densities more than 1.6 g/cm³ tend to storing water and restricts root growth. USDA (2008) states Thus, crops will be under stress as the soil is not efficient in establishment, air and water movement through the soil. Soil bulk density is a necessary soil characteristic to increase the compaction level by altering soil structure in highly related to pore space or porosity. High traffic tends to rise with depth and rises with compaction. It is also measures the compaction level of the soil. Bulk density the core ring method. Generally, the bulk density parameter among all the treatments. The bulk density measured using T1 a control treatment showed significantly the highest significant difference between T4 with T3 and T4 with T2. T2 was significantly higher than T3 while there was no significant difference between bulk density and porosity, the more pores a soil has, 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 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>
<thead>
<tr>
<th>Class</th>
<th>Hydraulic conductivity, K (cm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very slow</td>
<td>&lt; 0.125</td>
</tr>
<tr>
<td>Slow</td>
<td>0.125 – 0.500</td>
</tr>
<tr>
<td>Moderately slow</td>
<td>0.500 – 2.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>2.00 – 6.25</td>
</tr>
<tr>
<td>Moderately rapid</td>
<td>6.25 – 12.5</td>
</tr>
<tr>
<td>Rapid</td>
<td>12.5 – 25.00</td>
</tr>
<tr>
<td>Very rapid</td>
<td>&gt; 25.00</td>
</tr>
</tbody>
</table>

3.1.7 Soil Shear Strength
The results of shear strength from the suppletion 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/m²) < T2 (296.23 kN/m²) < T3 (293.06 kN/m²) < T1 (277.98 kN/m²). 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 is strongly correlated with soil organic carbon (SOC). 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., 2013).

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 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 different 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 differentiated 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 m²/m²), T3 (2070.4 m²/m²) and T4 (3801.6 m²/m²), compared to the control, T1 (515.0 m²/m²). 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/m³), T2 (1927.50 g/m³), T3 (1042.30 g/m³) and T4 (1514.40 g/m³). 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 µmol/m²) < T3 (30.53 µmol/m²) < T2 (45.97 µmol/m²) < T4 (47.03 µmol/m²). 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.

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...
(19.91 µmol/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/m² s), T3 (0.83 mmol/m² s) and T4 (1.95 mmol/m² s) compared to control treatment, T1 (0.27 mmol/m² 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/m² s), T2 (1.43 mol/m² s) and T3 (1.25 mol/m² s) compared to T1 (1.17 mol/m² 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/m² s) < T3 (21.30/m² s) < T4 (25.57/m² s) < T2 (26.67/m² 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)).

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.

https://doi.org/10.6703/IJASE.202212_19(4).003
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.

ACKNOWLEDGMENT

The authors would like to acknowledge the School of Graduate Studies, Faculty of Agriculture and, Universiti Putra Malaysia for the financial and technical support for their kind cooperation towards this research. This research grant awarded to Isharudin Md Isa: FRGS/1/2019/WAB01/UPM/03/1.

REFERENCES


architectural traits on soil shear resistance. Plant and Soil. 377. 43–61.
Kumar, R., Kumar, R., Prakash, O. 2019. Chapter-5 the impact of chemical fertilizers on our environment and ecosystem. Chief Editor, 35, 69.
Bozeman, USA.

https://doi.org/10.6703/IJASE.202212_19(4).003
USDA. 1996. Key to soil taxonomy. NRCS. Washington, DC.