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A REVIEW OF AVAILABLE WATER CAPACITY FROM ROCK FRAGMENTS MIXING MODEL IMPROVING USING PALM OIL MILL EFFLUENT SLUDGE AS AN ORGANIC AMENDMENT

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Introduction

Soils containing rock fragments represent about 30% of the Western European surface area and about 60% in the Mediterranean zone (Poesen & Lavee, 1994). In China, about 18% of the nation's land mass is mountains composed of stony soils. In Malaysia rock fragments within the soil profile is not becoming too demanding to be studied due to heavy precipitation throughout the years. The other advantages of rock fragments contribution is towards the soil media which important in urban agriculture the soil ratio of soil and rock fragments mixtures (soil composite) as a medium for plant growth. Thus, soils containing coarse fragments are important as a medium to grow plants and supply water. Most research so far has dealt with the effect of the rock fragment covers on infiltration and hydraulic conductivity or percolation processes on sloping areas and not in lowland areas. These variables are studied with the aim of understanding how their management contributes to the amount of water stored and the ability of plant roots to take up water, especially with respect to arid and semi-arid plants. The water flows in variably saturated porous media and the amount of water in the profile system can also be measured using the modelling approach.

This will generate important knowledge about how rock fragments interact with the root water uptake by native vegetation, which could in turn determine the pattern of water redistribution within the landscape and the integration of the surface and subsurface hydrological processes that contribute to the stabilisation of the ecosystem. Motivated by this knowledge gap, we set out to describe soil hydraulic properties using binary mixtures (i.e. rock fragment inclusions in a soil matrix) based on individual properties of the rock and soil. As a first step of this study, special attention was devoted to the SWRC, where the impact of rock content on the SWRC was predicted using specific equation model for 5 different mixing ratios of soil matrix and rock. The SWRC for each mixture was obtained from the mixing model analysis created using Van Genuchten retention curve model and the combination of mixing model based on rock fragments mixtures and water content parameters of selected soil textures. The resulting data for the studied mixtures yielded a family of SWRC indicating how the SWRC of the mixture is related to that of the individual media, i.e., soil and rock. A specific model is also developed to describe the hydraulic properties of the mixture as a function of the individual properties of the rock and soil matrix. A few types of rock fragments were used in the experiment to observe the effect and roles of rock fragments within the soil profile on water storage for root plants uptake. The first part of this project deals with the presence of rock fragments and provides information about: i) the significant effect of various types of rock fragments influencing hydrological characteristics of the mix composite substrate (soil + rock fragments); and ii) the available water content at field capacity in the profile that could be taken up by plant roots over time. So, the goal of this research component is to determine if rock fragments significantly affect the water storage and POME sludge might improve vegetation establishment. Rock fragments mixing with soil and by application of treated POME sludge as organic amendment might improve available water capacity and fertility status of the composite (soil+rock fragments + POME sludge). The increasing demand of palm oil was driven by the increasing consumption of vegetable oil due to the growing human population (Corley, 2009). Due to this condition, palm oil production had grown rapidly and led to a growing concern about its environmental and ecological impacts. Increasing global demand for palm oil was mainly supplied by the increasing production in Malaysia (Lee, 2009) and it was likely to increase in coming years (Wahid *et al.*, 2008). The competition for palm oil usage between food, the feedstock for chemicals and biodiesel had put palm oil in the limelight and resulted in a controversial global debate (Reijnder & Huijbregts, 2008). The debate had revealed the importance of considering sustainability for palm oil production (Tan *et al.*, 2010).

In Malaysia, there were 4.69 million hectares of land planted with oil palm with a total annual processing capacity of 92.78 million tonnes of oil palm fresh fruit (MPOB, 2009; Tan *et al.*, 2010; Wan Razali *et al.*, 2012). According to Tan *et al.* (2010), there were 406 currently active palm oil mills in Malaysia, which produced palm oil effluent mill (POME). POME was the most polluted organic residue generated from palm oil mill (Baharuddin *et al.*, 2010). POME was consisting high organic content mainly oil and fatty acids and able to support bacterial growth to reduce its pollution strength. Indeed, the anaerobic process was the most suitable approach for its treatment (Mumtaz *et al.*, 2008). Unfortunately, in Malaysia, the most popular method for POME treatment was the open pond system utilized by more than 85% of the mills due to low cost and economic value (Baharuddin *et al.*, 2010). POME sludge was consisting high nutrient value (Zakaria *et al.*, 1994). The contents of treated POME sludge was identified suitable and in accordance with the standard of WHO-ML for human consumption and safety in term of heavy metal elements and microorganism (Table 1). However, the sludge was having a bad odor and considered as a source of surface and ground pollution. Therefore, the industries player were focused on cost-effective and sustainable technologies to dispose this industrial sludge. According to Khairuddin *et al.,* 2016 in the recent studies showed that proper management and treatment processes of POME sludge in the ponds might utilize this abundant materials into the beneficial organic matter for plant consumption. Due to that, it is possible in the upcoming years equipped with proper treatment techniques and methodologies the abundant POME sludge issues would be resolved as it was possible to utilize as an organic fertilizer. According to Chan and Chooi (1984), palm oil mill effluent sludge was possible to be dried and used as a fertilizer due to its high nutrients content.

2. Rock fragments mixing model (RFM) and van Genuchten analysis

When observing the effects of rock fragments on the intensity of hydrological processes, a differentiation between rock fragments at the soil surface and rock fragments below the surface was important. Rock fragments that are resting on the soil surface or partly incorporated in the topsoil affect rainfall interception, rock flow (i.e. runoff generated by the rock surface), infiltration, overland flow (generation and hydraulics), as well as evaporation. Rock fragments situated below the soil surface affect percolation, infiltration rate and surface runoff. Poesen & Ingelmo-Sanchez (1992) found that the percentage of the rock fragment cover (determined by the distance between rock fragments) is an important factor in controlling the continuity of overland flow along a hillslope. It is important to understand the effects of rock fragments on the dynamics of moisture content on the soil surface and below.

More research needs to be done in order to characterize the relationship between the rock fragment covers with the water from rainfall to identify the conditions under which the water is infiltrating and percolating, and is stored. In a wet year (about 663 mm of rain during the growing season), Kosmas *et al.* (1994) observed that the biomass production of rain-fed wheat along catenas on shale-sandstone soils containing about 40% to 65% of rock fragments was 60 to 80% higher than the biomass production on marl soils that had no rock fragments at all. The different capacity of these two soil types to support wheat growth could be attributed to differences in clay mineralogy, soil structure and rock fragment content. Tetegan *et al.* (2015) demonstrated that the rock fragments could contribute to the available water content (AWC) of stony soils, and neglecting the rock fragments content in the soil profile might underestimate soil available water content (SAWC). Rock fragments could act as water reservoir in the soil for root uptake and water might exchange between rock fragments and soils within the profile (Mi *et al.*, 2016).

The van Genuchten (vG) function is often used to describe soil water retention curve (SWRC) of unsaturated soils and fractured rock. Water retention curve is the relationship between the water content, θ, and the soil water potential, ψ. This curve is also called the soil moisture characteristic. It is used to predict the soil water storage, water supply to the plants (field capacity) and soil aggregate stability. The equation was proposed by van Genuchten in 1980 with the expression as below:

The van Genuchten water retention model predicts rock fragments water content according to the matric potential using the following equation:

$$(\psi) = (\theta_S - \theta_r)\left[1 + (\alpha|\psi|)\tau_n\right]\tau(-m) \qquad (1)$$

where Ψ is the matric potential in cm or the x value; θs and θr are the residual and saturated water contents, respectively; and α, n and m are fitting parameters that are directly dependent on the shape of the θ (Ψ) curve. It is assumed that m is equal to 1 – 1/n, and the parameters θs, θr, α and n are used from the databases. This equation is used to obtain the amount of plant-available water for selected soil and rocks fragments without the application of the mixing model.

Typically, the parameters of the van Genuchten model (1980) were estimated by fitting the model against discrete (θ, ψ) data pairs that can be obtained using a pressure plate extractor (Dane *et al.* 2002). Such analyses are time-consuming. The alternative methods to obtain the soil water retention curve (SWRC) in a rapid way is vital. As such, pedotransfer functions have been proposed often to estimate either the parameters of the van Genuchten model (1980) or the soil water content at certain matric potentials using readily available soil properties. Therefore, determination of hydraulic properties through measurements that can be executed relatively fast and with a limited amount of work, has gained growing interest. In comparing various analytical expressions to describe the soil water retention curve (SWRC) between saturation and −1500 kPa Cornelis *et al.* (2005) demonstrated that the van Genuchten (1980) and (Kosugi, 1994) models were superior to others. Although the van Genuchten model often fails to describe the observed trend in matric potential beyond the residual water content, it remains widely used.

Most research has been focussed on the soil rather than the rock fragment water retention, consumption and water use, with little information on the combination or mixing rock fragments with soils. The mixing of rock fragments and soils may improve water availability in the profile compared to soils alone. The mixing model was created and modified in this experiment based on the formula of van Genuchten equation (1980) to estimate the available water content in the mixed profile. Generally, rock fragments alone could retain water even it is limited. Mixing of rock fragments and soils (mixing model from van Genuchten equation) may contribute to additional water storage because of contribution of rock fragments to water holding capacity. The ratio of rock fragments in the mixed model affects the amount of water storage as well as water exchange among the rock fragments and soils. More research is needed to investigate the relationship and distribution of water in rock fragments and soils when mixed in the same profile.

The mixing model equation was used to predict the water storage in rock fragments and soils on the amount of available water capacity. Water retention curves from rock fragments mixed with soils were simulated and plotted based on the van Genuchten mixing model equation:

$$\theta_1'' i'' = \left(\theta_1'' s, i'' - \theta \downarrow'' r, i''\right)\left[1 + \left(\alpha_1'' i'' [\psi]^{\uparrow}(ni)\right)\right]^{\uparrow}(mi) \quad (2)$$

$$\theta\ comp = \sum_{i=1}^{i=n} w_i \theta_i$$

$$\theta comp = w_R \theta_R + (1 - w_R)\theta_m$$

where θ_{comp} is water content of a mixture of rock fragments and soils or sand, θ_R, saturated water content of rock fragments, θ_M, saturated water content of soils or sand, W_R, percentage of rock fragments and soils or sand used in the mixing model analysis. The above equation was used to estimate available water content when the soils and rock fragments were mixed at different percentages ranging from 5 to 95% soil. Various patterns of water retention curves for the mixtures might provide useful information regarding plant available water. The simulation was done at field capacity and permanent wilting point for all the rock fragment mixed with selected soils. In the rock fragments mixing model (RFM), simulation was initiated from 10 kPa until 1500 kPa and the pattern from the mixing graph would show the amount of water content at -10 kPa and -1500 kPa (available water capacity) or plant available water. Plant available water was defined as the difference between the soil field capacity (θ_{fc}) and permanent wilting point (θ_{wp}) water contents. The equation is as below:

$$PAW = \theta_{fc} - \theta_{wp} \quad \textbf{(3)}$$

3. Treated Palm Oil Mill Effluent Sludge

Palm oil mill effluent (POME) consists of suspended solids and dissolves solids which were left in the mills and discharged into the treatment ponds commonly named as palm oil mill effluent sludge. Therefore, the amount of sludge was increased significantly due to the large quantity of POME production each year (Khairuddin *et al.*, 2016). POME sludge was consisting high nutrient value (Zakaria *et al.*, 1994). The contents of treated POME sludge was identified suitable and in accordance with the standard of WHO-ML for human consumption and safety in term of heavy metal elements and microorganism (Table 1). However, the sludge was having a bad odor and considered as a source of surface and ground pollution. Therefore, the industries player were focussed on cost-effective and sustainable technologies to dispose this industrial sludge. According to Khairuddin *et al.* 2016 in the recent studies showed that proper management and treatment processes such as hydraulic retention time (HRT) and water retention curve technique (WRC) in the ponds might utilize this abundant materials into beneficial organic matter for plant consumption. These processes might produce the new materials which is called as treated POME sludge (TPS).

Due to that, it is possible in the upcoming years equipped with proper treatment techniques and methodologies the abundant POME sludge issues will be resolved as it is possible to utilize as an organic fertilizer. Comparison between final compost and POME mixing with empty fruit bunch (Wan Razali *et al.*, 2012), POME anaerobic sludge (Baharuddin *et al.*, 2010) and POME sludge (Khairuddin *et al.*, 2016) were identified that the nutrients and heavy metals showed that there were insignificant difference. Nevertheless, the content of nitrogen, totally solid, volatile solid, ferrum, and calcium of POME sludge was higher rather than final compost and anaerobic POME sludge. In addition, the C/N ratio value showed that maturity stage of decomposition was below 15 which was already stable. According to Chan and Chooi (1984), palm oil mill effluent sludge was possible to be dried and used as a fertilizer due to it's high nutrients content. Drying was conducted in the open ponds, but during the raining seasons, this process was disrupted due to the slow rate of drying and overflow problem. . In the present study, the treated POME sludge was used as soil amendment for maize growth due to its high nutrients content after adopting some procedures in the open treatment ponds before it was applied as soil amendment.

Table 1: Physicochemical analysis of POME sludge

Parameter	POME Sludge (Khairuddin *et al.*, 2016)	Final compost (Wan Razali *et al.*, 2012)	POME anaerobic sludge (Baharuddin *et al.*, 2010)
Carbon (%)	25.53	38.5	31.5
Nitrogen (%)	4.21	2.7	4.7
C/N ratio	6.35	13.8	6.7
Moisture content (%)	68.46	49.3	95.0
pH value	7.40	7.5	7.40
Total solid (%)	32.40	-	-
Volatile solid (%)	89.43	-	-
Heavy metal elements	**POME Sludge (Khairuddin *et al.*, 2016)**	**Final compost (Wan Razali et al, 2010)**	**WHO-ML Standard**
Copper (mg/kg)	45.05 ± 2.87	70.40 ± 21.60	75.00
Chromium (mg/kg)	27.86 ± 0.55	9.30 ± 0.20	150.00
Cadmium (mg/kg)	0.41 ± 0.01	4.10 ± 0.50	1.90
Zinc (mg/kg)	130.11 ± 3.49	90.70 ± 10.00	140.00
Plumbum (mg/kg)	0.38 ± 0.10	4.20 ± 1.60	0.30
Nickel (mg/kg)	10.77 ± 0.15	n.d	67.00
Manganese (mg/kg)	422.56 ± 12.04	250.40 ± 25.10	500.00
Nutrient elements	**POME Sludge (Khairuddin *et al.*, 2016)**	**Final compost (Wan Razali et al, 2010)**	
Ferrum (%)	2.24 ± 0.02	1.20 ± 0.30	
Potassium (%)	0.03 ± 0.01	0.03 ± 0.20	
Calcium (%)	1.67 ± 0.04	0.70 ± 0.20	
Magnesium (%)	0.55 ± 0.02	1.00 ± 0.10	
Phosphorus (%)	0.08 ± 0.01	1.30 ± 0.20	
Sulfur (%)	0.30 ± 0.01	1.20 ± 0.40	

WHO-ML; Codex Alimentarius Commission (FAO/WHO). Food additives and contaminants. Joint FAO/WHO Food (2001)

4. Potential Usage of treated POME sludge in Agriculture

Usage of organic waste on land was necessary for sustainable agriculture (Silva, *et al.*, 2010). Furthermore, utilizing POME sludge might increase soil quality and environment as well as economic performances. On the other hand, application of organic matter based on oil palm waste such as empty fruit bunch (EFB), decanter cake and POME in agriculture had been well utilized (Embrandiri, *et al.*, 2013). However, the actual practices was different where the POME sludge was still left abundantly and underutilized by the industrial players. Proper management and treatments of POME sludge might become possible for the plantation to utilize it as fertilizer. According to Aroujo *et al.* (2009), the main intention was finding a solution in an ecological way to use POME sludge without environmental risks and recycling it as an organic waste. Meanwhile, the potential of organic waste with high content of organic matter and nutrients could be used as fertilizer for the plants (Singh, *et al.*, 2015; Melo, *et al.*, 2007). Nevertheless, the important characteristics of sludge was its nutrient quality, C/N ratio, trace elements, pH, moisture, and heavy metals. Indeed, these could give significant effect on soil nutrients and plant performances (Singh *et al.*, 2015). In the recent studies by Khairuddin *et al.*, (2016), proper management and treatment techniques applied, the POME sludge was able to be converted into an organic amendment (treated POME sludge)(TPS) for plant establishment. Significant results were produced on the effect of soil properties and plant growth after application of treated POME sludge (Khairuddin *et al.*, 2017a).

5. Water retention curves and rock fragments mixing model (RFM)

This study conceptually investigated how rock fragments contribute to the dynamics of available water at the soil surface and below using the van Genuchten water retention equation. Rock fragments with good porosity and hydraulic conductivity were chosen for the analysis of the mixtures with soils differing in texture. The mixtures tested in the present study ranged from 5% to 90% of rock fragments in soils. However, only the mixtures with 30%, 50% and 60% of rock fragments were presented to facilitate a comparison with the reported literature. The difference in water content greater than 10% was considered significantly different (Isabelle *et al.* 2003). In this experiment, 10 types of rock fragments were characterised; however, only five rock types were chosen as representative samples in terms of water holding capacity at variable matric potentials (-33 to -1500 kPa) measured by the pressure plate membrane method and modelled using the van Genuchten mixing model equation (Table 2.3). The lowest measurement point was -1500 kPa, the permanent wilting point (PWP) for most agricultural plants.

The water retention curves of weathered metamorphosed shale (Red Shale) measured by the pressure plate membrane method (Fig. 1A) and calculated by the van Genuchten mixing model (Fig. 1B) were in good agreement. There was no difference between measured and modelled water content at -33 kPa for Red Shale rock fragments. The available water capacity (AWC, between -33 kPa and -1500 kPa) of the Red Shale was 0.02 $cm^3\ cm^{-3}$ (Fig. 1C). In the mixture of 30% Red Shale rock fragments with silt loam soil, AWC was non-significantly lower (0.154 $cm^3\ cm^{-3}$) compared to silt loam soil (0.168 $cm^3\ cm^{-3}$) (Fig. 1C). When the proportion of rock fragments increased to 50% and 60% in the mixture with silt loam soil, the AWC decreased significantly compared to 30% mixture and silt loam soil (Fig. 1C).

We could assume that in the arid or semi-arid areas in which soil and rock fragments were mixed for conservation and rehabilitation purposes, if the presence of rock fragments did not exceed 30% (except for sandy soil), the available water content in the profile might not be significantly altered compared with soil. In a range of tested rock fragments (such as Red Shale, Ferry Sandstone, Permian Siltstone, Telfer and Weathered rock) there was significant difference in available water capacity between silt loam soil and 30% rock fragments mixtures.

The water content of Ferry Sandstone rock fragments between -33 kPa and -1500 kPa was relatively low (Fig. 2A). In contrast, silt loam soil had much higher water content than Ferry Sandstone rock (Fig. 2B). In comparison, at -33 kPa (field capacity), the water content was 0.393 $cm^3\ cm^{-3}$ in silt loam soil and 0.076 $cm^3\ cm^{-3}$ (80% lower) in Ferry Sandstone rock fragments (Fig. 2B). Hence, an increased proportion of rock fragments in the mixtures resulted in a decrease in the AWC (Fig. 2C). In general, most rock types tested in this experiment might retain substantial amounts of available water, with the 30% rock fragment mixtures having either comparable of available water content (AWC). Higher proportions of rock fragments (50% to 60%) in mixtures with soils might allow evaporation loss to occur and would lower the amount of water retained, potentially hindered root elongation and plant growth.

This might give us a different perspective and understanding on water storage within the soil horizon mixing with the rock fragments content. In a dry climate, where water storage was limited for the plants, water stored in or below rock layers was relatively safe from evaporative loss, thus it could be utilized effectively by the root systems. The mechanical impedance of rocks and hardpans may restrict the available root volume for water uptake. When plants lack water, they expand their root systems in the deep rock layers, widening gaps and exposing more rock surfaces to weathering (Schwinning, 2010). The capacity of plant roots to extract water held by rock fragments compared to the mixtures of rock fragments and soils needs to be explored more in the further work. Rock fragments may play an important role in certain conditions (e.g. where water is limited or the soil layers are shallow) providing water accessible to plants, thus increase remediation options in some ecosystems (eg. minesite rehabilitation).

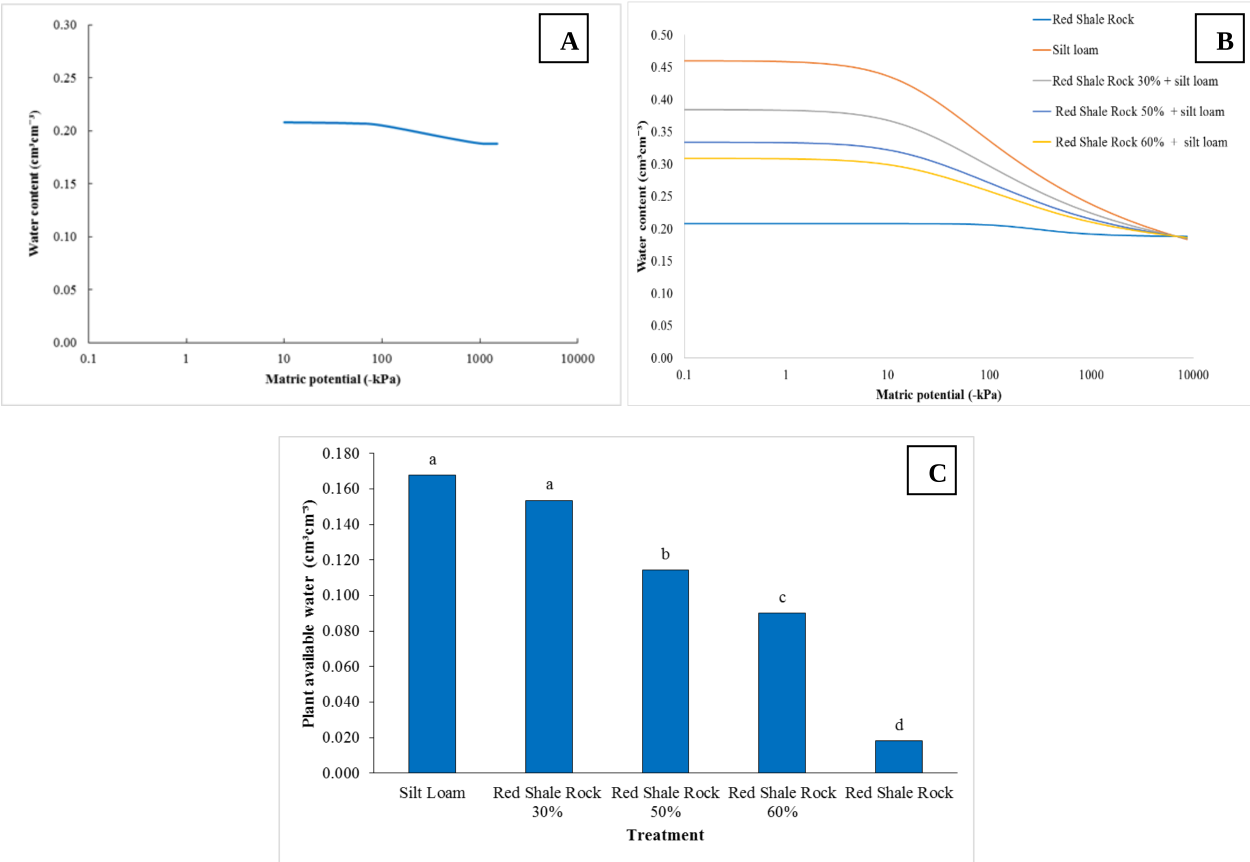

Fig. 1 : Water retention curve of Red Shale rock fragments measured using the pressure plate method (A) and calculated using the van Genuchten model (B) with predicted plant-available water capacity (PAW) (C) calculated from 1B. Bars with different letters are significantly different at ≥10%.

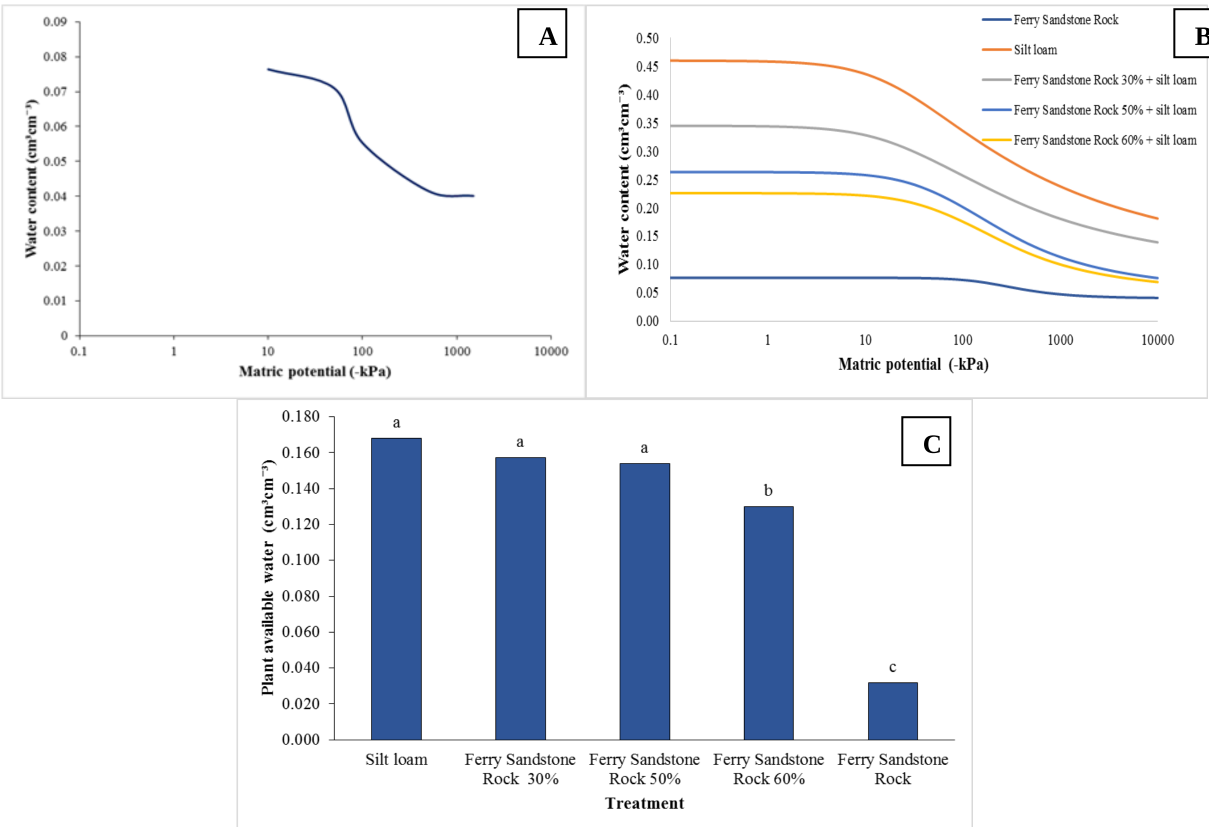

Fig. 2 : Water retention curve of Ferry Sandstone rock fragments measured using the pressure plate method (A) and calculated using the van Genuchten model (B) with predicted plant-available water capacity (PAW) (C) calculated from 2B. Bars with different letters are significantly different at ≥10%.

6. Soil chemical properties

According to Embrandiri *et al.* (2013) reported that palm oil mill effluent (POME), palm kernel cake, decanter cake, empty fruit bunch and palm kernel shell were potential to be processed and used as an organic matter amendment for land application. Recently, some studies were using decanter cake with lady's finger (Embrandiri *et al.*, 2013), tannery sludge with capsicum plants (Silva *et al.*, 2010), cowpea (Silva *et al.*, 2013) and olive mill waste with lettuce and chicory (Kelepsei and Tzortzakis, 2009) as their organic matter materials for soil amendment. Unfortunately, only a few studies were focused on POME sludge as a soil amendment for the plant growth. According to Khairuddin *et al.* (2016), the treated POME sludge was identified equally balance with C, N, and macronutrients (P, K, Ca, Mg, S, Na). Mostly, these elements were vital for soil fertility status and increased productivity of the crops. Moreover, heavy metals content in POME sludge were determined in accordance with the standard of WHO/FAO that safe for human consumption. POME sludge increased organic matter content, decreased bulk density and provided more nutrients in the soil. According to Hao *et al.* (2008), stated that the application of organic amendments generally elevates the soil organic matter and microbial biomass contents to a much greater extent. Indirectly, it could also assist in producing high yield as well as the better growth of the plant.

7. Soil physical properties

Application treated POME sludge might enhance soil physical properties and improved fertility status of the soil (Khairuddin *et al.* 2016). According to Dexter (1988), organic matter content reduced the soil bulk density and soil compaction. El-Shakweer *et al.* (2008) were also reported that the organic matter was able to increase soil porosity and infiltration rate. According to Hati and Bandyoopadhay (2011), the addition of organic matter increased aggregation and pore volume and showed a positive effect on the saturated hydraulic conductivity of the soil. Improvement of soil physical and hydraulic properties would increase crop yield and quality. The plant available water (PAW) was determined by the different of water content between field capacity and permanent wilting point in the soil. In addition, the plant available water might assist the efficiency of nutrients uptake in the soil to the plant (Karlen *et al.*, 1994).

8. The effects of POME sludge on plant growth

Growth morphology and performance was important to determine the potential biomass of the plant that affected the used of various fertilizer applications (Silva et al, 2010). Indeed, a similar effect was shown by organic fertilizer in the growth media (Singh and Agrawal, 2009; Silva et al, 2010). Some studies were shown the significant growth of shoot, root and total biomass of plants such as capsicum (Silva *et al.*, 2010), lady finger (Singh and Agrawal, 2009), Chinese cabbage (Wong, 1996), sesame plant (Gupta and Sinha, 2006) and beetroot (Aggarwal and Goyal, 2007). Gas exchanges properties were important to identify the needs of plant growth (Box, 1996). Moreover, there was important to observe the interaction between physicochemical needs with the gas exchange parameter including net photosynthesis (A_{net}), stomatal conductance (G_s), internal CO_2 concentration (C_i), and transpiration rate (E_L).

8.1. Growth morphology and performance

The effect of treated POME sludge on the morphology and growth parameter was vital to observe. Morphology and growth parameter was observed and measured such as plant height, diameter, leaf number, leaf area, root density, ears length, ears diameter, ears biomass, leaf biomass, shoot biomass and root biomass. Morphological analysis revealed that the performance of organic amendment positively affects the plant growth. Organic amendment based on oil palm had shown as the suitable substitute of inorganic fertilizers (Embrandiri *et al.*, 2013). The treated POME sludge showed a positive effect on the crop, due to the high nutrients content in the organic matter. All the measurements were directly influenced the physical growth of maize (Khairuddin *et al.* 2016).

Plant biomass was derived from the plant material that included leaves, brunches, barks, woods, and roots. Dry matter was the basic fundamental aspect of identifying the importance of biomass for the plant. These could be observed from the previous research publication on plant physiology. According to Silva *et al.* (2010) reported that total biomass was able to justify the effectiveness of the plant growth in any treatments in the plant trial. According to Hunt (1982), the growth parameter was formulated by correction of leaf area ratio (LAR) (1), specific leaf area (SLA) (2), leaf weight ratio (LWR) (3) and the root-shoot ratio (RSR) (4). Below are the details:

$$LAR\ (cm^2\ g^{-1}) = \frac{\text{Leaf area}}{\text{Total biomass}} \quad \textbf{(4)}$$

$$SLA\ (cm^2\ g^{-1}) = \frac{\text{Leaf area}}{\text{Leaf biomass}} \quad \textbf{(5)}$$

$$LWR\ (cm^2\ g^{-1}) = \frac{\text{Leaf biomass}}{\text{Total biomass}} \quad \textbf{(6)}$$

$$RSR\ (cm^2\ g^{-1}) = \frac{\text{Root biomass}}{\text{Shoot biomass}} \quad \textbf{(7)}$$

8.2 Gas exchange properties

According to Abdul-Hamid *et al.* (2011) the measurement of net photosynthesis (A_{net}), stomatal conductance (G_s), internal CO_2 concentration (C_i), and transpiration rate (E_L) were used to measure the respond of plants towards the environment. According to Silva *et al.* (2010), gas exchange content indicates the effectiveness of plant could obtain nutrients for the growth. An organic fertilizer from tannery sludge (Silva *et al.* 2010), POME decanter cake (Embtandiri *et al.*, 2013), and POME sludge – humic and fulvic acids (Mia and Shamsuddin, 2010) reported an increase in gas exchange and chlorophyll formation at growing stage. Additionally, chlorophyll content had also increased the pigment content in the plant. Meanwhile, there were no negative effects on plant growth after application of organic sludge (Silva *et al.*, 2010).

According to Abdul-Hamid *et al.* (2011), there was a positive linear between photosynthesis clean (A_{net}) and stomatal conductance (G_s) was obviously related to the environment and leaves morphology. In addition, the correlation could be modulated in the long term with the growth conditions such as nitrogen, light environment, and high CO_2 concentrations (Wong *et al.*, 1979). The combination pattern of stomata-photosynthesis model was the cause of the changes in physiological capacities of photosynthesis and patchy stomatal closure (Uddling *et al.*, 2005) and low leaf water potential (Kramer and Boyer, 1995 and Abdul-Hamid *et al.*, 2011). Furthermore, the abundance of CEC in soil affected the stomata conductivity for the gas exchanges on the guard cells and epidermal turgor in the cell (Franks *et al.*, 2001).

9. Effect of POME sludge on root length density and shear strength

Plant root system is important in the interaction with the soil that contributes more than shoot system. According to Hedley *et al.* (2010) reported that evaluations of plant root systems are particular limits with the soil matrix. However, analysis on the root density could possibly determine the potential production of the plants. The root density could highlight the reliability to sequester certain element such as carbon in the soil properties (Hedley *et al.*, 2010). Indeed, root density had the potential to increase water use efficiency by optimizing the used of subsoil water and to recapture nitrate (Besharat *et al.*, 2010).

Soil strength was derived from direct shear test method which the frictional resistance met by soil constituent particles when they were forced to slide over one another or to move out of interlocking positions (Khairuddin *et al.*, 2017). The shear strength extent to which stresses or forces were absorbed by solid-to-solid contact among the particles, cohesive forces related to chemical bonding of clay minerals, and surface tension forces within the moisture films in unsaturated soils (Isa *et al.*, 2017). The presence of roots would result in an overall increase of the soil strength. According to Khairuddin *et al.* (2017), the treated POME sludge was able to give positive effect by increasing soil shear strength with low cohesion and high angle of internal friction value which significantly contributed by the root densities. This arises from the combined effects of soil reinforcement by a mass of roots (Mohamad Nordin *et al.*, 2011) and soil moisture depletion by evapotranspiration (Ali and Osman, 2008). Other factors, which affected the soil strength was soil moisture content, particle size distribution (soil texture), and the mineralogical content of the different soil series.

Generally, the graph showed that the shear strength was obtained after the application of normal stress at 100 kN m^{-2}, 200 kN m^{-2} and 300 kN m^{-2} in all samples. The peak strength or shear strength was plotted for the different POME sludge treatments that were used in the experiment. The different types of POME sludge were differentiate based on maturity stage of decomposition in the treatment ponds. Relatively, the dumping pond (DP) treatment was low cohesion, c, while the angle of internal friction, φ, increased and the shear stress at failure was obtained from the shear strength equation. The maximum shear strength in DP treatment was 500.72 kN m^{-2}, φ was 30º and the root length density (RLD) was observed at 334.16 g m^{-3} (Table 2). The treatment with high root length density (RLD) in algae pond (ALP) with 271.7 g m^{-3} showed the decreased of cohesion value to 135 and φ value was slightly increased. The maize treated with DP treatment indicated high shear strength compared to all the treatments (Figure 3). (Ali and Osman, 2008) reported that roots system and roots length density (RLD) increased the shear strength of the soil. The cohesion value in control treatment was slightly lower than the other treatments. While the cohesion value (c) was low, the φ value tends to increase.

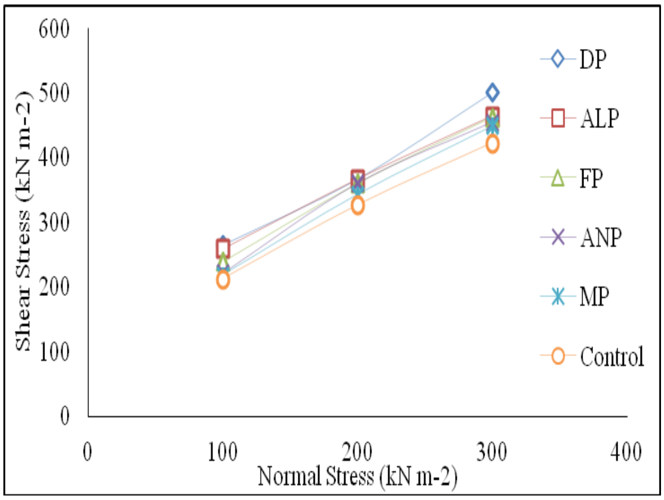

Fig. 3 : Relationship of shear stress and normal stress for POME sludge treatment (control, MP, ANP, FP, ALP, and DP) (Khairuddin *et al.*, 2017)

Table 2: Soil and POME sludge treatment indicated root density and shear strength parameter of Entisols (Khairuddin *et al.*, 2017)

Treatment	Root density (cm cm^{-3})	Cohesion (c)	Angle of Internal Friction (φ)	Shear strength (kN m^{-2}) (τ)
Control	75.53	140	25^{O}	422.95
MP	143.69	135	26^{O}	449.67
ANP	203.02	130	27^{O}	454.39
FP	258.24	120	28^{O}	462.83
ALP	271.7	100	29^{O}	464.14
DP	334.16	80	30^{O}	500.72

Note: MP sludge (Mixing ponds sludge), ANP sludge (Anaerobic ponds sludge), FP sludge (Facultative ponds sludge), ALP sludge (Algae ponds sludge) and DP sludge (Dumping ponds sludge).

10. Effect of POME sludge on microbial present

Microbial in POME sludge was vital in the digestion process. This study had identified that microbial of anaerobic bacteria was presesent such as methanogenic bacteria (1), acetogenic bacteria (2) and acidogenic bacteria (3) (Figure 4 and 5). According to Mata-Alvarez (2003) that these bacterial activities were important in the decomposition process. According to Kankal (2012) the anaerobic breakdown or digestion was assisted by the methanogenic bacteria.

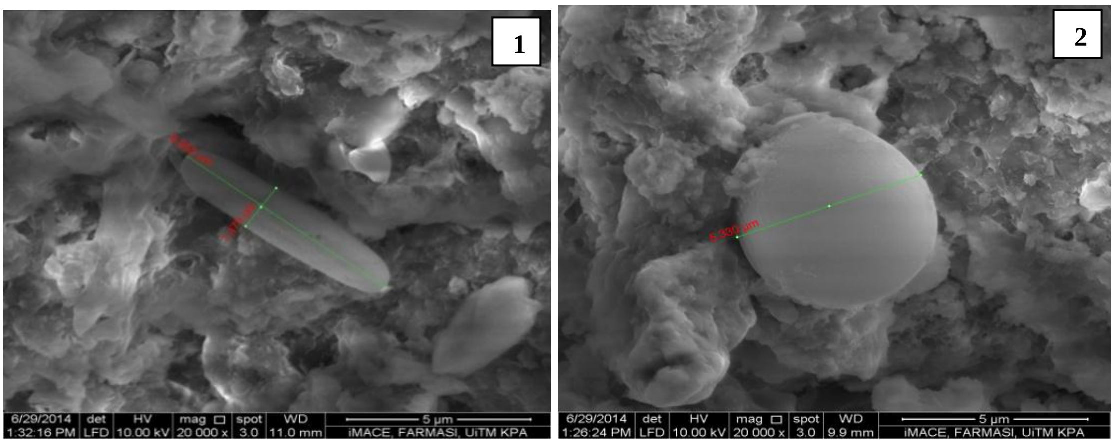

Fig. 4 : FESEM micrograph (Magnification 20000x) treated POME sludge structure with acetogenic and methanogenic bacteria in dumping pond. (Khairuddin *et al.,* 2016)

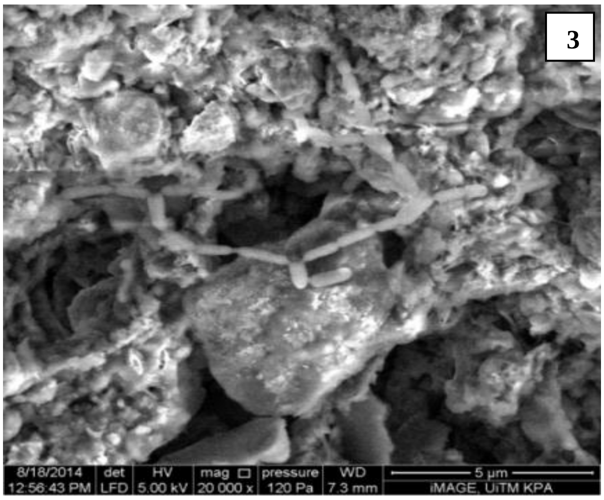

Fig. 5 : FESEM micrograph (Magnification 20000x) detected colonization of acidogenic bacteria in treated POME sludge. (Khairuddin *et al.*, 2016).

Conclusion

By using water retention measurements from rock fragments mixing model (RFM) analysis, I found some rock fragments were able to increase water content in the mixtures with soil (30% mixture), contributing to the available water capacity (AWC) that could be used for plant uptake. Mixing of 30% to 60% rock fragments with soil decreased AWC in case of silt loam and loam soils, but might increase it in case of sandy soil. Further research as part of the field experiment will be conducted to observe the performance of plant species at different proportion of rock fragments mixtures and the effects towards the plant growth.Treated POME sludge was potential and vital to be used as an alternative of soil organic amendments for the plants. The results had proven that treated POME sludge is safe to use in agriculture. Appropriate management and processes involved in the treatments ponds system was able to produce good quality of organic amendments with low heavy metals and rich in nutrients content required by the plant growth. For further research, combination application of appropriate rock fragments ratio based on van rock fragments mixing model (RFM) analysis with treated POME sludge (TPS) would improve soil physicochemical status of the composite (soil+rock fragments+treated POME sludge) and plant performances.

References

Abdul-Hamid, H.; Abdu, A.; Ismail, M.K. and Senin, A.L. (2011). Gas Exchange of Three Dipterocarp Species in a Reciprocal Planting. Asian Journal of Plant Sciences.

Aggarwal, H. and Goyal, D. (2007). Phytoremediation of some heavy metals by agronomic crops. Developments in environmental science, 5: 79-98.

Ahmad, A.; Ismail, S. and Bhatia, S. (2003).Water recycling from palm oil mill effluent (POME) using membrane technology. Desalination, 157(87): 95-101.

Ali, F.H. and Osman, N. (2008). Shear strength of a soil containing vegetation roots. Soils and Foundations, 48(4): 587-596.

Araujo, A.S.F.; Melo, W.J.; Santos, J.A. and Melo, V.P. (2009). Use of municipal and in-dustrial sludge in agricultural soil: responses of soil microbial and soil enzymes. In: Samuelson JP (Org.). Industrial waste: Environmental Impact, Disposal and Treatment. 1ed. New York: Nova Science: 349-367.

Arshad, M.A. and Martin, S. (2002). Identifying critical limits for soil quality indicators in agroecosystem. Agric. Ecosyst. Environment, 88: 153-160.

Baharuddin, A.S.; Lim, S.H.; Md Yusof, M.Z.; Abdul Rahman, N.A.; Md. Shah, U.K.; Hassan, M.A.; Wakisaka, M.; Sakai, K. and Shirai, Y. (2010). Effect of palm oil mill ef-fluent (POME) anaerobic sludge based compost using fourier transform infrared (FTIR) and nuclear magnetic resonance (NMR) analysis. African Journal Biotechnology, 10(41): 2427-2436.

Besharat, S.; Nazemi, A.H. and Sadraddini, A.A. (2010). Parametric Modeling of Root Length Density and Root Water Uptake in Unsaturated Soil. Turk Journal Agriculture For, 34: 439-449.

Bigdeli, M. and Seilsepour, M. (2008). Investigation of Metals Accumulation in Some Vegetables Irrigated with Waste Water in Share Rey-Iran and Toxicological Implications. American-Eurasian J. Agric. & Environ. Sci., 4 (1): 86-92.

Box, E.O. (1996). Plant functional types and climate at the global scale. Journal of Vegetation Science, 7(3): 309-320.

Chan, K.S. and Chooi, C.F. (1984). Ponding system for palm oil mill effluent treatment. In: Proceedings of the Regional Workshop on Palm Oil Mill Technology & Effluent Treatment: 185-192.

Codex Alimentarius Commission (FAO/WHO). (2001). Food additives and contaminants. Joint FAO/WHO Food, Standards Program; ALINORM 01/12A: 1-289.

Corley, R.H. (2009). How much palm oil do we need? Environment Science Policy 12(2):134-136.

Dexter, A.R. (1988). Advances in characterization of soil structure. Soil and tillage research, 11(3-4): 199-238.

El-Shakweer, M.H.A.; El-Sayad, E.A. and Ewees, M.S.A. (2008). Soil and plant analysis as a guide for interpretation of the improvement efficiency of organic conditioners added to different soil in Egypt. Common. Soil Sci. Plant Anal., 29(11-14): 2067-2088.

Embrandiri, A.; Singh, R.P. and Ibrahim, M.H. (2013). Biochemical, morphological, and yield responses of lady's finger plants to varying ratios of plam oil mill waste (decanter cake) application as a bio-fertilizer. International Journal of Recycling of Organic Waste in Agriculture, 2: 1-7.

Environment Protection Agency (EPA). (2000). Wastewater Technology Fact Sheet: Anaerobic Lagoons. Reviewed on 20 April 2017 at http://www.epa. gov/owm/ mtb/mtbfact.htm

Franks, P.J.; Buckley, T.N.; Shope, J.C. and Mott, K.A. (2001). Guard cell volume and pressure measured concurrently by confocal microscopy and the cell pressure probe. Plant Physiology, 125(4): 1577-1584.

Gasim, M.B.; Ismail, B.S.; Mir, S.I.; Rahim, S.A. and Toriman, M.E. (2011). The physico-chemical properties of four soil series in Tasik Chini, Pahang, Malaysia. Asian Journal of Earth Sciences, 4(2): 75.

Hao, X.H.; Liu, S.L.; Wu, J.S.; Hu, R.G.; Tong, C.L. and Su, Y.Y. (2008). Effect of long-term application of inorganic fertilizer and organic amendments on soil organic matter and microbial biomass in three subtropical paddy soils. Nutrient Cycling in Agro-ecosystems, 81(1): 17-24.

Hati, K. and Bandyoopadhay, K. (2011). Fertilizers (mineral, organic), effect on soil physical properties. Encyclopedia of Agrophysics (pp. 296-299). Springer Netherlands.

Hedley, M.; Kusumo, B.; Hedley, C. and Tuohy, M. (2010). Field Measurement of Root Density and Soil Organic Carbon Content Using Soil Spectral Reflectance. 19th World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane, Australia.

Hunt, R. (1982). Plant growth curves, the functional approach to plant growth analysis. London, Edward Arnold: 248.

Isa, I.; Shamshuddin, J. and Khairuddin, M.N. (2017). Effects of mix vegetation and root shear strength grown on carbonaceous shale. Asian J. Applied Sci., 11: 1-13.

Kankal, N.C.; Dhadse, S. and Kumari, B. (2012). Study of diverse methanogenic and non-methanogenic bacteria used for the enhancement of biogas production. Int. Journal Life Science Biotechnology & Pharma Research, 1(2).

Karlen, D.L. and Stott, D.E. (1994). A framework for evaluating physical and chemical indicators of soil quality. Defining soil quality for a sustainable environment (definingsoilqua): 53-72.

Kelepesi, S. and Tzortzakis, N.G. (2009). Olive mill wastes—a growing medium component for seedling and crop production of lettuce and chicory. International journal of vegetable science, 15(4): 325-339.

Khairuddin, M.N.; Isharudin M.I.; Abd Jamil, Z.; Hamdan, J. and Syahrizan, S. (2017). Shear Strength and Root Length Density Analyses of Entisols Treated with Palm Oil Mill Effluent (POME) Sludge. Soil & Environment 36(1): 90-114.

Khairuddin, M.N.; Zakaria, A.J.; Isa, I.M.; Jol, H.; Rahman, W.M.N.W.A. and Salleh, M.K.S. (2016). The Potential of Treated Palm Oil Mill Effluent (Pome) Sludge as an Organic Fertilizer. AGRIVITA, Journal of Agricultural Science, 38(2): 142-154.

Kramer, P.J. and Boyer, J.S. (1995). Water relations of plants and soils. Academic press.

Lam, M.K. and Lee, K.T. (2011). Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win–win strategies toward better environmental protection. Biotechnology Advances, 29(1): 124-141.

Lee, K.T. (2009). Life cycle assessment of palm oil diesel. Application Energy 8 (6): 189

Lorestani, A.A.Z. (2006). Biological treatment of palm oil mill effluent (POME) using an up-flow anaerobic sludge fixed film (UASFF) bioreactor (Doctoral dissertation, USM).

Mata-Alvarez, J. (2003). Biomethanization of the organic fraction of municipal solid wastes. IW Publication.

Melo, W.J.; Aguiar, O.S. and Melo, V.P. (2007). Nickel in a tropical soil treated with sewage sludge and cropped with maize in a long-term field study. Soil Biol Biochem., 39: 1341- 1347.

Mohamad Nordin, A.; Normaniza, O. and Faisal, H.A. (2011). Soil-root shear strength properties of some slope plants. Sains Malaysiana 40(10): 1065–1073.

Malaysian Palm Oil Board (MPOB). (2009). Malaysia oil palm statistic. Reviewed on 29 June 2019 at http://www.econ.mpob.gov.my/economy/annual/stat2009/area1_1.pdf

Malaysian Palm Oil Board (MPOB). (2008). Bio-fertilizer from palm oil biomass and POME solids by mobile composter.MPOB TT 381. Reviewed on 29 June 2019 at http://palmoilis.mpob.gov.my/publications/TOT/TT-381.pdf

Mia, M.B. and Shamsuddin, Z.H. (2010). Rhizobium as a crop enhancer and biofertilizer for increased cereal production. African journal of Biotechnology, 9(37): 6001-6009.

Mumtaz, T.; Abd-aziz, S.; Abdul Rahman, N.A.; Phang, L.Y.; Shirai, Y. and Hassan, M.A. (2008). Pilot-scale of recovery of low molecular weight organic acids from anaer-obically treated palm oil mill effluent (POME) with energy integrated system. African Journal Biotechnology, 21: 3900-3905.

Okwute, L.O. and Isu, N.R. (2007). The environmental impact of palm oil mill effluent (POME) on some physicochemical parameters and total aerobic bioload of soil at a dump Site in Anyigba, Kogi State, Nigeria. African Journal of Agricultural Research, 2(12): 656-662.

Reijnders, L. and Huijbregts, M.A.J. (2008). Palm oil and the emission of carbon-based greenhouse gases. Journal of cleaner production, 16(4): 477-482.

Rupani, P.F.; Singh, R.P.; Ibrahim, M.H. and Esa, N. (2010). Review of current palm oil mill effluent (POME) treatment methods, vermi-composting as a sustainable practice. World Applied Sciences Journal 11(1): 70–81.

Silva, M.D.; Ferreira Araújo, A.S.; Pinheiro Leal Nunes, L.A.; de Melo, W.J. and Pratap Singh, R. (2013). Heavy metals in cowpea (*Vigna unguiculata* L.) after tannery sludge compost amendment. Chilean journal of agricultural research, 73(3): 282-287.

Silva, J.D.; Leal, T.T.; Araújo, A.S.; Araujo, R.M.; Gomes, R.L.; Melo, W.J. and Singh, R.P. (2010). Effect of different tannery sludge compost amendment rates on growth, biomass accumulation and yield responses of Capsicum plants. Waste Management, 30(10): 1976-1980.

Singh, R.P.; Sarkar, A.; Sengupta, C.; Singh, P.; Miranda, A.R.L.; Nunes, L.A.P.L.; Ferreira de Araujo, A.S. and José de Melo, W. (2015). Effect of utilization of organic waste as agricultural amendment on soil microbial biomass. Annual Research & Review in Biology 7(3): 155-162.

Singh, R.P. and Agrawal, M. (2009). Use of sewage sludge as fertilizer supplement for *Abelmoschus esculentus* plants: physiological, biochemical and growth responses. Inter-national Journal of Environmental Waste Management 3: 91– 106.

Tan, K.T.; Lee, K.T.; Mohamed, A.R. and Bhatia, S. (2010). Palm oil: addressing issues and towards sustainable development. Renewable Sustainable Energy Review 13(2): 420.

Uddling, J.; Hall, M.; Wallin, G. and Karlsson, P.E. (2005). Measuring and modelling stomatal conductance and photosynthesis in mature birch in Sweden. Agricultural and Forest Meteorology, 132(1): 115-131.

Wahid, M.B.S.; Balu, N. and Ismail, N. (2008). EU's renewable energy directive: possible implications on Malaysian palm oil trade. Oil Palm Ind. Economic Journal (8): 1.

Wan Razali, W.A.; Baharuddin, A.S.; Talib, A.T.; Sulaiman, A.; Naim, M.N.; Hassan, M.A. and Shirai, Y. (2012). Degradation of oil palm empty bunches (OPEFB) fibre during composting process using in-vessel composter. BioResources 7(4): 4786-4805.

Wong, J.W.; Li, G. and Wong, M.H. (1996). The growth of Brassica chinensis in heavymetal contaminated sewage sludge compost from Hong Kong. Bioresource Technology 58: 309–313.

Wong, S.C.; Cowan, I.R. and Farquhar, G.D. (1979). Stomatal Conductance Correlates with Photosynthetic Capacity. Nature 282

Zakaria, Z.Z.; Khalid, H. and Hamdan, A.B. (1994). Guidelines on land application of palm oil mill effluent (POME). PORIM Bulletin Palm Oil Research Institute Malaysia: 28.