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Effect of Amending Organic and Inorganic Fertilizer on Selected Soil Physical Properties in Entisols

Mohd Nizar Khairuddin[1,3], Isharudin Md. Isa[2*], Abd. Jamil Zakaria[1] and Abdul Rahym Abdul Rani[2]

[1] Institute of Agrobiotechnology, Universiti Sultan Zainal Abidin, Campus Besut, Malaysia
[2] Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Malaysia
[3] Felda Global Ventures (FGV) Research and Development Pte. Ltd., Level 14, Menara Felda, Kuala Lumpur, Malaysia

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[*] Corresponding author:
E-mail: imi@upm.edu.my

ABSTRACT

Application of organic amendment has become a substantial option and it is originated from oil palm waste. The integrated application of organic and inorganic amendment on crops could effectively gain high yield of production. After application of treatments, variables such as pressure head, water content, hydraulic capacity, hydraulic conductivity, and diffusivity are important to determine and observe its effect on soil physical properties using RETC model. This study was conducted to investigate the influence of organic and inorganic amendments on Rasau soil series (Entisols). The comparison was made on the effect of organic amendments (Biogreen–BG and treated POME Sludge-TPS), and NPK fertilizer, and on maize yield which two of the treatments are the combination of organic and inorganic amendments (BG+NPK and TPS+NPK). The soil water holding capacity for NPK+TPS treatment was the highest compared to the control treatment. Hydraulic conductivity (Ks) was shown higher in NPK+BG treatment compared to the other treatments. In addition, the soil physical properties measurement in each treatment improved the soil hydraulic capacity uptake and moisture content. The combination of organic and inorganic fertilizer has shown a significant result in improving soil hydraulic properties compared to the NPK and control treatment.

INTRODUCTION

Nowadays, the amount of organic waste produced by the industries from palm oil production is significant; furthermore, it is produced at specific points and daily. Despite high economic return, the palm oil mill also generates large amounts of waste such as palm oil mill effluent (POME) (60 %), empty fruit bunch (EFB) (23 %), mesocarp fibre (12 %), shell (5 %) for every ton of fresh fruit bunch (FFB) (Baharuddin et al., 2011). POME sludge is half of the POME waste. POME sludge contains high moisture content and nutrient (Nutongkaew, Duangsuwan, Prasertsan, S., & Prasertsan, P., 2014). In addition, it was safe for human consumption based on WHO/FAO standard for heavy metal content (Khairuddin, Md Isa, Zakaria, & Syahlan, 2017).

Potentially, POME sludge can be processed as an organic amendment for crops. However, the critical nutrient such as phosphorus is found low in the organic amendment and difficult to meet crop nutrient demands through organic amendment alone (Morris, Kelly, Kopicki, & Byerlee, 2007). In Malaysia, 90 % of the inorganic amendment was used to maintain the agricultural production (Nur Aainaa, Ahmed, Kasim, & Ab. Majid, 2015). Morris, Kelly, Kopicki, & Byerlee (2007) stated that inorganic fertilizers are known for negative impact on the environment and high cost if poorly managed. According to Omidire, Shange, Khan, Bean, R., & Bean, J. (2015), an inorganic amendment is highly released of nutrients required by the plant and no decomposition process occurs. Anjanappa, Venkatesh, & Kumara (2012) reported

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that the combinations of inorganic and organic amendments are shown as very good potential on the early stage of plant growth and might increase crops productivity. The positive effects of the organic and inorganic combination were reported by Sarhan, Mohammed, & Teli (2011) especially on the growth, yield and fruit quality of summer squash.

Entisols are clarified as poor quality of soil based on low nutrient properties and crop yield (Anda & Kurnia, 2010). According to Sujaul, Ismail, Tayeb, Muhammad Barzani, & Sahibin (2016) the Rasau series (Entisols) consisted mainly of fine sandy clay loam and the organic matter content is low, find the texture, poor grades, friable, the terrain is flat to undulating, cation exchange capacity (CEC) < 5 cmol(+) per kilogram of soil and low base saturation. Rasau Series was low in pH at 3.65, low electrical conductivity (EC) 2.2 dS m^{-1}, high of phosphorus (P) 4.66 μg g^{-1} in the surface layer and high of potassium (K) 34.78 μg g^{-1} (Gasim, Ismail, Mir, Rahim, & Toriman, 2011). In this experiment the maize (*Zea mays* L.) Hibrimas was selected due to its commonly used in Malaysia as a test crop (Nur Aainaa, Ahmed, Kasim, & Ab. Majid, 2015). The soil water holding capacity, soil water content, and hydraulic conductivity ultimately needed for effective crops growth and survival. Soil water retention data are described with the equations from the van Genuchten model whereas the pore size distribution model is used to predict the saturated hydraulic conductivity function. The Retention Curve (RETC) model was used to observe the soil water retention and hydraulic conductivity functions of unsaturated soils in this experiment.

MATERIALS AND METHODS

The Rasau soil series was obtained from a farm in Universiti Teknologi Mara (Pahang), Bandar Tun Abdul Razak Jengka, Pahang, Malaysia (N 3.741582, E 102.544312) from February 2015 until June 2016. The study was conducted to investigate the selected Biogreen (BG), Treated POME Sludge (TPS) (Khairuddin et al., 2016) and NPK (60 kg N ha^{-1}, 60 kg P ha^{-1}, and 40 kg K ha^{-1}) (Ahmed, Sumalatha, & Muhamad, 2010). In this study, have six treatment planted with maize (*Zea mays* L.) Hibrimas using transplanting method (Table 1). The experimental design was arranged in a factorial randomized completely block design (RCBD) with 3 replications. Eight kilograms of soil was used per polybag based on the in-situ soil's bulk density with the pot size of 25 cm (top diameter) × 21 cm (bottom diameter) × 21 cm (height).

Table 1. Treatments in polybag using Maize (*Zea mays* L.) Hibrimas.

Treatment	Vegetation	Amendments
T1	Maize Hibrimas	Without fertilizer (Control)
T2	Maize Hibrimas	Biogreen (BG)
T3	Maize Hibrimas	Treated POME Sludge (TPS)
T4	Maize Hibrimas	NPK
T5	Maize Hibrimas	NPK + Biogreen (NPK+BG)
T6	Maize Hibrimas	NPK + Treated POME Sludge (NPK+TPS)

The selection of maize type was based on the common practices in Malaysia (Nur Aainaa, Ahmed, Kasim, & Ab. Majid, 2015) and high yield of production (MARDI, 2015). Data were tested using RETC Model to observe the water retention and hydraulic conductivity pattern, respectively. The retention model was important to describe the soil water retention function where the subscripts r and s are denoted residual and saturated water contents. The hydraulic properties in each treatment were calculated by using equation (1) Van Genuchten – Mualem, A (m=1-1/n) (Van Genuchten, 1980).

$$Ks = \theta r + \frac{\theta s - \theta r}{[1+(\alpha h)n]m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where *Ks* = Saturated hydraulic conductivity; *Theta*; *θr = Theta r*; *θs = Theta s*; *αh = Alpha h*; *n = n value*; *m = 1-1/n.*

According to Van Genuchten, Leij, & Yates (1991), five independent parameters (*θr*, *θs*, *α*, *n*, *m*) and the residual, and saturated water contents are considered as empirical parameters. They are defined in the retention model and fitted for the water retention function (Ghanbarian-Alavijeh, Liaghat, Huang, & Van Genuchten, 2010). The most general formulation arises when the parameters *m* and *n* are assumed to be independent. The parameters are estimated with an algorithm described by Georgoulis, Iske, & Levesle (2011).

Table 2. Fitting values for parameters in the equation of Van Genuchten – Mualem, A (m=1-1/n) for water retention curve.

Treatment	Sand (%)	Silt (%)	Clays (%)	Bulk density (BD) (g cm^{-3})	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α (1/cm)	n (-)	Ks (kPa)
Control	55	32	13	1.320	0.0491	0.4123	0.0155	1.4758	46.72
BG	55	32	13	1.303	0.0495	0.4161	0.0152	1.4775	49.80
TPS	55	32	13	1.290	0.0497	0.419	0.015	1.4787	52.29
NPK	55	32	13	1.264	0.0502	0.425	0.0145	1.4806	57.67
NPK + BG	55	32	13	1.253	0.0504	0.4276	0.0144	1.4812	60.11
NPK + TPS	55	32	13	1.257	0.0502	0.4243	0.0146	1.4804	59.82

Remarks: BG (Biogreen); TPS (Treated POME sludge); NPK (Nitrogen, Phosphorus, Pottasium); NPK+BG (Nitrogen, Phosphorus, Pottasium + Biogreen); NPK+TPS (Nitrogen, Phosphorus, Pottasium + Treated POME sludge), θ_r = theta r θ_s = theta s; α = alpha; n = n value, K_s = Saturated hydraulic conductivity.

RESULTS AND DISCUSSION

Soil Physical Properties

The result showed that the Rasau soil series was inherently infertile, characterized by quite acidic (pH = 5.40), low of organic matter (OM) content (0.4-1.56 %), bulk density value was (1.43 g m^{-3}), the value of cation exchange capacity (CEC) was within the range of 1.96 to 2.06 meq.100 g^{-1} and porosity value was at 56.04 % (Gasim, Ismail, Mir, Rahim, & Toriman, 2011). In general, pH, OM, and exchangeable Al were lower than the optimum requirement for plant growth. The Rasau soil series contained a low amount of OM due to the sandy loam texture (Sand = 55 %, Silt = 32 %, Clay = 13 %). On the other hand, the concentrations of available bases P (4.66 to 7.96 ug g^{-1}), Mg (3.49 to 29.68 ug g^{-1}) and available K (21.05 to 56.20 ug g^{-1}) was relatively low for plant growth (Gasim et al., 2011). Overall, these physicochemical conditions might restrict the plant establishment in this study. The significant application of of BG, TPS or mixture of NPK, BG and TPS amendments which contained an adequate amount of macro- and micronutrients might enhance the maize yield in this study. Nevertheless, the treatments increased the physical properties of Rasau soil series based on the hydraulic properties and plant available water.

Soil Hydraulic Properties

There are several important methods to estimate the soil water content and saturated hydraulic conductivity (Ks), and prediction of the parameters equation. The RETC model used was to fit and compare the parameters of the soil moisture retention data (Vereecken et al., 2010). Table 2 shows the fitting values at each of the treatment. In this study, the water content, pressure head, and hydraulic conductivity were calculated and predicted from the model. Table 2 shows that there is different texture, θ r and θ s (residual and saturated soil water content), respectively, α and n are Van Genuchten, (1980) parameter, and Ks (hydraulic conductivity) of the Entisols in all treatments.

The ANOVA shows the interaction of bulk density and hydraulic conductivity in Table 3. There was a significant interaction between treatment effects and soil bulk density (1.28*) and hydraulic conductivity (54.40*). This was further revealed by the correlation analysis (Table 4) which indicated that a high positive correlation of hydraulic conductivity with the treatments (r = 0.976**). However, bulk density was observed as negatively correlated with r = -0.976**. According to Mahmood-ul-Hassan, Rafique, & Rashid (2013), increasing nutrient input to the soil with the application of treatments (organic and inorganic) might be able to enhance the crop growth significantly and improve the soil quality. Hence, the low bulk density and significant effect of the hydraulic conductivity was resulted by the treatments: BG, TPS, NPK, NPK+BG and NPK+TPS, respectively.

Table 3. The ANOVA of bulk density and hydraulic conductivity from the treatments (control, BG, TPS, NPK, NPK+BG, NPK+TPS).

	Bulk density (BD) (g cm^{-3})	Hydraulic conductivity (Ks) (kPa)
Treatment	1.28*	54.40*

Remarks: * = significant at p > 0.05

Table 4. Correlations between treatment of bulk density and hydraulic conductivity.

	Bulk density (BD) (g cm^{-3})	Hydraulic conductivity (Ks) (kPa)
Treatment	-0.976**	0.976**

Remarks: ** = highly significant at p > 0.01

Relationships between Pressure Head and Water Content

Fig. 1 shows the predicted relative hydraulic conductivity as a function of both the pressure head (0.1 kPa – saturation, 1 kPa, 10 kPa, 33 kPa – filed capacity, 1500 kPa – permanent wilting point) and water content (m^3 m^{-3}). The treatment of NPK+BG showed the lowest bulk density (1.253 g cm^{-3}) which was significantly different compared to the other treatments. Soil bulk density was one of the soil properties used to indicate soil porosity and compaction status, which influenced soil physical and chemical characteristics such as soil texture, the constituent of minerals (Ghestem, Veylon, Bernard, Vanel, & Stokes, 2014) and the amount of organic matter in soil. Bulk density was commonly known related to soil porosity.

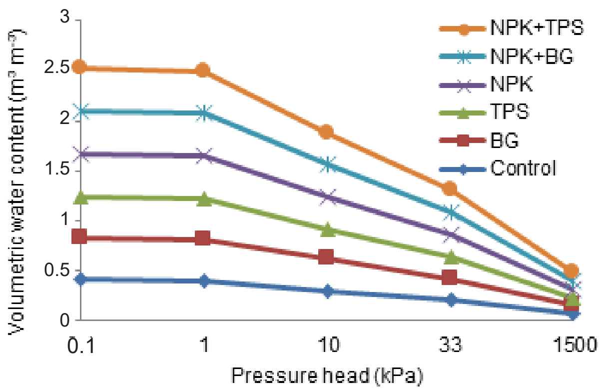

Fig. 1. Nutrient leaching of: (a) Na, (b) Ca, (c) total Al, (d) Mg, and (e) K at 1.5 m soil depth in the fertilized and frond stacked areas in smallholder palm oil plantations, Jambi, Sumatra, Indonesia.

The pressure head and water content (θs) showed the relative hydraulic conductivity in the control (0.22501 kPa), BG (0.22625 kPa), NPK (0.22625 kPa) and NPK + BG (0.22601 kPa) which was increased based on the treatment's effect. However, the treatment of NPK+TPS reduced the soil hydraulic conductivity (0.22563 kPa) and the optimum scale of bulk density was at 1.257 g cm^{-3}. There were many factors that could affect the soil hydraulic conductivity. Soil with a high percentage of clay might indicate slow infiltration rate compared to the sandy soil (Mahmood-ul-Hassan, Rafique, & Rashid, 2013). High bulk density was correlated to low soil pores and might also cause low value in soil hydraulic conductivity. The predicted curve indicated excellent fitting for the retention curves data in the models together with the Van Genuchten – Mualem equation (m=1-1/n) which extracted from the RETC.

Relationships between Water Content and Hydraulic Conductivity

Application of organic amendment (BG and TPS) showed a substantial effect on the hydraulic conductivity at the saturated condition. The average value of the soil hydraulic conductivity (Ks) at different water content in the treatments and control is illustrated in Fig 2. Incorporation of organic matter was able to increase the amount of potassium in the amended soils. At all level of water content, organic matter amendment showed the effect of K content was more obvious in NPK+TPS and NPK+BG-amended soil, compared to BG and TPS. In example, the Ks was increased by 89.5 % in (NPK+TPS), 88.2 % (NPK+BG), 85.4 % (NPK), 82.9 % (BG), 81.2 % (TPS) and 79.8 % (control). The increased of Ks with the addition of NPK+TPS and NPK+BG might associate with the increase of soil aggregation and macroporosity. Although this research did not measure soil aggregation, the calculation of macro- and mesoporosity enabled it to draw the above proposition. The effects of TPS and BG amendments on the saturated hydraulic conductivity (Ks) were similar in all five pressure heads compared to the water content (Fig. 1). The increase of water content associated with each of the treatment such as NPK+TPS, NPK+BG, NPK, TPS, and BG amendments which showed a significant effect on the hydraulic conductivity from the RETC model.

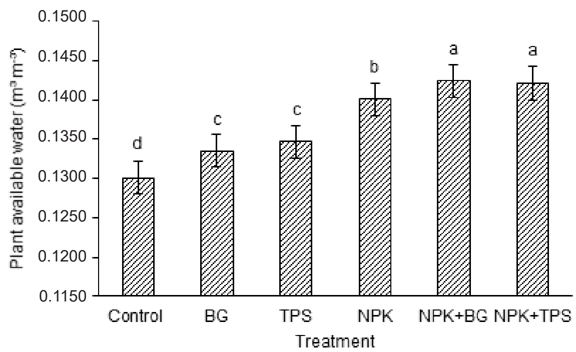

Fig. 2. The available water capacity of treatments: control, BG, TPS, NPK, NPK+BG, and NPK+TPS.

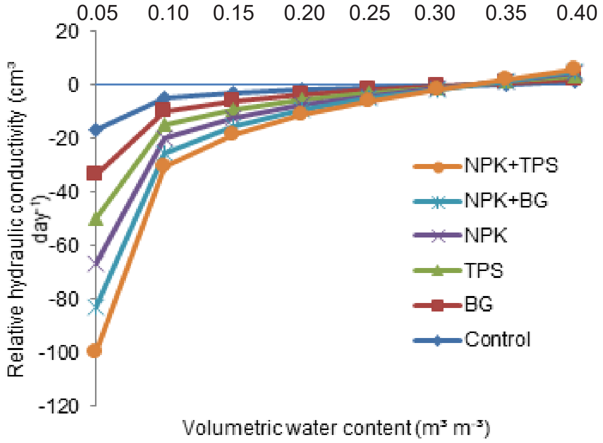

Fig. 3. Relationship of water content (θs) and hydraulic conductivity (Ks) using RETC model in the treatments: control, BG, TPS, NPK, NPK+BG and NPK+TPS.

The soil water retention curve based on the prediction of relative hydraulic conductivity as a function of both water content (θs) and hydraulic conductivity (Ks) (Fig. 3). Hydraulic properties among all treatments varied significantly in decreasing order; NPK+BG (1.1685 $cm^3 day^{-1}$) > NPK+TPS (1.200875 $cm^3 day^{-1}$) > NPK (1.24 $cm^3 day^{-1}$) > TPS (1.256 $cm^3 day^{-1}$) > BG (1.2605 $cm^3 day^{-1}$) > Control (1.2605 $cm^3 day^{-1}$). In order to produce the model of soil physical processes related to the soil water content, it is important to know the hydraulic properties of the soil (Rubio, Llorens, & Gallart, 2008). Alpha (α) is an empirical parameter (L-l) whose inverse is often referred to as the air entry value or bubbling pressure (Kadhim, 2011). According to Alvarez-Acosta, Lascano, & Stroosnijder (2012), the importance of characterizing the soil hydraulic parameters was to understand the occurrence and movement of water in the field, sloping area, and water catchment which also correlated to soil types and texture.

Plant Available Water

The plant available water capacity is the portion of water that can be absorbed by plant roots (Rodriguez-Iturbe & Porporato, 2005). According to the definition, it is the amount of water available, stored, or released between field capacity and the permanent wilting point based on equation (2)

PAW = FC – PWP..................... (2)

Where PAW (plant available water); FC (Water content at field capacity); PWP (Water content at a permanent wilting point.

Fig. 2 illustrates the available water capacity analysis between treatment control, BG, TPS, NPK, NPK+BG, and NPK+TPS, respectively. In this experiment, after the treatment was applied, the available water capacity (AWC) increased, control (0.1335 $m^3 m^{-3}$) < BG (0.1347 $m^3 m^{-3}$) < TPS (0.1319 $m^3 m^{-3}$) < NPK (0.1415 $m^3 m^{-3}$) < NPK+BG (0.1424 $m^3 m^{-3}$) < NPK+TPS (0.1421 $m^3 m^{-3}$). The application of the organic and inorganic amendments in Rasau soil series might increase the available water for the plant roots uptake. Available water capacity (AWC) near the soil surface is important at the seedling stage while roots are very shallow (Mbah, 2012). According to Ali & Talukder (2008), the soil texture might indicate different ability in water holding capacity, but adequate amount of available water capacity (AWC) might become more conducive for high biomass productivity in sustaining adequate water supply to the plant during the drought season.

CONCLUSION

Overall, the current study provided the information in soil physical properties by fitting the experimental data using RETC model on different treatments such as BG and TPS (organic), then NPK, NPK+BG, and NPK+TPS on Rasau soil series. In this study, modelling of hydraulic properties has shown a positive effect on BG, and TPS (organic amendment) and NPK, NPK+BG and NPK+TPS (inorganic amendment) in enhancing the maize growth. Subsequent application of NPK, BG, and TPS might ameliorate the chemical constraints and facilitate soil hydraulic conductivity within the soil profile effectively. The results proved that the combination of organic and inorganic applications enhanced hydraulic properties, water content, and available water capacity. Therefore, the yield of maize might also increase significantly.

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