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Ameliorating Plant Available Water by Addition of Treated Palm Oil Mill Effluent (POME) Sludge on Entisols

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Abstract

Palm oil mill contributed a significant benefit to agro-based industry and social-economic for Malaysia. The treated POME sludge was produced from the open treatment ponds and palm oil mill effluent (POME) without any treatment is considered as a polluted wastewater. This study is to determine the effect of POME sludge on Entisols for plant available water (PAW). The data obtained from this study were selected to measure physicochemical parameters (bulk density, porosity, compaction, organic matter), hydraulic parameter (hydraulic conductivity, hydraulic capacity and water retention) to determine the PAW. The POME sludge from different treatment ponds (control, mixing pond, anaerobic pond, facultative pond, algae pond and dumping pond) was applied to the *Zea mays* (Hibrimas) as a test crops. The results showed that maize treated with POME sludge from the dumping pond indicated significant difference on soil organic matter, bulk density, porosity, soil compaction and plant available water compared to mixing and anaerobic ponds. As a conclusion, POME sludge from the dumping might improve soil physical properties of Entisols. The dumping pond sludge has significant potential to be used as an organic amendment for plant growth in the future.

Keywords: POME sludge, selected soil physical properties, plant available water

1. Introduction

In Malaysia, palm oil industry has contributed almost RM53 billion annually and expected to achieve RM178 billion in 2020 (MPOB, 2010). According to MPOB (2015), nearly 415 mills were operating in Peninsular Malaysia, Sabah and Sarawak to process all the fresh fruit bunches. However, the fresh fruit bunch could produce 26.7 million tonnes of solid waste from the palm oil such as empty fruit bunches (EFB), palm pressed fibres (PPF) and palm oil mill effluent (POME) (Yacob et al., 2005). It is estimated that nearly 50-60% of palm oil waste is POME (Baharuddin et al., 2010).

In the mills, POME was treated in the treatment ponds before it was discharged into the river. After treated, POME produced sediment in the treatment ponds and it was called as POME sludge. According to Khairuddin et al. (2016), the POME sludge was consisted of some nutrients including nitrogen, potassium, sulfur and carbon that can be utilized as an organic fertilizer. It has high moisture content and the pH of 8.4. In addition, the heavy metal content was confirmed at the safety level to use and followed the standard requirement by Codex Alimentarius Commission (FAO/WHO) (2001).

In this study, Rasau series based on USDA soil taxonomy known as Entisols was used to observe the effect of treated POME sludge on selected soil physical properties and hydraulic characteristics after application of treatments. Gasim et al. (2011) stated that Rasau series was consisted of mainly sandy loam and low organic matter content. Mostly, Rasau series was characterized as sandy soil texture with more than 54% of sand, silt is around 30%-32% and the clay content is with an average of 13%. The soil physical properties such as bulk density, soil porosity, soil compaction, hydraulic properties, soil losses and yield were observed in this experiment.

Finding from this research was expected to enhance soil physical properties and improves fertility status of the soil by addition of organic matter. According to Dexter (1988), organic matter content affected the soil bulk density and soil compaction. El-Shakweer et al. (2008) also reported that the organic matter was able to increase soil porosity and infiltration rate. Hydraulic properties is been observed for determine the hydraulic conductivity and capacity in the soil. According to Hati and Bandyoopadhay (2011), they reported that addition of organic matter results increase aggregation and pore volume has positive effect on the saturated hydraulic conductivity of the soil. Improvement of soil physical and hydraulic properties would increase crop yield and quality.

In this study, the plant available water (PAW) is important to justify the difference in water content between field capacity and permanent wilting point in treatment and soil. In addition, by determine the quality and quantity of the plant available water and effectiveness of nutrient uptake in the soil that suitable for plant (Karlen et al., 1994). This also response for yield and phenology is closely related to plant available water capacity (Yang et al., 2014).

The objectives of this study were to determine the effect of treated POME sludge from mixing pond (MP), anaerobic pond (ANP), facultative pond (FP), algae pond (ALP), dumping pond (DP) and un-amended soil (Control) on soil physical properties and plant available water on Rasau series (Entisols).

2. Method

The experimental site was located at Research Farm of the Universiti Teknologi MARA Pahang, Campus Jengka, Pahang, Malaysia (3.7562° N, 102.5611° E) for a period of February 2015 to June 2016. The POME sludge samples were taken from palm oil mill, Felda Jengka 8, Bandar Tun Abdul Razak Jengka, Pahang, Malaysia from different treatment ponds system (mixing, anaerobic, facultative, algae and dumping). The POME treatment system was set up at different Hydraulic Retention Time (HRT) process such as: cooling ponds (1 day), mixing ponds (2 days), anaerobic ponds (45 days), facultative ponds (20 days) and algae ponds (7 days). The dumping ponds was used as dislodging sediment for maintenance purposes two times a year.

The soil and POME sludge was dried, powdered and sieved through a 2 mm size. The Rasau soil series (Entisols) was dug up from 10 cm deep and dried, homogenized and sieved. The study was conducted consisted in polybag 16 × 20 cm and planted with *Zea mays* (Hibrimas variety) in randomized complete blocks design (RCBD). Treatments in the amount of 50 g per polybag with different POME sludge (mixing, anaerobic, facultative, algae and dumping) were used as soil amendments with un-amended soil as control (C).

Bulk density was measured using 10 g of soil sample that was dried in the oven at 105 °C and transfer into a measuring cylinder and gently tapped for compaction (g cm^{-3}) (Radojevic & Bashkin, 2006). Soil porosity test was carried out using a cylindrical ring of 100 cm^3 volume with three replicates to determine a total porosity by the core method (Huang et al., 2005). Meanwhile, soil compaction test was used to determine the compaction status of the soil samples (Torbin et al., 1995).

To determine the soil hydraulic properties, RETC modeling was used based on Van Genuchten – Mualem, A (m = 1 – 1/n) (Van Genuchten, 1980):

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

The water retention curve model was used to describe the soil water retention function where the subscripts of r and s denoted as residual and saturated water contents, respectively. According to Van Genuchten et al. (1991), five independent parameters (θr, θs, α, n, m) and that the residual and saturated water contents are considered here as an empirical parameters. They are defined the retention model, and fitted to observe the data using water retention model (Van Genuchten et al., 1991). 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 Marquardt (1963).

Statistical analyses were conducted using SAS 9.4 statistical package (SAS, 2007). Analysis of variance (ANOVA) was conducted to test the treatments effect while means of treatment were compared using Tukey test at $P < 0.05$.

3. Results and Discussion

3.1 Selected Physiochemical Properties

Table 1 shows the changes of POME sludge's bulk density from the different treatment ponds. In general, the highest bulk density was identified in control (C) (1.44 g cm^{-3}), MP (1.27 g cm^{-3}), ANP (1.26 g cm^{-3}), FP (1.23 g cm^{-3}), ALP (1.19 g cm^{-3}) and DP (1.03 g cm^{-3}). According to USDA (2008), loose, porous soils and rich in organic matter was found as low bulk density. Moreover, Khalid et al. (1992) clarified that the effect of organic matter on the reduction of dry bulk density in soil was similar to the dumping pond (DP treatment) in this experiment.

The soil porosity presented in Table 1 increased significantly in C (45%) and DP (61%), respectively, whereas no significant difference was reported in MP (52%), ANP (52%), FP (53%) and ALP (54%). According to Pagliai et al. (1993), a soil structure will improve with the increased of soil porosity. Soil compaction analysis revealed that there was significant difference of compaction in each treatment (Table 1).

The study showed that compaction status was declining from MP (224.08 kPa) > ANP (172.37 kPa) > DP (115.49 kPa) treatments compared to the control (448.17 kPa). However, there was no significant changes observed in FP (163.75 kPa) and ALP (163.75 kPa). Decreased in compaction was the indicator of high organic matter content in the POME sludge. In addition, soil compaction mostly related to soil bulk density (Panayiotopoulos et al., 1994) and similar result was observed in this experiment.

The organic matter content in DP treatment was 2.68%, whereas for ALP, FP, ANP and MP there were 2.65%, 2.32%, 2.32% and 2.01% reduction in each treatment compared to the control (1.15%). Table 1 shows that there was significant difference between the DP, MP and control treatments, respectively. Thus, the POME sludge might increase organic matter content, decreased bulk density and provided more nutrients to the soil. According to Pascual, et al. (1997), organic amendments was shown a greater effect in decreasing the C:N ratio.

Table 1. Bulk density, soil porosity, soil compaction and organic matter in different POME sludge treatment

	Control	MP	ANP	FP	ALP	DP
Bulk density (g/m³)	1.44a	1.27ab	1.26ab	1.23b	1.20b	1.03c
Porosity (%)	45.03c	52.08b	52.45b	53.68b	54.81b	61.32a
Soil compaction (kPa)	448.16a	224.08b	172.37bc	163.75bc	163.75bc	115.49c
Organic matter (%)	1.15c	2.01b	2.32ab	2.32ab	2.65a	2.68a

Note. Means with the same letter are not significantly different at $p < 0.05$.

3.2 Hydraulic Parameters

Result of hydraulic characteristics of different POME sludge are presented in Table 2. Table 2 shows that there is a different texture, θr and θs (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.

Table 2. Hydraulic parameter of *van Genuchten Mualem*, A ($m = 1 - 1/n$) equation for retention curve.

Treatment	Control	MP	ANP	FP	ALP	DP
Sand (%)	55	55	55	55	55	55
Silt (%)	32	32	32	32	32	32
Silt (%)	13	13	13	13	13	13
θ r (cm^3/cm^3)	0.047	0.050	0.050	0.051	0.052	0.552
θ s (cm^3/cm^3)	0.386	0.423	0.426	0.434	0.441	0.488
α (1/cm)	0.018	0.015	0.015	0.014	0.014	0.012
n (-)	1.452	1.480	1.481	1.482	1.483	1.479
Ks (cm/day)	29.64	56.38	58.54	66.07	74.03	143.35

There was significant different in hydraulic conductivity in each treatment applied followed by ALP (74.03 cm/day), FP (66.07 cm/day), ANP (58.54 cm/day) and MP treatments (56.38 cm/day) (Figure 1). There was significant different of the hydraulic conductivity (Ks) in DP (143.35 cm/day) that was due to low bulk density existed in the dumping pond sludge treatment.

Correlation analysis revealed that hydraulic conductivity and bulk density was highly correlated (R^2 = 0.925) (Figure 2). According to Gwenzi et al. (2011) attributed the incorporating of bulk density and soil texture (silt and clay) was important to determine the hydraulic conductivity in the soil residue. Therefore, high hydraulic conductivity (Ks) could cause the decreased in soil bulk density and increased the total porosity. Figure 2 indicated that the organic matter content was increased, control (1.15%) < MP (2.01%) < ALP (2.32%) < FP (2.33%) < ALP (2.65%) < DP (2.68%) after application of treatments. Hati et al (2011) identified that addition of organic amendment improved the aggregation status of the soil. Soil permeability is a function of effective pore volume, increased pore volume and influence the hydraulic conductivity of the soil (Hati et al., 2011). Similar results was found in this experiment by adding the treated POME sludge as a soil treatment.

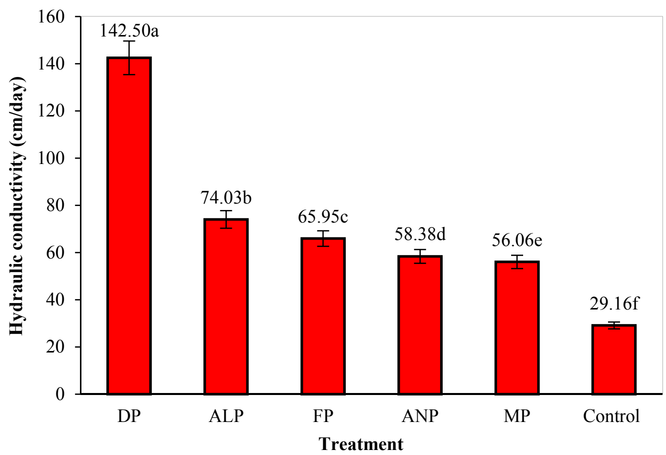

Figure 1. Hydraulic conductivity from different treatment ponds: control, MP, ANP, FP, ALP and DP

Note. Means with the same letter are not significantly different at $p < 0.05$.

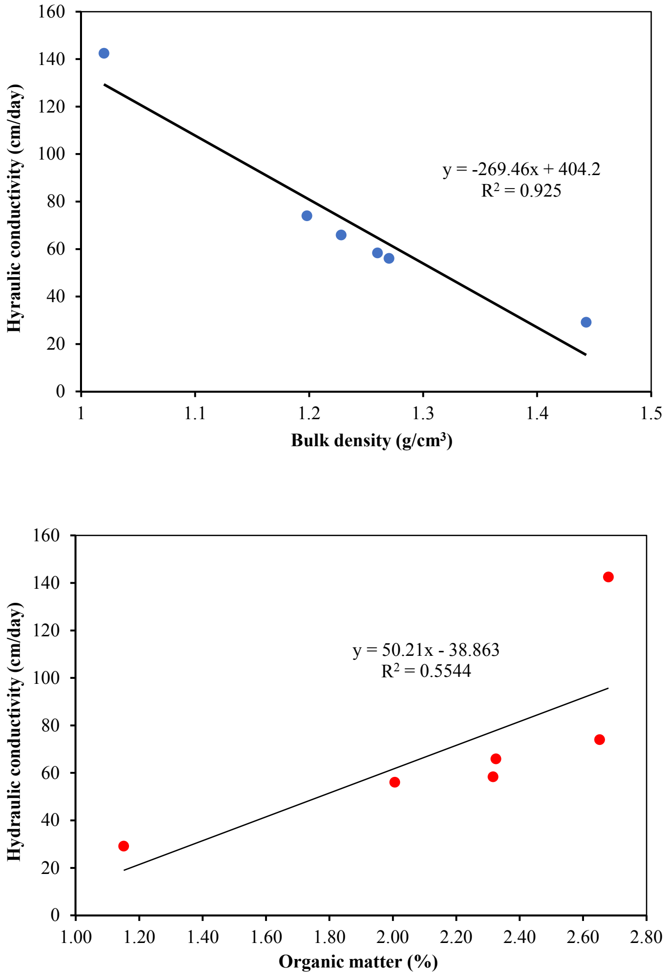

Figure 2. Correlation between hydraulic conductivity (cm/day) measured by bulk density (g/cm^3) and organic matter (%)

3.3 Plant Available Water (PAW)

Figure 3 shows the relationship of water content and soil hydraulic conductivity. Based on the prediction of relative hydraulic conductivity, the soil water retention curve acts as a function in both of water content and hydraulic conductivity (Ks) as shown in Figure 3. Hydraulic properties among all treatments varied significantly in an increasing order: C (29.64 cm/day) < MP (56.38 cm/day) < ANP (58.54 cm/day) < FP (66.07 cm/day) < ALP (74.03 cm/day) < DP (143.35 cm/day) respectively.

The increased in the hydraulic properties was correlated to the bulk density and soil organic matter. Besides that, the increased of water content might be associated with the treatment of C, MP, ANP, FP, ALP and DP which showed significant effect on the hydraulic conductivity based on Van Genuchtem–Mualem model, A (m = 1 – 1/n).

Therefore, the hydraulic conductivity was also increased due to the high organic matter content. It is proven by Nemes et al. (2005) that the organic matter might affect the pore-size distribution of the soil through soil structure development which also influenced the hydraulic conductivity.

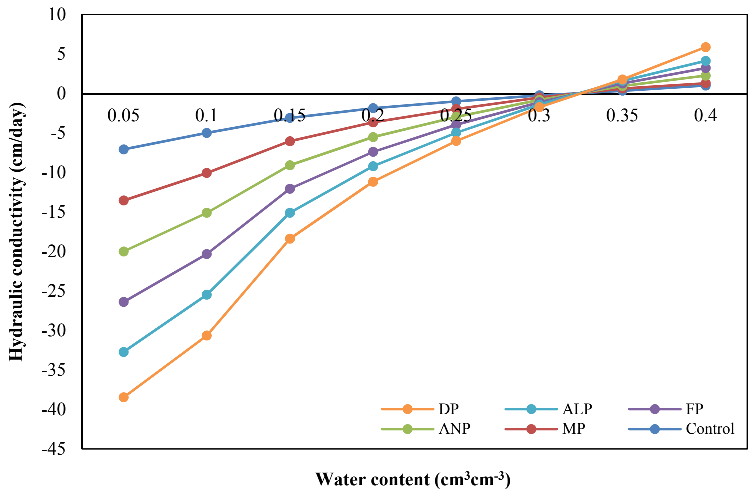

Figure 3. Relationship between water content (cm^3cm^{-3}) and hydraulic conductivity (cm/day) by RETC model in every treatment

According to Romano et al. (2002), while the time-based approximation is used to estimate field capacity, pressure head based approximation was used to estimate its capacity in the laboratory. For example, a commonly used approximation of water content at field capacity for coarse textured soil is 100 kPa based on Romano et al. (2002). Figure 4 illustrates the plant available water among the treatments and there was significant difference in DP treatment (0.22 cm cm^{-3}) compared to the control treatment (0.16 cm cm^{-3}).

As the treatment was applied in this experiment, the trend of plant available water (PAW) increased in the following order: C < MP < ANP < FP < ALP < DP. The dumping pond (DP) treatment showed the highest amount of plant available water (PAW) compared to the other treatments.

This was due to the high organic matter content and low bulk density which increased the plant available water. The USDA (1998) stated that organic matter content increased the plant available water. As an example, each 1% of organic matter added to the soil might increase 1.5% of plant available water (PAW).

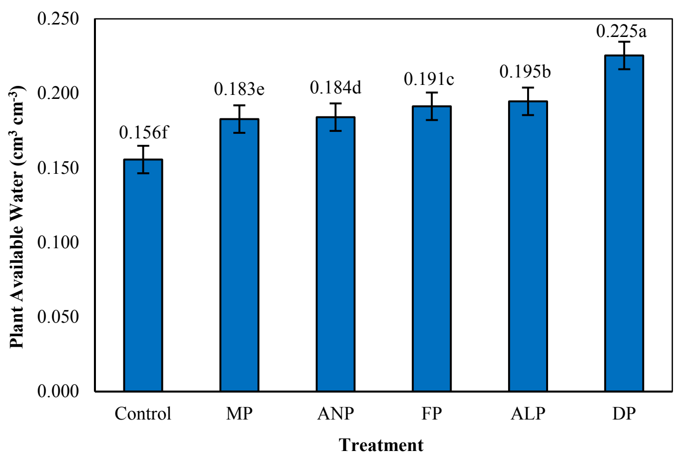

Figure 4. Plant Available Water (PAW) after treatment application

4. Conclusion

The Rasau soil series in this experiment was shown significant results after application of treatments in some selected soil physical properties. The significant results were observed on soil bulk density, porosity, soil compaction and organic matter with POME sludge from DP (dumping pond). With the present of high organic matter content, low bulk density and less compacted soil, DP treatment showed the best result in plant available water for plant growth. The other treatments were also shown significant effect on plant available water compared to the control treatment. As a conclusion, the DP treatment was the best treatment that could ameliorate soil physical properties, hydraulic properties and plant available water. Therefore, the growth performance of crops might also be increased significantly.

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Appendix

Appendix 1. Bulk density, soil porosity, soil compaction and organic matter in different POME sludge treatment

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Note. MP: Mixing pond sludge; ANP: Anaerobic pond sludge; FP: Facultative pond sludge; ALP: Algae pond sludge; DP: Dumping pond sludge. Means with the same letter are not significantly different at $p < 0.05$.

Appendix 2. Hydraulic parameter of *van Genuchten Mualem*, A ($m = 1 - 1/n$) equation for retention curve

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Silt (%)	32	32	32	32	32	32
Silt (%)	13	13	13	13	13	13
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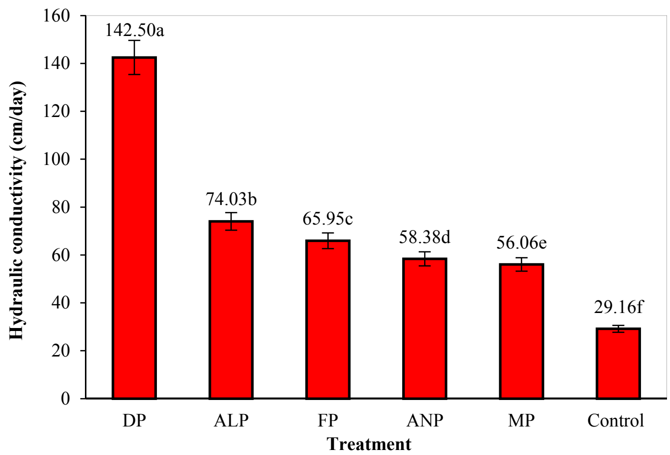
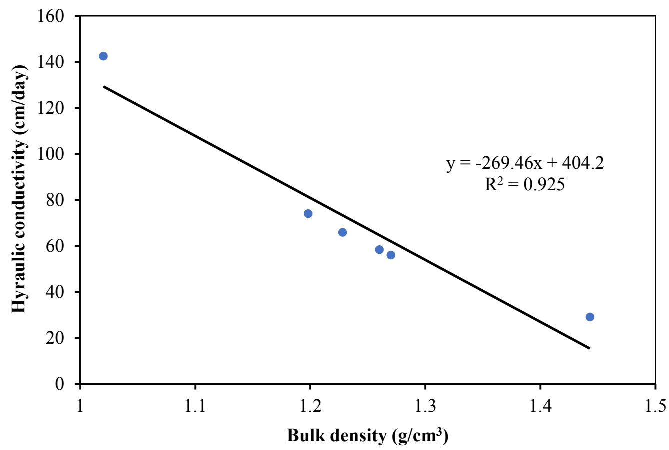
Ks (cm/day)	29.64	56.38	58.54	66.07	74.03	143.35

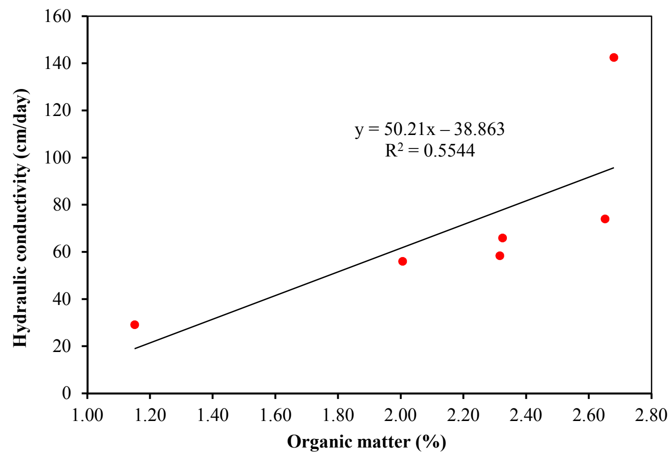
Note. MP: Mixing pond sludge; ANP: Anaerobic pond sludge; FP: Facultative pond sludge; ALP: Algae pond sludge; DP: Dumping pond sludge; θr: Theta r; θs: Theta s; α: Alpha; n: Volumetric water content; Ks: hydraulic conductivity.



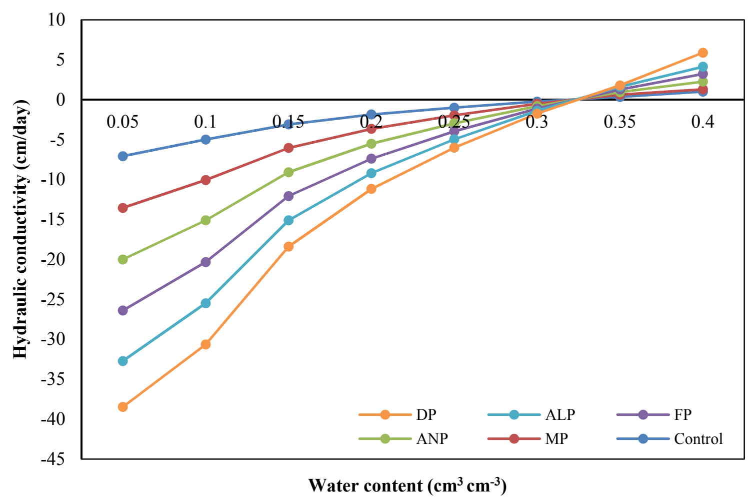
Appendix 3. Hydraulic conductivity from different treatment ponds: control, MP, ANP, FP, ALP and DP

Note. Means with the same letter are not significantly different at $p < 0.05$.

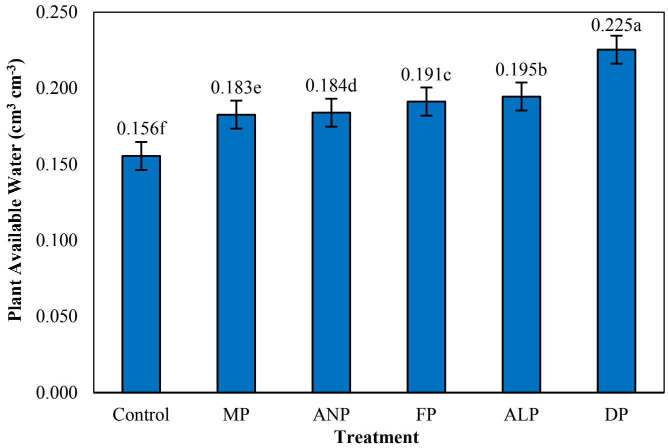




Appendix 4. Correlation between hydraulic conductivity (cm/day) measured by bulk density (g/cm^3) and organic matter (%)



Appendix 5. Relationship between water content (cm^3 cm^{-3}) and hydraulic conductivity (cm/day) by RETC model in every treatment



Appendix 6. Plant Available Water (PAW) after treatment application