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Perlis State Soil Series: Plant Available Water, Field Capacity, Permanent Wilting Point, and its Uncertainty

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ABSTRACT

Hydrological cycle is affecting the recycling of water in the human sphere. A smaller scale of the environment like Perlis state is also in constant exchange of water with its surrounding environment like atmospheric air, soil, groundwater, lake, and river. This study focusses on the Perlis state soil. Water enters the soil because of rainfall event. The event is known as water infiltration. However, human activities like irrigation have speed up the exchange of water in the soils resulting not only bulk water movement but also chemical transports such as pesticide, herbicide, nutrients, and other soluble substances. This study is intended study the water carrying capacity of the Perlis soils, i.e. field capacity, permanent wilting point, and plant available water to demonstrate the amount of water that can be supplied to the soil without any wastage. The study identifies ten soil series in Perlis state that can be broadly divided into five categories. Among the soil series, Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, and Tualang soil series were found to constitute the highest plant available water that it could store more water for crop usage than the other soil series. Also, the study investigates the uncertainty of plant available water caused by different input parameters within one standard deviation. The study concludes that crop irrigation at field capacity was necessary to avoid water wastage than irrigation at fully saturated soil water content.

1. Introduction

In any region, a self-sustaining water supply is a critical component of socioeconomic growth [1]. According to a report by the Northern Corridor Implementation Authority (NCIA) [2], Perlis state's ability to sustain its water supply is dependent on its ability to extend its water supply capabilities and fix leaks in the current supply system in order to improve water delivery. Furthermore, because agricultural activities account for 70% of water extraction from groundwater and water courses, water irrigation efficiency is required to ensure the sustainability of water resources [3]. The remaining 20% and 10% are allocated to industry and residential consumption, respectively. Farmers' customary agricultural practice, according to the National Water Resources Study report [4], was to over-irrigate the crop field due to the high value product versus the low cost of water delivery.

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Water ponding [5] and probable water pollution in groundwater due to pollutant transfer by dissolving herbicides/pesticides and fertilizers [6] could result from an excessive supply of water to soil. In fact, supplying excessive amount of water into the soil could result in landslide [7]. Inadequate water irrigation may result in lower crop output or, in the worst-case scenario, crop collapse [8]. Thus, sensing or knowing the amount of water in the soil is important [9]. As a result, the purpose of irrigation is to provide enough water to avoid drought and to prevent deeper water penetration into groundwater or water ponding on the topsoil. The soil water content level at permanent wilting point (PWP) and field capacity (FC) are the amounts of water present in the soil that describe these parameters.

By gravitational force, a saturated soil drains to a soil water content level known as FC [10], [11]. The amount of soil water in the soil is further reduced by evaporation [12] and crop roots uptake [13]. The soil condition reaches a stage known as permanent wilting point (PWP) [14] at a specific extent of soil water decline. Wilt is a term used to describe a situation in which there is inadequate soil water content to maintain fundamental water transport operations in crop water consumption. As a result, the situation is approaching agricultural production reduction [15], [16] and crop failure. Plant accessible water (PAW) is the quantity of water available in the soil for plant absorption in order to grow and generate [17]. These variables have not yet been investigated in Malaysia's Perlis state.

Water irrigation efficiency is measured by the FC, PWP, and PAW. Water was not wasted due to gravity drainage because a suitable amount of water was supplied without exceeding FC. The goal of this study is to assess the soil water retention capacity in Perlis, Malaysia, in order to meet the water demand of crop production. The study's goals are to (1) identify the soil series in Perlis, and classify the soil series into soil texture, (2) calculate the soil series' FC, PWP, and PAW, and (3) quantify the uncertainty of PAW. The current work was extended from Goh and Fadhli [18].

2. Methodology

2.1 Perlis State Soil Series Determination

The number of soil series in Perlis state was determined using the Soil Survey Staff [19]. The location of the soil series is not always indicated by the name of the soil series. The name given to a series alludes to a feature that was discovered when it was first discovered. The soil was categorized into percentages of clay, sand, and silt in general. This data was utilized to figure out what kind of soil texture there was.

2.2 Soil Texture Classification

The soil texture was determined using the silt, sand, and clay composition data collected for each soil series. This was accomplished using a freely available soil texture calculator [20]. Apart from sand, silt, and clay, there are twelve different types of soil textures, ranging from coarser textures such as loamy sand to moderately coarse textures such as sandy clay loam to fine textures such as silty clay.

2.3 The Field Capacity, Permanent Wilting Point, and Plant Available Water Determination

The soil water characteristic curve was calculated using the soil texture. The relationship between soil water content and soil moisture suction pressure is determined by the characteristic curve. At a suction pressure of -330 cm, the field capacity (FC) soil water content was determined, while the permanent wilting point (PWP) was assessed at a suction pressure of -15000 cm. The difference between FC and the PAW was used to calculate the plant available water (PAW).

2.4 The Uncertainty of Plant Available Water

The plant available water (PAW) was derived from the input of four parameters. They were residual water content (θ_r), saturated water content (θ_s), alpha (α) and fitting coefficient of m. As the input changes resulted by the uncertainty of the individual parameter, the PAW determined from the FC and the PWP that were determined by characteristic curve given by van Genuchten equation that depends on the four parameters would have varied, accordingly. In this study, one standard deviation of the input parameters was used to establish the lower, average and the higher values for each parameter. All the possible combinations of the input parameters in generating the PAW were investigated.

3. Results and Discussion

3.1 Soil Series of Perlis State

Perlis state can be roughly classified into soil series, steep land, and lake and pond, according to the current Department of Agriculture land space classification. The state's soil was split into ten different soil series. They were Chengai, Kangar, Telemong-Akob-Lanar Tempatan, Hutan-Semberin, Sogomana-Sitiawan-Manik, Holyrood-Lunas, Harimau-Tampoi, Gajah Mati-Munchong-Melaka, Kundor-Sedaka-Kangkong, and Tualang-Idris.

3.2 Perlis State Soil Texture

The soil texture was used to classify the identified soil series. When there were two or more soil series in a group, the one that appeared earliest was considered the site's most dominant soil series. Clay soil texture was found to be dominant in the Perlis state soil series. The sandy clay, sandy loam, and sandy clay loam come next. Harimau-Tampoi was shown to be sandy clay, whilst Telemong-Akob-Lanar Tempatan and Holyrood-Lunas were discovered to be sandy loam and sandy clay loam, respectively. Clay soil texture was assigned to the rest of the soil series. In the following discussion, soil series were grouped respectively, and the soil series were addressed directly.

3.3 Soil Water Content of FC, PWP, and PAW in Perlis State

The water characteristic curves of the four categories observed on the Perlis state soil series were determined. The curve depicts the relationship between the condition of soil suction pressure and the amount of water in the soil. The water characteristic of the soil series is depicted in Figure 1. Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, and Tualang soil series have the highest FC (0.33 m^3/m^3), PWP (0.19 m^3/m^3), and PAW (0.14 m^3/m^3), but Harimau soil series has the lowest PAW (0.09 m^3/m^3). The PAW values of the Telemong and Holyrood soil series were in the middle of the Chengai and Harimau soil series. The fact that the previous soil series has the highest PAW indicates that the soil kept more readily available water for plant consumption, requiring less frequent irrigation.

The FC indicates the amount of water stored in the soil at the given pressure of -330 cm, which is the soil suction pressure head after gravitational drainage. The negative value implies the suction pressure in the soil is in equilibrium with the amount of water present. The static water amount and pressure do not give direct implication on the availability of water to plant suction. The plant available water, i.e. PAW, is identified when there is a change in water content resulted by a change in suction pressure. As plant roots gradually increasing the water suction up to the pressure point of -15000 cm, i.e. PWP, the amount of water retained in the soil gradually released and absorbed by plant root, and a new equilibrium of water amount present in the soil, which is much lesser than before. Hence, the amount of water released by a unit pressure increment is an important indicator. The amount of water releases in mm^3 per unit m^3 soil per unit pressure increment ($mm^3/m^3/Pa$) has the highest estimate given by Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, Tualang at 99.5, then followed by Holyrood at 82.1, and Telemong and Harimau at 73.5 and 60.9, respectively. The observation has similar trend as the PAW discussed previously.

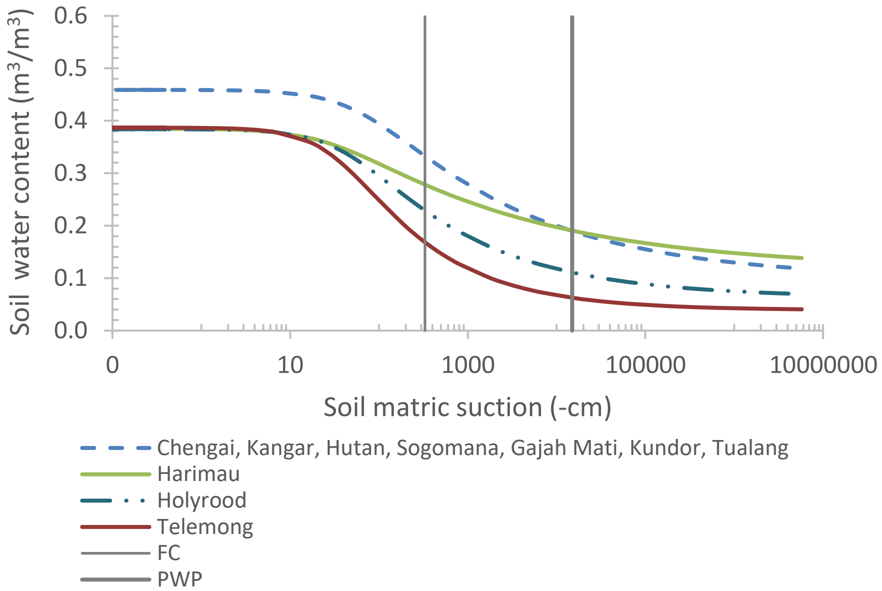
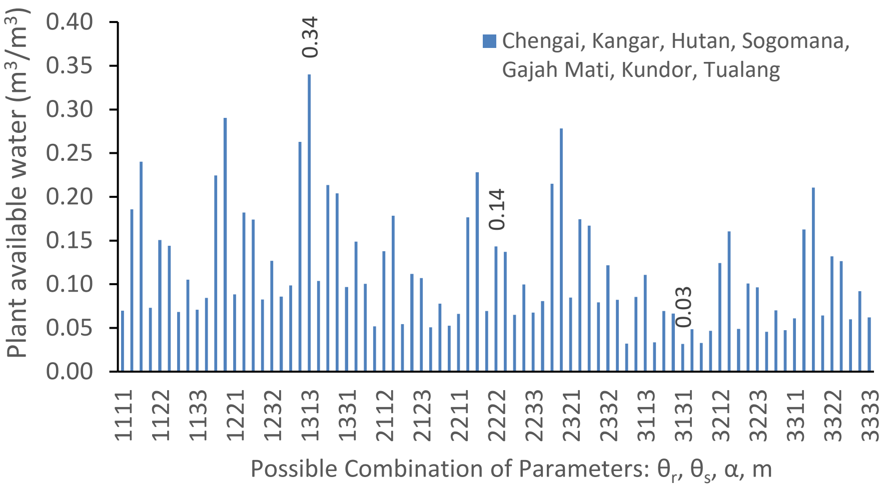


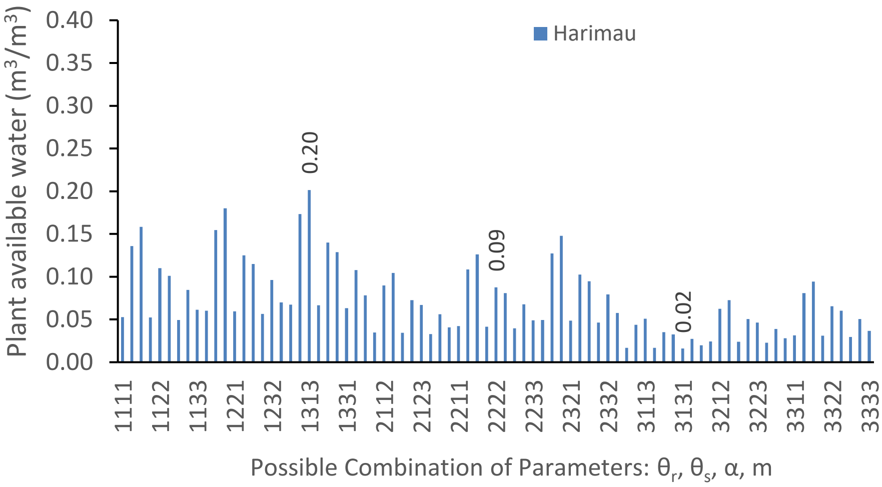
Fig. 1. The characteristic curve of the characterized soil series. Note that the vertical lines indicate field capacity and permanent wilting point at suction pressures of -330 and -15000 cm, respectively.

3.4 The Uncertainty of PAW

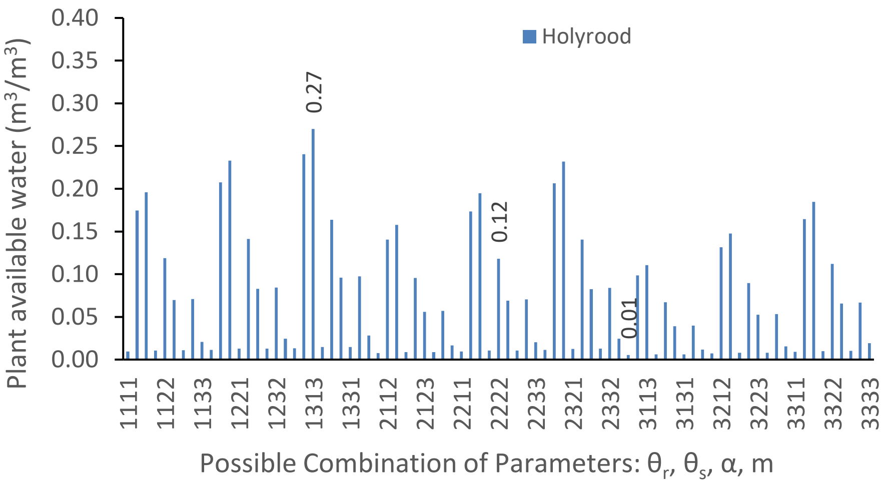
Figure 2 refers to the uncertainty of PAW values. The values estimated based on all possible combinations of four parameters, and they are residual water content (θ_r), saturated water content (θ_s), alpha (α) and fitting coefficient of m. Each parameter has three possible values that were lower, average and the upper values. Based on four parameters and three possible values, 3^4 = 81 possible combinations have been identified. The PAW for each possible combination has been estimated and the value is showed in Figure 2. The 2222 refers to the four parameters at their average values to estimate the PAW. Figure 2(a) showed the highest, average and the lowest values of PAW at 0.34, 0.14 and 0.03 m^3/m^3, respectively. Like the PAW estimated using Figure 1, the Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, Tualang soil series remained the greatest for highest, average and lowest of PAW values observed in Figure 2, while the lowest PAW demonstrated by Harimau when compared to other soil series. Also, the Telemong and Holyrood soil series have PAW value in between those of Chengai and Harimau soil series. The uncertainty study in all fours soil series groups, Figures 2(a)-(d), showed that the lower value of θ_r, higher value of θ_s, lower value of α, and higher value of m, i.e. 1313, give the highest PAW value, while the opposite range of the parameters' values, i.e. 3131, showed the lowest PAW value.


Plant available water (m3/m3)
Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, Tualang
0.34
0.14
0.03
Possible Combination of Parameters: θr, θs, α, m

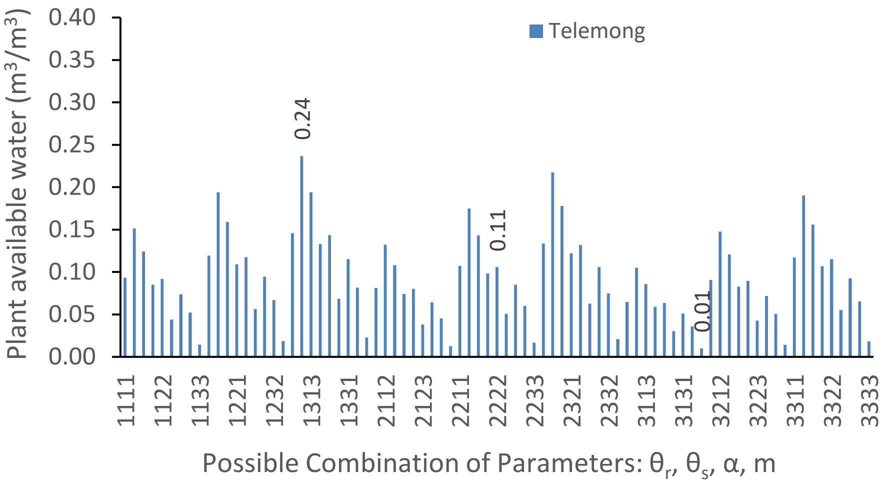
(a)


Plant available water (m3/m3)
Harimau
0.20
0.09
0.02
Possible Combination of Parameters: θr, θs, α, m

(b)


Plant available water (m3/m3)
Holyrood
0.27
0.12
0.01
Possible Combination of Parameters: θr, θs, α, m

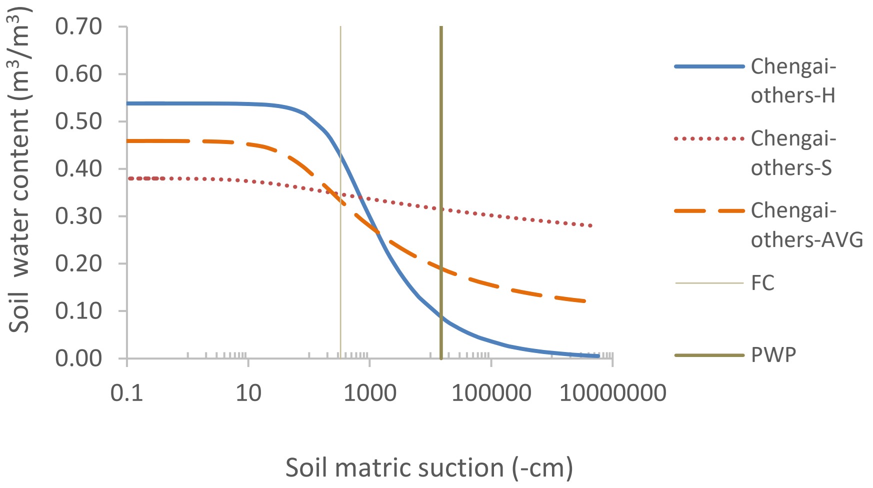
(c)



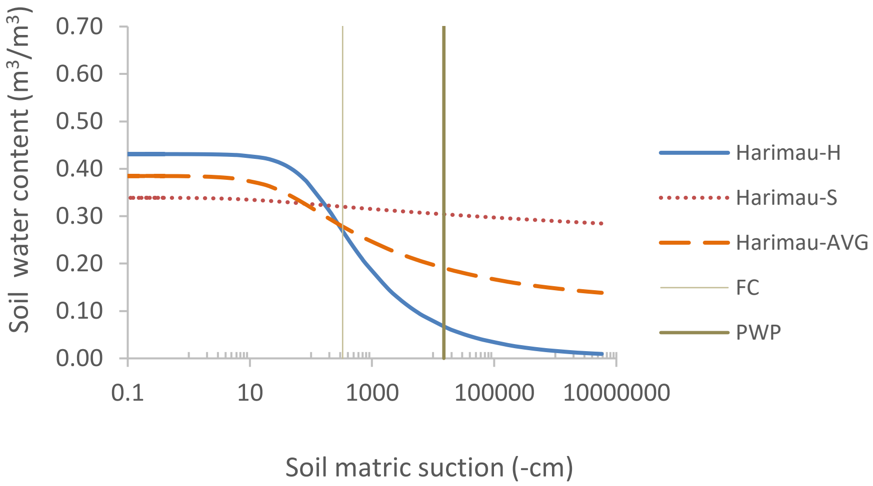
(d)

Fig. 2. The uncertainty of plant available water (PAW) resulted by uncertainty in the values of parameters for residual water content (θ_r), saturated water content (θ_s), alpha (α) and fitting coefficient of *m*. Based on one standard deviation, each parameter has the lower value (label as 1), the average value (label as 2), and the higher value (label as 3). Based on 3 possible values given by 4 parameters, there were 81 possible combinations to estimate the PAW for each possible combination. The label 1232 on y-axis refers to lower value for θ_r, average value for θ_s, the highest value for α, and the average value for *m*. (a) Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, Tualang soil series, (b) Harimau soil series, (c) Holyrood soil series, and (d) Telemong soil series

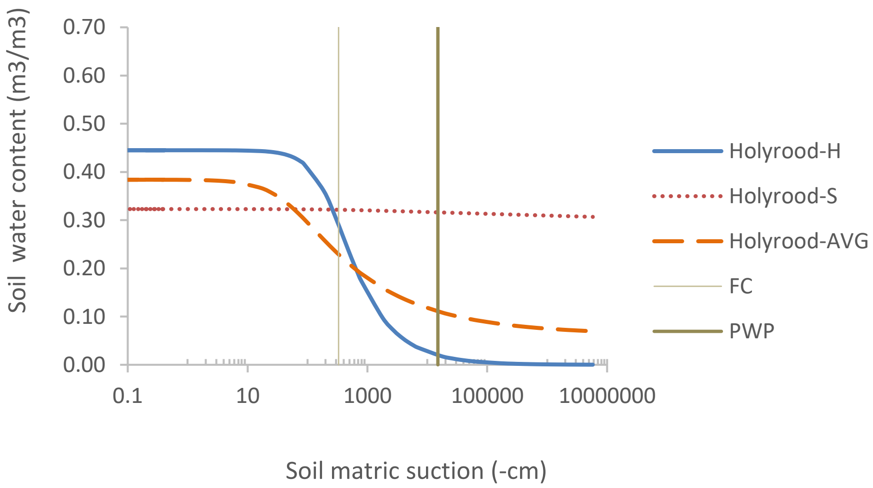
To demonstrate the range of characteristic curves generated by the uncertainty of four input parameters on the characteristic curve, Figure 3 is plotted. In the general, the steepest decline in the characteristic curve over the suction pressure heads between the FC and PWP identifies the highest (H) PAW. Similarly, the lowest the decline in the characteristic curve over the suction pressure heads between the FC and PWP as the smallest (S) PAW. The AVG indicates average value of the four parameters in estimating the PAW, hence, AVG PAW. The smallest PAW represented by an almost flat characteristic curve. Also note that the characteristic curve with the lowest PAW does not necessarily imply the lowest in PWP as demonstrated in Figure 3(a)-(d). An almost flat curve is the only criteria needed to result in the lowest PAW. However, the characteristic curves with the highest PAW tend to have the lowest PWP and the highest FC, as demonstrated in all the figures. Moreover, the characteristic curve also showed an early decline in soil water content with increasing suction pressure before the onset of FC. The range of soil moisture in the pressure region before the FC was susceptible to gravitational drainage with limit window opportunity for plant absorption, while the pressure region after the PWP was strongly bonded to the soil that was similarly not available to plant root absorption.


Soil water content (m³/m³)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.1
10
1000
100000
10000000
Soil matric suction (-cm)
Chengai-others-H
Chengai-others-S
Chengai-others-AVG
FC
PWP

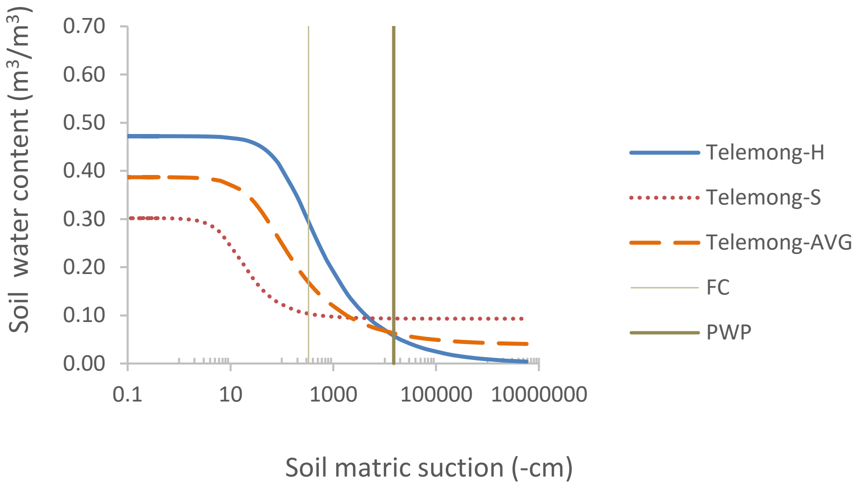
(a)


Soil water content (m³/m³)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.1
10
1000
100000
10000000
Soil matric suction (-cm)
Harimau-H
Harimau-S
Harimau-AVG
FC
PWP

(b)


Soil water content (m3/m3)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.1
10
1000
100000
10000000
Soil matric suction (-cm)
Holyrood-H
Holyrood-S
Holyrood-AVG
FC
PWP

(c)



(d)

Fig. 3. The characteristic curves given by the highest, average and lowest values of PAW. (a) Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, Tualang soil series, (b) Harimau soil series, (c) Holyrood soil series, and (d) Telemong soil series

4. Conclusions

Ten soil series were identified in Perlis state. The soil series were largely dominated by clay soil with few fell under sandy clay loam and sandy loam. The Chengai, Kangar, Hutan, Sogomana, Gajah Mati, Kundor, and Tualang soil series exhibit the greatest PAW which indicates the soil could store more water for crop usage than the other three soil series. While keeping the soil water content at FC sufficiently address the crop water need, over irrigate the soil to fully saturated soil water content would result in water wastage because of drainage by gravitational pull. Also, the study on the uncertainty of PAW indicates that the lowest PAW resulted by a near-flat characteristic curve within the FC and PWP regions, and the highest PAW was given by the steepest decline on curve in the region.

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