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TERENGGANU SOIL SERIES TEXTURAL CLASSIFICATION AND ITS IMPLICATION ON WATER CONSERVATION

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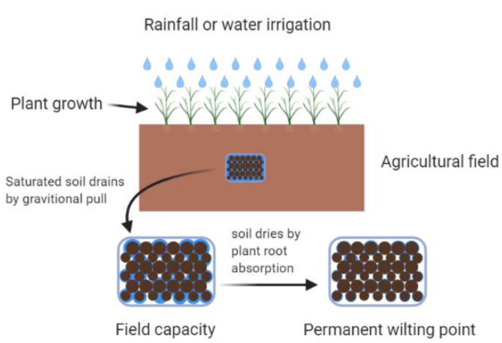
Graphical abstract



Abstract

The updated Terengganu soil series has been made known to the public in 2018 by the Department of Agriculture, Malaysia. One of the most important physical aspects not quantify is the parameter relating to soil's ability to contain water and allow water infiltration. This information is necessary to help farmers to know the soil suitability characteristics. In the current study, we retrieve the soil particle size of the soil series for further investigation. A pedotransfer function was used to estimate the soil water retention. The properties were then used to estimate the field capacity (FC), permanent wilting point (PWP), and the plant available water (PAW). In this study, we found twelve soil series in Terengganu state. The soil series were categorized into clay, sand, loamy sand, silty clay loam, and clay loam. Batu Hitam, Tasik, Lubok Kiat, Kampong Pusu, Tok Yong, Jerangau, and Tersat Series were found as clay soil. Jambu and Rhu Tapai Series as sand soil. Rudua, Gondang, and Kuala Brang Series corresponded to clay loam, silty clay loam, and loamy sand. Among the soil series, Gondang Series appeared to be the most preferred soil for plantation due to its ability to give the highest plant available water, a lower water infiltration duration than clay, and it required lesser water for irrigation than the clay soil.

Keywords: Soil water content, irrigation water supply, water-saving, plantation soil, Rosetta

Abstrak

Siri-siri tanah di Terengganu telah dikemaskini dan diterbitkan pada tahun 2018 oleh Jabatan Pertanian, Malaysia. Salah satu aspek fizik utama yang tidak diambil kira adalah parameter berkaitan kemampuan tanah untuk menyimpan air dan kadar penyusupan air. Maklumat ini diperlukan untuk membantu petani mengetahui ciri kesesuaian tanah bagi mengekalkan kelembapannya. Dalam kajian ini, kami mengambil kira sebaran saiz partikel tanah berdasarkan siri tanah untuk penyelidikan lanjut. Pedotransfer digunakan untuk menganggar sifat hidraulik tanah. Sifat-sifat tersebut kemudian digunakan untuk mengira kapasiti ladang, titik layu tetap dan air tersedia tanaman. Kajian ini membawa kami kepada penemuan dua belas siri tanah di Terengganu. Siri-siri tanah dikategorikan sebagai tanah lempung (liat), pasir, pasir berlom, lom lempung berlodak, dan lom berlempung. Batu Hitam, Tasik, Lubok Kiat, Kampong Pusu, Tok Yong, Jerangau, dan Tersat dijumpai sebagai tanah liat. Jambu dan Rhu Tapai sebagai tanah pasir. Rudua, Gondang, dan Kuala Brang masing-masing ialah lom berlempung, lom lempung berlodak dan pasir berlom. Di antara rangkaian tanah, siri Gondang merupakan tanah yang paling sesuai untuk perkebunan kerana kemampuannya untuk memberikan air tersedia tanaman yang paling tinggi, tempoh penyusupan dan keperluan air untuk pengairan yang lebih rendah berbanding tanah liat.

Kata kunci: kandungan air tanah, bekalan air pengairan, penjimatan air, tanah perladangan, Rosetta

1.0 INTRODUCTION

As the Malaysian population continues to rise annually at the rate of 1.1% to 32 million people in 2020 [1], food security and water security will gradually become a matter of great concern [2]. Adding to the pressure would be food supply chain interruption by COVID-19 [3]. Soil is the medium where vegetables and fruits are grown, yet the soil is a non-renewable resource [4]. Soil is also the medium where water is being stored for plant absorption [5].

When rain first hits the soil, rainwater separates into two parts. A portion of water infiltrates into the soil, while a water portion stays on top of the soil. Also, a small amount is partially evaporated [6]. Water that enters the ground could further infiltrate deep into the ground by a deep penetration process to form groundwater [7]. Water that remains in the soil would be stored in the soil as soil moisture content which is often reported as the ratio of water volume and the soil volume [8]. The water that remains above the ground could lead to ponding water when standing water appears above the soil [9]. The water becomes runoff when it starts to flow from high to low elevation and eventually ends up in the water stream like a river [10].

The water stored in the soil after rainfall or irrigation is essential to plantation management [11]–[13]. The water stored in the soil after being allowed to drain by the gravitational force is known as field capacity [14]. The field capacity (FC) is the soil moisture content from the cumulative water molecules attached to the soil surfaces after gravitational pull [15], [16]. The soil water content could further decline due to plant root absorption [17] and water evaporation [6]. The resulting soil water content is known as the permanent wilting point (PWP) when the water molecules firmly attach to the soil surfaces [18] and unavailable to plant root absorption. The soil moisture content by the FC minus the PWP is known as the plant available water (PAW) [19]. The PAW indicates the water volume in a unit soil volume available to plant root absorption.

The purpose of field water irrigation is to maintain the soil moisture content within the PAW range. Any soil moisture content above the FC would be lost by gravitational pull [20], and below the PWP would be unavailable to plant root absorption. Alternatively, apply a field moisture sensor to estimate the soil moisture level [21], but at the expense of additional cost. Site assessment to determine soil suitability by measuring the soil water content is costly and time-consuming. An early assessment tool like pedotransfer functions that infer the soil water retention curve from soil particle distribution can help when a limited financial resource is available.

The updated Terengganu soil series have recently been reported by the Department of Agriculture, Malaysia [22]. However, the information does not immediately translate into water irrigation management [23]. The current study aims to reveal an early site assessment tool to evaluate the Terengganu soil series regarding the plantation water supply. The objectives of the study are to (1) classify Terengganu soil series into soil textures, (2) infer the soil hydraulic properties, (3) determine the FC, PWP and PAW, and (4) conduct water infiltration into different soil textures to estimate the water infiltration duration and water supply to a specified soil depth. The current research findings would reveal the implication of different soil textures on water consumption in terms of water infiltration rate and water irrigation duration.

2.0 METHODOLOGY

2.1 Determination of the Terengganu Soil Series and the Soil Textures

Over a hundred soil series in Malaysia are available from the Soil Survey Staff [1]. The soil series located in the Terengganu state were identified. Each soil series has its analytical data, such as percentages of different particle sizes. The particle sizes were reported over different soil depths. In this study, soil particle sizes were summarized into three particle sizes: sand, silt, and clay. Soil particle size classification was necessary information to determine soil texture.

2.2 Soil Texture Determination

Each identified soil series has its percentages of sand, clay, and silt. The percentages determine the soil texture using a calculator by Rosetta [2]. Rosetta allows estimate of soil texture and also it provides pedotransfer functions. Alternative soil texture calculators can also be found in Van Lear [3]. Soil texture was determined because it could be used to estimate soil ability in retaining soil water content.

2.3 Soil Hydraulic Functions Analysis

Soil texture information was inputted into Rosetta software [2]. The software generates the van Genuchten equation parameters [4]. The parameters of the van Genuchten equation represents the characteristic curve and the unsaturated hydraulic conductivity function, as below,

$$\theta_L = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + \left|\alpha \psi_m\right|^n\right]^{1-1/n}} \quad (1)$$

$$K = K_s \left(\frac{\theta_L - \theta_r}{\theta_s - \theta_r}\right)^L \left\{1 - \left[1 - \left(\frac{\theta_L - \theta_r}{\theta_s - \theta_r}\right)^{1/m}\right]^m\right\}^2 \quad (2)$$

where θ_L is soil moisture content (m^3·m^{-3}), ψ_m is soil matric suction (-m), K is unsaturated hydraulic conductivity (m·s^{-1}), α and n as fitting curve parameters, L is an empirical pore tortuosity/connectivity parameter, θ_s is saturated soil water content (m^3·m^{-3}), θ_r is residual soil water content (m^3·m^{-3}), K_s is saturated hydraulic conductivity (m·s^{-1}), and m as a fitting parameter where $m = 1 - 1/n$. Table 1 shows the parameters for Eqn. (1) used in Richards' equation.

Table 1 van Genuchten equation parameters

Soil texture	Clay	C loam	L sand	Sand	S C L
α (m^{-1})	1.496	1.581	3.475	3.524	2.109
m	0.202	0.294	0.427	0.685	0.248
θ_r (m^3·m^{-3})	0.098	0.079	0.049	0.053	0.063
θ_s (m^3·m^{-3})	0.459	0.442	0.390	0.375	0.384
K_s (m·s^{-1})	3.43E-07	5.79E-07	2.82E-06	2.83E-06	8.03E-07
L	-1.561	-0.763	-0.874	-0.930	-1.280
n	1.253	1.416	1.746	3.177	1.330

Note: C loam is clay loam, L sand is loamy sand, S C L is sandy clay loam. The fitting parameters retrieved from Schaap [24].

The water retention function is given by the soil moisture content and the soil matric suction. The unsaturated hydraulic conductivity function relates the saturated hydraulic conductivity and the soil water content. Also, unsaturated hydraulic conductivity indicates the easiness of water movement in the soil. A high unsaturated hydraulic conductivity implies a fast movement of water in the soil. Both functions were necessary to estimate water infiltration, governed by Richards' equation [5].

2.4 Estimation of Field Capacity (FC), Permanent Wilting Point (PWP), Plant Available Water (PAW)

The water retention function in Eqn. (1) relates the amount of soil water and soil matric suction. Also, it implies that, at a steady-state condition, the soil's wetness level corresponds to the soil matric suction on the water. The FC was estimated by soil matric suction at -330 cm, and the PWP was at -15000 cm [6]. The corresponding soil matric suction use as input into Eqn. (1) to estimate the soil moisture content of FC and PWP. These values were used to estimate the plant available water (PAW) by taking the soil wetness at FC minus the soil wetness at PWP [7], [8]. The PAW indicates the amount of water available for plant root uptake.

2.5 Soil Water Infiltration

The PAW, FC, and PWP relate to the quantity of water in the soil for plant root absorption. However, the water supply into the soil, such as the rate at which water must infiltrate into the soil to achieve the desired soil water content, is unknown. In this study, water infiltrates into the soil at field capacity soil water content was investigated. The field capacity indicates the level at which water became plant available. The Richards' equation [5] was used to estimate the rate of water infiltration [9], as below,

$$\frac{\partial \theta_L}{\partial t} = \frac{\partial}{\partial z}\left[K\left(\frac{\partial \psi_m}{\partial \theta_L}\right)\frac{\partial \theta_L}{\partial z} - K\right] \quad (3)$$

where t is the time (s), and z is vertical space (m). The equation is oriented positively downward. Richards' equation is a mass balance equation that governed the mass flux of water in space and time.

Richards' equation was solved using finite difference solution by converting Eqn. (3) into a set of algebras [10], as below,

$$\begin{aligned}\frac{\theta_{L(k)}^{\;n+1}}{\Delta t}-\frac{\theta_{L(k)}^{\;n}}{\Delta t}=&\frac{K_{k+1/2}\left(\partial\psi_m/\partial\theta_L\right)_{k+1/2}\theta_{L(k+1)}^{\;n+1}}{(\Delta z)^2}\\&-\frac{K_{k+1/2}\left(\partial\psi_m/\partial\theta_L\right)_{k+1/2}\theta_{L(k)}^{\;n+1}}{(\Delta z)^2}\\&-\frac{K_{k-1/2}\left(\partial\psi_m/\partial\theta_L\right)_{k-1/2}\theta_{L(k)}^{\;n+1}}{(\Delta z)^2}\\&+\frac{K_{k-1/2}\left(\partial\psi_m/\partial\theta_L\right)_{k-1/2}\theta_{L(k-1)}^{\;n+1}}{(\Delta z)^2}\\&-\frac{K_{k+1/2}\vec{k}}{\Delta z}+\frac{K_{k-1/2}\vec{k}}{\Delta z}\end{aligned}\qquad(4)$$

where k is the center of the cell, which is oriented in the vertical direction. $k+1/2$ is the interface of a cell that is located in between cell k and $k+1$. Similarly, for $k-1/2$ is the interface of the cell that is located in between cell $k-1$ and k. The n and $n+1$ are the existing and the new iterated variables, respectively. Δt is time step size and Δz is spatial size. Refer to Goh and Noborio [11] for the explanation of the numerical scheme.

3.0 RESULTS AND DISCUSSION

Twelve soil series were distributed over the five districts of Terengganu state. In Besut district, the Batu Hitam Series was found. In the Setiu district, there were Jambu, Rhu Tapai, and Rudua Series. Gondang, Tasik, Lubok Kiat, Kampong Pusu and Tok Yong Series were found in Kuala Terengganu district. Jerangau and Tersat Series were located in the Hulu Terengganu district, while Kuala Brang Series was in the Kemaman district [22]. Only Kampong Pusu has been reported in previous studies [12], the other eleven series were not reported before on its soil textures.

Table 2 Terengganu soil series and its soil texture

Soil texture	Soil Series
Clay	Batu Hitam Series[a], Tasik Series[c], Lubok Kiat Series[c], Kampong Pusu Series[c], Tok Yong Series[c], Jerangau Series[d], Tersat Series[d]
Sand	Jambu Series[b], Rhu Tapai Series[b]
Loamy sand	Rudua Series[b]
Silty clay loam	Gondang Series[c]
Clay loam	Kuala Brang Series[e]

Note: [a] Besut district, [b] Setiu district, [c] Kuala Terengganu district, [d] Hulu Terengganu district, [e] Kemaman district.

The soil in Besut was found as clay soil (Table 2). Jambu and Rhu Tapai were found as sand soil, whereas Rudua was loamy sand. All the soil series in Kuala Terengganu were discovered as clay, except Gondang Series was found as silty clay loam. In comparison, all soils in Hulu Terengganu were clay. Kuala Brang Series, in Kemaman, was clay loam soil. Overall, most soil series in Terengganu were clay, followed by sand, loamy sand, silty clay loam, and clay loam.

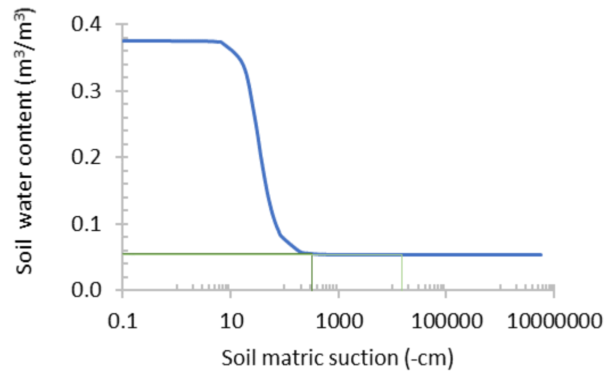


Figure 1 Water retention curve for sand (Jambu, Rhu Tapai Series) at FC (-330 cm) and PWP (-15000 cm) corresponding to soil water contents of 0.055 and 0.053 m³/m³

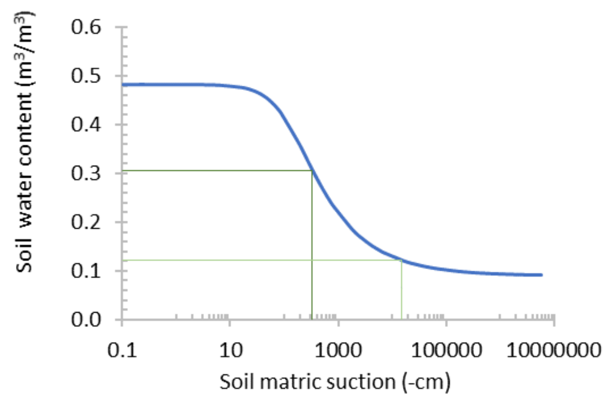


Figure 2 Water retention curve for silty clay loam (Gondang Series) at FC (-330 cm) and PWP (-15000 cm) corresponding to soil water contents of 0.306 and 0.122 m³/m³

The soil series contains information on the soil particle distribution. The particle fractions in clay, sand, and silt determine the soil texture. Soil textural information relates to the water characteristic of the soil. Figures 1 and 2 show the soil water content was decreasing with the rising soil matric suction. The water-saturated soil only begins to drain water after exceeding a certain amount of soil matric suction threshold [33]. At suction greater than the threshold of soil matric suction, the soil water content decreases rapidly. The threshold point appears slightly higher in the silty clay loam, clay loam, and clay than the sand and loamy sand. Further increasing to the extreme high soil matric suction would result in the lowest plateau soil moisture content.

Furthermore, silty clay loam, clay loam, and clay soils can retain a greater soil moisture than sand and loamy sand at similar soil matric suction levels [34]. The sand soil (Figure 3) exhibits a steeper decreasing soil water content among the soil series. Limited distribution of attraction forces of sand particles on water molecules could be the reason for sand soil's sudden sharp decline in the soil moisture content. Other soil types have a relatively steady decline in soil moisture content. Sand exhibits a low soil matric suction-threshold value, which could be due to an overall low particle attraction forces on water molecules.

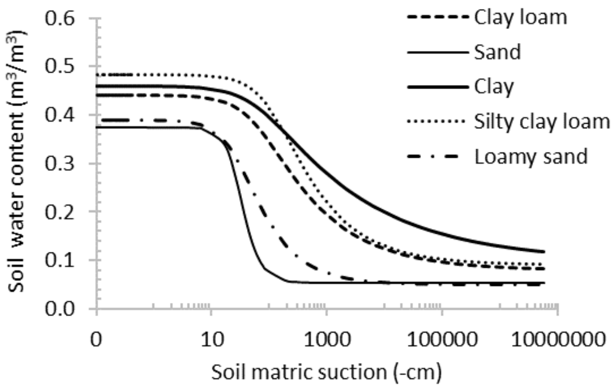


Figure 3 Water retention curves for all sand, clay, clay loam, silty clay loam, and loamy sand

Table 3 Permanent wilting point (PWP), field capacity (FC), and plant available water (PAW)

Parameters	FC @ -330 cm	PWP @ -15000 cm	PAW
Clay	0.3329	0.1897	0.1432
Sand	0.0545	0.053	0.0015
Loamy sand	0.1039	0.0522	0.0517
Silty clay loam	0.3059	0.1216	0.1843
Clay loam	0.2568	0.1164	0.1404

Field capacity (FC) and permanent wilting point (PWP) values estimated from the curve lines were based on the soil matric suction of -330 and -15000 cm, respectively [28]. Table 3 shows the estimated FC, PWP, and the PAW on different soil types based on the Terengganu soil series. The reason for clay and sand or loamy sand has the highest and the lowest PWP, respectively, corresponds to the slow and fast decline in soil moisture content at rising soil matric suction (Figure 3). Similarly, the curve lines in Figure 3 showed higher FC values of clay, clay loam, and silty clay loam than sand and loamy sand, as in Table 3. Silty clay loam was found to have the highest PAW, whereas sand has the lowest PAW. The almost identical FC and PWP, as shown in Figure 1, explains the reason for sand soil having the lowest PAW. The low PAW of Jambu (sand), Rhu Tapai (sand), and Rhudua (loamy sand) soil series would likely encounter frequent water-stress environments should irrigation become a limiting factor. The Gondang soil series with the highest PAW would be the most promising soil for water holding capacity and water conservation.

Water supply management in the agricultural field requires more information than the PAW values. For instance, the water supply rate and the duration needed for a soil depth to achieve a specific water content are required. The former involves infrastructure management and cost in supplying the water. While the latter determines the plant roots' depth water supply to the level of sufficient soil water content. Figure 4 showed the water infiltration profiles at different durations simulated by Richards' equation [35]–[38]. Among the soil textures, sand and silty clay loam correspond to the highest and the lowest hydraulic conductivity. For instance, for water to infiltrate into 1.2 m of soil depth, the sandy soil was five times faster than the silty clay loam. Hence, to supply water in an adequate amount to 1.2 m deep on silty clay loam (Gondang Series) requires a much longer duration than the sandy soil (Jambu, Rhu Tapai Series) in an intermittent irrigation method.

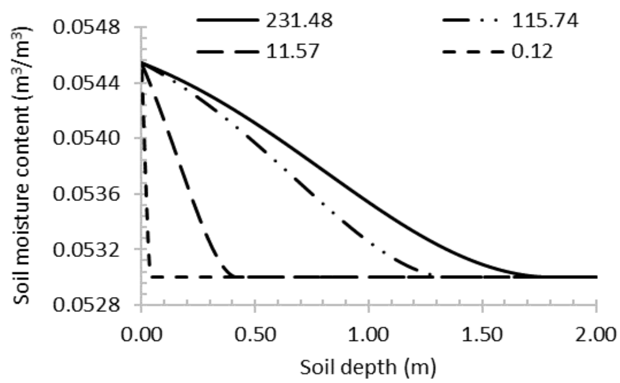


Figure 4 Water infiltration profile on the sand (Jambu, Rhu Tapai Series) at 0.12, 11.57, 115.74, 231.48 days. Water infiltrates into the soil at field capacity

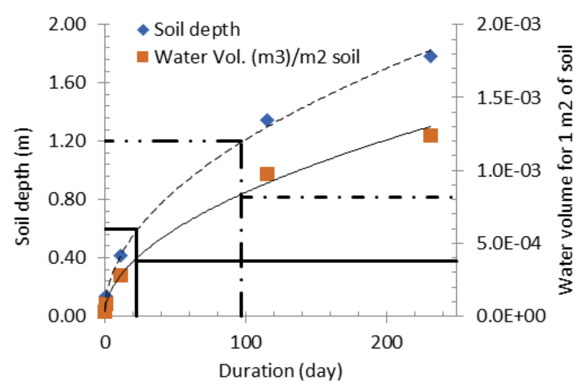


Figure 5 Relation of soil depth, infiltration duration, and infiltrated water height for sand (Jambu, Rhu Tapai Series)

Figure 5 relates the soil depth, duration, and the water supply volume over the area of the agriculture field (or accumulated water supply). The ratio of water supply volume and duration gives the required water supply rate. For sand, for water to reach the 0.6 m depth, silty clay loam required 5.8 times longer than the duration needed for sand soil at a similar depth. The water supply rate ratio between silty clay loam and sand was 46 times, which implies the former ability to store more water. The observation was consistent with the highest PAW given by silty clay loam as in Table 3. Similarly, when the water infiltrates 1.2 m soil depth, it takes longer duration and needed more water supply volume than the 0.6 m soil depth.

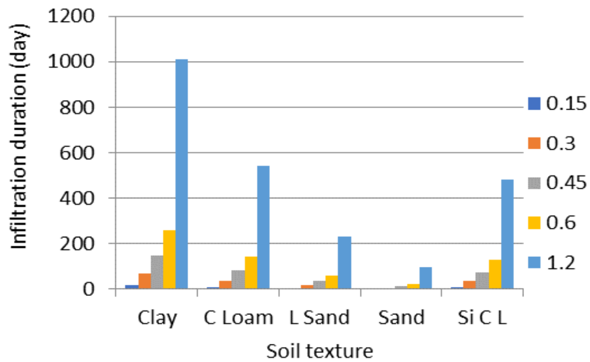


Figure 6 The required duration for water infiltrated into the soil depths (0.15, 0.3, 0.45, 0.6, 1.2 m) and textures. Note: C Loam, L Sand, Si C L corresponding to clay loam, loamy sand, silty clay loam

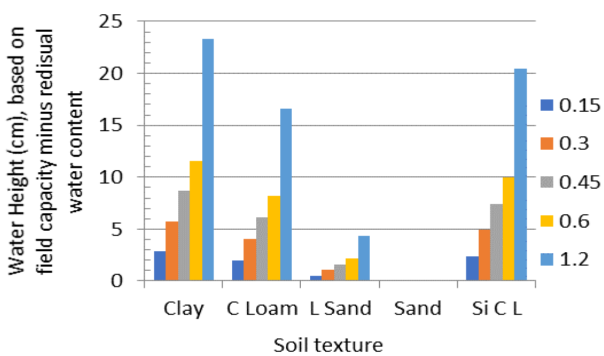


Figure 7 The water height (in cm) that has infiltrated into the soil depths (0.15, 0.3, 0.45, 0.6, 1.2 m) and textures. Note: C Loam, L Sand, Si C L corresponding to clay loam, loamy sand, silty clay loam

Figures 6 and 7 showed the relation between soil textures, water infiltration duration, soil depth, and water height. In general, the water infiltration duration increased with increasing soil depth. The deeper the soil depth, the higher the water height needed to irrigate the soil. The ratio of water height and water infiltration duration allows one to estimate the rate of water infiltration or the rate of water supply. The water infiltration rate in decreasing order was silty clay loam, clay loam, clay, loamy sand, and sand. For instance, at 0.15 m of soil depth, the water infiltration rate was the highest at 2.599E-03 m/day on silty clay loam and the lowest at 6.7E-05 m/day on the sand. The decreasing order of the rank remains unchanged for all the other soil depths.

Furthermore, Figure 6 relates the soil depth needed for irrigation water to the water infiltration duration. Using the same soil depth and refer to Figure 7, the required water height to irrigate the soil can be estimated. The soil depth would be plant root depth to be wetted by infiltrated water. The sand's water heights to irrigate the soil depths were too low to be visible in Figure 7. The silty clay loam (Gondang Series) appears to need less water infiltration duration (Figure 6) and water height (Figure 7) than clay (Batu Hitam, Tasik, Lubok Kiat, Kampong Pusu, Tok Yong, Jerangau, Tersat Series), even though it has a larger PAW than the clay. While sand consistently showed the lowest PAW, water infiltration duration, and water height. Overall, the Gondang soil is the most preferred among the five soils because of its shorter water infiltration duration than clay. It requires lesser water height than clay, yet it has the highest PAW than all the other soils.

4.0 CONCLUSION

Twelve soil series identify in Terengganu state were categorized into soil textures of loamy sand, sand, silty clay loam, clay, and clay loam. The soil textures based on the percentage of particles relates to specific soil hydraulic properties. The properties describes the relation of soil moisture content and soil matric suction. The FC, PWP, and PAW for different soil textures were successfully estimated. The Batu Hitam, Tasik, Lubok Kiat, Kampong Pusu, Tok Yong, Jerangau, and Tersat Series were found as clay soil. They could not retain as much water as the silty clay loam that is the Gondang Series. Other soil series' ability to contain water was less than that of clay and silty clay loam. When considering PAW, water-saving, and water infiltration duration, the Gondang Series was preferred over the other soil series. Furthermore, the current estimated water infiltration duration, water height, and water infiltrated soil depth would be a useful guide to farmers in comparing water usage between soil textures in Terengganu state.

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