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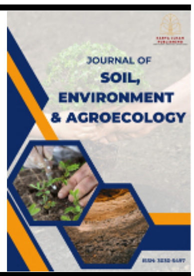

Estimating Water Supply Requirement on Pahang Soil Series to Achieve a Minimal Water Consumption for Resource Efficiency in Agroecology

Sunny Goh Eng Giap[1,*], Mohammad Fadhli Ahmad[1], Rudiyanto[2]

[1] Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu
[2] Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

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ABSTRACT

Agroecology has ten elements that can be implement in the agricultural activities and food systems to achieve a more sustainable future in producing and consuming foods. Water saving is one of the important attributes of agroecological practices. In this study, we are investigating soil series information provided by the Department of Agriculture, Malaysia. There are 34 soil series identified in Pahang state. The existing information provided with the soil series do not guide the implementation of irrigation management in terms of water consumption requirement for plantation land management. The current study converts soil series information into soil textures. There are seven soil textures determined in Pahang states. They were Clay, Silty Clay, Clay Loam, Silty Clay Loam, Sandy Clay Loam, Loam, and Sand. Soil textures were used to estimate soil hydraulic properties to represent the soil series. Soil field capacity, permanent wilting point, and plant available water were determined. Water infiltration simulation was carried out on all soil textures, and it was found silty clay loam (Gugut Series, Setol Series) was one of the best soil textures in terms of water infiltration time, and water retention in the soil. The information derived from the current study can be used for land management planning to estimate the irrigation water supply needed, which will be useful for cost estimation and water resource management.

1. Introduction

Agroecology is a relatively term new in Malaysia when compared to others like sustainability, or even the word environment. The term agroecology carried ten elements, that each of them represents a crucial aspect of agricultural systems when applied to its optimum level will have significant positive impact in improving social, environment, and economics. Generally, it can be viewed as sustainability, but it emphasizes more on ecology, agricultural and food systems. Hence, agroecology is a narrow down of sustainability into the scope of agricultural and food systems with harmonious interaction with environment, plant, animal, and human beings.

*Corresponding author.
E-mail address: sunnygoh@gmail.com

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Some of the agroecological practices have been widely used by farmers, for example, recycling of agricultural solid wastes, reduce usage of synthetic chemicals in plantation, reduce in water consumption and pollution, and so on. Conservation of water consumption in agricultural field is related to several agroecological practices, and it relates to the state of soil conditions. Some of the agroecological practices include better soil health improvement, mulching, agroforestry, diverse cropping systems, water harvesting, managing animal grazing, effective irrigation technique, contour farming, green manure, climate smart agriculture, and integrated water resource management. Below includes the discussion of how these practices can help conserving water consumption in the agriculture plantation.

A better soil health improvement may indicate a good amount of soil organic matter [1]. Soil high in soil organic matter tends to have better soil moisture holding capacity, that may help to reduce the frequency in field irrigation. Adding to the improvement is the soil organic matter acts as partial heat insulation on soil surface from direct sunlight [2] in the daytime that further reduce the loss of water due to evaporation. Mulching is another effective approach to preserve soil moisture content [3]. This is achieved using field substance such as leaves, wood chips, and straw, that these substances prevent weed growth by preventing light penetration, limit evaporation, thus retain soil moisture a bit longer than the soil without it. Agroforestry is a method which forest plants co-exist in harmony with crop and animal farming systems [4]. The advantage of such system is that the natural forest microclimate limits evaporation and it increases the rate of water infiltration, thus sustaining soil moisture content for a longer time. Polyculture and crop rotations is known to improve soil structure and health [5], for instance, adding taproot plants will increase vertical soil penetration for better water infiltration [6] and water seep into a deeper soil depth. Region with limited water supply can explore water harvesting technique such as rainwater harvesting [7], swales construction [8], terracing [9], that such systems increase storage ability of the soil and slow the runoff speed of water. Manging grazing animals is effective to avoid exposing soil surface to direct contact of sunlight [10] and rainwater direct impacts to conserve soil moisture content.

All those stated previously are external factors affecting soil moisture content. Irrespective of these factors, soil consists of a composite of soil particles with other living and non-living organic matters. Soil particles in bulk can be generally categorized as soil texture which consists of three components as sand, silt, and clay, which are named based on their particle sizes with sand the largest to clay the smallest particles. Different composition of sand, silt, and clay represent different soil texture implies moisture storage ability of the soil. Commonly, sand store less water than the clay soil texture [11].

Water from rainfall or irrigation enter the soil. Some of it drain out of the soil due to gravitational pull or force. The leftover water is better known as soil moisture content at field capacity (FC). The water is readily available for plant absorption until it reaches permanent wilting point (PWP) that is a point where soil moisture has reached its most minimum level that plant roots absorption will be weaker than the suction of soil particles on the moisture leftover in the soil. The plant available water (PAW) is then calculated by the difference between FC and PWP [12]. This water is not entirely exclusive to plant root, flora, and fauna in the soil, it can be loss by evaporation due to heat from sunlight, upward soil temperature gradient, and even wind blow at the soil surface. Nevertheless, it is important to estimate the moisture availability in soil that it could have implications for plantation management [13] in terms of water consumption needed, cost related to it, piping system, and potential policy implications on social and environmental related issues like pollution in water, and water resources stress when it becomes limited in supply.

Soil is an important asset to Pahang state, Malaysia, yet not much information is available publicly regarding soil texture that translates into farming usability like soil moisture storage ability. Pahang state contributes 4.5% of national GDP that its three largest economic activities distributed as 49% in services, 23% agriculture, and 22.1% manufacturing [14]. Agriculture contributes a significant amount to economic development and growth to Pahang state, hence, providing essential information regarding soil for public references regarding soil moisture holding ability is a useful tool for plantation land development as well as the consideration of inclusion into policy decision making tool by the authority in the future. The current study includes the updated Pahang state soil series that have been made available by the Department of Agriculture, Malaysia [15].

In this study, we aimed to translate soil series into information that will be useful for water irrigation management. The objective of this study includes: (1) converting soil series in Pahang state into soil texture information that will be useful for irrigation water management, (2) translate soil textural information in soil hydraulic properties to estimate soil moisture field capacity, permanent wilting point, and plant available water, and (3) simulate water infiltration at soil moisture at field capacity into the predicted soil textures, and relate soil depths, with time for infiltrated water to reach the soil depth, and also the amount of water needed irrigate the land area.

2. Methodology

2.1 Soil Series of Pahang State, Malaysia

The Soil Survey Staff [15] was referred for the soil series in the state of Pahang, Malaysia. The name of the soil series may not always indicate where it is located. A series' name refers to a characteristic that was first identified at the time of its discovery. Each soil series came with layers of soil that each layer may have different soil texture. Hence, the layers were averaged out to determine single percentage for each soil components as in silt, sand, and clay, that this information was used in the classification of soil texture.

2.2 Identification of the Soil Texture of Pahang State

Using the information gathered on the composition of silt, sand, and clay for each soil series, the soil texture was identified. A free soil texture calculator was used to achieve this [16]. Twelve distinct varieties of soil textures exist, including sand, silt, and clay. These range from coarser textures like loamy sand to slightly coarser textures like sandy clay loam to finer textures like silty clay.

2.3 Soil Properties Related to Moisture Content in the Soil

The soil texture was used to estimate soil water characteristic curve. The characteristic curve establishes the link between soil moisture suction pressure with soil moisture content. The soil field capacity (FC) moisture content was identified at a -330 cm suction pressure. For the soil permanent wilting point (PWP) moisture content, a -15000 cm was used [17]. Both of this information allow the estimation of soil plant available water (PAW) moisture content that was determined using the difference of value between FC and PWP.

2.4 Simulation of Soil Water Infiltration

The amount of water in the soil that is absorbed by plant roots depends on the PAW, FC, and PWP. It is uncertain, although, how much water enters the soil and how quickly it must do so to reach the appropriate soil moisture content and soil depths for plant roots absorption. This study investigated how much water percolates into the soil at soil field capacity moisture content at the soil surface, thus, it can estimate the soil moisture content level at different soil depths, and the time it needed for water to reach the desired soil depths. The level at which water became plant accessible is indicated by a minimum level value that is above permanent wilting point soil moisture content value.

The parameters used in the van Genuchten equation were generated [18]. The hydraulic conductivity function and the characteristic curve were represented by the van Genuchten equation's parameters as follows:

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

$$K = K_s (Se)^L \left\{ 1 - \left[1 - (Se)^{1/m} \right]^m \right\}^2 \tag{2}$$

$$Se = \frac{\theta_L - \theta_r}{\theta_s - \theta_r} \tag{3}$$

where θ_L is taken as the soil moisture (m^3/m^3), K is hydraulic conductivity under unsaturated condition (K), α and n are commonly used constants, L is an empirical pore related parameter, θ_s is soil moisture content under saturated condition (m^3/m^3), θ_r is minimum level of soil moisture (m^3/m^3), K_s is hydraulic conductivity in saturated water soil condition (m/s), and m as a fitting constant that is related by the relation $m = 1 - \frac{1}{n}$.

The water infiltration process [19] from the soil surface to different soil depths can be estimated using Richards' equation [20],

$$\partial \theta_L \Big/ \partial t = \frac{\partial}{\partial z} \left[K \left(\partial \psi_m \Big/ \partial \theta_L \right) \partial \theta_L \Big/ \partial z - K \right] \tag{4}$$

where t is the simulation time (s), z is the height of the soil body (m) that it is positive pointing from top to bottom. The time and space are captured by theoretical equation derived by Richards equation that it is guided by the mass balance principle.

Equation (4) by itself is not a ready form for implementation for any programming language. To simulate water infiltration using software, the equation was approximated by algebra equation as follows [21],

$$\begin{aligned} \frac{\theta_{L(k)}{}^{n+1}}{\Delta t} = & \frac{K_{k+1/2} (\partial \psi_m / \partial \theta_L)_{k+1/2} \theta_{L(k+1)}{}^{n+1}}{(\Delta z)^2} - \frac{K_{k+1/2} (\partial \psi_m / \partial \theta_L)_{k+1/2} \theta_{L(k)}{}^{n+1}}{(\Delta z)^2} - \frac{K_{k-1/2} (\partial \psi_m / \partial \theta_L)_{k-1/2} \theta_{L(k)}{}^{n+1}}{(\Delta z)^2} \\ & + \frac{K_{k-1/2} (\partial \psi_m / \partial \theta_L)_{k-1/2} \theta_{L(k-1)}{}^{n+1}}{(\Delta z)^2} - \frac{K_{k+1/2} \vec{k}}{\Delta z} + \frac{K_{k-1/2} \vec{k}}{\Delta z} + \frac{\theta_{L(k)}{}^{n}}{\Delta t} \end{aligned} \tag{5}$$

where k is the square middle that is it directed vertically from top to bottom over the soil depth. $k+1/2$ is in between square k and $k+1$, while $k-1/2$ is placed in between square $k-1$ and k. The n and $n+1$ refer to the current and the incoming iteration variables, respectively. Δt is small time taken in the simulation and Δz is the square size used after dividing the soil depths to many step sizes. The method used in solving Eq. (5) can be retrieved in references of many numerical scheme [22].

3. Results and Discussion

3.1 Soil Series of Pahang State

In the state of Pahang, Malaysia, there were thirty-four soil series identified and reported by the Department of Agriculture [15]. They were distributed all over Pahang land area. The soil series were Benta Series, Jempol Series, Kuantan Series, Lanchang Series, Mai Series, Rengam Series, Segamat Series, Selimber Series, Batu Anam Series, Batu Lapan Series,Bungor Series,Chat Series, Gol Series, Jeram Series, Kemuning Series, Munchong Series, Musang Series, Mentara Series, Merhamah Series, Persit Series, Sagu Series, Jerneh Series, Tangga Series, Temerloh Series, Gugut Series, Meranti Series, Setol Series, Baging Series, Rompin Series, Katong Series, Klau Series, Ulu Dong Series, Tavy Series, Bungor Series.

The soil series maybe useful indication on the chemical properties for planting purposes as provided by the original reference of Department of Agriculture, however, it does not provide useful indication on water management, for example the water infiltration relating to the amount of water needed to irrigate different soil depths, and the waiting time for irrigation [23]. Therefore, further processing of the raw data is necessary to reveal useful information.

3.2 The Soil Textural Classification of the Pahang State

Soil series in Pahang state captured soil particles segregation information in terms of its different sizes. The sizes are sand, silt, and clay. Each soil series carried this information, and it is used to identify the soil texture for each soil series. Figure 1 shows the results of the classification of soil series into soil textures that represented by the red filled cycle with number in it. It appears most of these soil series fall under the clay soil texture, followed by sandy clay loam, silty clay, and so on. The least identified soil texture is the loam soil that is represented by Selimber Series. The grouping of soil series into soil textural classification has important similarity on physical appearance, as in particle size, which indicate similar attributes like water retention curve or better known as soil characteristic curve to relate soil moisture content with soil matric suction. This information allowed the estimation of some water related parameters that are necessary to indicate water holding capacity in the soil.

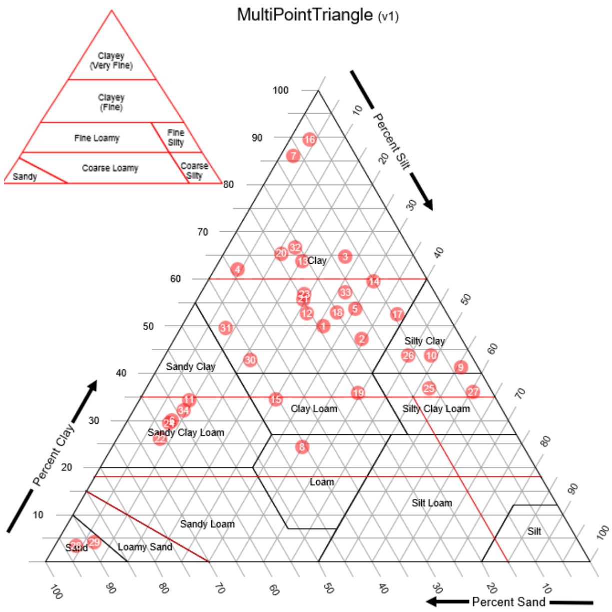

Fig. 1. Soil texture classification based on 34 soil series in Pahang. Note: 1-Benta Series; 2-Jempol Series; 3-Kuantan Series; 4-Lanchang Series; 5-Mai Series; 6-Rengam Series; 7-Segamat Series; 8-Selimber Series; 9-Batu Anam Series; 10-Batu Lapan Series; 11-Bungor Series; 12-Chat Series; 13-Gol Series; 14-Jeram Series; 15-Kemuning Series; 16-Munchong Series; 17-Musang Series; 18-Mentara Series; 19-Merhamah Series; 20-Persit Series; 21-Sagu Series; 22-Jerneh Series; 23-Tangga Series; 24-Temerloh Series; 25-Gugut Series; 26-

Meranti Series; 27-Setol Series; 28-Baging Series; 29-Rompin Series; 30-Katong Series; 31-Klau Series; 32-Ulu Dong Series; 33-Tavy Series; 34-Bungor Series

3.3 Soil Field Capacity Moisture, Soil Permanent Wilting Point Moisture, and Soil Plant Available Water

Seven characteristic curves for Pahang series were identified. Each characteristic curve represents a specific soil texture. A total of thirty-four soil series are represented by seven soil textures, thus, multiple soil series may be classified under the same soil textures. Each soil texture indicates a specific relation to relate soil moisture content with soil matric suction. The relation changes with maximum soil moisture content (completely saturated soil) that gradually reducing its values to the minimum soil moisture content (residual amount of water in the soil) as the soil attraction forces (soil matric suction) continue to increase in value, for example, tens of thousands of kilopascals.

The estimated FC, PWP, and PAW are shown in Table 1. The FC refers to amount of water stored in the soil after drainage of water by the effect of gravity. The water that stayed in the soil at FC is readily available for plant roots absorption as well as releasing in the form of evaporation. Soil FC moisture content is not entirely extractable by plant roots because a portion of soil FC moisture content will be soil PWP moisture content, which at the point of soil matric suction pressure that restricts plant root absorption. For this reason, the amount of water that is accessible for plant roots absorption is limited to the difference between soil FC minus PWP moisture contents. The result of this is known soil PAW.

Table 1
Pahang soil series and its classification of soil texture

Parameter	Soil texture						
	Clay	Si Clay	C loam	Si C L	S C L	Loam	Sand
FC (m3/m3) @ -330 cm	0.3329	0.3215	0.2568	0.3059	0.2290	0.2360	0.0545
PWP (m3/m3) @ -15000 cm	0.1897	0.1743	0.1164	0.1216	0.1109	0.0912	0.0530
PAW (m3/m3)	0.1432	0.1472	0.1404	0.1843	0.1181	0.1449	0.0015

Note: C loam is clay loam, S C L is sandy clay loam, Si Clay is silty clay, Si C L is silty clay loam

Clearly, soil series classified under clay soil (Benta Series, Jempol Series, Kuantan Series, Lanchang Series, Mai Series, Segamat Series, Chat Series, Gol Series, Jeram Series, Munchong Series, Musang Series, Mentara Series, Persit Series, Sagu Series, Tangga Series, Katong Series, Klau Series, Ulu Dong Series, Tavy Series) constitutes the greatest FC value, whereas sandy soil (Baging Series, Rompin Series) has the lowest FC value. Silty clay soil (Batu Anam Series, Batu Lapan Series, Meranti Series) gives the second largest FC value, followed by silty clay loam soil (Gugut Series, Setol Series), clay loam soil (Kemuning Series, Merhamah Series), and loamy soil (Selimber Series). However, after subtracting PWP from FC, the highest soil PAW goes to silty clay loam, followed by silty clay, loam, clay, while the least PAW is given by sandy soil. Knowingly, it is not surprising to have sand as the lowest PAW, it is important to note that silty clay loam soil has a PAW that is 11,851% greater than sandy soil. The percentage is suggesting the number of time (or frequency) at which sandy soil must be irrigated to achieve the same effect of water holding for the water consumption of the silty clay loam. A similar comparison has revealed that 56% in sandy clay loam, 31% (clay loam), 29% (clay), 27% (loam), and 25% (silty clay). Thus, silty clay loam is profoundly more effective soil for water storage for plant consumption, yet there are only two out of 34 soil series found in the Pahang state representing silty clay loam. Considering a large area of land use for plantation, changing the soil texture would be impossible. A more practical approach to deal with soil having difficulty in holding water would be to alter the soil layer by applying specific techniques such as mulching, organic matter amendment, and others that have been reported by many in the literatures [24-28].

3.4 Water Infiltration Simulation on Pahang State Soil Series

More data is needed for agricultural water supply management than just PAW values. The PAW value is significantly important to indicate the amount of the maximum amount of moisture store in soil accessible for plant consumption, additional information is needed, for example, the rate of water supply and the amount of time needed at a given soil depth to reach a given moisture content are necessary. The PAW information entails managing the infrastructure and the cost of water delivery. The rate of water supply and the amount of time, however, establishes the depth at which water is supplied to plant roots up to a sufficient soil water content.

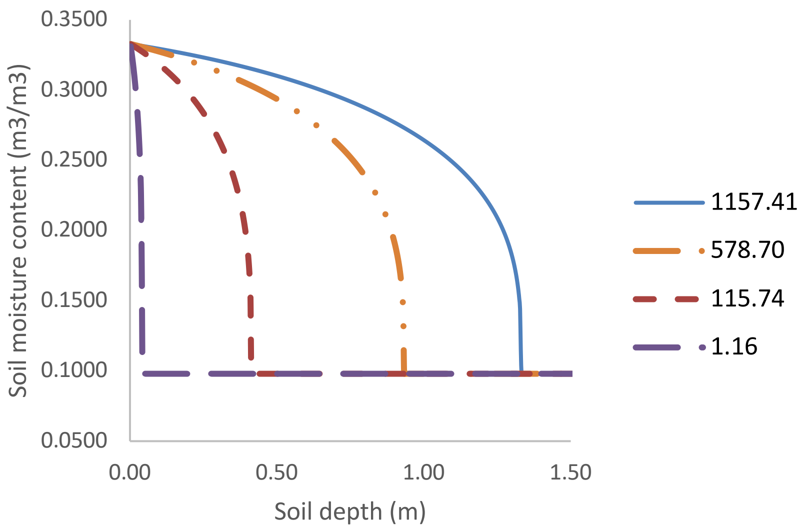

Fig. 2. Water infiltration into the clay soil after 1.16, 115.74, 578.71, and 1157.41 days. Water entering the clay soil (Benta Series, Jempol Series, Kuantan Series, Lanchang Series, Mai Series, Segamat Series, Chat Series, Gol Series, Jeram Series, Munchong Series, Musang Series, Mentara Series, Persit Series, Sagu Series, Tangga Series, Katong Series, Klau Series, Ulu Dong Series, Tavy Series) at field capacity (0.3329 m^3/m^3).

Figure 2 shows the soil moisture profiles at different clay soil depths resulted by different time of water simulation. A similar soil profile is shown in Fig. 3 by loamy soil. It is important to note that water infiltration is set to occur at the soil field capacity moisture content so that water loss by gravitational pull is limited to the very minimum. Thus, it is evident that clay soil appeared to have a soil moisture value at the soil surface at field capacity that is greater than that of the soil surface moisture content at field capacity of the loamy soil. The result of the simulation depicts at similar time of water infiltration, for example the time at 579 days, the soil moisture profile of loamy soil has penetrated deeper into the soil than the clayey soil, refer Figs. 2 and 3. This difference is not an isolated case, the other five soil textures also have different soil moisture infiltration profiles. Therefore, the implication is that to achieve soil field capacity moisture content at similar soil depths, clayey soil requires more time than that of loamy soil.

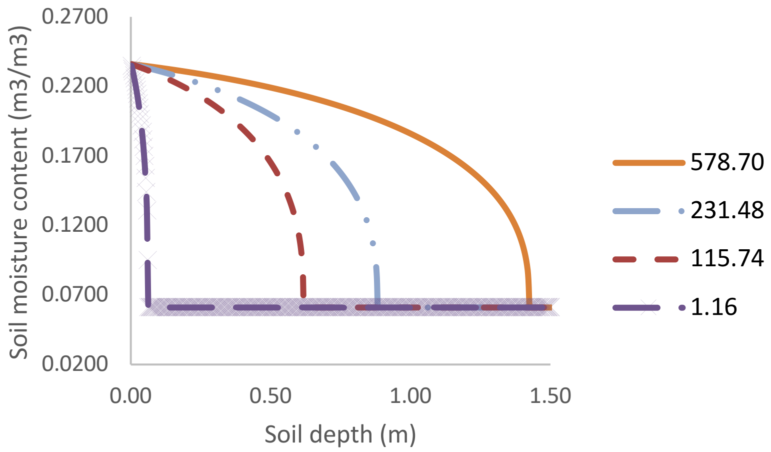

Fig. 3. Water infiltration into the loamy soil after 1.16, 115.74, 231.48, and 578.71 days. Water entering the loamy soil (Selimber Series) at field capacity (0.2360 m^3/m^3).

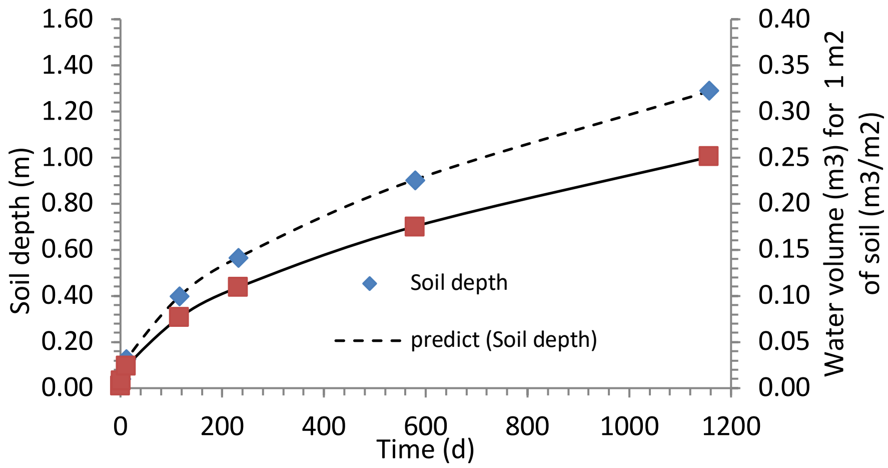

Fig. 4. Clay soil depths infiltrated by water, time for water to reach clay soil depths, the amount of water (m^3 of water/m^2 of land area) has infiltrated clay soil depths

Figures 4 and 5 depicted the relation between simulation time, soil depth at which the soil moisture content has achieved its field capacity value, and the amount of water (reported in water height (m^3 water volume/m^2 soil area)) has reached the soil depth as indicated [29]. This information is valuable for land management because plantations require irrigation. Irrigation implies the necessary cost of water supply, other than the one-time cost for infrastructure and maintenance. When irrigation is supplied, care should be taken not to avoid wastage, which is why water used in irrigation is supplied at soil field capacity moisture content at the soil surface so that no water is loss by gravitational pull as drainage. In addition, the duration (time) is estimated to reveal the necessary waiting time to be overcome from the time-lag between the beginning of water supply until the end of soil depth moisture content to be reached. In addition to the information depicted in Figs. 2 and 3, the Figs. 4 and 5 provided more informative in helping decision making on land management in irrigation. The information in Figs. 4 and 5 and from other soil textures in Pahang state (not shown here), was extracted for further analysis as depicted in Figs. 6 and 7.

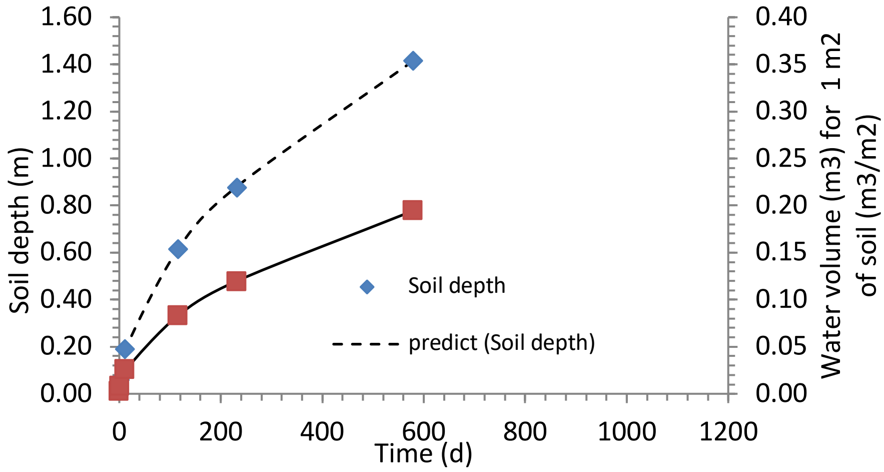

Fig. 5. Loamy soil depths infiltrated by water, time for water to reach loamy soil depths, the amount of water (m^3 of water/m^2 of land area) has infiltrated loam soil depths.

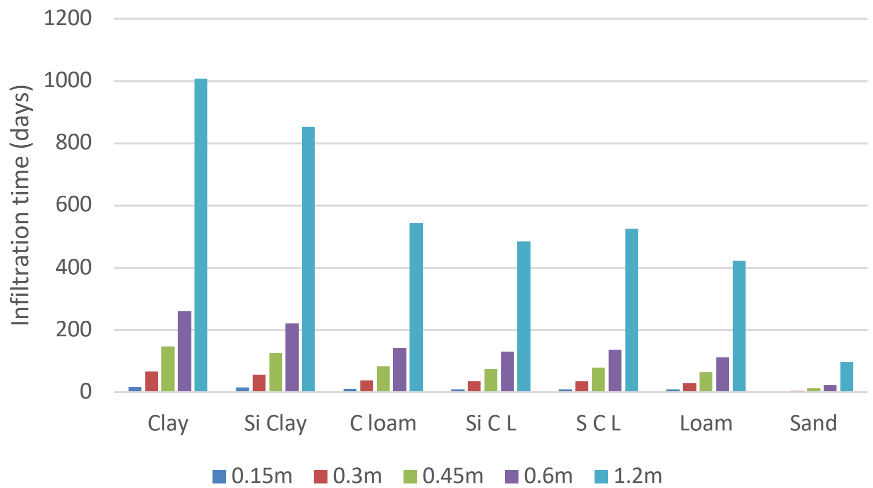

Fig. 6. Time of water infiltration to reach the soil depths of 0.15, 0.30, 0.45, 0.60, and 1.20 m for different soil textures. Note: C loam is clay loam, S C L is sandy clay loam, Si Clay is silty clay, Si C L is silty clay loam.

Different types of plant have different root depths [30]. The information provided in Figs. 6 and 7 will be useful when estimation is required for plants with specific root depth, for example, 0.15, 0.3, 0.45, 0.6, and 1.2m. One could check Fig. 7 for required water volume, and Fig. 6 for time needed for the water supply to reach the soil depth. While the time estimation given in Fig. 6 may seems impractical for soil depth of 1.2m to wait for 1000 days in order for water supply to reach the required soil depth, the estimation is still in preliminary estimation stage that this value would change if the water supply at the soil surface is supplied at water saturation level, which would speed up the water infiltration time, hence, reducing the waiting time significantly. Theoretically, this is possible, but nothing more than hypothesis can be stated at the current point until further investigation is carried out. Nevertheless, Fig. 6 clearly showed the clayey soil exhibits the longest infiltration time at all soil depths, whereas sandy soil remained the lowest waiting time. In terms of supply of water, sandy soil required the least water, and clayey required the most water to irrigate of soil depths presented. Among the seven soil textures presented, silty clay loam soil (Gugut Series, Setol Series) may represent the desirable soil texture that requires a moderately short infiltration time with moderately high soil moisture content to irrigate the soil. However, most soil series in Pahang state are dominated by clayey soil (Benta Series, Jempol Series, Kuantan Series, Lanchang Series, Mai Series, Segamat Series, Chat Series, Gol Series, Jeram Series, Munchong Series, Musang Series, Mentara Series, Persit Series, Sagu Series, Tangga Series, Katong Series, Klau Series, Ulu Dong Series, Tavy Series), which is suggesting farmers are most probably must deal with more clayey soil than any other soil textures, hence, alternative exploration of soil amendments may be necessary, which is beyond the scope of the current study. Nonetheless, the current study reveals useful information that is important for early site assessment for water supply management that would establish the foundation for further exploration.

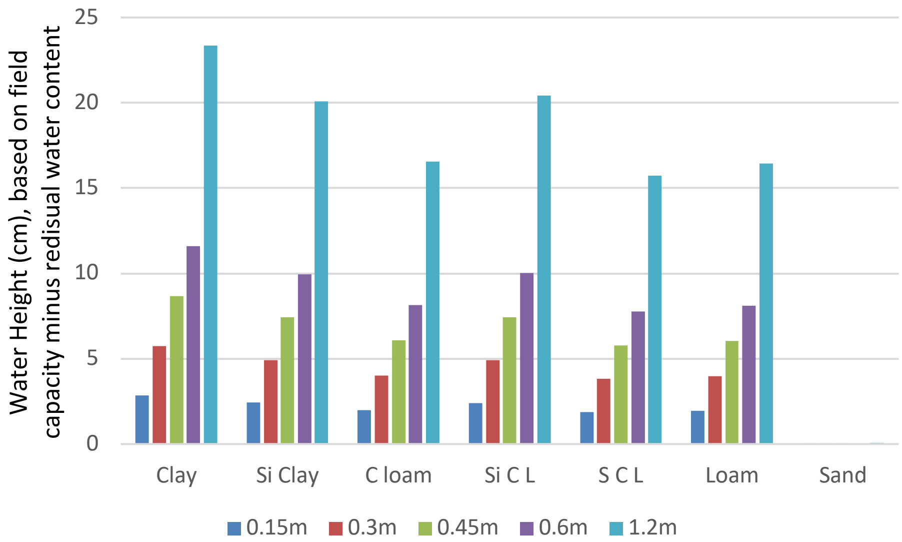

Fig. 7. The amount of water (m^3 of water/m^2 of land area) has infiltrated soil depths for different soil textures. Note: C loam is clay loam, S C L is sandy clay loam, Si Clay is silty clay, Si C L is silty clay loam.

6. Conclusion

Conservation of water consumption in agricultural field is one of the agroecological attributes. To achieve this objective, soil series information on Pahang state were investigated. Currently, there are limited information available on Pahang state that is useful for irrigation management. The information published by Department of Agriculture, Malaysia are providing physical chemical properties of the soil that is able to indicate the suitability of the soil for the types of plant to be planted. The current study converts the soil particles composition information provided by the Department of Agriculture into soil textures for further investigation of its hydraulic properties in the soil. There are 34 soil series identified in Pahang state. Of these soil series, seven soil textures were identified, they are Clay, Silty Clay, Clay Loam, Silty Clay Loam, Sandy Clay Loam, Loam, and Sand. The soil texture was used to generate soil hydraulic properties to relate soil moisture content with soil matric suction, which then used to quantify soil field capacity, permanent wilting point, and plant available water moisture content. Further analysis was carried out to simulate water infiltration into the soil at soil field capacity moisture content that soil moisture content profiles were generated at different soil depths. An extended analysis was carried out that identified the relationship between simulation time, soil depth, and the needed water supply. Silty clay loam soil (Gugut Series, Setol Series) was found to be the best optimise between those stated parameters, but other soil textures like clayey related soil series can be improved to shorten water infiltration time by soil organic amendment to increase soil bulk density, or soil organic matter amendments on sandy soil to increase soil moisture retention.

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