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MODEL OF SOIL WATER CONTENTS FOR VARIOUS SOIL TEXTURES

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The increase of food demand must be followed by increased agriculture production. A form of this food increase is using dry land agriculture. Dry land is widely available in Indonesia but it lacks good soil water storage characteristics. Therefore, a research is conducted to understand the ability of soil to store water. The objective of research are to develop mathematic model of unsaturated soil vertical water flow in the soil media through various textures and to learn the ability of many soils in storing the water after a wetting phase. Research method is experiment to construct the mathematic model which is then compared with data of experiment result. The observed parameter is water content in the soil which is examined during drying process. The drying process is providing the water into sandy loam texture soil. Water is allowed to freely drain. The observation then involves sampling the water content for 84 hours or 3.5 days, precisely once every 12 hours. Result of the analysis over sandy loam showed that the composition of this loam is 9% clay, 80% sand, 11% silt, 27% field capacity, 8.68% permanent wilting point, 18.6 water availability, 1.24 gmcm^{-3} soil content weight, and 2.69% organic matter. The hard textured soils are not able to store water in the longer term, while the soft textured soils are able to store water for a longer term.

INTRODUCTION

Soil is the result of the transformation of mineral substances and organic earth and formed due to the influence of environmental factors are working in a very long time. Soil is the medium for plants and bases of life for animals and humans (Sutanto, 2005). Soil contains substances that plants need to live one of which is water. Water is one of the essential components needed by plants to grow, develop and produce. Water that can be absorbed by plants is water that is in the pores of the soil in the root zone. A soil water content of agricultural land can be lost to the air through direct evaporation from the soil surface and evaporation through plants. The water can be lost due to land management that is not in accordance with the principles of soil and water conservation (Kamagi and Kumolontang, 2009). Water movement in the soil is very important, the movement of water from the soil through evaporation and is or drainage, and from soil to plant roots. Water movement in soil occurs as the liquid flow in saturated soil conditions, and the flow of liquid and vapor in unsaturated soil conditions (Foth, 1984).

Based on the importance of water content in the soil for plant growth study was conducted to study and formulate mathematical models of vertical ground water flow in the unsaturated soil media of various textures and studied the ability of various soil retain water after wetting phase. The results of these studies are expected composition of models that can be used to predict the moisture content of various soil textures (Assouline and Tartakovsky, 2001). Law to calculate the transfer of water through the soil saturated condition known as Darcy's law is also commonly used in calculating permeability. In fact, Darcy's law also involves hydraulic conductivity and hydraulic gradient as a parameter. Darcy's law to describe the flow of water saturated conditions quantitatively. Darcy's law is a quantitative measure water flow in saturated soil and formulated as follows:

$$q = J = -Ki \qquad (1)$$

where J is the velocity of water flow, K is hydraulic conductivity and, i is hydraulic gradient. (Baskoro and Tarigan, 2007).

Darcy's law shows that the velocity of water flow (J) is proportional to the hydraulic gradient (i). Hydraulic conductivity (K) is constant which confirms the relationship between the flow velocity is proportional to the hydraulic gradient. Measures that determine the speed of the water flow and hydraulic gradient in determining hydraulic conductivity can vary (Lopez, 2007).

Caputo and Stepanyants (2007) explained that the Richards equation is the basic equation in the theory of groundwater flow in unsaturated porous media pass which was introduced in 1931. Jury et al., (1991) mentions that the Richards equation is non-linear equations resulting from the merger Darcy-Buckingham law with the law of conservation of mass, assuming that the air phase are in constant atmospheric pressure and the water phase is not compressed.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left\{K(\psi)(\frac{\partial \psi}{\partial z}+1)\right\} \qquad (2)$$

where: K is the hydraulic conductivity of unsaturated flow (cms^{-1}), ψ is potential matrix (cmH_2O), Z is vertical distance in a positive direction, θ is water capacity (cm^3cm^{-1}), t is time (s).

Hydraulic conductivity (K) is the ratio between the gradient hydraulic discharge or drainage angle and gradient curves. In saturated soil with a stable structure the hydraulic conductivity is characterized by a fixed value the amount of about 10^{-2} - 10^{-3} cmcm^{-1} for sandy soils and 10^{-4} - 10^{-7} cmcm^{-1} for clay soils. Hydraulic conductivity (K) is not only a characteristic of the soil itself, because K depends on the soil and fluid attributes together (Lopez, 2007).

Soil hydraulic conductivity arises because of the capillary pores are interconnected with each other. Quantitatively the saturated hydraulic conductivity can be interpreted as the speed of movement of a liquid in a porous medium in the saturated state, in this case the fluid is water and the soil is porous media. Determination of hydraulic conductivity based on Darcy's law. Hydraulic conductivity in Darcy's law is expressed as a factor K in Equation 3 as follows:

$$V = \frac{KdH}{dz} \tag{3}$$

where: V is velocity (LT^{-1}), K is hydraulic conductivity (LT^{-1}), and dH/dz is hydraulic potential gradient.

The conceptual model is considered to be a group of fine straight capillary tubes with a uniform radius, so that the movement of water in the tubes is considered to have the same speed, as well as influenced by porosity, hydraulic conductivity also depends on the viscosity and density of the soil water. This relationship can be shown by Equation 4 as follows

$$K = \frac{K''\eta}{gp} \tag{4}$$

where: K is saturated hydraulic conductivity (ms^{-1}), K'' is permeability that depends on the density and viscosity (m^2), p is density of the liquid (gas) (kgm^{-3}), g is acceleration of gravity (ms^{-2}), η is viscosity of the liquid (gas) (kgm^{-1}s^{-1}).

METHODOLOGY

Materials used in the research are a sandy loam soil and water which are used as an indicator of the water content in the soil. The tools used are a dessicator, ring, digital scales, pressure plate apparatus, and oven. The research begins with the manufacture of composite formulations soil is a conditioned soil as a sandy loam soil. Then place the in a medium-sized container 430 cm wide 30 cm length 100 cm tall made of glass with a thickness of 1 cm. The base of the rock layers of zeolite media were given then the thick fibers of each 5 cm. The method used is an experimental method and mathematical models to compare the moisture content in the soil water content predicted results with experimental.

This research takes some of the data such as t volumetric water content (θ), soil water retention (Θ), matric head (h), soil saturated hydraulic conductivity (Ks) and unsaturated hydraulic conductivity as a function of soil matric head (Kh). Volumetric water content (θ) obtained by conducting laboratory tests on soil formulation by taking soil from the container using a drill at a depth of 0 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, and 80 cm.

The relationship of volumetric soil water content (θ) with the matric head (h) was measured in the soil physics Laboratory, University of Brawijaya, Malang, Indonesia, with soil samples using a set of tools and pressure plate apparatus, namely by way of placing the soil sample into the pressure plate apparatus.

Water content (θ) at each matric head (h) is obtained by a volumetric method as follows:

$$\theta = \frac{\frac{(BBT - BKT)}{\rho}}{VT} \tag{5}$$

where: θ is volumetric water content (gg^{-1} or $mlml^{-1}$), *BBT* is weight wet soil (g), *BKT* is weight dry soil (*g*), *VT* is volume of soil total (ml), ρ is density of pure water (ρ = 1 gml^{-1}).

The results of measurements of water content are used as information in making the relationship curve between soil water content (θ) with the matrix head (*h*).

Soil water retention is obtained by using the equation Mualem (1976), as follows:

$$\Theta = \frac{\theta - \theta r}{\theta s - \theta r} \tag{6}$$

where: Θ is effective saturation, θ is volumetric water content (gg^{-1} or $mlml^{-1}$), when the water content θr = h is in the smallest conditions, when the water content θs = h are in the greatest condition.

Soil saturated hydraulic conductivity (Ks) was measured by the method of Constant head developed by De Boodt (1967) (Prijono, 2011), with the following stages: Soil samples with the tube immersed in a tub of water to a height of 1 cm below the surface of this part of the tube for 24 hours. Soil sample tube was transferred to the device with the determination of saturated hydraulic conductivity, and water flowed into the device. After high water in constant gauges, water dripping measured in predefined time intervals, then Ks is calculated using Equation 7:

$$K = \frac{qL}{(A * t * H} \tag{7}$$

where: *K* is hydraulic conductivity (cms^{-1}), *q* is the volume of water collected (cm^3), *L* is high soil sample (cm), *A* is surface area of soil (cm^2), *t* is time spent by *q* (s), *H* is difference in water levels inside and outside the sample (cm).

Having obtained the effective saturation values and soil saturated hydraulic conductivity of the soil with a sandy loam texture, and then the data is used as the information in the calculation of unsaturated hydraulic conductivity. Unsaturated hydraulic conductivity calculations using the van Genuchten equation (1980) as follows:

$$K(\theta) = Ks\Theta^{\frac{1}{2}}\left[1 - (1 - \Theta^{\frac{1}{m}})^m\right]^2 \tag{8}$$

where: $K(\theta)$ is unsaturated soil hydraulic conductivity (cms^{-1}), *Ks* is saturated soil hydraulic conductivity (cms^{-1}), Θ = effective saturation, and m=1-(1/n). Therefore the unsaturated water flow model using a one-dimensional Richards equation is shown as Equation 9.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left\{K(h)\left(\frac{\partial h}{\partial z} + 1\right)\right\} + s \tag{9}$$

where: $K(h)$ is hydraulic conductivity of unsaturated flow head function matrix (cms^{-1}), θ is water content (cm^3cm^{-3}), h is matric head (cm), s is water uptake by the roots ($mlml^{-1}s^{-1}$), z is vertical distance in a positive direction (cm), t is time (s).

RESULTS AND DISCUSSION

Soil characteristics

The studied soil is homogeneous and composite soil. Soil physical and chemical properties are shown in Table 1. The soil has a coarse texture with sand particle content of as much as 80%, 11% and clay silt 9%.

Table 1. Soil Physical and Chemical Properties

Soil Texture Class	Sandy Clay
Sand (%)	80
silt (%)	11
Clay (%)	9
Fill weight (gcm^{-3})	1.24
Total porosity (% volume)	47.36
Pore Drainage (% volume)	20.08
Holder pore water (% by volume)	8.68
Available Water (% by volume)	18.6
Hydraulic conductivity (cmh^{-1})	13.2
Organic Matter (%)	2.69
pH	6.6
CEC ($cmolkg^{-1}$)	17.80
KB (%)	44

Table 1 shows that the soil has more sand particles that have a coarse texture soils with organic matter at 2..69%, which has a bulk density was about 1.24 $grcm^3$. Total porosity of the soil low at 47.36%, but has a drainage pore high at 20.08%.

Characteristics of Soil Moisture

The resulting soil moisture characteristics can be expressed in the form of the relationship curve between soil matrix suction (pF) with soil water content (θ). curve is presented in Figure 1.

Soil samples were placed at the site of the tube showed that the water content in the soil in the content conditions of permanent wilting point of 8.68%. Available water content in the soil of 18.6%. Water available in the soil due to lower coarse soil texture and organic matter content slightly. Soil texture and soil organic matter is very important in the availability of water in the soil, the coarser particles of the soil, the available water in the soil is low. The less organic material, the lower the level of water available in the soil.

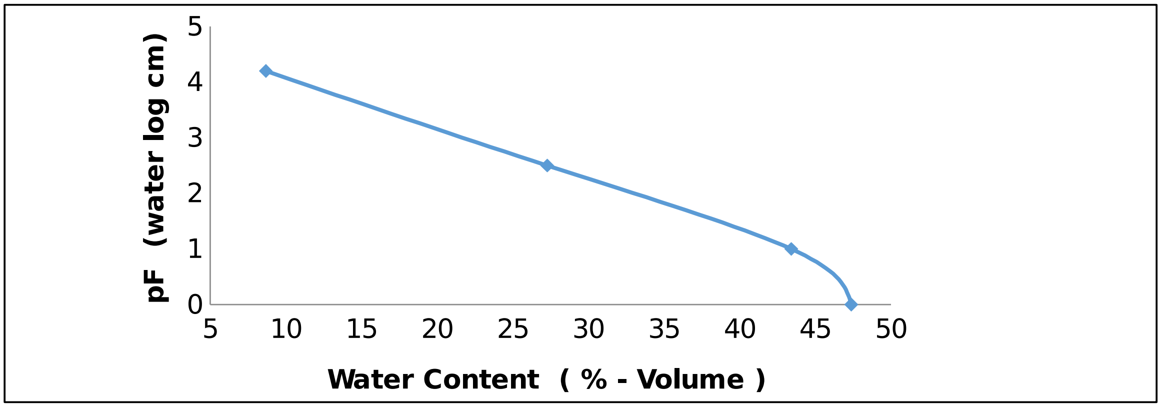

Figure 1. Curve relationship between soil matrix suction (pF) with soil water content (θ).

Soil Using Matlab Software Water Movement in Unsaturated

By definition MATLAB (Matrix Laboratory) is a program for the analysis and numerical computation and is an advanced mathematical programming language created with the idea to use nature and form of a matrix. MATLAB programs can be used to analyze the water content of the soil generally in unsaturated conditions. Water content in the unsaturated soil conditions can be predicted by using MATLAB-based program using Darcy's law. Estimation of soil water content in unsaturated conditions (unsaturated) using MATLAB created by Hornberger and Wiberg (2005). Flowchart of mathematical models that are arranged can be seen in Figure 2 below:

Soil Water Content in Prediction Results

Water content predictions obtained from the input data obtained from observations of the physical properties of the soil into the MATLAB software. The data obtained is soil porosity, soil depth, soil hydraulic conductivity, infiltration rate, residual water content (residual water content), a, n, time, matrix suction. Such data can be seen in Table 2.

Moisture content in the soil obtained predictions of entering data into the MATLAB software can be seen in Figure 3.

Figure 3 shows that the prediction of soil moisture content in more and more reduced. The rate of decline in water levels occurred in most of the central part of the soil depth, while at the top and the water content has decreased, but the decrease in water content is very small, this is because of the soil conditions have drainage pores larger than the pore holders water so less able to hold water well.

Soil Water Content in Experimental Results

Water content contained in the soil at the experimental activity can be seen in Table 3. Table 3 shows that the water content more and more reduced, because of the condition of the soil that has a rough texture, so the water levels drop rather quickly. The rate of decline in ground water levels resulting from the condition of the physical properties of the soil.

Prediction Experiment with the Calibration Data

Experimental and predicted water content calibration is performed by comparing two data. Comparison of experimental results with predictions can be illustrated in Figure 4 to Figure 11.

Table 2. Sandy clay input data

Soil Condition	Value
Soil Depth (cm)	85
Infiltration velocity (cmhour^{-1})	1.2
Matric suction bottom (cm)	0
Residual water content (cm^{3}cm^{-3})	0.08
Porosity	0.47
Maximum time (days)	3.5
a	0.021
n	1.61
Hydraulic Conductivity (cmhour^{-1})	13.2

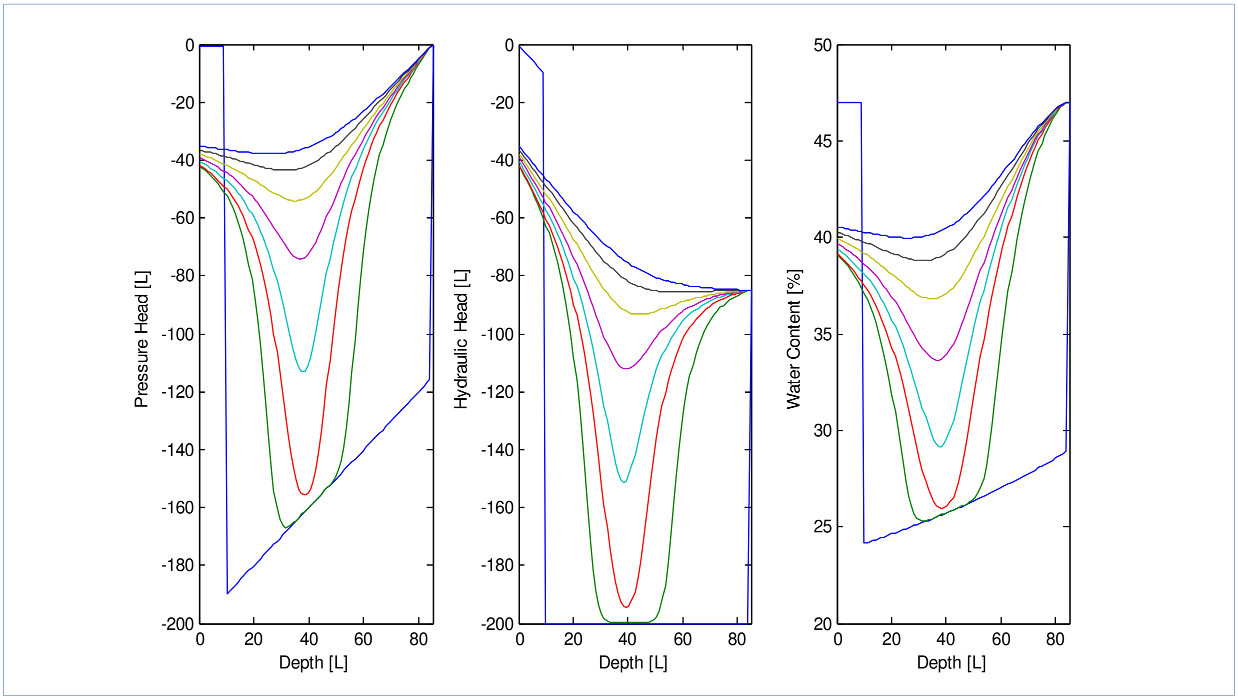

Figure 3. Water content in sandy loam soil prediction

Figure 4 to Figure 11 show that the water content experiments with water levels predicted to equally time has decreased and it can be concluded that the value of the water content in the soil experiments with predictions do not differ much, this is evidenced by the value of determination of 83.81%, so that the models that have been developed to predict the ability of soil to store water various textures.

After calibration of the models, it was found that the experimental results with the results predicted no significant differences, so that from the models included in the MATLAB software can be used to predict the water content in various soil types by entering the required parameters is soil porosity, depth soil, soil hydraulic conductivity, a, n, time, sucking down the matrix, infiltration rate and residual water content (residual water content). Figure 11 is the result of water level predictions using computational models with the help of MATLAB software that uses the input data according to the parameters of various types of soil, the input data can be seen in Table 4.

Table 3. Moisture Experiment

Time (hour)	Depth (cm)	Experiment water content (%-volume)
0	0	45.04
	10	25.36
	20	26.33
	30	27.84
	40	27.94
	50	28.63
	60	29.08
	70	29.94
	80	30.87
12	0	41.6
	10	40.54
	20	40.32
	30	40.32
	40	40.4
	50	41.56
	60	42.56
	70	45.33
	80	45.87
24	0	41.03
	10	40.08
	20	39.87
	30	39.35
	40	39.82
	50	40.88
	60	41.93
	70	45.12
	80	45.54
36	0	40.94
	10	39.85
	20	38.57
	30	37.2
	40	38.44
	50	39.88
	60	41.07
	70	44.67
	80	45.33

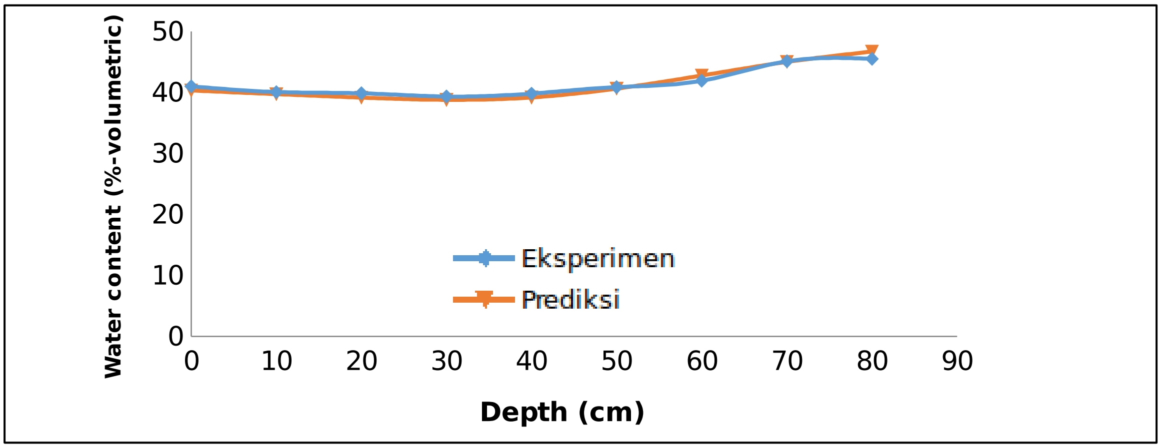

Figure 4. Water content at various depths versus time (0 hours)

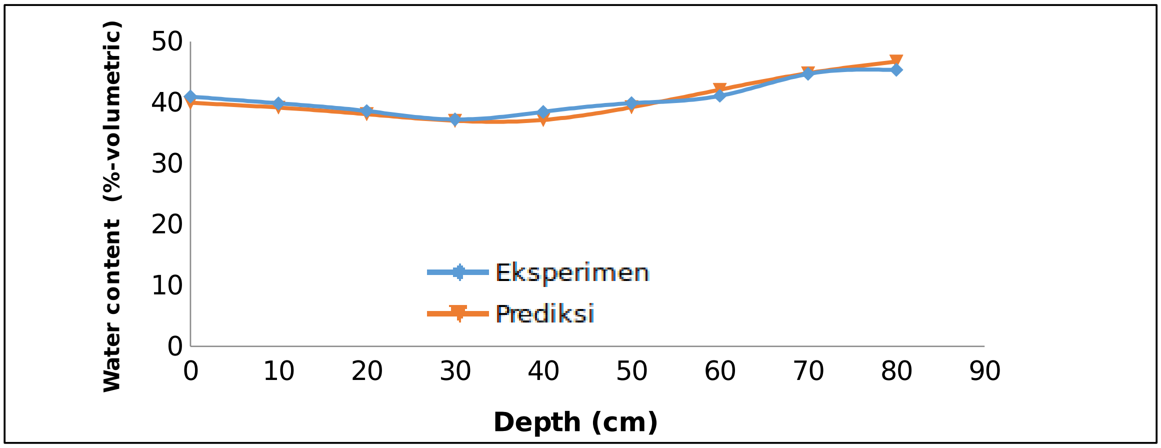

Figure 5. Water content at various depths versus time (12 hours)

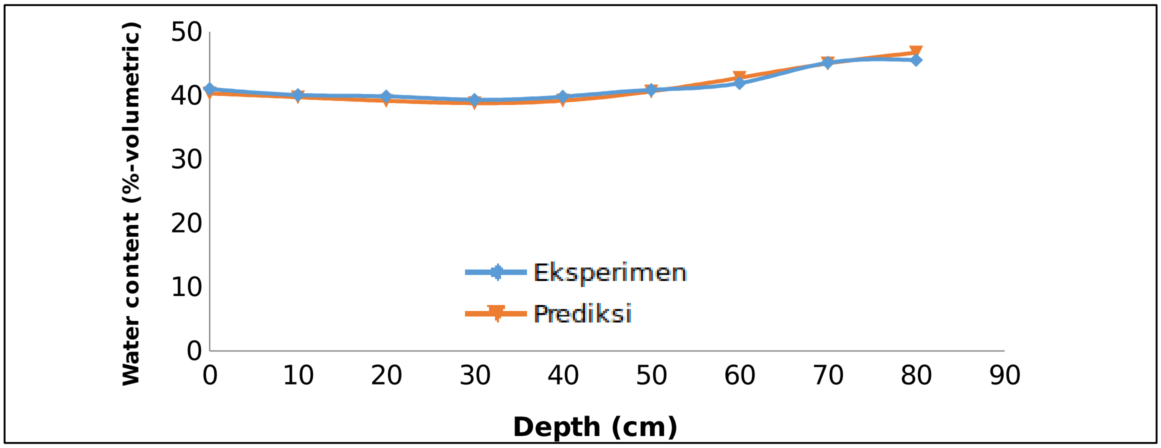

Figure 6. Water content at various depths versus time (24 hours)

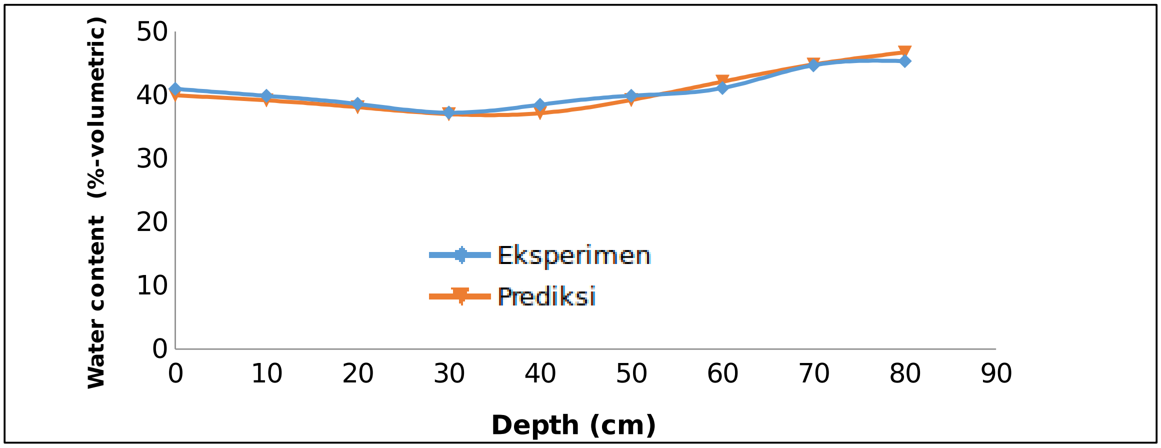

Figure 7. Water content at various depths versus time (36 hours)

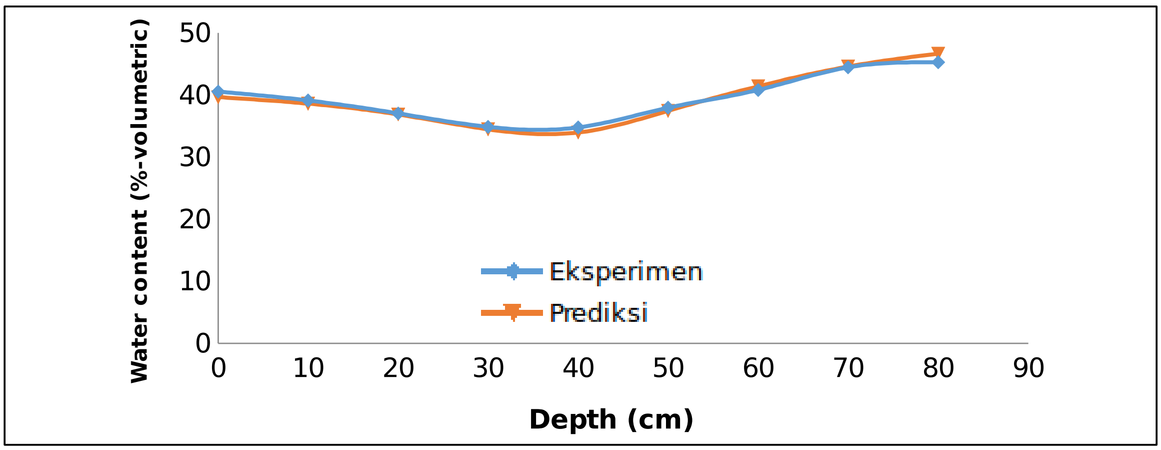

Figure 8. Water content at various depths versus time (48 hours)

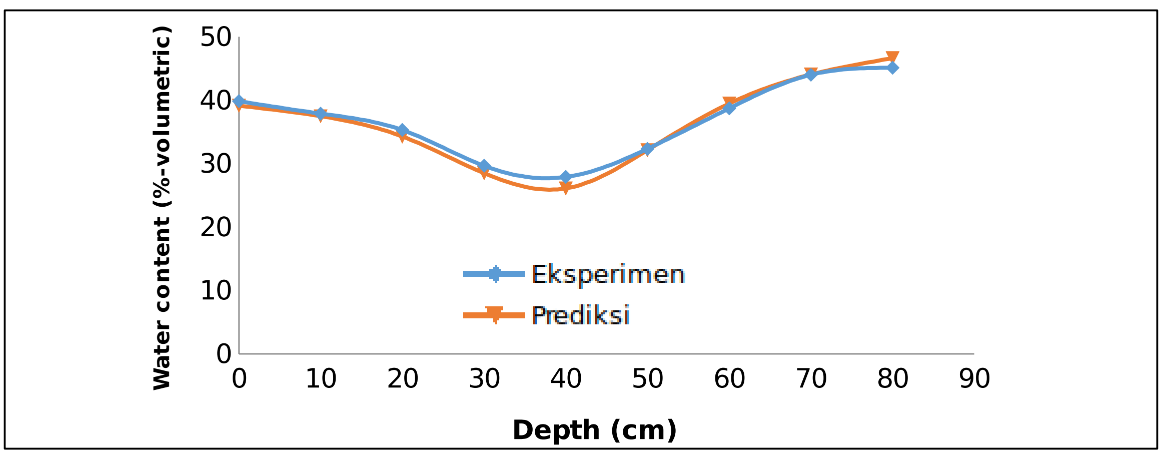

Figure 9. Water content at various depths versus time (60 hours)

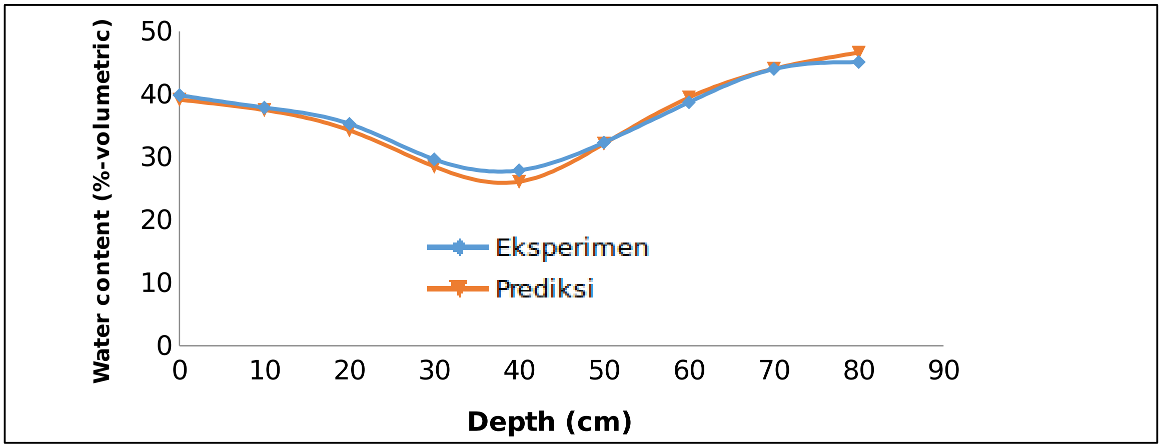

Figure 10. Water content at various depths versus time (72 hours)

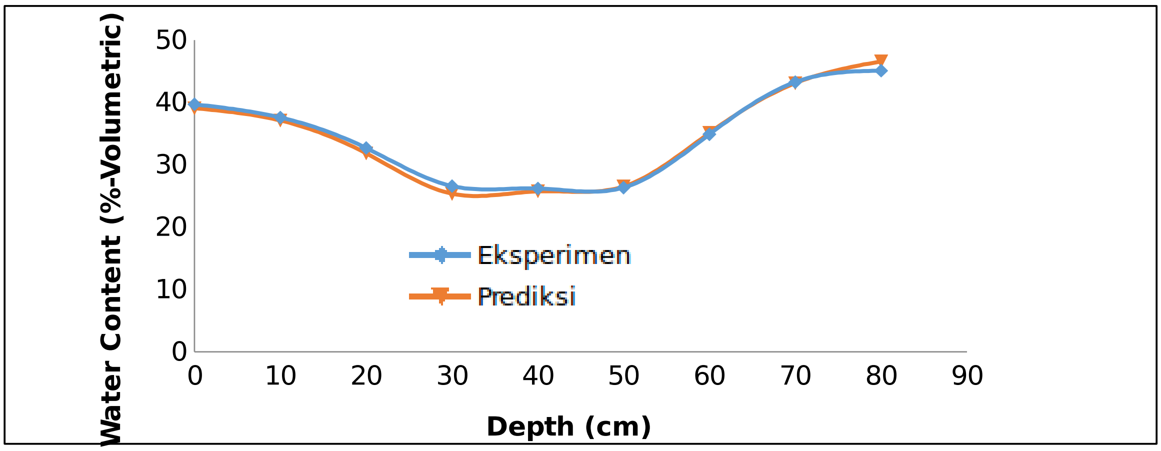

Figure 11. Water content at various depths versus time (84 hours).

Table 4. Various soil texture input data.

Soil Texture	**Sand**	**Sandy Loam**	**Silty Loam**	**Clayey Loam**	**Clay**
Soil Depth (cm)	85	85	85	85	85
Infiltration speed (cmh^{-1})	1.61	1.27	1.1	0.252	0.024
Matric suction under (cm)	0	0	0	0	0
Residual water content (cm^3cm^{-3})	0.058	0.08	0.061	0.129	0.102
Porosity	0.37	0.47	0.48	0.49	0.51
Maximum time (day)	3.5	3.5	3.5	3.5	3.5
a	0.035	0.021	0.019	0.030	0.021
n	3.19	1.61	1.39	1.37	1.20
Hydraulic conductivity (cmh^{-1})	21.07	13.2	3.0	1.0	1.08

Parameters in predicting water content in the soil is used as input data in MATLAB software. MATLAB software is run and the water content in the soil obtained predictions of various soil types can be seen in Figure 12:

Figure 12 it can be concluded that the drying process, the moisture content in the soil can be predicted in a variety of soil textures. Water content in the soil on all types of soil texture more and more reduced. The rate of decline in soil water content on sandy loam soil texture to different times with water content in soil texture others. Drying rate on sandy soil water content is greater than in the sandy loam soil, whereas the rate of soil water content is very small decline occurred in soil with clay texture, this is because the clay soil has a texture finer than sandy soil so it can hold more water better than soil that has a coarse soil texture.

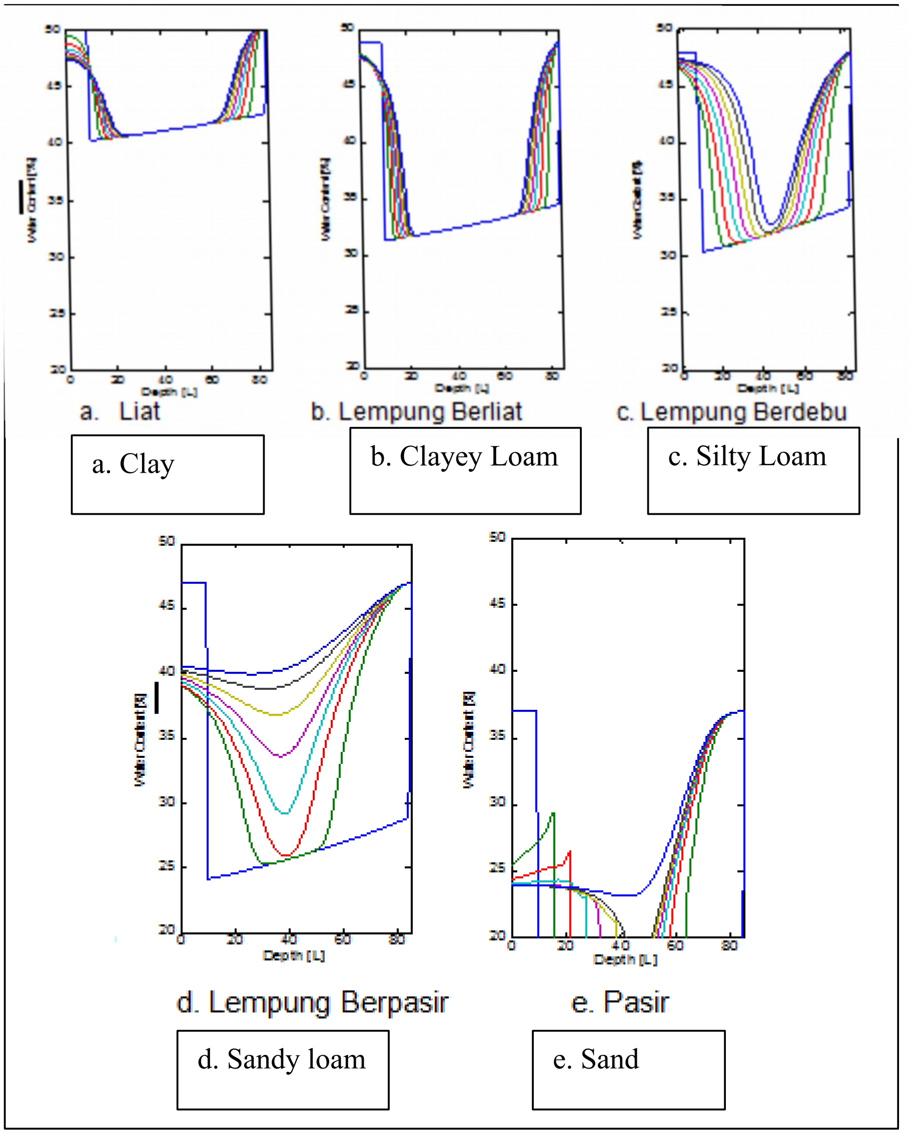

Figure 12. Water content at different soil textures

CONCLUSION

Conclusions of this research are mathematical models that have been developed can be used to predict the unsaturated vertical flow of water on a variety of soil texture classes. Developed mathematical models that can be accepted by 83.81% of the value of determination and ability of the sandy loam soil in retaining moisture in the soil is not good, with a total porosity of 47.36% and 20.08% of pore drainage. Fine soil can hold water longer than soil with coarse texture.

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