The experimental research on establishment of the soil water retention curves (pF) in order to determine water content and suitable irrigation amount for dry crops at the droughty region of the southern central part of Vietnam

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● **Abstract:** The correlation result of the experimental research on establishing the soil water retention curves (pF) at the drought region of the Southern Central part of Vietnam has been closely (R2 from 0.96÷0.99). The calculated results of soil water capacity show that the rate of total available soil water compared with field capacity is fairly high, from 76.20% (soil layer 0÷10cm) to 80.68% (the whole layer 0÷60cm). Average of feature moisture content of the layer (0 ÷ 60cm): Saturated moisture (θbh): 34.49% volume, field capacity (θfc): 21.02% volume, wilting moisture (θwp): 4.06% volume. Correlation analysis and establishment of the linear regression equation between: the soil water retention curves (pF) and soil water content, calibration results are suitable with high correlation coefficient, linear regression functions have been built accordingly and overall deductive meaning. The experimental results and calculations are very important in order to apply in determining soil moisture process through measuring equipments and the appropriate irrigation water amount for popular dry crops at the droughty region of the Southern Central Part of Vietnam.

● **Key words:** Available soil water; Correlation; Dry crops; Readily available soil water; Regression; Soil water retention curves (pF).

1. Introduction

The soil water retention curve (pF - Retention curve or pF curve) is a basic and important feature of soil - water properties, using the pF curve has increased accuracy in forcasting water requirment, it is saving water while improving crop productivity, because the irrigation volume will be determined corresponding a reasonable soil moisture during cultivation, the water loss amount can concurrently be identified due to water transfers to the deep soil layer if soil moisture content exceeds the field capacity. Therefore, studies concerning soil water properties have applied it, such as: the pF curve were applied in mathematical model for forecasting irrigation needs for crops, in which was for coffee in Hawaii - USA (Gutierez M.V. and Meinzer F.C., 1994). Utilizing the relationship between soil moisture and the pF curve in determining the moisture diffusion coefficient has helped simulating moisture transmission more favorably (Molz F.J. and Remson I., 1970). The utility of the pF curve in determining the moisture diffusion coefficient to evaluate the root system's water suction capacity has been demonstrated (Rowse H.R. and Stone D.A., 1978). Application of the pF curve in researching on the relationship between root density and water suction of soybean by establishing relationships between soil moisture - water suction pressure and soil moisture - root density according to each plant growth and development stage, research results have presented analyses of plant biomass, fruits, seeds and roots that are closely related to irrigation schedule and moisture (Reicosky D.C. et al, 1998). In coastal agricultural production areas affected by salinity intrusion, the pF curve has been applied for studying, evaluating salty movement and spreading dissolving substance in the soil under the effect of plant root system or the drainage problem of desalination (Gray W.G. and Pinder G.F., 1976; Raats P.A.C., 1976).

When the soil is in the unsaturated condition, with different soil types at the same moisture value, their moisture pressure is also different. Therefore, the pF curve of each soil type is established to express the relationship between moisture content and moisture pressure of that soil. So far, there are three methods to establish the pF curve: (1) Theoretical method is to predict the pF curve from the grain-cumulative curve (Haverkamp R. and Parlange J.Y, 1986); (2) Experimental one has been realized by many scientists, that was press the sample under high pressure to determine the pF curve (pF) for some main soil types in Vietnam, including soil groups as follows: Ferric Acrisols at Hoa Binh province, Ferric Acrisols, Dystric fluvisols at the Day and Red rivers, Haplic Acrisols at Ha Noi; Gleyic Solonchaks at Hai Phong City and Quang Ninh province, Luvic Arenosols at Ninh Thuan province (Tran Viet On, 2002); and (3) The semi-experimetal one is to find the dependent connectedness of the pF curve with physical and chemical properties of the soil, in order to determine a quantitative regression line for these relationships to classify the soil, then establish a common pF curve for that soil group (Gupta S.C. and Larson W.E., 1979).

The droughty regions of Binh Thuan and Ninh Thuan provinces have a large arable land with relatively similar soil characteristics (fine sand soil), the area is about 10,807ha in Ninh Thuan and about 117,487ha in Binh Thuan. Currently, farmers are cultivating plants as vines, apple, dragon fruit, sugarcane, asparagus, eggplant, tomato, onions, garlic, chili, peanut, etc. at these lands, irrigation for plants mainly by traditional method wastes water. Even in case where a farming area is installed with a water saving irrigation system (drip/sprinkler irrigation), it is still wastable water (Thai Hung Tran et al, 2016) because farmers have not got irrigation schedule information as irrigation water amount, frequency and timing for each crop type, especially the readily available water in the soil for the crop to use. Therefore, experimental research on determination of the pF curve and readily available water is necessary to serve establishment of a suitable water saving irrigation schedule for dry crops and enhance water efficiency, especially important for droughty regions.

2. Theoretical basic, objectives, research content and methods

2.1 Theoretical basis

a) The soil water retention curves (pF)

In the first function by Brooks & Corey (1964), the actual water tension, ψ, is given by:

Theo tác giby:rooks, R.H Corey (1966), áp lực hút ẩm thực tế, ψ, như sau:

$$S_e = \left(\frac{\psi}{\psi_a}\right)^{-\lambda} \quad (1)$$

Where: ψa is the air-entry tension and ψ is the pore size distribution index.

The effective saturation, Se, is defined as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (2)$$

Where: θ s is the porosity, θr is the residual water content and θ is the actual water content;

As an alternative expression to the Brooks & Corey expressions, the water retention function by Van Genuchten. M.T. (1980) has been introduced:

$$S_e = \frac{1}{(1+(\alpha\psi)^{gn})^{gm}} \quad (3)$$

Where: α, gn and gm are empirical parameters;

Equations (1) and (3) are only to data corresponding to tensions below a threshold value, ψx (Figure 1).

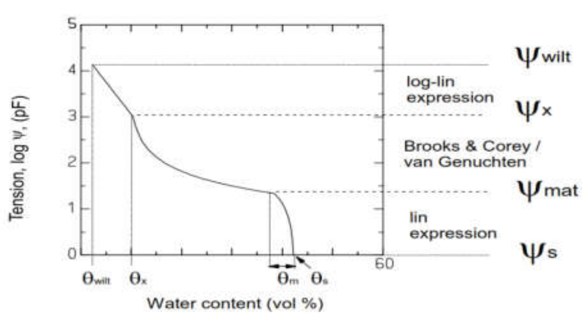


Figure 1: An example of how three different expressions in the water retention curve are used in different ranges. The pF value corresponds to the logarithm of tension expressed in cm.

$$\frac{\log\left(\frac{\psi}{\psi_x}\right)}{\log\left(\frac{\psi_{wilt}}{\psi_x}\right)} = \frac{\theta_x - \theta}{\theta_x - \theta_{wilt}} \quad \psi x < \psi < \psi wilt \quad (4)$$

Where: θx is the threshold water content at the threshold tension, ψx, θwilt is water content at wilting point, defined as a tension of 15,000 cm water, i.e., ψwilt;

In the range close to saturation, i.e. from *θ*s to *θ*m a linear expression is used for the relationship between water content, *θ*, and water tension, (ψ).

$$\psi = \psi_{mat} - \frac{(\theta - \theta_s}{\theta_,} \quad \psi s < \psi < \psi mat \quad (5)$$

Where: ψmat is the tension that corresponds to a water content of θs - θm;

b) Total available water (TAW) and Readily available water (RAW) for crops

The available water (AW) in the root zone is the difference between the water content at field capacity and wilting point (FAO/UNESCO/ISRIC, 1991). Therefore, the available water in the soil layer (i) with the thickness dz as follows:

AW(i) = 1,000*(θfc – θwp)* dz(i) = 1,000*θaw(i) * dz(i) (mm) (6)

Where:

θaw is available water content (cm^3/cm^3);

θfc is water content at field capacity (cm^3/cm^3);

θwp is water content at wilting point (cm^3/cm^3).

dz(i): the thickness in the soil layer (i) (m).

Total available water of the whole layers is calculated as follows:

$$TAW = \sum_1^n AW_{(i)} = 1{,}000 \sum_1^n \theta_{aw(i)} \quad (mm)$$

(7)

Where is i = 1 → n: increment of soil depth.

In theory, water is available until wilting point, but when water in the soil decreases, soil suction forces increases making difficulty for roots to extract water from the soil. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the active roots to respond to the transpiration demand. This limit point is called the suitable minimum water content (θp) or water stress point of crops (p). If the soil water content drops below θp, plant growth and development will be impacted strickenly, and product yield and quality decrease.

Applying the index p is average fraction of TAW which can help plant roots to absort water easily (before θp value), p is used to calculate Readily Available Water (RAW) for crops (FAO/UNESCO/ISRIC, 1991). The higher the index p, tthe greater the useful water amount for the crops. The value of p depends on the plant type, the different stages of plant growth, the evapotranspiration amount and the soil structure. RAW is calculated as follows:

$$RAW = p * TAW \quad (mm) \qquad (8)$$

Where p is fraction of TAW which can help plant roots to absort water easily, occurs [0÷1].

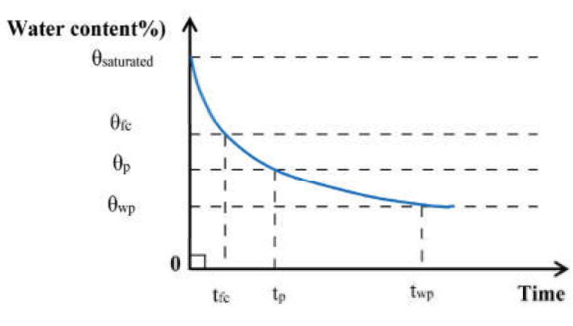


Figure 2: Diagram of water content changes

Where: tfc is the time for water content to decrease from θsaturated to θfc; twp is the time for water content to decrease from θfc to θwp;

2.2 Research objectives

Establish the water retention curve (pF) and identify RAW to serve in researching on suitable water irrigation schedule and improving water use efficiency, especially for water droughty region (droughty one) in the South Central part of Vietnam.

2.3 Research contents

Describe the soil profile;

Take field soil samples and experiment the mechanical, physical and chemical properties of soil in the laboratory;

Experiment to extract water in the soil samples by the water suction measument equipment;

Establish the water retention curve (pF), identify TAW and RAW for crops;

2.4 Research approach and Methods

Approach reality and theory comprehensively, combine with selective inheritance from the concerning scientific research;

Experiment at the field and in the laboratory, analyse mechanical and physical characteristics of soil (Le Van Khoa et al, 1996);

Correlation method to determine the relationship between soil moisture and ater suction, by taking field soil samples then using a vacuum flask with different values of suction pressures to determine the corresponding points of the experimental water retention curve (pF curve);

Summary, processing and analyse experimental results. Establish the pF curve to serve for ditermination of suitable irrigation schedule for crops as a basis for scaling up the application scope.

3. Results and discussion

3.1 Description of the soil profile and test of soil physical and chemical properties

a) Description of the soil profile

Table 1: Description of the soil profile with the layer from 0 ÷ 60cm

Order	Layer	Depth (cm)	Properties of the soil layers
1	Layer 1	0÷20	Fine sandy soil is grayish-brown, in soil with roots, the soil is more porous than the lower layers.
2	Layer 2	20÷40	Fine sandy soil is yellowish-gray, in soil without roots, the soil is tighter than the layer 0 ÷ 20cm.
3	Layer 3	40÷60	Fine sandy soil is yellowish-gray, in soil without roots, the soil is tighter than the layer 0 ÷ 40 cm.

Figure 3: The soil profile at the experimental model

b) Physical and chemical properties of the soil at the experimental model

According to the Soil Map of Binh Thuan province (Pham Quang Khanh, 2003), the soil in the experimental area is cultivated sandy soil, which is acidic (Dystri Haplic Arenosols ÷ ARh.d following the FAO/UNESCO's classification). The soil physical parameters analyzed in the laboratory include: the density test was used cylindrical sampling ring, the soil structure was analyzed by the Robinson suction method graded by USDA/Soil Taxonomy (Soil survey staff, 1998)

The soil analysis results of the physical and mechanical properties have showed that the soil structure was fine and porous sand, helping the roots to absorb water and oxygen easily. The chemical properties was as follows: the soil surface layer (0 ÷ 20cm) was heavily acidic, two layers with the depth of 20 ÷ 40cm and 40 ÷ 60cm were also a acidic soil group; organic content (humus) of the layer 0 ÷ 10cm was poor, the remaining 2 layers were at very poor level; factors of total and digestion nitrogen, total phosphorus and potassium in all three soil layers were very poor level, digestion phosphorus and potassium were medium; these substances in the layer (0 ÷ 20cm) were higher than those ones in two below layers.

The content of N, P and K in the layer 0 ÷ 20cm was higher than those ones in the 2 floors. In parallel with the irrigation regime to maintain regular moisture, it is necessary to apply more lime powder, organic fertilizer and finishing with N, P and K fertilizers appropriately to reclaim the soil and provide nutrients for crops, ensuring stable development and increasing crop yield.

Table 2: The result of physical properties of the soil

Layer (cm)	Grain size analysis								Physical properties					
	Sand (%)					Silt (%)		Clay (%)	Density		Spec. Gra.	Saturation	Porosity	Void Ratio
	Medium		Fine			Coarse	Fine		Wet	Dry				
	2.0 ÷ 0.8[illegible]	0.8[illegible] ÷ 0.4[illegible]	0.4[illegible]5 ÷ 0.2[illegible]	0.[illegible]÷ 0.106	0.106 ÷ 0.07[illegible]	0.07[illegible] ÷ 0.01	0.01÷ 0.00[illegible]	< 0.00[illegible]	γw (g/cm[illegible])	γd (g/cm3)	Δ	S (%)	n (%)	eo
0÷[illegible]0		4.30	47.60	41.[illegible]0	1.70	0.40	0.[illegible]0	4.00	1.60	1.[illegible]6	2.6[illegible]	8.86	40.99	0.6[illegible]
20÷40		[illegible].[illegible]0	47.40	36.10	6.40	0.[illegible]0	0.[illegible]0	[illegible].60	1.[illegible]6	1.[illegible]1	2.63	13.[illegible]0	42.70	0.7[illegible]
40÷60		[illegible].80	48.[illegible]0	3[illegible].20	6.10	0.46	0.[illegible]0	[illegible].74	1.68	1.6[illegible]	2.64	1[illegible].70	[illegible]8.66	0.6[illegible]

Table 3: The result of chemical properties of the soil

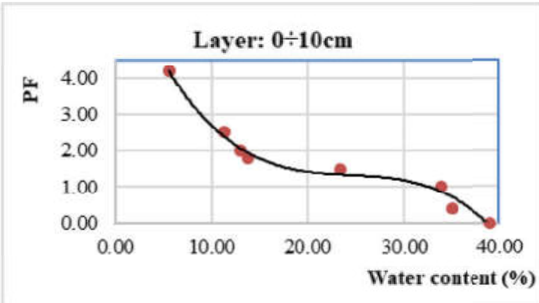
Layer (cm)	pH_{H2O} (1:5)	pH_{KCl} ([illegible]:5)	TSMT	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Fe_{TS}	K_2O dt	N dt	$_2O_5$ dt	$Al^{3+}+H^+$	N_{TS}	P_2O_5 ts	K_2O ts	Humus
			mg/100g									meq/100g	%			
0÷[illegible]0	4.88	4.1[illegible]	61.0	8.6	[illegible]3.6	1[illegible].2	4.3	14.[illegible]	1[illegible].1	0.94	[illegible]9.6	[illegible].7	0.06	0.0[illegible]	0.3[illegible]	1.04
[illegible]0÷40	4.1[illegible]	[illegible].7[illegible]	17.[illegible]	2.1	4.[illegible]	[illegible].2	[illegible].9	8.9	7.[illegible]	0.86	7.[illegible]	6.9	0.03	0.0[illegible]	0.18	0.6[illegible]
40÷60	4.02	[illegible].[illegible]8	16.2	2.0	4.[illegible]	[illegible].0	[illegible].6	8.2	6.1	0.78	6.4	7.0	0.02	0.01	0.1[illegible]	0.47

3.2 The water retention curve (pF curve)

Establishing the pF curve of the cultivated soil layers for application in determining soil moisture process in time and space (Van Genuchten, 1980). The result of the curve is expressed as the logarithmic ratio between the hydraulic h (kPa) and the water volume (cm^3/cm^3), the correlation is quite closely with high coefficient R2 (from 0.96 ÷ 0. 99). These experimental pF curves of 6 soil layers are typical fine sandy soil with the shape of quite homogeneous curves and gentle slope.

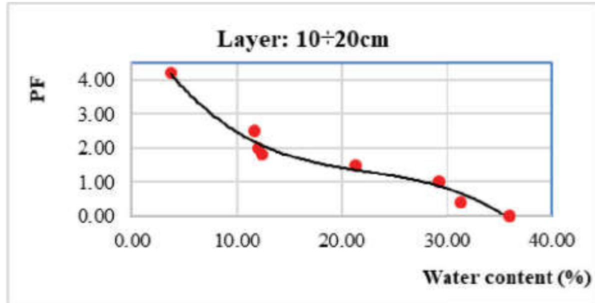
Figure 4: The experiment for determining the water retention curve (pF) for the soil layers

Order	Pressure	Water content (%) at							
	h (pF)	0.0	0.4	1.0	1.5	1.8	2.0	2.5	4.2
	h (cm)	0.0	2.5	10.0	31.6	63.1	100.0	316.2	15848.9
	h (bar)	0.0	0.002	0.010	0.031	0.062	0.098	0.310	15.543
	Depth (cm)	Measured by Sand Box						Measured by pF Box	
1	0÷10	39.10	35.00	33.90	23.40	13.70	12.93	11.30	5.57
2	10÷20	35.93	31.33	29.23	21.33	12.40	12.10	11.67	3.76
3	20÷30	35.10	31.57	29.80	21.33	11.77	11.30	10.70	3.82
4	30÷40	31.60	29.57	28.07	20.23	11.43	11.00	10.27	4.61
5	40÷50	33.00	30.43	28.57	20.20	11.43	10.97	10.30	3.39
6	50÷60	32.23	30.03	27.87	19.63	10.97	10.63	10.20	3.23



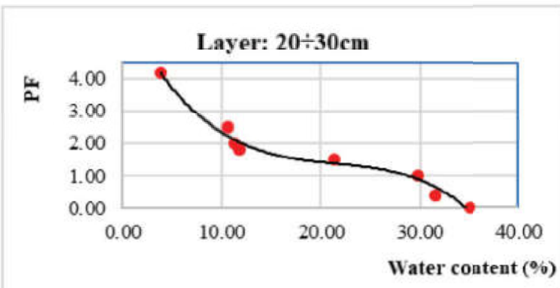
H = -0.0004w3 + 0.0284w2 - 0.7069w +7.3072

R^2 = 0.9835



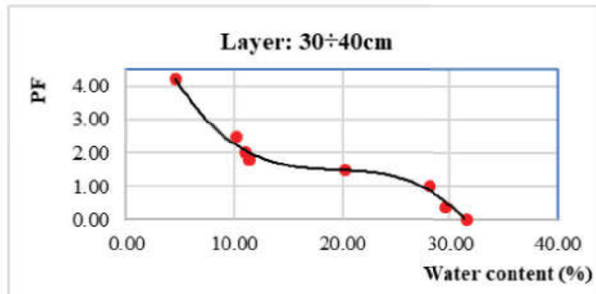
H = -0.0003w3 + 0.0206w2 - 0.5106w + 5.8261

R^2 = 0.9747



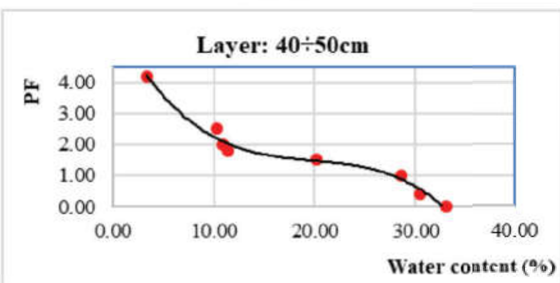
H = -0.0004w3 + 0.0271w2 - 0.6098w + 6.1498

R^2 = 0.9794



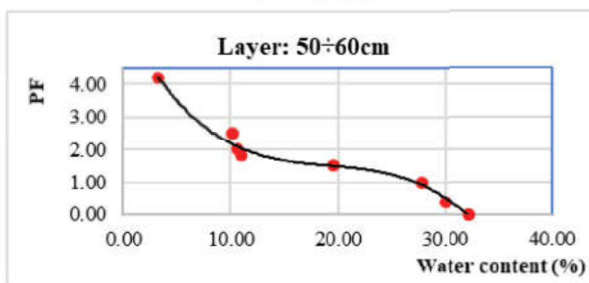
H = -0.0008w3 + 0.045w2 - 0.8891w + 7.4391

R^2 = 0.9861



H = -0.0005w3 + 0.0301w2 - 0.6266w + 6.0099

R^2 = 0.9838



H = -0.0005w3 + 0.0316w2 - 0.6382w + 5.962

R^2 = 0.9828

Fifure 5: The water retention curve (pF) of the soil layers

3.3 Available water of the soil and readily available water for crops

a) Available water (AW) and Total available water (TAW) of the soil

Calculation results show that the available water of the soil is highest in the soil layer 0 ÷ 10cm, with a value of 17.83mm of water, the next one is in the layer 10 ÷ 20cm with 17.58mm of water, layer 20 ÷ 30cm with 17.52mm water and the lowest one is in the layer 30 ÷ 40cm with 15.62mm of water, two layers 40 ÷ 50cm and 50 ÷ 60cm have medium value. Thus, the water amount ratio what dry crops can use (of soil layers) is about 55 ÷ 80% field capacity.

Regarding the soil layer containing active roots 0 ÷ 20cm (for crops with a shallow active root system, close to the soil surface), the total water amount at field capacity (TWfc) is 44.73 mm, the total available water of the soil is 35.40mm (equal 79.14% of TWfc). For the soil layer 0 ÷ 40cm, TWfc is 86.3mm, TAW is 68.54mm (equal 79.42% of TWfc). In the whole experimental soil layer 0 ÷ 60cm, TWfc is 126.13mm, TAW is 101.76mm (equal 80.68% of TWfc).

Order	Layer (cm	dz (mm)	θfc (cm^3/cm^3	Wfc (mm water)	TWfc (mm water)	θwp (cm^3/cm^3)	Wwp (mm water	TWwp (mm water)	θfc (cm^3/cm^3	AW (mm water)	TAW (mm water)	Comparison TAW/TWfc (%)
(1)	(2)	(3)	P	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	0 ÷ 10	100	0.2340	23.40	23.40	0.0557	5.57	5.57	0.1783	17.83	17.83	76.20
2	10 ÷ 20	100	0.2133	21.33	44.73	0.0376	3.76	9.33	0.1758	17.58	35.40	79.14
3	20 ÷ 30	100	0.2133	21.33	66.07	0.0382	3.82	13.15	0.1752	17.52	52.92	80.10
4	30 ÷ 40	100	0.2023	20.23	86.30	0.0461	4.61	17.76	0.1562	15.62	68.54	79.42
5	40 ÷ 50	100	0.2020	20.20	106.50	0.0339	3.39	21.14	0.1681	16.81	85.36	80.15
6	50 ÷ 60	100	0.1963	19.63	126.13	0.0323	3.23	24.37	0.1640	16.40	101.76	80.68

Where: θfc, θwp are water content at field capacity and wilting point; θaw is available water content;

Wfc, TWfc are the stored water amount and the total accumulated water amount at field capacity;

Wwp, TWwp are the stored water amount and the total accumulated water amount at wilting point;

b) Readily available water (RAW) and Total readily available water (TRAW) for crops

The droughty region are two provinces Binh Thuan and Ninh Thuan in the Southern Central Part of Vietnam, where are being cultivated main plants as vine, dragon fruit tree, apple, sugarcane, vegetable (asparagus, eggplant, tomato, onion, garlic, peanut, cassava, maize), etc. For water saving irrigation to help plants in absorbing water easily, the suitable minimum water content (θp) should be determined. Selecting the index p (FAO/UNESCO/ISRIC, 1991) corresponded with the region's dry crops to determine θp and calculate the available water for the plants, as follows: Vine: 0.35, dragon fruit tree: 0.6, apple: 0.5, sugarcane: 0.65; vegetables: 0.4; Onion and garlic: 0.3.

Calculation results showed that, for: (1) Vine, in the soil layer containing the active root system 0÷40cm, the Total readily available water (TRAW) was 23.99mm (equal 35.0% of TAW and 27.8% of TWfc, the suitable minimum water content (θp) was 14.77% volume; (2) Dragon fruit tree, in the soil layer of the active roots 0÷40cm, TRAW was 41.13mm (equal 60.0% of TAW and 47.65% of TWfc), θp was 10.86% volume; (3) Apple, in the soil layer of the active roots 0÷60cm, TRAW was 50.88mm (equal 50.0% of TAW and 40.34% of TWfc), θp was 11.43% volume; (4) Sugarcane, in the soil layer of the active roots 0÷40cm, TRAW was 44.55mm (equal 65.0% of TAW and 51.63% of TWfc), θp was 10.08% volume; (5) Vegetables, in the soil layer of the active roots 0÷30cm, TRAW was 21.17mm (equal 40.0% of TAW and 32.04% of TWfc), θp was 14.33% volume; (6) Onion and Garlic, in the soil layer of the active roots 0÷20cm, TRAW was 10.62mm (equal 30.0% of TAW and 23.74% of TWfc), θp was 16.06% volume.

	Layer (cm)	θaw (cm^3/cm^3)	AW (mm water)	Index	RAW (mm water)	TRAW (mm water)	Comparison TRAW/TWfc (%)	θp (cm^3/cm^3)	Wp (mm water)	TWp (mm water)	Comparison θp/θfc (%)
(1)	(2)	(3)	P	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Vine	0 ÷ 10	0.1783	17.83	0.35	6.24	6.24	26.66	0.1716	17.16	17.16	73.34
	10 ÷ 20	0.1758	17.58	0.35	6.15	12.39	27.70	0.1518	15.18	32.34	71.16
	20 ÷ 30	0.1752	17.52	0.35	6.13	18.52	28.04	0.1520	15.20	47.54	71.26
	30 ÷ 40	0.1562	15.62	0.35	5.47	23.99	27.80	0.1477	14.77	62.31	72.97
Dragon fruit tree	0 ÷ 10	0.1783	17.83	0.60	10.70	10.70	45.71	0.1270	12.70	12.70	54.29
	10 ÷ 20	0.1758	17.58	0.60	10.55	21.24	47.49	0.1079	10.79	23.49	50.57
	20 ÷ 30	0.1752	17.52	0.60	10.51	31.75	48.06	0.1082	10.82	34.31	50.73
	30 ÷ 40	0.1562	15.62	0.60	9.37	41.13	47.65	0.1086	10.86	45.17	53.67
Apple	0 ÷ 10	0.1783	17.83	0.50	8.91	8.91	38.09	0.1449	14.49	14.49	61.91
	10 ÷ 20	0.1758	17.58	0.50	8.79	17.70	39.57	0.1255	12.55	27.03	58.80
	20 ÷ 30	0.1752	17.52	0.50	8.76	26.46	40.05	0.1258	12.58	39.61	58.95
	30 ÷ 40	0.1562	15.62	0.50	7.81	34.27	39.71	0.1242	12.42	52.03	61.39
	40 ÷ 50	0.1681	16.81	0.50	8.41	42.68	40.07	0.1179	11.79	63.82	58.38
	50 ÷ 60	0.1640	16.40	0.50	8.20	50.88	40.34	0.1143	11.43	75.25	58.23
Sugarcane	0 ÷ 10	0.1783	17.83	0.65	11.59	11.59	49.52	0.1181	11.81	11.81	50.48
	10 ÷ 20	0.1758	17.58	0.65	11.42	23.01	51.44	0.0991	9.91	21.72	46.45
	20 ÷ 30	0.1752	17.52	0.65	11.39	34.40	52.07	0.0995	9.95	31.67	46.63
	30 ÷ 40	0.1562	15.62	0.65	10.16	44.55	51.63	0.1008	10.08	41.75	49.81
Vegetables (asparagus, eggplant, tomato...)	0 ÷ 10	0.1783	17.83	0.40	7.13	7.13	30.47	0.1627	16.27	16.27	69.53
	10 ÷ 20	0.1758	17.58	0.40	7.03	14.16	31.66	0.1430	14.30	30.57	67.04
	20 ÷ 30	0.1752	17.52	0.40	7.01	21.17	32.04	0.1433	14.33	44.90	67.16
Onion, Garlic	0 ÷ 10	0.1783	17.83	0.30	5.35	5.35	22.85	0.1805	18.05	18.05	77.15
	10 ÷ 20	0.1758	17.58	0.30	5.27	10.62	23.74	0.1606	16.06	34.11	75.28

Where:

+ AW is available water of the soil; θp is the suitable minimum water content at water stress p;

+ RAW is Readily available water for crops; TRAW is Total readily available water for crops;

+ Wp is water amount at water stress p; TWp is Total water amount at water stress p;

3.4 Correlation and linear regresstion between the water retention curve and water amount in the soil (TAWpF1.5 và TRAWpF)

a) Correlation analysis

The analysis result of Pearson correlation of elements is as follows:

The correlation coefficient r = - 0.929 (value > 0.5, the sign (-) indicates the amount of accumulated water increasing following the soil layer depth; Verifying the correlation coefficient (r) with Sig. equals to 0.004 < 0.05 (confident level at 95%). Thus, the quantities have avery close correlation with each other.

b) Linear regresstion establishment

(1) f(TAW) = f(θpF1.5),

(2) f(TraW) = f(θpF)

The Adjusted R2 = 0.828 > 0.5, ensuring that independent variables have a significant impact on the change of the dependent variable;;

Verifying F with Sig. equals 0.007 < 0.05 (confident level at 95%), ensuring that the linear regression models have been established appropriately and inferred general significantly;

T-test of regression coefficients with Sig. equals 0.005 < 0.05 (confident level at 95%), ensuring that the coefficients of the linear regression model are non-zero and significant;

VIF magnification coefficient of the model is less than 10 and Eigenvalue > 1;

Histogram of regression standardized residual shows the residual distribution is standard asymptotic when the Mean is nearly 0 and the standard deviation is 0.894 (approximately 1).

Table 7: Verifying result and establishment of the linear regression equations between the water retention curve and water amount in the soil (TAWpF1.5 và TRAWpF)

Order	Relationship between the elements	|r|	R2	F	t	VIF	Eigenvalue	Regression equation
		> 0,5	*> 0,5*	*<0,05*	*<0,05*	*< 10*	*> 1*	
1	f(TAW) = f(θpF1.5)	0.929	0.828	0.007	0.005	1.00	1.998	TAW = 0.929* θpF1.5
2	f(TRAW) = f(θpF)	0.929	0.828	0.007	0.005	1.00	1.998	TRAW = 0.929* θpF

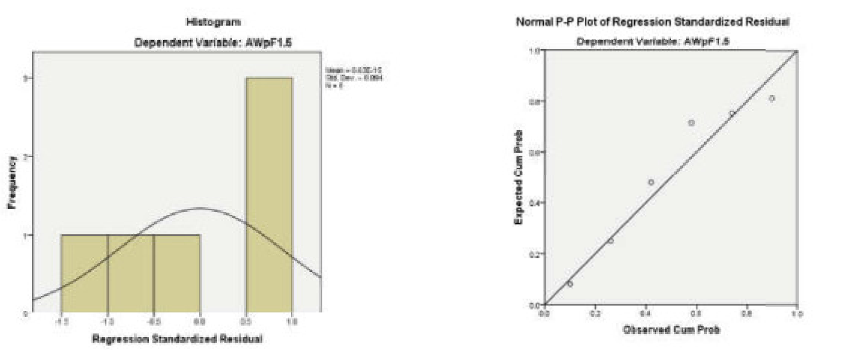


Figure 6: Histogram of regression standardized residual and the linear regression between the water retention curve and water amount in the soil.

Comment: The water retention curve has a close relationship with the water amount in the soil, the trend of the graph is positive with the slope (Beta is 0.929 closed to 1), the verifying results ensure the requirements, the correlation coefficient is high, the linear regression equations have been established appropriately and inferred general significantly.

4. Conclusion

The soil analysis results of the physical and mechanical properties have showed that the soil structure was fine and porous sand, helping the roots to absorb water and oxygen easily. The soil was very acidic and nutrient-poor. Regular moisture needs to be maintained, additional lime, organic fertilizers and appropriate N - P - K fertilizers to improve the soil and provide nutrients for crops, ensuring stable development and increasing crop yield.

The research results on establishing the water retention curve (pF) of cultivated land in the droughty region have a closely correlation (R2 from 0.96 ÷ 0.99), the shape of the curves is quite homogeneous and typical for fine sandy soil, low water storage capacity, but available water in the soil compared to water amount at field capacity, from 76.20% (layer 0 ÷ 10cm) to 80.68 % (layer 50 ÷ 60cm). The average moisture values of the whole layer (0 ÷ 60cm) at: Saturated (θs): 34.49% volume, field capacity (θfc): 21.02% volume, wilting point (θwp): 4.06% volume;

Among the three crops (vine, dragon fruit tree and sugarcane) with the active root system of 0 ÷ 40cm, the vine has the lowest RAW, the next are dragon fruit and sugarcane. Apple with the active root system of 0 ÷ 60 cm, has moderate RAW. Garlic, Onion and other vegetables with shallow active root system (from 20 ÷ 30cm), the RAW is quite low, so these crops will suffer from water shortage if non-regularly irrigated. When soil moisture decreases to the suitable minimum water content (at the water stress point of crops (p)), it necessarily water immediately to ensure good development plant and high yield.

Establishment the correlation and linear regression equations between: the water retention curve (pF) and water amount in the soil. Linear regression equations are appropriately and infer general significantly. These experimental results and calculations are very important for establishing the scientific arguments to identify appropriate irrigation schedule for crops, improve water use efficiency and help plants growing well, ensuring product quality requirements.

For perennial plants (fruit and industrial) such as cashew, coffee, cocoa, mango, jackfruit, longan, etc., the proposal to establish the water retention curve (pF) of the soil layer, from 60cm deep until 85 ÷ 90% of the active root system to serve calculating RAW and determining suitable irrigation schedules for those trees.

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