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TRAN THAI HUNG

RESEARCH ON SOIL MOISTURE DYNAMIC OF DRIP IRRIGATION TECHNIQUE IN ORDER TO DETERMINE THE SUITABLE IRRIGATION SCHEDULE FOR GRAPE LEAVES IN THE WATER SCARCE REGION

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1. ASSOC PROF. DR VO KHAC TRI

2. PROF. DR LE SAM

Reviewer 1:

Reviewer 2:

Reviewer 3:

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INTRODUCTION

1. RESEARCHING IMPERATIVE

Ninh Thuan and Binh Thuan are two provinces in the driest region of the South Central part of Vietnam where there is the lowest precipitation of the country and the unequal distribution by time. Therefore, water resources for production should be utilised reasonably. The research on suitable water saving irrigation schedule for high economic crops is very important and necessary. Previous studies have often focused on the aspect of crops irrigation schedule for each irrigation technique, not much attention to soil moisture dynamic in the space of the active roots.

In the World, grape leaves (Vitis Amurensis) is cultivated a lot in USA, Turkey, Greece, Brazil… In Vietnam, the grape leaves variety named IAC 572 has been imported from Brazil by YERGAT FOOD Co., Ltd and Binh Thuan Socioeconomy development Centre (SEDEC) since 1999÷2010 for cultivating and exporting leaf production. Due to Grape leaves suitable for natural conditions in the South Central region (Ninh Thuan, Binh Thuan, Dong Nai provinces… so the plants developed very well and obtained high profit. There have not been any studies on suitable irrigation schedule for Grape leaves so far, especially in the water scare tropics (droughty region) of the South Central part. Therefore, ***Research on soil moisture dynamic of drip irrigation technique in order to determine the suitable irrigation schedule for Grape leaves in the water scarce region of the South Central part of Vietnam*** was done, it aimed for clarifying the current urgent matters**.**

2. OBJECTIVES, OBJECT, SCOPE, CONTENTS AND METHODS

Objectives:

(1) Determine water infiltration spread and soil moisture dynamic of drip irrigation technique;

(2) Propose the suitable schedule of water saving irrigation (drip irrigation technique) for Grape leaves cultivated at the water scarce region (the droughty one) in the South Central part, consisting of: Irrigation frequency, water amount and irrigation time for each growth stage;

Research object: Research for a plant: Grape leaves in the water scarce region of Ninh Thuan and Binh Thuan; farming technique was row (furrow). The main irrigation was drip one (sprinkler only improved microclimate);

Research scope: at the water scarce region (the droughty one) of Vietnam, including two provinces: Ninh Thuan and Binh Thuan; weather condition is sunny and hot, less precipitation; main soil is fine sand; privation of water surface condition; water saving irrigation experiment was carried out at Binh Thuan province;

Research contents: Overview of research field;

Field survey, design and establishment of the experimental model for researching on suitable irrigation schedule for Grape leaves;

Experiment of irrigation, observation of water infiltration and soil moisture dynamic by time and space. Establishment of correlation and linear regressions of water infiltration and soil moisture dynamic;

Experiment of plant developing and growing process following the frequency, water amount and irrigation time for growth stages of a seasonal crops. Establishment of correlation and linear regressions of variables including: Meteorology (temperaturer, humidity, sunshine, wind, precipitation, evaporation) – Crop water requirement - Crop yields;

Application of the Coup Model for simulating moisture and heat transfer in the soil-plant-air system of drip irrigation technique;

Propose the suitable schedule of water saving irrigation (drip irrigation technique) for Grape leaves;

Approachability: Approached comprehensively, systematically and practically, from general to detail; Inherited, selected knowledge experience, researches and databases; Approached ecosystem, sustainable and effective development; Minimized waste of land and water resources; Inherited/applied modern science and technology, achievements in irrigation and production, harvest and advanced products preservation.

Research method: Theoretical analysis, collection and systematization; Selective inheritance and analysis of the research experience; Field survey; Laboratory and field experiments; Statistical data analysis; Mathematical modeling of water infiltration and moisture dynamics in drip irrigation.

3. SIGNIFICANCES AND NEW CONTRIBUTIONS OF THE THESIS

Scientific significances:

The research has established the pF Retention curve for cultivated soil – fine sand (named: Dystri Haplic Arenosols-ARh.d) of the water scarce region (the droughty one) to be the scientific basis for determining the suitable schedule of water saving irrigation for dry crops;

The research has established the correlation of Soil-Water-Crops-Climate to be the scientific basis of applied researches in irrigating for dry crops at the water scarce region (the droughty one);

The research has identified basic criteia of irrigation research and efficiency by drip irrigation technique for Grape leaves at the water scarce region (the droughty one) in the South Central part of Vietnam.

Practical significances:

Grape leaves are of high economic value, but water lack for irrigation is an issue that hinders large development. Research results will help farmers to save and improve the water use efficiency, serving the plant development on a larger scale to become a strong crop;

The research results are a reasonable choice for the conversion of crop structure towards diversification of highly economical (sustainable) crops and adaptation to natural conditions in water scarce region;

Applying research results to simplify the irrigation work, contributing to the plan for irrigation and development of exploitative and utilizable models of land-water resources for sustainable production and environmental protection.

New contributions of the thesis:

(1) Established the Soil Water Retention curves (pF) for cultivated soil (named: Dystri Haplic Arenosols-ARh.d) in order to effectively develop drip irrigation technique for every crops at the water scarce region (the droughty one) in the South Central part of Vietnam;

(2) Simulated water infiltration and soil moisture dynamic in the cultivated soil layer (active roots area) of the Grape leaves;

(3) Propose the suitable schedule of water saving irrigation (drip irrigation technique) for Grape leaves cultivated at the water scarce region (the drought one) in the South Central part of Vietnam.

4. THE THESIS STRUCTURE

The thesis is presented in 136 pages, consisting of 36 tables, 53 illustrative figures and explanation. The main thesis contents are 4 main chapters, Introduction and Conclusions - Recommendations, as follows:

Introduction

Chapter 1: Overview of the research field;

Chapter 2: Theoretical basis and experimental layout;

Chapter 3: Experimental results and simulation of water infiltration, soil moisture dynamic of drip irrigation technique;

Chapter 4: Experimental results and establishment of the suitable irrigation schedule for Grape leaves in the water scarce region;

Conclusions and Recommendations.

The annex is presented in 145 pages, consisting of 105 tables and 99 illustrative figures and explanation *"Summarizing the planting, care and harvesting of Grape leaves"*.

CHAPTER I: OVERVIEW OF THE RESEARCH FIELD

I.1 RESEARCH ON WATER MOVEMENT IN SOIL-WATER-PLANT SYSTEM

The water regime of the soil is considered to be consisting of the phenomena of water entering the soil, its movement, keeping it in the soil layers and consuming it from the soil. Scientists believe that water infiltration in soil can be divided into two phases: (1) Unstable infiltration, and (2) Permeability one. Research on water spread in the soil in order to determine the irrigation method and suitable water amount for each plant to improve water efficiency.

I.2 STUDY ON HYGROSCOPIC PRESSURE AND SOIL MOISTURE TO APPLY FOR CROP IRRIGATION AND DRAINAGE

There are two methods to determine the hygroscopic pressure of the soil: (1) Direct measurement using measuring devices (Tensiometer, Capilarimeter or Vacum chamber); (2) Indirect method is the utilization of instruments to measure certain parameters related to hygroscopic pressure by dependency functions, then calculate the hygroscopic one.

Determination of soil moisture by various methods: Weight, block and thermal capacity, Neutron tube, Time Domain Reflectrometry TDR);

A soil water retention curve (pF) of each soil type is established to indicate the relationship between the hygroscopic pressure (h) and the soil moisture (θ). There are three methods to establish the pF retention curve: theory, experiment and semi-experiment. Application of the pF curve to: forecast irrigation demand for crops; establish the relationship between moisture-hygroscopic pressure-root density and water uptake of plant; evaluate salt transportation and soluble spread in soil; serve the irrigation for dry crops... Experimental research on the pF curve establishment to calculate the available soil water and readily available soil water for plants and determie the suitable water-saving irrigation schedule at the scarce region (droughty one) in the South Central region is almost unnoticed. Therefore, in order to improve the water use efficiency in production, it is necessary to establish the pF retention curve;

Experimental study on infiltration to inspect water lack/redudant irrigation is little interested in performing, mainly in analysis of physical and chemical properties, although results of this infiltration study are very important, because it is possible to happen redudant water during extended irrigation time (water will penetrate through active root zone). Therefore, most of the farmers have irrigated by traditional method, the irrigation time and water amount depend on the subjective people who is directly producing, causes a lot of waste water.

Currently, water saving irrigation technique has been applied widely in the world, countries like USA, Israel, Australia, Spain, Germany... have many experiences and achievements in this field, technological application and management of water saving irrigation in agricultural production, it can replace most conventional irrigation systems and bring high economic efficiency. In Vietnam, farmers have step by step replaced traditional irrigation methods by this irrigation system, helping to save water and improve productivity and product quality.

Previous research has not yet paid much attention to soil moisture dynamic in the active root zone, so it has not been applied to determine the irrigation schedule for dry crops. Soil moisture of different irrigation techniques is different in time and space, so when drip irrigation technique is applied to practical production, there should be specific research on this matter, in which soil moisture is measured by the hours of the day, to see crops' effective water absorption, avoiding water lack/redudant irrigation when the optimal moisture zone exceeds or less than root space, then the correct irrigation rate will be determined for the following seasons

Irrigation schedule studies have been performed with a number of different methods for many dry crops. However, published results that determine the actual daily meteorological conditions to ensure sufficient water for crops have not been widely available yet, which limits the farmers' irrigation work, especially at the water scarce region (droughty one) in the South Central part.

Studies on vines in Vietnam are quite extensive, however the irrigation study has been performed very limited for a long time, it is no longer suitable for the present and future. Grape leaves is new, promising and economically productive in Vietnam, its irrigation schedule has been performed, the irrigation is subjective and mainly by the traditional method (waste water). Therefore, the scientific basis of irrigation schedule and care for Grape leaves is necessarily studied and determined in detail, especially in drip irrigation at the water scarce region in the South Central part.

I.3 CHARACTERISTICS OF RESEARCH REGION

Ninh Thuan and Binh Thuan provinces have the most dry and rainy climate of Vietnam. Although the rivers and reservoirs at two provinces are quite plantiful, but due to the uneven rainfall in space and time, they are severely depleted in the dry season. Annual crop losses due to drought are high. In 2016, total area must stop producing in Ninh Thuan about 10,260ha: Winter-Spring crop was 5,775ha (rice 2,645ha, other farm produce 3,130ha); Summer crop was 4,495ha of rice. In Binh Thuan province, the total area of annual crops damaged until 2nd, 2016 was 1,400ha, including 150ha of rice (concentrated in districs as: Duc Linh 97ha, Ham Thuan Bac 19ha, Ham Tan 34ha), 300ha dragon fruit, 200ha cashew, 700ha sugarcane ... in Ham Tan.

The fallow land area of the two provinces is quite rich, but due to the inadequate condition of the water source so local people can not cultivate regularly and it greatly impact on the social of the whole region. Therefore, the application of water saving irrigation solution for crops is very necessary.

CHAPTER II
THEORETICAL BASIS AND EXPERIMENTAL LAYOUT

II.1 THEORETICAL BASIS

II.1.1 Theoretical basis of water movement in the soil

Darcy's Law (for water flow in the saturated soil)

Flow discharge passes the unit of area A of the saturated soil mass:

$$Q = K * \left(\frac{H2-H1}{\Delta L}\right) * A \qquad (2.1)$$

Where: H_1 and H_2: hydraulic head at inlet and outlet (cm);

Δ_L: the length of the saturated soil mass following the flow (cm);

A: area of the saturated soil mass is perpendicular to the flow (cm^2);

Q: Flow discharge passes the saturated soil mass (cm^3/s);

The stable permeability passes the unit of area A in per time unit:

$$V = \frac{Q}{A} = K * j \qquad (2.2)$$

Where: K: the hydraulic conductivity (cm/s);

J: the hydraulic gradient = $\frac{H2-H1}{\Delta L}$ (cm/cm);

The water flow in the unsaturated soil

The water flow in the unsaturated soil by Richards (1931):

$$q_w = -k_w\left(\frac{\partial\psi}{\partial z} - 1\right) - D_v\frac{\partial Cv}{\partial z} + q_{bypass} \qquad (2.3)$$

Where: k_w: the unsaturated hydraulic conductivity;

ψ: the water tension; z: infiltration depth;

C_v: the concentration of vapour in soil air;

D_v: the diffusion coefficient for vapour in the soil;

q_{bypass}: bypass flow in the macro-pores;

q_{mat}: the matrix flow;

q_w: total water flow is the sum of $qmat$, q_v (vapour flow), and q_{bypass};

The general equation for unsaturated water flow follows from the law of mass conservation:

$$q = \frac{(\theta_1 - \theta_2)}{\Delta t}\Delta z \quad (2.7) \quad or \quad \frac{q}{\Delta z} = \frac{(\theta_2 - \theta_1)}{\Delta t} \quad (2.8)$$

Where: θ: the soil water content;

Equations (2.3) and (2.7) are two basic ones to calculate the soil water content.

II.1.2 Soil hydraulic functions

a) Water retention curve (pF)

Actual water tension, ψ, by Brook & Corey (1964), is given by:

$$S_e = \left(\frac{\psi}{\psi_a}\right)^{-\lambda} \qquad (2.11)$$

Where: ψ_a: the air-entry tension; λ: the pore size distribution index;

The effective saturation, S_e, is defined as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{2.12}$$

Where: θ: the actual water content; θ_s: the porocity; θ_r: the residual water content (or water content that gradient dθ/dh becomes zero);

The water retention function by Van Genuchten (1980), has been introduced:

$$S_e = \frac{1}{(1+(\alpha\psi)^{g_n})^{g_m}} \tag{2.13}$$

Where: α, g_n and g_m: are empirical parameters;

b) Unsaturated Conductivity

The unsaturated conductivity, k_w^* is given by Mualem (1976):

$$k_w^* = k_{mat} S_e^{\left(n+2+\frac{2}{\lambda}\right)} \tag{2.16}$$

If function (2.11) for water retention is used, the unsaturated conductivity, k_w^* is definded as:

$$k_w^* = k_{mat} \left(\frac{\psi_a}{\psi}\right)^{2+(2+n)\lambda} \tag{2.17}$$

Where: k_{mat}: the saturated matrix conductivity;

n: a parameter accounting for pore correlation and flow path tortuosity;

Using the Van Genuchten equation (2.13), k_w^* is given:

$$k_w^* = k_{mat} \frac{\left(1-(\alpha\psi)^{g_n^{-1}}(1+(\alpha\psi)^{g_n})^{-g_m}\right)^2}{(1+(\alpha\psi)^{g_n})^{\frac{g_m}{2}}} \tag{2.18}$$

Where: α, g_n and g_m: are empirical parameters; (the same as (2.13));

As alternative options to the equations of Mualem eqs. (2.16)÷(2.18) the unsaturated hydraulic conductivity, k_w^*, can either be caluclated as a simple power function of relative saturation:

$$k_w^* = k_{mat} \left(\frac{\theta}{\theta_s}\right)^{P_{nr}} \tag{2.19}$$

Or as a simple power function of effective saturation:

$$k_w^* = k_{mat} S_e^{P_{ne}} \tag{2.20}$$

Where: P_{nr}, and P_{ne}: parameters; S_e: the effective saturation;

k_{mat}: the saturated matrix conductivity;

θ_s: the water content at saturation; θ: actual water content;

The total hydraulic conductivity close to saturation is calculated as:

$$k_w^* = 10^{\left(log(k_w^*(\theta_s-\theta_m))+\frac{\theta-\theta_s+\theta_m}{\theta_m}log\left(\frac{k_{sat}}{k_{w(\theta_s-\theta_m)}}\right)\right)} \tag{2.21}$$

Where: k_{sat}: the saturated total conductivity, including the macropores, $k_w^*(\theta_s - \theta_m)$: hydraulic conductivity below $(\theta_s - \theta_m)$ at ψ_{mat}, calculated from equations (2.16) ÷ (2.18);

c) Soil water availability and readily available soil water: Following FAO, soil water availability in the layer (i) with thickness dz:

$$AW_{(i)} = 1000*(\theta_{fc} - \theta_{wp})* dz_{(i)} = 1000*\theta_{aw(i)} * dz_{(i)} \text{ (mm)} \qquad (2.22)$$

Where: AW: available soil water in the layer i) with thickness dz (mm).

θ_{aw}, θ_{fc}: available water content and field capacity (m^3/m^3 or cm^3/cm^3);

θ_{wp}: water content at wilting point (m^3/m^3 or cm^3/cm^3);

$dz_{(i)}$: thickness of soil layer (i) (m).

Total available water content of all soil layers is calculated as:

$$TAW = \sum_1^n AW_{(i)} = 1000 \sum_1^n \theta_{aw(i)} * dz_{(i)} \qquad (mm) \quad (2.23)$$

Where: i = 1 → n: ascending order of soil layer.

TAW: Total available water content (cumulation) of all soil layers z.

- Readily available water (RAW) is calculated as:

$$RAW = p * TAW \qquad (mm) \quad (2.24)$$

Where: RAW: the readily available soil water in the layer z.

p: average fraction of (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs [0 ÷ 1].

II.2 CALCULATION OF WATER REQUIREMENT FOR CROPS

Total evaporation of a irrigation frequency (CK) n:

$$E_{pan(n)} = \sum_{i=1}^{n} E_{pan(i)} \qquad (mm) \quad (2.25)$$

Reference crop evapotranspiration of the irrigation frequency (ETo):

$$ETo_{(i)} = Kpan * Epan_{(n)} \qquad \text{(mm)} \quad (2.26)$$

Where: $E_{pan(i)}$: Total daily evaporation *(mm); K_{pan}: pan coefficient; n: irrigation frequency: 2 days (**CK2**), 3 days (**CK3**) or 4 days (**CK4**) per time;*

Crop evapotranspiration or crop water need:

$$ETc = Kc * ETo \ (2.27) \text{ or } Wcrop = Kc*ETo \qquad (mm) \quad (2.28)$$

Crop irrigation requirement (basic amount) of the irrigation frequency n:

$$Ist_{(n)} = ETc - P_{(n)} \qquad (mm) \quad (2.29)$$

Where: Kc: crop factor;

$P_{(n)}$: effective precipitation of the irrigation frequency n (mm);

$Ist_{(n)}$: Crop irrigation requirement of the irrigation frequency n (mm);

After calculating Ist (basic irrigation amount) of the irrigation frequency n (mm), established more 2 other water amounts of experimental irrigation for comparing: changed up and down 25% of Ist (called: high and low irrigation amount), the coresponding factors: $m_{(1)}$ = 1.25 (high water level), $m_{(2)}$ = 1.00 (basic water level or medium one), $m_{(3)}$ = 0.75 (low water level).

Irrigation water rate for every experimental block (j) of the irrigation frequency n is calculated as:

$$I_{m(j)} = m_{(j)} * Ist_{(n)}/K_{ef} = m_{(j)} * (ETc - P_{(n)})/K_{ef} \qquad (mm) \quad (2.30)$$

Total Irrigation water amount for every experimental block (j):

$$W_{block(j)} = I_{m(j)} * F_{block} = I_{m(j)} * 10^{-3} * (1,1 * bi * L_b)(m^3) \quad (2.31)$$

Where: $I_{m(j)}$: Irrigation water rate for every experimental block (j);

K_{ef}: drip irrigation system efficiency; $m_{(j)}$: water level factor;

$W_{block(j)}$: Total water amount for every experimental block (j) (m^3);

F_{block}: canopy shaded area on the ground at 12:00 (m^2);

10^{-3}: factor of unit conversion from mm to m;

Bi, L_b: canopy shaded width and length on the ground at 12:00 (m).

Irrigation experiment and observation of crop data was carried out in three seasons including: growing and developing stages; changes of tree-trunk, leaves, roots and mass of living organisms...

II.3. EXPERIMENTAL LAYOUT

II.3.1. Location and characteristics of the experimental model

The experimental model was located at the South of the National highway No 1A (between the National highway 1A and the East sea), at Thuan Quy Commune, Ham Thuan Nam District, Binh Thuan Province;

Total area was 20,000m^2 (shown in Figure 2.7). The experimental period was in 3 crop seasons (dry ones), from January, 2012 to May, 2013.

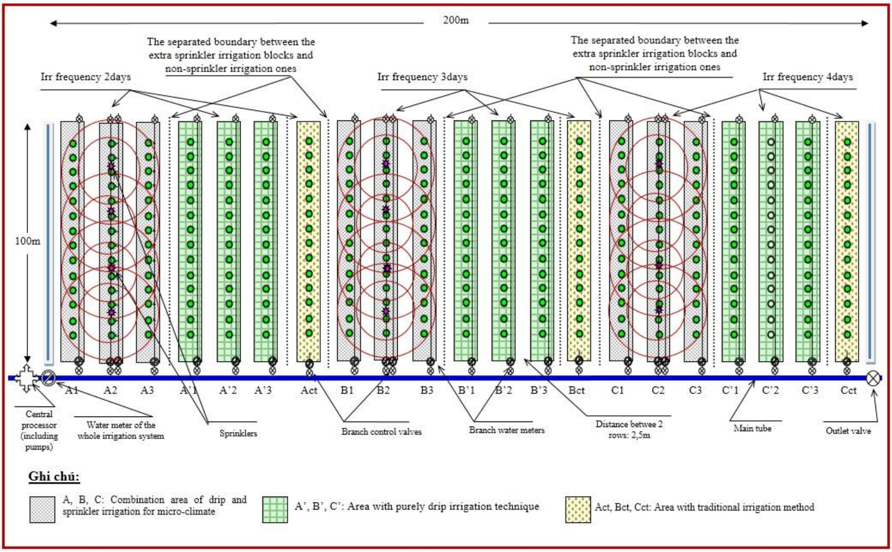


Figure 2.7: The sketch of the experimental model to research on water-saving irrigation schedule for Grape leaves at the scarce region region in the South Central part of Vietnam

II.3.2. Experimental research content

Description of soil profile, test of the physical and chemical properties of soil and irrigation water; Set up the experimental model;

Experiment for establishing of the Soil Water Retention curves (pF);

Experiment for determining the saturated hydraulic conductivity at the field and in the laboratory;

Experiment of water infiltration and establishment of correlation about soil moisture dynamic;

Meteorological measurement for determining the irrigation schedule;

Experimental Irrigation and observation of crop development;

Result analyses and proposal of the suitable irrigation schedule for Grape leaves at the water scarce region in the South Central part of Vietnam;

CHAPTER III:

EXPERIMENTAL RESULTS AND SIMULATION OF WATER INFILTRATION, SOIL MOISTURE DYNAMIC OF DRIP IRRIGATION TECHNIQUE

III.1 STEADY INFILTRATION AT THE FIELD AND IN THE LABORATORY OF SATURATED SOIL

At the field, the layer 0÷20cm has a hydraulic conductivity of 1.176 cm/minute, layer 20÷40cm is 1.152cm/min, layer 40÷60cm is 1.111 cm/min. In the laboratory, the hydraulic conductivity of layer 0÷20cm is high, vertical conductivity: k_z = 1.848cm/min; horizontal one: k_r = 1.510 cm/min.

III.2 WATER INFILTRATION PROCESS

III.2.1 Infiltration process at the field

The statistical analysis results showed that the infiltration depth (Z) and radius on the surface (R) at the cultivated area were larger than that one at the non-tree place (KoTC):

CK2: Despite surface evaporation, the soil still contains high moisture, so water infiltrated into the horizontal direction more than the deep one;

CK3: moisture content in soil was lower than CK2 so the water infiltrated into all three directions: horizontal, oblique and vertical ones;

CK4: it had a long time of irrigation frequency so the soil was drier and the moisture content decreased more than CK2 and CK3, the permeability velocity in CK4 was the highest, water infiltrated into the deep direction more than the horizontal one;

Non-tree place (KoTC): Z_{ck2}max: 43.37cm, R_{ck2}max: 21.60cm; Z_{ck3}max: 45.13cm, R_{ck3}max: 20.1cm; Z_{ck4}max: 45.61cm, R_{ck4}max: 18.38cm;

Grape leaves cultivation place with drip irrigation technique (TKN): Z_{ck2}max: 44.53cm, R_{ck2}max: 23.4cm; Z_{ck3}max: 46.03cm, R_{ck3}max: 21.50cm; Z_{ck4}max: 47.53cm, R_{ck4}max: 19.95cm;

Graphing correlative relationship between the factors: Z, R, W, t, V_Z, $V_{R,}$ the determination coefficients of correlation were high (R^2 > 0.90)

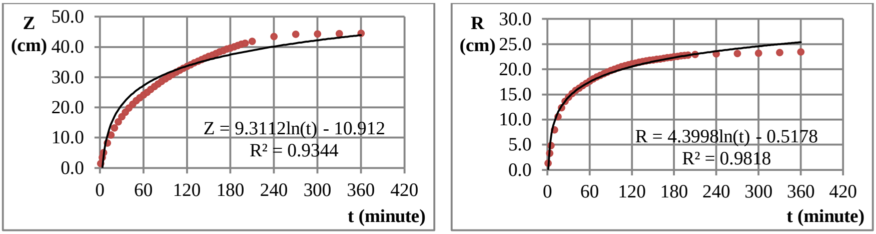


Figure 3.5: Correlation graph between the factors of two-day irrigation frequency (CK2) (At the tree place with water saving irrigation)

III.2.2 Infiltration process at the laboratory

The observation results of infiltration process at the laboratory had the tends like the field results, as follows: Z_{ck}max: 47.7cm, R_{ck4}max: 25.2cm;

Graphing correlative relationship between the factors: Z_{lab}, R_{lab}, W, t, Vz_{lab}, V_{Rlab}, the determination coefficients of correlation were high (R^2 >0.90)

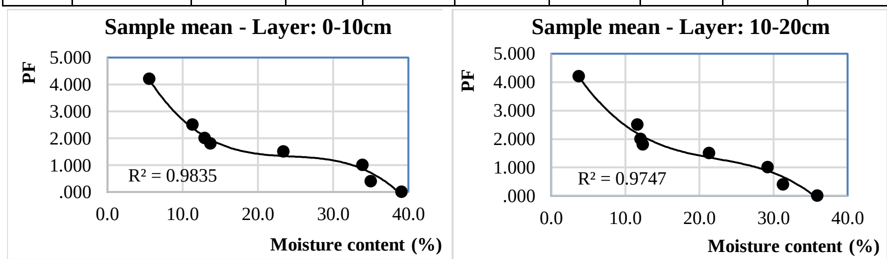
III.3 WATER MAINTENANCE FEATURE AND AVAILABLE WATER

III.3.1 The pF Retention curve (pF curve)

Applied Van Genuchten's model (1980) for establishing the pF curve to determine soil moisture dynamic, correlation coefficient R^2 from 0.96 ÷ 0.99. The pF curve of six soil layers are typical for the fine sandy soil with relatively uniform curves and gentle slope.

Table 3.4: Measurement results of the pF Retention curve (sample mean)

Order	Pressure	Soil moisture content (% volume)							
	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**
	Layer (cm)	**Measured sand box**						**Measured 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
7	0÷40	35.43	31.87	30.25	21.58	12.33	11.83	10.98	4.44
8	0÷60	34.49	31.32	29.57	21.02	11.95	11.49	10.74	4.06



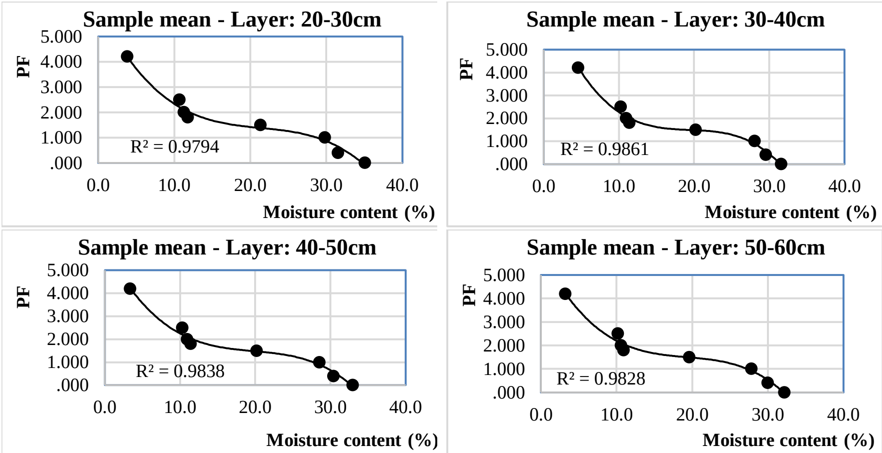


Figure 3.10: The pF retention curve by soil layer

Table 3.5: Cumulative water reserves, available water and readily available water for Grape leaves

Order	Layer (cm)	θ_{fc} (cm^3/cm^3)	W_{fc} (mm)	TW_{fc} (mm)	θ_{wp} (cm^3/cm^3)	W_{wp} (mm)	TW_{wp} (mm)	θ_{aw} (cm^3/cm^3)	AW (mm)	TAW (mm)	Factor P	RAW (mm)	TRAW (mm water)	θ_p (cm^3/cm^3)	θ_p (% TT)
1	0÷10	0,1293	12,93	12,93	0,0557	5,57	5,57	0,0736	7,36	7,36	0,35	2,58	2,58	0,1036	80,08
2	10÷20	0,1210	12,10	25,03	0,0376	3,76	9,33	0,0834	8,34	15,70	0,35	2,92	5,50	0,0918	75,87
3	20÷30	0,1130	11,30	36,33	0,0382	3,82	13,15	0,0748	7,48	23,19	0,35	2,62	8,12	0,0868	76,82
4	30÷40	0,1100	11,00	47,33	0,0461	4,61	17,76	0,0639	6,39	29,58	-	-	-	-	-
5	40÷50	0,1097	10,97	58,30	0,0339	3,39	21,14	0,0758	7,58	37,16	-	-	-	-	-
6	50÷60	0,1063	10,63	68,93	0,0323	3,23	24,37	0,0740	7,40	44,56	-	-	-	-	-

Where: θ_{fc}, θ_{wp}, θ_{aw}: *the water content at field capacity, wilting point and available water;*
W_{fc}, TW_{fc}: *the water amount and total cumulative water amount of soil at field capacity;*
W_{wp}, TW_{wp}: *the water amount and total cumulative water amount of soil at wilting point;*
AW, TAW: the available water and total cumulative water amount of soil;
p : the mean factor of total water amount (TAW);
RAW, TRAW: the readily available water and total readily available water for crops;
θ_p *: the suitable minimum water content (the point P);*

III.3.2 The storage capacity of available water and the readily available water for crops

For the soil layer containing active roots of the plant from 0 ÷ 20cm (for plants with shallow roots near the ground surface), θ_{fc} is 25.03 mm, TAW is 15.70mm (making up 62.73% θ_{fc}). In the whole layer 0 ÷ 60cm, θ_{fc} is 68.93mm, TAW is 44.56mm (making up 64.64% θ_{fc});

Total readily available water for widespread dry crops at the water scarce region in the South Central part, as follows: **Vine:** TRAW: 10.36mm (making up 35.0% TAW). θp: 8.76% volume (V); **Dragon:** TRAW:

17.75mm (60.0% TAW). θp: 7.17% V; **Apple:** TRAW: 22.28mm (50.0% TAW). θp: 6.93% V; **Sugar cane:** TRAW: 19.22mm (65.0% TRAW). θp: 6.85% V; **Vegetables:** TRAW: 9.27mm (40.0% TAW). θp: 8.31% V; **Union-garlic:** TRAW: 4.71mm (30.0% TAW). θp: 9.6% V.

With Grape leaves, in the soil layer containing active roots of the plant 0÷20cm, TRAW is: 5.50mm (35.0% TAW), θp: 9.18÷10.36% V. When the soil moisture decreases to the suitable minimum water content θp, plant should be immediately irrigated water to absorb for well development.

III.4 EXPERIMENTAL RESEARCH ON SOIL MOISTURE DYNAMIC

III.4.1 The soil moisture dynamic following the soil depth

At the end of the irrigation frequency, maximum moisture content was CK2, the medium one was CK3, the lowest one was CK4. At the area of KoTC: the upper layer moisture was smaller than the lower layer one. At the area of TKN: the moisture in the soil layer containing active roots was lower than other layers; the bottom layer was less affected by the meteorological factors and was not absorbed by the roots, so this layer moisture was higher than upper layers. At traditional irrigation area (CT): the lower layer moisture was smaller than the upper layer one because the active roots were mainly contained at below layer getting more water than the upper one.

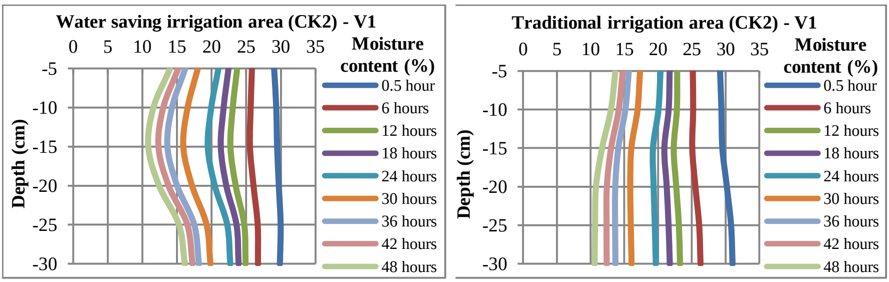


Figure 3.12: Moisture content following time and soil depth at two locations –V1

III.4.2 The soil moisture dynamic following the irrigation frequency

a) At the KoTC: moisture content comparison with θp of dry crops at the end of the irrigation frequency, the results weree as follows: garlic onions, vegetables, tomatoes, apples, dragon, sugarcane... When farmers apply water saving irrigation technique, irrigation frequency should not be longthened more than 4 days; with drought plants (sugarcane, dragon...) can be irrigated with medium frequency (3 days), because plants with high sensitivity to water such as vegetables, tomatoes and onions will be waterless on the last days of the frequency. To avoid loss of productivity and product quality after harvesting, the irrigation frequency should be short (2 days).

b) At the TKN: Most of soil moisture at the end of CK3 and CK4 were less than θp, in which the moisture in layer 10 ÷ 20cm of CK4 was sometimes equal to or approximately the moisture θwp, it made difficulty for plant water absorption. Moisture at the end of CK2 was higher than θp, which ensures for the crops sufficiently absorbed water to grow well.

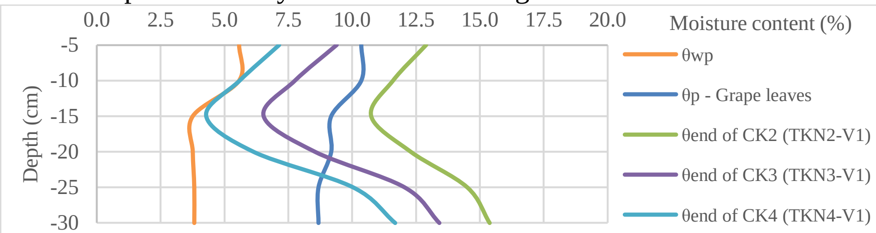
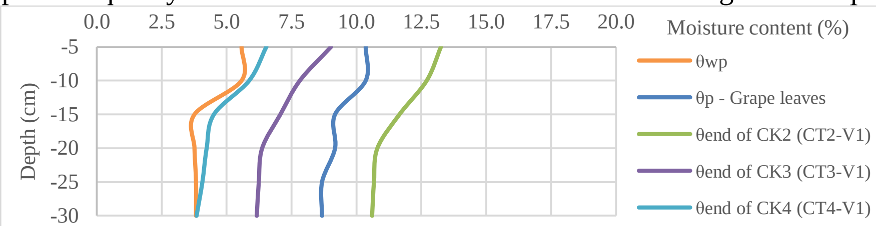


Figure 3.15: Moisture content comparison with θwp và θp at the end of frequencies – At the water saving irrigation area (TKN) - V1 season.

c) At the traditional irrigation area for Grape leaves (CT):

The moisture content at the end of CK3 and CK4 were lower than θp, even CK4 was approximately θwp, when crops had high water demand, trees absorbed water difficultly and light wilt, it was affecting the productivity and product quality of the whole season. Moisture of CK2 was higher than θp.



Hình 3.16: Moisture content comparison with θwp và θp at the end of frequencies – At the traditional irrigation area (CT) - V1 season

III.5.3 The soil moisture dynamic following time (o'clock)

a) At the KoTC: the smallest moisture decrease was from 21:00PM÷3:00AM; the third one was from 3:00AM÷9:00AM; the second one was from 15:00PM÷21:00PM and only lower than decrease from 9:00AM÷15:00PM; the largest one was from 9:00AM÷15:00PM. Layer 0÷5cm had the largest decrease, the next ones were layers 5÷10cm, 10÷15cm, 15÷20cm, 20÷25cm and 25÷30cm in turn.

b) At the TKN: Considering the moisture decrease between the soil layers, there was a clear difference in order compared to the KoTC, due to the roots' water absorption moving to the trunk and leaves for photosynthesis, metabolism for developing and thermal balance. Reduction order was: the layer 10÷15cm had the largest decrease, the next ones were layers 5÷10cm, 15÷20cm, 0÷5cm, 20÷25cm and 25÷ 30cm in turn.

c) At the CT: Daily moisture decrease was also as the TKN. Considering the moisture decrease between the soil layers, there was a clear difference in the order compared to the KoTC and TKN, the soil layer 20÷30cm had the greatest moisture decrease, the next ones were layers 15÷20cm, 10÷15cm, 5÷10cm and 0÷5cm in turn.

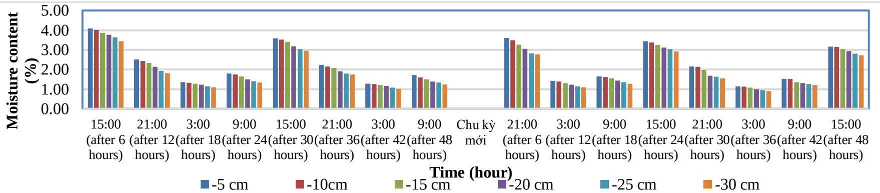


Figure 3.18: Daily moisture decrease of soil layers - at the KoTC, CK2-V1

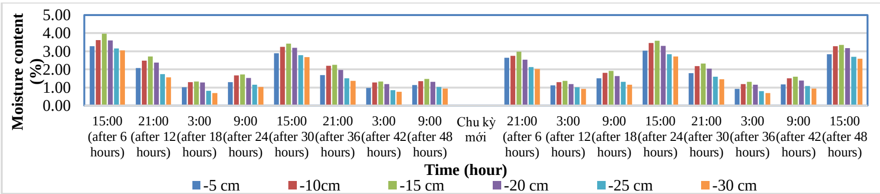


Figure 3.19: Daily moisture decrease of soil layers - at the TKN, CK2 - V1

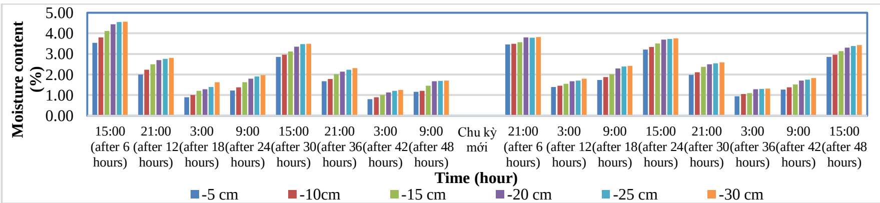


Figure 3.20: Daily moisture decrease of soil layers - at the CT, CK2 - V1

III.5 APPLIED THE COUP MODEL FOR SIMULATING SOIL MOISTURE DYNAMIC IN THE SOIL-PLANT-AIR SYSTEM

III.5.1 Introduction of the Coup Model

The original name of the Coup Model was the Soil Model developed for simulating the water and heat movement for any cover-crop soil by the soil profile depth. The basic theory consists of: (1) Laws of mass and energy conservation; (2) Flow in the soil (Darcy's Law) or temperature (Fourier's Law).

III.6.2 Applied the Coup Model for simulating soil moisture dynamic in the soil-plant-air system

a) Data input: Input meteorological data, irrigation water, crops (leaf, root…), soil characteristic… to sheets as: Document, Run Info, Switches, Parameters, Parameter tables, Model files…;

Simulation for 3 seasons: V1 from 01/01 ÷ 30/4/2012, V2 from 01/9 ÷ 30/12/2012; V3 from 01/01 ÷ 30/4/2013.

b) Analysis of simulation results

Established the pF retention curve by the Coup Model based on soil properties, these results were quite similar with the measurement results of suction pressure in the laboratory.

Soil moisture dynamic: moisture at the beginning of the crop season was low. After irrigating, the moisture increased and maintained higher than at the begining time, this result was also consistent with the field actual observation. The evapotranspiration (soil and leaf) during the irrigation and the crop development, the amplitude was from 0.5÷4mm/day. Water absorption of the roots was from 0÷2mm/day the evapotranspiration. The soil temperature change was following the depth, the layer 0÷5cm was from 18÷22^{0}C, the amplitude of lower layers decreased from 1.5÷2^{0}C and quite evenly by time. The concentrated development of active roots by simulation result was similar to the active root development in the field.

III.6 EXPERIMENTAL DATA TEST, CORRELATION ANALYSIS AND LINEAR REGRESSION ESTABLISHMENT

Data processing by statistical analysis, Cronbach's Alpha reliability testing and Exploratory factor analysis. Mean different test of statistical significance by One-way Analysis of Variance (ANOVA), in which the Levene Statistic test - homogeneous variance, F test - statistically significant difference (ANOVA) and Welch test - a supposition breach of heterogeneity variances. The test results are statistically required for calculation, analyzing and establishing linear regression equations between the factors.

Test results of correlation coefficient ensure the correlation of factors are very closely. The regression equations are as follows:

Table 3.15: Regression equations of the water infiltration in soil

Area	Relation of factors	CK2	CK3	CK4
TKN	**f (Z) = f (t)**	$Z_2 = 0,957t_2$	$Z_3 = 0,969t_3$	$Z_4 = 0,961t_4$
	f (Z) = f (W, R)	$Z_2 = 0,481W_2 + 0,555R_2$	$Z_3 = 0,596W_3 + 0,445R_3$	$Z_4 = 0,582W_4 + 0,467R_4$
	f (Vz) = f (W, R)	$Vz_2 = 0,397W_2 - 1,300R_2$	$Vz_3 = 0,357W_3 - 1,253R_3$	$Vz_4 = 0,289W_4 - 1,199R_4$
	f (R) = f (t)	$R_2 = 0,858t_2$	$R_3 = 0,838t_3$	$R_4 = 0,813t_4$
	f (R) = f (W)	$R_2 = 0,858W_2$	$R_3 = 0,838W_3$	$R_4 = 0,813W_4$
	f (V_R) = f (W, R)	$V_{R2} = 0,554W_2 - 1,417R_2$	$V_{R3} = 0,488W_3 - 1,355R_3$	$V_{R4} = 0,432W_4 - 1,296R_4$

Table 3.16: Test results and establishment of regression equations between the pF retention curve – $TAW_{(pF2)}$ and the pF retention curve – $TRAW_{(pF)}$

Or-der	Relation of factors	$\|r\|$	R^2	F	t	VIF	Eigen-value	Regression equations
		> 0,5	*> 0,5*	*<0,05*	*<0,05*	*< 10*	*> 1*	
1	**f**(TAW) **= f**(θ_{pF2})	0,946	0,868	0,004	0,004	1,00	1,998	TAW = 0,946* θ_{pF2}
2	**f**(TRAW) **= f**(θ_{pF})	0,946	0,868	0,004	0,004	1,00	1,998	TRAW = 0,946* θ_{pF}

Table 3.17: Regression equations of soil moisture (θzi) and the pF curve

Order	Season	Area	Layer Zi (cm)	CK2	CK3	CK4
1	V1 and V3	TKN	0 ÷ 5	$\theta z_5 = 0{,}952*\theta_{pF}$	$\theta z_5 = 0{,}946*\theta_{pF}$	$\theta z_5 = 0{,}942*\theta_{pF}$
			5 ÷ 10	$\theta z_{10} = 0{,}953*\theta_{pF}$	$\theta z_{10} = 0{,}949*\theta_{pF}$	$\theta z_{10} = 0{,}946*\theta_{pF}$
			10 ÷ 15	$\theta z_{15} = 0{,}955*\theta_{pF}$	$\theta z_{15} = 0{,}952*\theta_{pF}$	$\theta z_{15} = 0{,}950*\theta_{pF}$
			15 ÷ 20	$\theta z_{20} = 0{,}955*\theta_{pF}$	$\theta z_{20} = 0{,}951*\theta_{pF}$	$\theta z_{20} = 0{,}948*\theta_{pF}$
			20 ÷ 25	$\theta z_{25} = 0{,}949*\theta_{pF}$	$\theta z_{25} = 0{,}942*\theta_{pF}$	$\theta z_{25} = 0{,}939*\theta_{pF}$
			25 ÷ 30	$\theta z_{30} = 0{,}947*\theta_{pF}$	$\theta z_{30} = 0{,}939*\theta_{pF}$	$\theta z_{30} = 0{,}937*\theta_{pF}$
2	V2	TKN	0 ÷ 5	$\theta z_5 = 0{,}948*\theta_{pF}$	$\theta z_5 = 0{,}948*\theta_{pF}$	$\theta z_5 = 0{,}941*\theta_{pF}$
			5 ÷ 10	$\theta z_{10} = 0{,}951*\theta_{pF}$	$\theta z_{10} = 0{,}950*\theta_{pF}$	$\theta z_{10} = 0{,}946*\theta_{pF}$
			10 ÷ 15	$\theta z_{15} = 0{,}954*\theta_{pF}$	$\theta z_{15} = 0{,}952*\theta_{pF}$	$\theta z_{15} = 0{,}950*\theta_{pF}$
			15 ÷ 20	$\theta z_{20} = 0{,}954*\theta_{pF}$	$\theta z_{20} = 0{,}953*\theta_{pF}$	$\theta z_{20} = 0{,}947*\theta_{pF}$
			20 ÷ 25	$\theta z_{25} = 0{,}941*\theta_{pF}$	$\theta z_{25} = 0{,}941*\theta_{pF}$	$\theta z_{25} = 0{,}937*\theta_{pF}$
			25 ÷ 30	$\theta z_{30} = 0{,}939*\theta_{pF}$	$\theta z_{30} = 0{,}937*\theta_{pF}$	$\theta z_{30} = 0{,}934*\theta_{pF}$

CHAPTER IV:
EXPERIMENTAL RESULTS AND ESTABLISHMENT OF THE SUITABLE IRRIGATION SCHEDULE FOR GRAPE LEAVES IN THE WATER SCARCE REGION

IV.1 IRRGATION WATER AMOUNT FOR CROPS

IV.1.1 Comparison of water amount for each irrigation time

Statistical analysis results of infiltration experiment showed that irrigation water amounts of CK2: 1.05 liter/dripper (or 5.383m^3/ha, infiltration depth Z = 24.1cm, active root depth 14.6 ÷ 15.4cm; CK3: 1.053 lit/drip (or 5.973m^3/ha, Z = 23.8cm, root depth 16.8 ÷17.7cm) and CK4: 0.8825 lit/drip (or 4.523m^3/ha, Z = 23.8cm, root depth 19.0÷20.2cm) for comparison as:

Irrigation times of A3 and A'3 (low water level $m_{(3)}$ in CK2) with water content was smaller than 5.383m^3/ha occupying the highest rate, it means that the excess water was the lowest. At the end of the irrigation frequency, the soil still maintained moisture for plants to absorb and grow well, get high yield. At other blocks of CK2 (irrigation level $m_{(1)}$ and $m_{(2)}$), especially CK3 and CK4 (for all $m_{(1)}$, $m_{(2)}$ and $m_{(3)}$), there was a water part infiltrated deeply and over-root zone causing water waste, at the end of CK3 and CK4, moisture still reduced, not enough water for plants to absorb and develop.

IV.1.2 Comparison of water amount following the irrigation frequency

In 3 seasons as: (1) **CK2** (comparison with Act): A1-A’1 saved 67,603 ÷ 106,459m^3/ha; A2-A’2 saved 162,619 ÷ 192,619m^3/ha; A3-A’3 saved 227,764 ÷ 287,635m^3/ha. (2) **CK3** (comparison with Bct): B1-B’1 saved 74,118 ÷ 116,009m^3/ha; B2-B’2 saved 150,086 ÷ 208,410m^3/ha; B3-B’3 saved 226,054 ÷ 306,581m^3/ha. (3) **CK4** (comparison with Cct): C1 - C’1 saved 136,881 ÷ 207,816 m^3/ha; C2 - C'2 saved 215,397 ÷ 295,747m^3/ha; C3 - C'3 saved 293,913 ÷ 391,083 m^3/ha.

IV.1.3 Comparison of the highest water amount - Block Cct

All experimental blocks have lower irrigation water amount than block Cct, in which blocks with low water level ($m_{(3)}$) were equal 40÷50% of Cct.

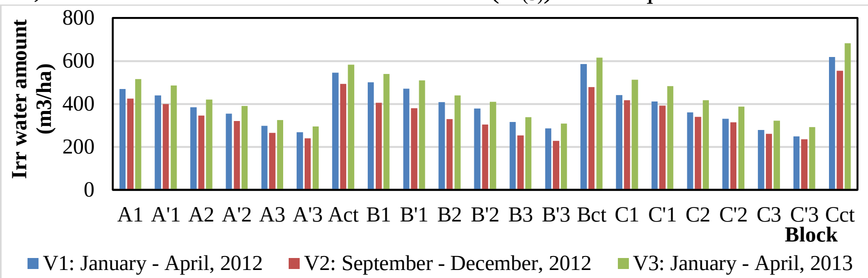


Figure 4.4: Total irrigation water amount for crops in three seasons

IV.2 EFFICENCY OF WATER SAVING IRRIGATION TECHNIQUE TO CROPS' DEVELOPMENT AND YIELD

IV.2.1 Descriptive statistics analysis of the leaf development

The statistical analysis results of harvested leaves were quite small standard deviations compared to sample mean. Leaves of blocks with extra sprinkler irrigation developed faster and more equally than blocks' purely drip irrigation. The leaves of CK2 growed faster and more equally than CK3 and CK4. In CK3 and CK4, the leaf development of blocks' high water level was faster than medium and less water level. Block C'3 (CK4) had some leaves waiting for 40 days to achieve the required size. The leaf development order is as follows: ***Blocks A1, A2, A3 > A'1, A'2, A'3 and Act > B1, B2, B3 > B'1, B'2, B'3 and Bct > C1, C2, C3 > C'1, C'2, C'3 and Cct***.

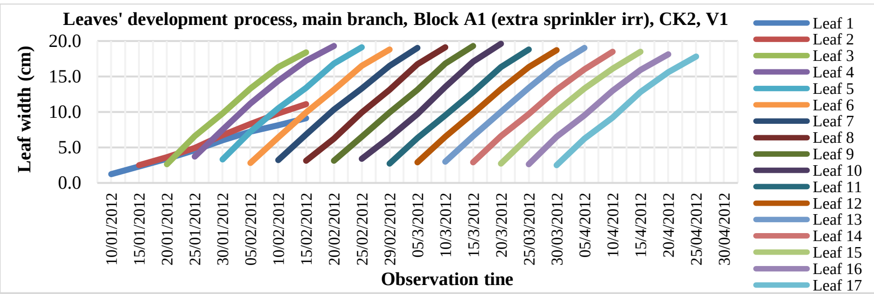


Figure 4.5: Grape leaves' development process in the season V1

IV.2.2 Development of the tree-trunk and active roots

The trunk perimeter of CK2 was larger than CK3 & CK4, but the difference was a little. The roots of water-saving irrigated plants tended to thrive in arable layer (0÷20cm) which regularly maintains moisture.

IV.2.3 Biomass of leaves and tree-trunk

The water rate of the leaves and trunk was quite large, season V2 has more water rate than in V1 and V3; in CK2 was larger than in CK3 and CK4.

IV.2.4 Product harvest process and crop yield

Compared to the same irrigation frequencies, the leaf weight of the sprinkler irrigation blocks was greater than in other ones. The productivity of CK2 was higher than CK3 and CK4 (the same irrigation level). The CK2 had yield at the harvest beginning not much difference with the next harvests, harvest time of large scale was more early than CK3 and CK4. In CK3 and CK4, yield at the harvest beginning was low, usually concentrated in the middle and late seasons (because the leaves growed more slowly than CK2).

The productivity order of blocks is as follows: ***A1, A2, A3, A'1, A'2, A'3, Act > B1, B2, B3, B'1, B'2, B'3, Bct > C1, C2, C3, C'1, C'2, C'3, Cct***

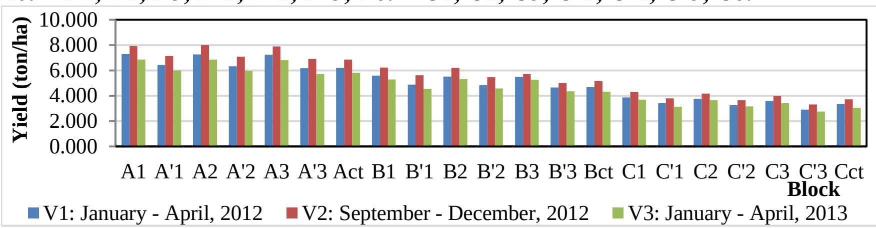


Figure 4.8: Crop yield of experimental blocks - in three seasons

IV.3 WATER USE EFFICIENCY - WUE

Sprinkler irrigation blocks' WUE were higher than purely drip and traditional irrigation ones. Blocks' WUE in CK2 were higher than CK3 and CK4. In the same irrigation frequencies, WUE of low irrigation level blocks ($m_{(3)}$) was the highest, the next by medium one ($m_{(2)}$) and high one ($m_{(1)}$).

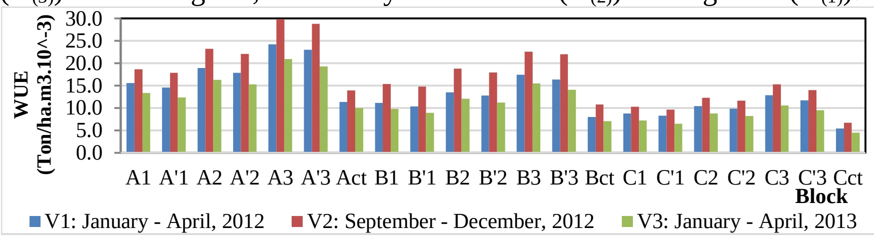


Figure 4.9: Water use efficiency of the whole season

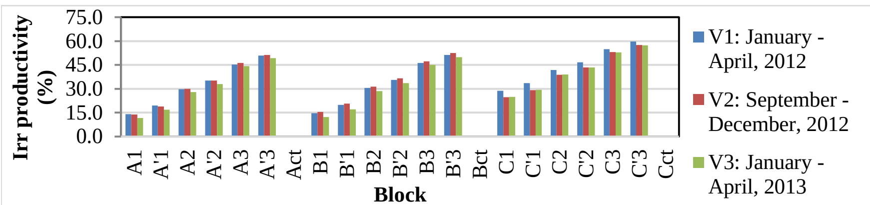


Figure 4.11: Irrigation productivity of the whole season

IV.4 EXPERIMENTAL DATA TEST, CORRELATION ANALYSIS AND LINEAR REGRESSION ESTABLISHMENT

Reliable tests of irrigation and crop development data (Cronbach's Alpha, EFA, One-Way ANOVA…) are statistically required for detailed assessing and analyzing.

The correlation analysis results of Pearson (r > 0,5), $R^2 > 0,5$, test of F, t with Sig.= 0,0001 < 0,05 (reliability is 95%), VIF < 10, Eigenvalue > 1, which are satisfied for establishing linear regression equations, as followed:

(1) f (ETo) = f (t, h, s, w, p) - (Meteorological regression)

Where: *Eto: Evaporation is dependent variable; t: temperature, h: air humidity, s: sunshine, w:wind and p: precipitation are independent variables*

(2) f (Im) = f (ETo) - (Regression of irrigation water - Evaporation)

(3) f (Ym) = f (Ym) - (Regression of crop yield - irrigation water)

Table 4.8: Linear regression equations of factors

Or-der	Irr. frequency	Season	**V1** (from January 1st ÷ April 30th)		**V2** (from September 1st ÷ December 30th)	
		Linear regression equations	**f (ETo) = f (t, h, s, w, p)**		**f (ETo) = f (t, h, s, w, p)**	
			$ETo_{(V1)}$ = 0.112t - 0.415h + 0.308s + 0.587w - 0.049p		$ETo_{(V2)}$ = - 0.021t - 0.458h + 0.355s + 0.540w - 0.053p	
			f (Im) = f (ETo)	**f (Ym) = f (Im)**	**f (Im) = f (ETo)**	**f (Ym) = f (Im)**
1	**2**	m1 = 1.25	$I_{1.25} = 0.875*ETo_{1.25}$	$Y_{1.25} = 0.994*I_{1.25}$	$I_{1.25} = 0.952*ETo_{1.25}$	$Y_{1.25} = 0.997*I_{1.25}$
		m2 = 1.00	$I_{1.00} = 0.877*ETo_{1.00}$	$Y_{1.00} = 0.994*I_{1.00}$	$I_{1.00} = 0.951*ETo_{1.00}$	$Y_{1.00} = 0.997*I_{1.00}$
		m3 = 0.75	$I_{0.75} = 0.879*ETo_{0.75}$	$Y_{0.75} = 0.994*I_{0.75}$	$I_{0.75} = 0.951*ETo_{0.75}$	$Y_{0.75} = 0.997*I_{0.75}$
2	**3**	m1 = 1.25	$I_{1.25} = 0.855*ETo_{1.25}$	$Y_{1.25} = 0.993*I_{1.25}$	$I_{1.25} = 0.943*ETo_{1.25}$	$Y_{1.25} = 0.995*I_{1.25}$
		m2 = 1.00	$I_{1.00} = 0.855*ETo_{1.00}$	$Y_{1.00} = 0.993*I_{1.00}$	$I_{1.00} = 0.945*ETo_{1.00}$	$Y_{1.00} = 0.996*I_{1.00}$
		m3 = 0.75	$I_{0.75} = 0.854*ETo_{0.75}$	$Y_{0.75} = 0.993*I_{0.75}$	$I_{0.75} = 0.945*ETo_{0.75}$	$Y_{0.75} = 0.996*I_{0.75}$
3	**4**	m1 = 1.25	$I_{1.25} = 0.858*ETo_{1.25}$	$Y_{1.25} = 0.981*I_{1.25}$	$I_{1.25} = 0.921*ETo_{1.25}$	$Y_{1.25} = 0.997*I_{1.25}$
		m2 = 1.00	$I_{1.00} = 0.863*ETo_{1.00}$	$Y_{1.00} = 0.980*I_{1.00}$	$I_{1.00} = 0.919*ETo_{1.00}$	$Y_{1.00} = 0.997*I_{1.00}$
		m3 = 0.75	$I_{0.75} = 0.862*ETo_{0.75}$	$Y_{0.75} = 0.979*I_{0.75}$	$I_{0.75} = 0.920*ETo_{0.75}$	$Y_{0.75} = 0.998*I_{0.75}$

IV.5 THE DRIP IRRIGATION SCHEDULE FOR GRAPE LEAVES

(1) Total time of canopy development and leaf harvest is about 4 months

(2) Irrigation frequency is 2days; Apply drip irrigation level with less water (m = 0.75);

(3) Drip irrigation amount (Im) is calculated from evaporation (ETo), daily effective precipitation (P) and crop coefficient (Kc) following each growing and developing stage of crops, or

(4) Drip irrigation one (Im) is also calculated with 0.725 (litter/one tree per time) equally 3.745 (m^3/one hectare per time) in order to maintain moisture in the active root layer, avoid deep infiltration causing waste water.

Table 4.9: Crop coefficient Kc of drip irrigation for Grape leaves

Growing stage	**Developing sprout**	**Developing tree**			**The 1st time cut the top of the trellis**	**Developing tree directs down**		**The 2nd time cut the top of the trellis**	**Developing tree directs down**		
		Directs up the top of the trellis		**Directs down**							
Time	10-20/01	21-31/01	01-10/02	11-20/02	21-29/02	01-10/3	11-20/3	21-31/3	01-10/4	11-20/4	21-30/4
Kc	0,30	0,45	0,55	0,60	0,65	0,65	0,70	0,70	0,65	0,65	0,55
Irrigation water rate (mm)	8.929	12.137	14.712	14.712	13.241	14.712	14.712	16.183	14.712	14.712	12.505
Irrigation water rate (m^3/ha)	11.365	15.450	18.727	18.727	16.854	18.727	18.727	20.599	18.727	18.727	15.918
Linear regression equations	$ETo_{(V1)} = 0,112t - 0,415h + 0,308s + 0,587w - 0,049p$ $I_{0,75} = 0,879*ETo_{0,75}$ $Y_{0,75} = 0,994*I_{0,75}$										
Time	10-20/9	21-30/9	01-10/10	11-20/10	21-31/10	01-10/11	11-20/11	21-30/11	01-10/12	11-20/12	21-30/12
Kc	0,25	0,30	0,45	0,55	0,60	0,60	0,65	0,65	0,60	0,60	0,55
Irrigation water rate (mm)	8.929	12.137	14.712	14.712	13.241	14.712	14.712	14.712	14.712	14.712	12.505
Irrigation water rate (m^3/ha)	11.365	15.450	18.727	18.727	16.854	18.727	18.727	18.727	18.727	18.727	15.918
Linear regression equations	$ETo_{(V1)} = 0,112t - 0,415h + 0,308s + 0,587w - 0,049p$ $I_{0,75} = 0,879*ETo_{0,75}$ $Y_{0,75} = 0,994*I_{0,75}$										

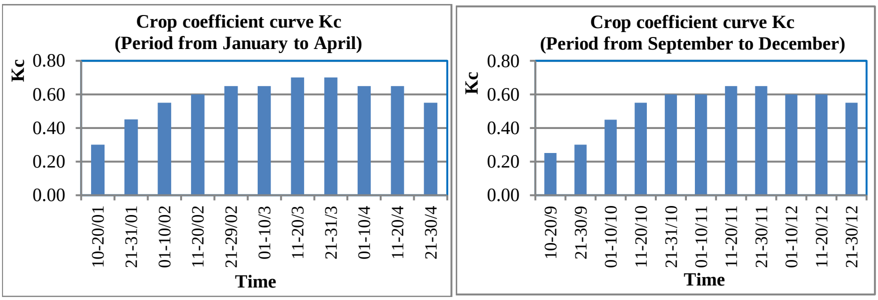


Figure 4.13: Crop coefficient curve Kc of drip irrigation for Grape leaves

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The thesis has achieved new major results as follows :

➢ **As regards water spread in soil of drip irrigation technique (water infiltration)**

1.1) Investigated water infiltration spread in soil at 3 places: soil without cultivating, plants with water saving irrigation and in the laboratory, results as: vertical velocity (Vz) and infiltration depth (Z) are bigger than horizontal velocity (V_R) and average radius of wetting front on horizontal direction (R). The results were showed that ***after irrigating in 40 ÷ 50 minutes, water spread completely covering the active root area (0 ÷***

20cm deep). The establishment of correlation and linear regressions of following variables: Z, R, W, Vz, V_R, with satisfatory test results and high correlation coefficient, linear regression models were suitable and significant to infer the general in order to apply into production reality.

- **As regards establishment of the pF Retention curve (pF curve)**

1.2) Established the pF curve for cultivated soil of the water scarce region in the South Central part, in order to apply it in calculating the readily available soil water (RAW), the correlation is very close ($R^2 > 0.9$).

(1.2.1) Total available soil water (TAW) in comparision with water content is from 56.91% (layer 0÷10cm) to 64.64% (layer 50÷60cm);

*(1.2.2) Total readily available soil water (TRAW) and the suitable minimum water content (θp) for popular dry crops at the water scarce region as follows: **Vine**: 10.35mm. θp: 8.76%TT; **Dragon tree**: 17.75mm. θp: 7.17%TT; **Apple**: 22.28mm. θp: 6.93%TT; **Sugar-cane**: 19.22mm. θp: 6.85%TT; **Vegetables**: 9.27mm. θp: 8.31%TT; **Onion-Garlic**: 4.71mm. θp: 9.6%TT. **Cultivated soil needs be irrigated to maitain moisture content from the suitable min water content (θp) to field capacity (θ_{fc})**.*

- **As regards research on soil moisture dynamic**

1.3) Determined soil moisture dynamic at non-plant and plant places of the water scarce region in the South Central part. The results are showed:

(1.3.1) At the KoTC: moisture increased in soil layers depth (Z), the layer (0÷5cm) had the smallest value, the layer (25÷30cm) had the biggest one;

*(1.3.2) At the TKN: moisture in the layer (0÷10cm) decreased fast because roots absorbed water for plant development. Moisture in layer (20÷30cm) decreased the most slowly in comparision with above layers because of non-root, water mainly infiltrated deeply but not absorbent by roots. Thus, **from the layer (20 ÷ 30cm) to the bottom, irrigation water was less effective for Grape leaves, so it should be paid attention to limit the water to infiltrate deeply into this soil layer;***

*(1.3.3) Moisture at the TKN: **CK2**: moisture at the end of frequency was higher than θp, crops were not deprived of water. **CK3** and **CK4**: were supplied more water than CK2, therefore a lot of water infiltrated deeply, at the beginning and middle of the frequency, crops got enough water; but at the end of frequency, moisture decreased and was lower than θp, it sometimes closed to wilting point (θwp), crops were short of water. For this reason, the CK2 for Grave leaves is suggested to develop well;*

(1.3.4) At the CT: moisture decreased in the soil layer depth (Z) (because active roots were deep). Decreasing amount of this place was greater than the KoTC and TKN (because water mainly infiltrated deeply);

(1.3.5) In daytime moisture decreased greater than in the evening and at night; moisture in the afternoon decreased greater than in the morning. The greatest decreasing amount was from 9:0AM to 15:0PM. Therefore, farmers should irrigate in the morning for crops to absorb much water during the process of photosynthesis, metabolism and body heat balance;

(1.3.6) Established the correlation and linear regressions of variables: (a) Infiltration, (b) pF curve and water amount in soil, (c) pF curve and water content of each layer. Test results were satisfied and correlation coefficient was high, linear regression models were suitable and significant to infer the general.

- **As regards research on simulation of soil moisture dynamic**

1.4) Applied the Coup Model for simulating moisture and heat transfer in the soil-plant-air system with the results approached field observations.

- **Proposed the suitable schedule of water saving irrigation (drip irrigation technique) for Grape leaves**

1.5) The thesis has showed as follows:

(1.5.1) CK2 with less water level ($m_{(3)}$) had the lowest excess water, the soil ensured the moisture absorption and well development of crops to achieve high productivity. Experimental blocks of: CK2 with $m_{(1)}$ and $m_{(2)}$), CK3 and CK4 supplied water infiltrated over active root area to become waste; at the end of the irrigation frequency, moisture reduced and crops could not absorb enough water for developing well;

(1.5.2) Less water level ($m_{(3)}$) saved a lot of water in comparision with two others irrigation levels ($m_{(1)}$) and ($m_{(2)}$);

(1.5.3) The blocks with drip and extra sprinkler system had higher water use efficiency than the pure drip irrigation blocks and control ones. The blocks of CK2 had higher water use efficiency than CK3 and CK4. The water use efficiency of blocks with less water level ($m_{(3)}$) was the highest;

(1.5.4) Irrigation productivity which applied saving irrigation technique showed that: The order of productivity in each irrigation frequency also decreased from the low water level ($m_{(3)}$) to the high water one ($m_{(1)}$);

(1.5.5) The trees' development in the drip and extra sprinkler blocks was faster and better, early and more productive harvest, concentrating and homogenizing than the pure drip irrigation blocks and control ones;

(1.5.6) Profit of the drip and extra sprinkler blocks was higher than the pure drip irrigation blocks and control ones. Blocks of CK2> CK3 >CK4;

(1.5.7) Established the correlation and linear regressions of variables: Meteorology – Crop water requirement - Crop yields from the field experiments with satisfatory test results, high correlation coefficient, linear regression models is suitable and significant to infer the general;

(1.5.8) Proposed the suitable schedule of water saving irrigation (drip irrigation technique) for Grape leaves in the water scarce region in the South Central part of Vietnam, as follows:

(1) Total time of canopy development and leaf harvest is about 4 months;

(2) Irrigation frequency is 2days; Apply drip irrigation level with less water (m = 0.75);

(3) Drip irrigation amount (Im) is calculated from evaporation (ETo), daily effective precipitation (P) and crop coefficient (Kc) following each growing and developing stage of crops, or

(4) Drip irrigation one (Im) is also calculated with 0.725 (litter/one tree per time) equally 3.745 (m^3/one hectare per time) to maintain moisture in the active root layer, avoid deep infiltration causing waste water.

2. RECOMMENDATIONS

2.1) Research on the pF Retention curve (pF curve) for the main types of land used in agricultural production, including the South Central part.

2.2) Need establish the supplemental pF curve of the soil layer from -60cm down to a depth of 85÷90% of the active roots for the perennial plants such as: cashew, coffee tree, cocoa-tree, mango, custard-apple…, to calculate TRAW and determine the suitable irrigation schedule;

2.3) At the scarce region (droughty one) of the South Central part with severe weather conditions, to reduce water loss by deep infiltration, the farmers should increase clay or humus, colloid for the soil, and concurrently apply the short-term irrigation frequency to maintain moisture content, ensuring that crops can absorb enought water and grow well;

2.4) Using the drip irrigation technique, to enhance water use efficency at the similar condition region and crop characteristics like Grape leaves, for water to infiltrate over the active root layer, the soil only needs be irrigated from 40÷50minutes for the depth (0÷20cm), or from 90÷100minutes for the depth (0÷30cm), or from 180÷190minutes for the depth (0÷40cm), then stop watering to avoid waste water of deep infiltration, concurrently apply the irrigation schedule CK2 for the moisture in the suitable range ($\theta_p \div \theta_{fc}$);

2.5) More study on infiltration of ununiform soil layers, unequal terrain, water-table changing and effecting to plants for effective application in practical production;

2.6) Study on short time forecast of the meteorological elements for irrigation water calculation and effective determination of climate to the crop development.

THE AUTHOR'S PUBLICATIONS

I. International articles

[1] Tran Thai Hung, Xing Wengang, Zhang Juan. (2007). *The Technique of Economic Irrigation*. The International Journal of Effective utilization or Agricultural soil & water resources and protection of environment, China. pp 160 ÷ 164.

[2] Tran Thai Hung, Xing Wengang, Hoang Cam Chau. (2008). *Research on suitable drip irrigation schedule for tomato*. Center for Science and Technology Development, Ministry of Education, China.

[3] Tran Thai Hung, Xing Wengang. (2009). *Research on infiltration flow and soil moisture dynamics according to soil depth for drip irrigation technique*. Center for Science and Technology Development, Ministry of Education, China.

[4] Tran Thai Hung, Vo Khac Tri, Le Sam. (2016). *Research on Infiltration Spread in Soil of Drip Irrigation Technique for Grape Leaves at the Water Scarce Region of Vietnam.* International Journal of Agricultural Science and Technology (IJAST). DEStech Publications, Inc. USA. Vol 4, No. 2 – August 2016, pp. 45 ÷ 54.

II. Domestic articles

[5] Tran Thai Hung. (2009). *Research on infiltration flow and soil moisture dynamics according to soil depth for drip irrigation technique*. Journal of Water Resource Research 2009. Agricultural press. Vietnamese. No. 11, pp. 185 ÷ 197.

[6] Tran Thai Hung, Nguyen Van Lan, Le Sam. (2014). *Research on potential assessment and propose solutions of sustainable and suitable utilization and exploitation to water resources for rural development in the Central coastal region of Vietnam*. Journal of Water Resources Science and Technology. Vietnamese. No. 21, pp. 32 ÷ 40.

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[9] Tran Thai Hung, Vo Khac Tri, Le Sam. (2016). *Experimental research on suitable irrigation schedule for grape leaves with the drip irrigation technique at the water scarce region*. Journal of Water Resources & Environmental Engineering. Vietnamese. No. 55, pp. 73 ÷ 82.

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[11] Tran Thai Hung. (2018). *Experimental study of soil moisture dynamic of the drip irrigation to determine the suitable irrigation schedule for grape leaves at the water scarce region (droughty region).* Journal of Water Resources Science and Technology. Vietnamese. No. 42, pp. 65 ÷ 77.

[12] Tran Thai Hung. (2018). *Experimental research on infiltration process in soil of drip irrigation technique for water saving irrigation for dry crops at the droughty region in the south central part of Vietnam.* Journal of Water Resources Science and Technology. Vietnamese. No. 47 (Publication was accepted in September 2018).

GUIDING FOR RESEARCH AND TEACHING IN THE THESIS CONTENT

1) Co-guided two Swedish students of the Royal Institute of Technology (KTH) for field experiment research in 2012 and completing the university thesis in 2013:
Students' name: (1) Sara Andersson; (2) Julia Cavell
Thesis name: *Long-term water modelling of the Soil-Plant-Atmosphere System*
- A study conducted for the growing of Grape Leaves with drip irrigation in Binh Thuan Province, Vietnam.

2) Taught 24 trainees at the Department of Agriculture and Rural Development of Binh Thuan province, November 2011 on the topic of: Effective and economical water utilization of irrigation for some crops.