Evapotranspiration-Based for Crop Cultivation with Deficit Irrigation Scheme

by

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Chapter 1

INTRODUCTION

In crop agriculture water is the most essential for the growth and development of the vegetable crops. The plants obtain its mineral nutrients from the soil by transporting it through water. The water is used for transpiration which its two main functions are to transport water and send nutrients to the leaves. However, the water in the soil can be lost due to different ways: evaporation and transpiration of the plant. As the soil dries, it becomes more difficult for the plant to absorb water from the soil. Most of the crops require a sustainable supply of water during its growing period. Therefore, efficient irrigation is needed to maintain the soil and water requirement of a crop. On the other hand, irrigation water is slowly becoming limited not only in arid and semi-arid regions but also in the regions where rainfall is abundant. Thus, water management and conservation are necessary to practice in agriculture. Furthermore, irrigation systems consume large amount not just of water but also of electricity (Perez, 2016). Submersible pumps are needed for irrigation systems that use groundwater as water source. Irrigation systems usually obtain their source of water deep underground or to rivers nearby.

Several studies have focused on determination of evapotranspiration (ET). ET can be defined as the process when it loses the moisture in the soil by evaporation and transpiration from the plants (FAO, 1998). Determining of evapotranspiration for specific vegetable crops (ET_c) is significant for irrigation scheduling and agricultural water management (Irmak et al., 2005). However, the demand for water is globally increasing. In vegetable crop agriculture, the use of water is mainly for irrigation, which is affected due to decreased in supply. Deficit irrigation is a method of maximizing water consumption, which can increase the efficient usage of water (Kirda, 2002).

Water is very important to the growth and development of a plant. It transports nutrient and sugar from the soil going up to the plant, which helps in the transpiration process. Water keeps the plant moist, flexible, and helps the plant make its own food. Too much or too little amount of water can affect the growth and development of the plant. Plant usually breath to their roots. When there is too much water in the soil, the plant cannot intake gasses and the nutrient of the soil depreciate. On the other hand, too little water for a plant means it is not getting the nutrients it needs from the water or the soil. Little by little the plant will dry up and eventually will die. Deficit irrigation is a technique that maximizes water without affecting the growth of the plant. The water is being reduced to a certain amount and determine the effect of it to the plant. One of the bases in determining the effect of deficit irrigation to the plant is by its crop yield. The crop yield of a plant that is fully watered is being compared to the crop yield of a plant that has been reduced in water.

The general objective of this study is to develop an evapotranspiration-based (ET) irrigation system with deficit irrigation applied in a normal farm for crops. Specifically, this study aims: (1) To develop an irrigation system to a backyard based on evapotranspiration. (2) To implement deficit irrigation that will impose application of 100%, 75% and 50% crop water requirement based on Penman-Monteith equation. (3) To determine the performance and functionality of ET-based irrigation system and the effect of deficit irrigation such as the height and the fruit yield to the crop.

Upon Completion of this research, the study will greatly help farmers by providing them an alternative way of irrigating their farm based on empirical formula of water loss.

Knowing the amount of water that leaves to ground or the evapotranspiration makes it possible to determine how much water needs to be added back. In addition, the Food and Agriculture Organization of the United Nations (FAO) recommends farmers to use evapotranspiration process in irrigation system. The advantage of using evapotranspiration-based evaporation will also prevent the underground contamination of soil, in which to much supply of water reduce the nutrients of the soil.

This study focuses on the development of a controlled irrigation system for the Solanum Melongena (Eggplant) plant which is also computed by the system software based from meteorological data readings of temperature, humidity, radiation and wind speed. Deficit irrigation water scheme will be applied in this ET-based irrigation system. This system will impose irrigation rates based on 100%, 75% and 50% crop water requirement. This study is an ET-based irrigation system using Penman-Monteith equation. The implementation and testing of the Deficit irrigation system will be in a backyard.

Chapter 2

REVIEW OF RELATED LITERATURE

Water in the Earth Surface

According Du Plessis, water is one of the most available substances found in the environment, making up the oceans, seas, lakes, rivers and underground water sources of the earth. Approximately 75% of the Earth's surface is covered by water. However, it is only an estimate that the dynamic nature and permanent water movements make it difficult to reliably assess the total groundwater. Furthermore, agricultural activities dominate all other sectors on earth when it comes to water usage. The use of water resources by the agricultural sector includes water used for irrigation, livestock, fisheries and aquaculture. The water removed for agricultural purposes is used exclusively for irrigation. In low- and middle-income countries, the percentage of agricultural water used for irrigation is relatively higher. An alarming fact is that in low- and middle-income countries, between 15 and 35% of the water released for irrigation purposes is used in an unsustainable manner.

On the other hand, the Philippines water allotment in agriculture sector for its irrigation is one of the highest, next to the industrial and domestic uses (Arrogante, 2018). In a 2007 report entitled the state of water resources in the Philippines, the agriculture sector consumed around 85.27% of the country's water supply. Also, it was found that agriculture yielded wastewater about 29% of the total wastewater in the country. It also predicts a water deficit will occur in 2025, that only 1,907 cubic meters of fresh water would be available for each person per year.

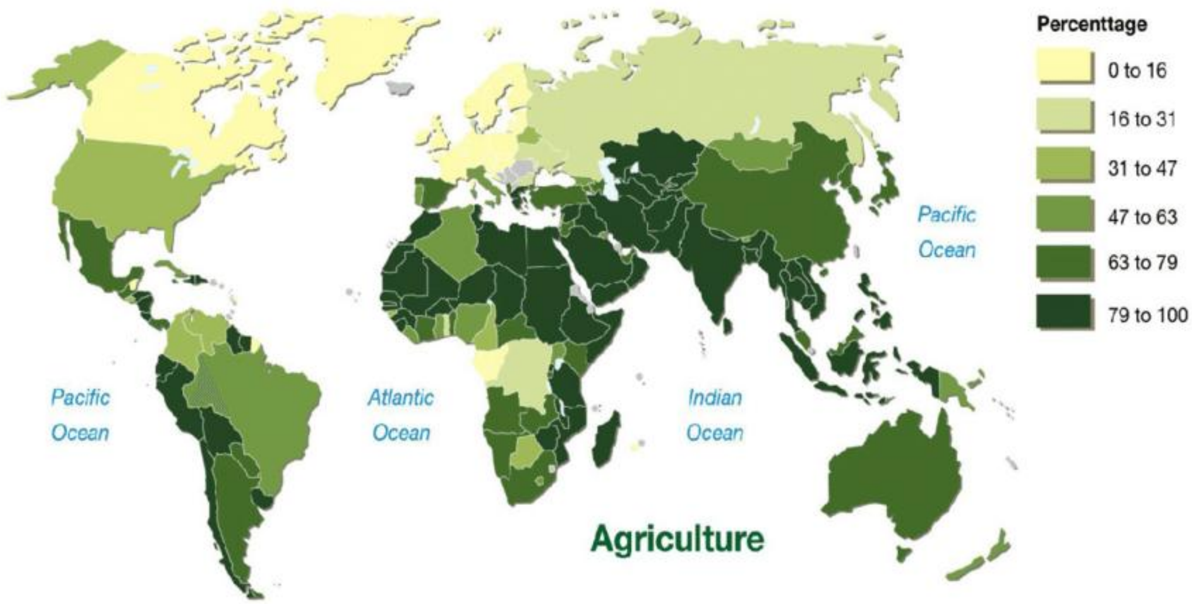


Figure 2.1 FAO Agricultural Water Usage Across the World

Figure 2.1 shows the water usage for agricultural activities across the world. This data was recorded during the year 2000 by The Food and Agriculture Organization of the United Nations (FAO).

Evapotranspiration

According to Irmak and Haman, evapotranspiration is a combined process of both evaporations from soil and plant surfaces and transpiration through plant canopies. Evaporation is the transfer of liquid surface water into vapor in the atmosphere. Evaporation occurs when the number of moving molecules that break from the water surface and escape into the air as vapor is larger than the number that re-enter the water surface from the air and become entrapped in the liquid. Evaporation occurs when the number of moving molecules that break from the water surface and escape into the air as vapor is larger than the number that re-enter the water surface from the air and become entrapped in the liquid (Huffman, 2013). Transpiration is composed of vaporized liquid water found in the plant tissue and the removal of vapor into the atmosphere. Through stomata, which is the small opening of the plant leafs where gases and water vapor pass, crops mainly lose the water. The water, including some nutrients, is supplemented by the roots and transferred through the plant. Practically all water absorbed is lost through transpiration and only a small proportion is used within the plant (Allen et al., 1998). Moreover, Evapotranspiration (ET) is a significant process in terrestrial systems, where it represents a link among the hydrological, carbon, and energy. About 60% of rainfall re-enters the atmosphere through transpiration (T) and evaporation (E), but this amount can reach 90% in agricultural ecosystems (Wang et al, 2018). By getting precise estimation and measurement of ET and its elements (Evaporation and Transpiration), and the quantity of water require to maintain a healthy landscape in agricultural ecosystem are critical both for managing irrigation and for improving crop yield. Furthermore, evapotranspiration relies on the use of specialized equations, namely: Hargreaves-Samani and Penman-Monteith in determining the amount of water loss through evaporation and transpiration of the plant (Fernando, 2018).

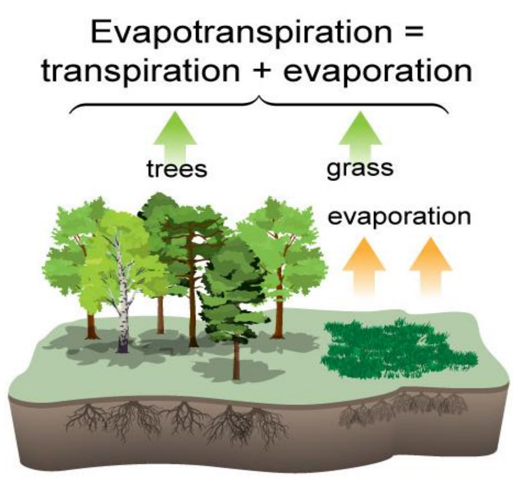


Figure 2.2 Concept of Evapotranspiration

Figure 2.2 shows the concept of evapotranspiration, wherein evapotranspiration is the sum of evaporation of water from the soil and the transpiration of the plant.

Factors Affecting Evapotranspiration

According to Harris, there are many factors that affect evapotranspiration, such as weather, crop, environmental condition, and management. The weather factors affecting evapotranspiration (ET) are radiation, air temperature, humidity and wind speed. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ET_o). It represents the ET from a standardized vegetated surface. Crop type, variety and development stage affect the rate of ET from crops grown in large, well-managed paddocks. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop root characteristics result in different ET levels in different crop types under identical environmental conditions. Factors that limit crop development reduce ET – for example, soil salinity, inadequate nutrition, soil compaction, diseases and pests. ET is also affected by groundcover, plant density and soil water content. The ET rate is also affected by management practices that affect the climate and crop. Cultivation practices and irrigation method can alter the microclimate and affect the crop characteristics or the wetting of the soil and crop surface. Windbreaks reduce wind velocities and decrease ET rate of the field directly beyond the barrier. Micro-irrigation systems that apply water directly to the root zone of crops leave the major part of the soil surface dry, thereby limiting evaporation losses. Surface mulches, when the crop is small, substantially reduce soil evaporation.

Evapotranspiration Concept

Reference Crop Evapotranspiration (ET_o)

According to Zhang et al., the reference crop evapotranspiration (ET_o) is a key parameter of crop water requirement and can be used to represent the water demand. Under natural water supply conditions, rainfall and ET_o are two related random hydrologic variables of the weather system with relevance for irrigation management and planning. Many related studies have indicated that the spatio-temporal characteristics of rainfall and ET_o can explain the changes of the natural water supply and demand in the irrigation district. The correlations between rainfall and ET_o are also explored to forecast and estimate their change trends or characteristics.

FAO Penman-Monteith Equation

The FAO Penman-Monteith model was used to calculate potential evapotranspiration from a vegetated surface. PM model needs the input of four kinds of meteorological data sets (temperature, wind speed, radiation and relative humidity). The International Commission for Irrigation and Drainage and FAO has suggested the use of PM model as a universal model for calculating ET_o, and to evaluate other models (Rawat, 2019).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2.1}$$

where:

ET_0 = Reference ET (mm/day)

R_n = net radiation (MJ/m^{2}day)

G = Soil Heat Flux (MJ/m^{2}day)

γ = Psychrometric Constant (kPa/ ^{o}C)

T = Mean Daily Air Temperature at 2m Height (^{o}C)

U_2 = Wind Speed at 2m Height (m/s^2)

e_s = Saturation Vapour Pressure Deficit (kPa)

e_a = Actual Vapour Pressure Deficit (kPa)

Δ = Slope Vapour Pressure Curve (kPa/ ^{o}C)

Crop Evapotranspiration Under Standard Condition

Crop ET under standard conditions (ET_C) is the ET from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. A crop coefficient (K_C) is used to estimate ET_C from the Penman-Monteith estimate for ET_O.

$$ET_c = K_c \times ET_o \qquad (2.2)$$

where:

ETc = Crop ET under standard conditions

K_c = Crop Coefficient

ET_o = Reference Crop Evapotranspiration

ET_C differs from ET_O under the same climatic conditions due to differences in leaf structure, stomatal characteristics, aerodynamic properties and solar radiation reflectance. The crop coefficient for a given crop changes from sowing until harvest. On the other hand, standard crop coefficients relate to crops under disease free, well fertilized, optimum soil moisture and full production conditions. Often crops do not meet these conditions, and the crop coefficient (KC) can be adjusted under these circumstances to better reflect the actual crop conditions (Harris, 2012).

Table 2.1 Crop Coefficients (K_C) for major irrigated field crops

Crop	**K_c initial**	**K_c mid-season**	**K_c end of season**
Barley	0.30	1.15	0.25
Chickpea	0.40	1.00	0.35
Cotton	0.35	1.15 – 1.20	0.70 – 0.70
Maize	0.30	1.20	0.35
Navy Bean	0.40	1.15	0.35
Peanut	0.40	1.15	0.60
Sorghum	0.30	1.00 – 1.10	0.55
Soybeans	0.40	1.15	0.50
Sunflower	0.35	1.15	0.35
Wheat	0.30	1.15	0.25

Deficit Irrigation

The main agricultural use of water is for irrigation and is therefore affected by reduced supply (Kirda, 2002). Irrigation technologies and irrigation scheduling are different methods that has been discovered to possibly increase the efficient use of water in areas with insufficient water resources. As the irrigation techniques develops, the study found that it is possible to grow a crop without its full water requirement to proper allocate the use of water. Deficit irrigation is a strategy in agriculture to maximize the crop water requirement. In response to limited supplies, the use of water-deficient irrigation (defined as water below the total crop water requirement) is an important tool for achieving the goal of reducing irrigation water usage (Fereres et al., 2006).

Solanum Melongena

The eggplant (*Solanum melongena*) is a native of the subtropical areas of south-eastern Asia and was introduced into Europe by early Arab traders. Eggplant is a summer-growing vegetable that requires warm to hot conditions. The optimum growing temperature range is 21°–30° C, with a maximum of 35° C and a minimum of 18° C. The optimum soil temperature for seed germination is 24°–32° C. Eggplant is in the Solanaceae family, as are tomato (*Solanum lycopersicon*) and pepper (*Capsicum annum*) and shares similar environmental and cultural requirements as those crops. However, in contrast to tomato and pepper, eggplant crop can tolerate greater levels of drought stress (Díaz-Pérez, 2015). There are several studies on eggplant irrigation carried out in Asia, Africa, and Europe (Aujla et al., 2007; Gaveh et al., 2011; Karam et al., 2011) showing that eggplant can be produced at moderate levels of drought stress without major impact on fruit yield.

Chapter 3

METHODOLOGY

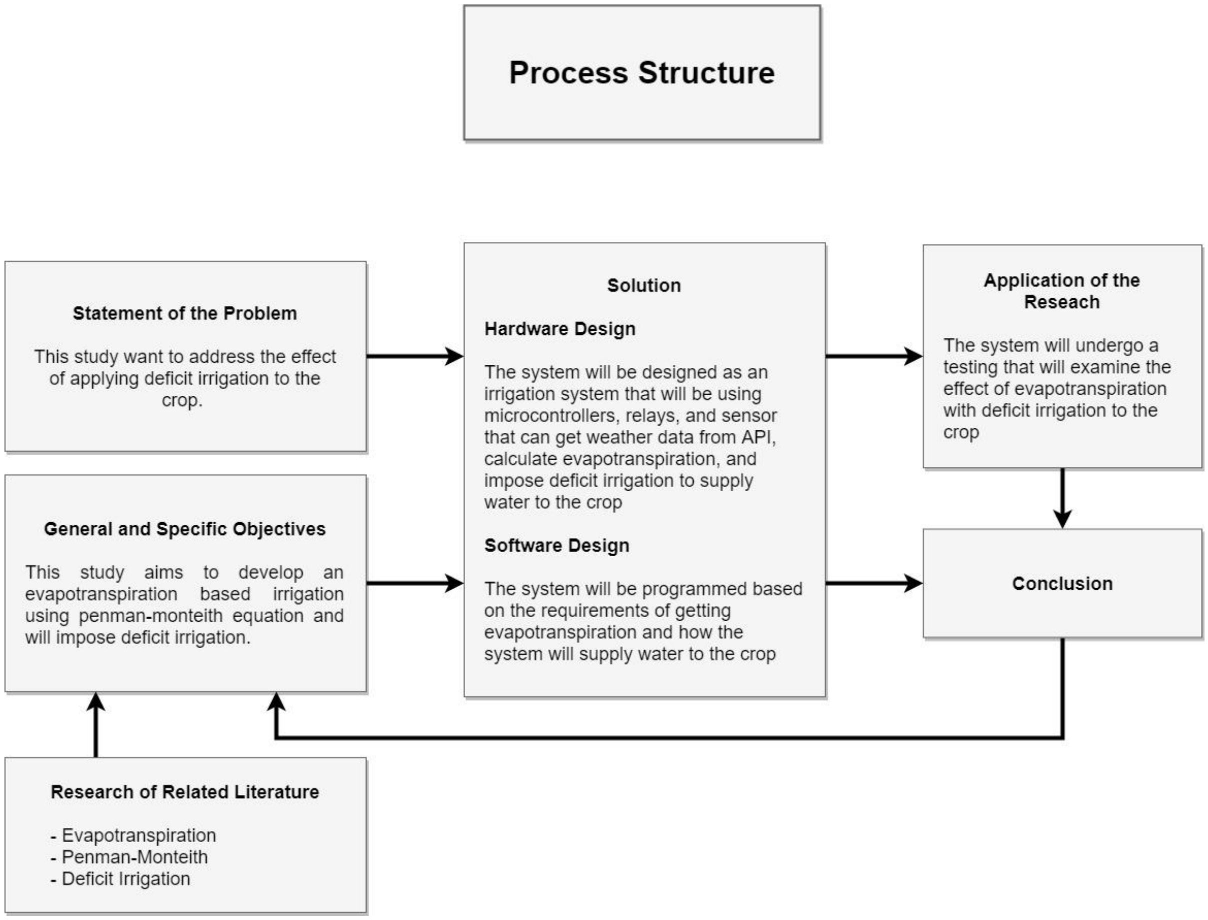


Figure 3.1 Constructive Research Method

Figure 3.1 shows the constructive research methodology, which is basically the blue print for the researchers to follow. Constructive research methodology is more of theories, hypotheses, and case studies. Constructive research methodology investigates practical problem having an academic approach in theoretical contribution and has the practical relevance, the body of knowledge, the projection of appropriate solution, implementation and execution of solution and the result which is related to the theory.

The process will initially start in identifying or stating up the problem. Wherein, the problem address by this study is effect of deficit irrigation to the growth of a plant which is the solanum melongena (eggplant) through it crop yield. The crop yield of a fully watered solanum melongena (eggplant) will be compared to the crop yield of a less waters solanum melongena (eggplant) based on the deficit irrigation scheme. Even though, there are lots of research that addresses the same problem, there is a need to rework and add some functionalities that will improve the occurring system.

The next process specifies the general and specific objective of the research that will address the statement of the problem. The general objective of this study is to develop an evapotranspiration-based (ET) irrigation system with deficit irrigation applied in a normal farm for crops. Specifically, this study aims: (1) To develop an irrigation system to an open field based on evapotranspiration. (2) To implement deficit irrigation that will impose application of 100%, 75% and 50% crop water requirement based on Penman-Monteith equation. (3) To determine the performance and functionality of ET-based irrigation system and the effect of deficit irrigation to the crop.

After citing the objective, gathering and collecting supporting papers such as related literature, journals, and researches. These papers will justify and support the objectives to solve the problem. It also helps to determine the hardware components that can be used and the software algorithms to be used. The conceptual framework of the system is developed after this process. Where in the inputs of the system will be the data coming from the weather station API and from the water flow sensor. The process will be the processing of input data and the calculation the reference crop evapotranspiration (ET_o) and the crop evapotranspiration (ET_c). All the data will be displayed to the LCD and will store to the microSD, and the system will dispense the exact amount of water needed by the crops.

The solution of the problem will incorporate hardware design and software development. The concept of hardware design, list components, and schematic diagram of the system is included in the hardware development. This paper will design an irrigation system that will be using microcontrollers, relays, and sensor that can get weather data from API, calculate evapotranspiration, and impose deficit irrigation to supply water to the crop. The microcontroller will be the main component of the system, it will be used to get information to the API and sensor, calculate values with programmed algorithms, and control other components of the system. The software development encapsulates the process of the system, flowcharts and algorithms. The system will fetch meteorological data such as temperature, humidity, radiation, and wind speed from the weather station API to be able to calculate the reference crop evapotranspiration (ET_o) and the crop evapotranspiration (ET_c). From the calculate the reference crop evapotranspiration (ET_o) and the crop evapotranspiration (ET_c), the deficit irrigation will be imposed and will supply the exact amount of water needed by the crops.

The application of the research process will cater the experimentation and testing of the system. This process will evaluate the performance and functionality of the system, through its characteristic such as the height and the bearing of the crop. The system will also be tested in imposing deficit irrigation limiting water supply to 100%, 75% and 50% crop water requirement based on Penman-Monteith equation.

The conclusion of the research will be the summary of the analysis of the research. This will be the justification if the ET-based Irrigation based on Penman-Monteith with Deficit Scheme is effective in cultivating eggplant. Together with the conclusion is the recommendation for the future researcher to improve more the system in the future.

Conceptual Framework

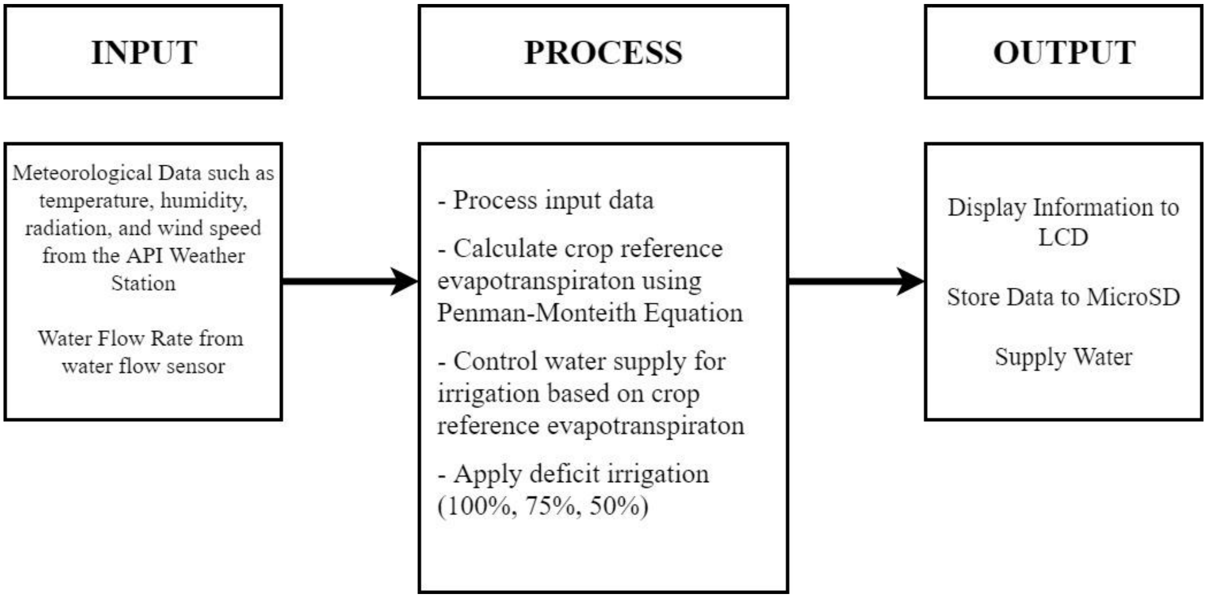


Figure 3.2 Conceptual Framework

Figure 3.2 shows the conceptual framework of the system. The system will be getting an input information from the water flow sensor and the API weather station. The water flow sensor will get the water flow rate which will be used to control the supply of water. The system will get weather information from the API weather station to determine the needed data such as temperature, humidity, radiation, and wind speed. This information fetched from the API will be stored to the microSD and will be processed by the microcontroller. The system will convert and calculate important information that will be using to determine the crop reference evapotranspiration (ET_o). The reference crop evapotranspiration (ET_o) can be computed using the FAO Penman-Monteith equation. The FAO Penman-Monteith equation can be computed with a given average temperature and other meteorological data. The crop evapotranspiration (ET_c) can be computed by the system using the ETo and Kc values. The crop evapotranspiration (ET_c) will be the basis of how much water will be supply to the crop. Furthermore, Deficit irrigation will be imposed which will be based on the crop evapotranspiration (ET_c). The system will impose 100%, 75% and 50% water deficit. The LCD screen will be used to display the daily average temperature and the reference crop evapotranspiration. The data gathered and computed by the system will be stored in the MicroSD.

Hardware Design Concept

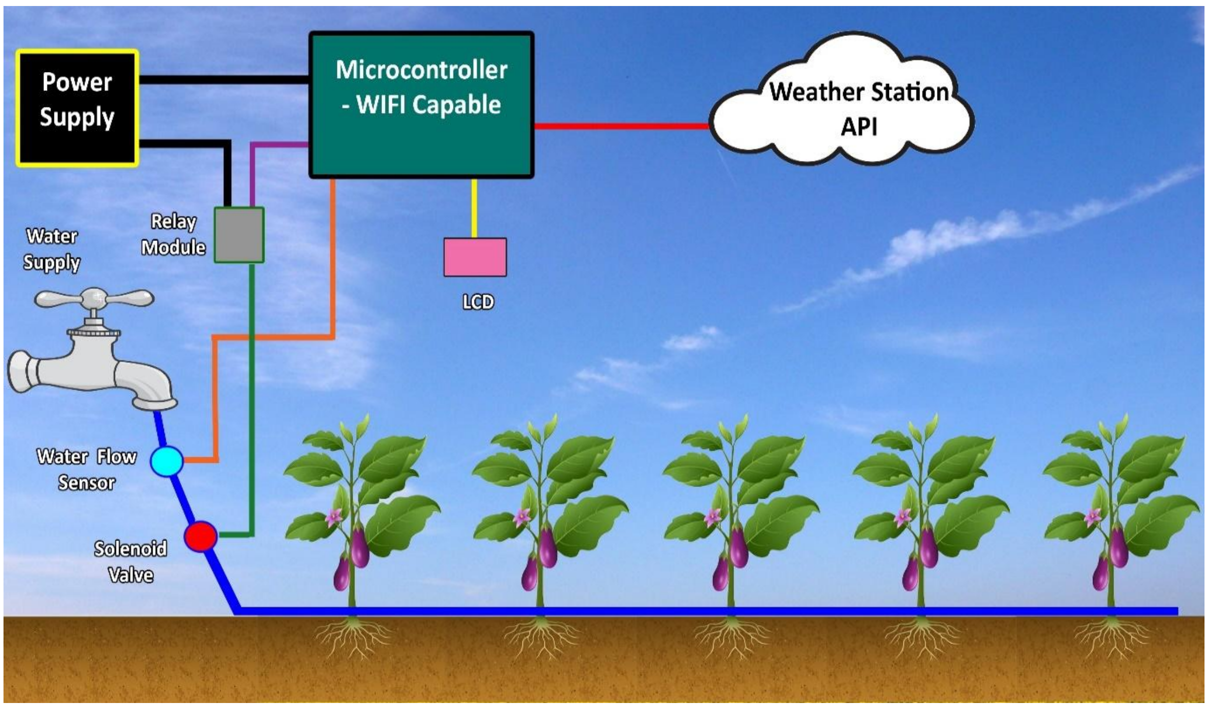


Figure 3.3 Hardware Design Concept

Figure 3.3 shows the overview hardware design concept of the ET-Based Irrigation Based on Penman-Monteith Equation Crop Cultivation with Deficit Irrigation system. The system is composed of a microcontroller, relay module, water flow sensor, solenoid vale, and LCD. The microcontroller will serve as the main component of the system, in which is used to get inputs from the API weather station and built-in sensors, calculate values with programmed algorithms, and control other components of the system. The system will fetch data from the API weather station which contains meteorological data such as temperature, humidity, radiation, and wind speed. The data received by the microcontroller will be stored to the microSD. The data saved in the microSD will be processed by the microcontroller to be able to use in determining the crop reference evapotranspiration (ET_o), which will be the basis on how the system will irrigate the crop. The crop reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) will be displayed in LCD and stored in microSD. The system will turn on the solenoid valve every day that will dispense the exact amount of water needed by the crops. The system will measure the water flow rate and compares it to the amount of water calculated by the system to be supplied to the crop. If the water flow reaches the certain amount of water needed, the system will stop the irrigation.

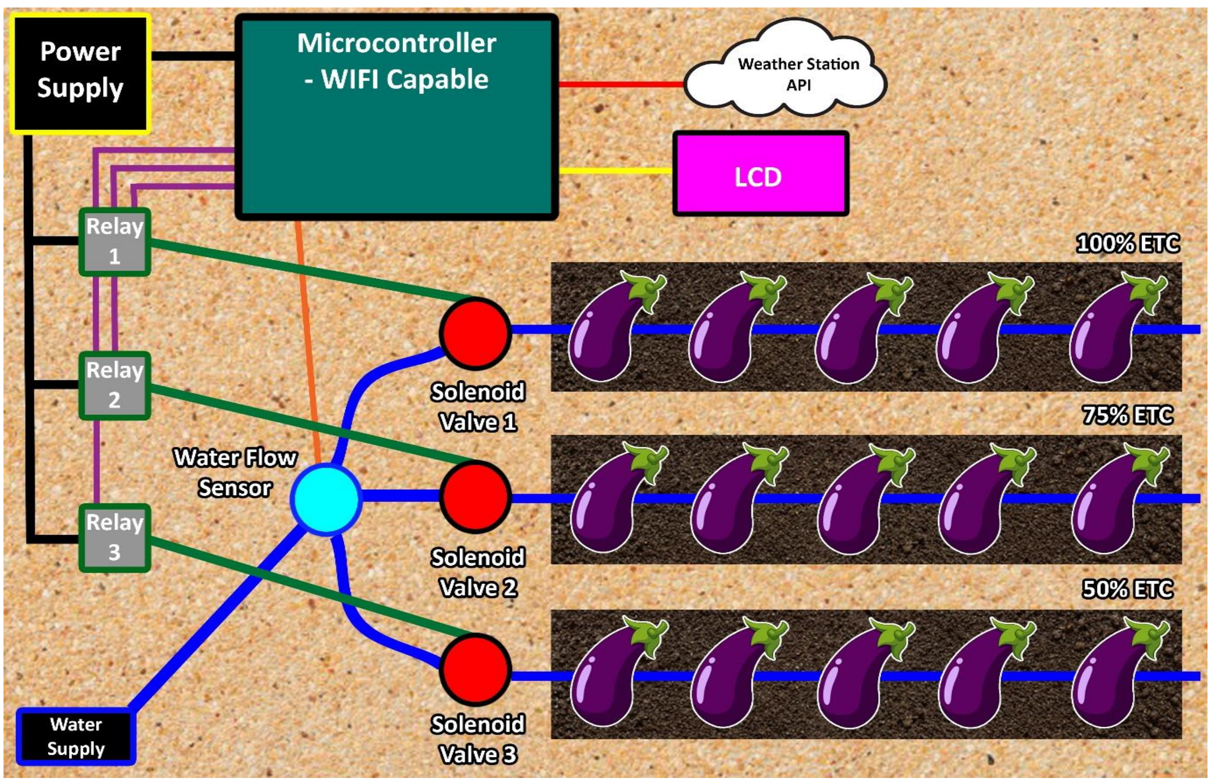


Figure 3.4 System Layout (Top View)

Figure 3.4 shows the top view layout of the ET-Based Irrigation Based on Penman-Monteith Equation Crop Cultivation with Deficit Irrigation system.

Hardware Components and Specifications

Table 3.1 Hardware Components Listing

Component	Specification	Description
YF-S201 Water Flow Sensor 	• Working Voltage: 5 to 18V DC • Max Current Draw: 15 mA at 5V • Output Type: 5V TTL • Flow Rate: 1 to 30 Liters / Minute • Temperature Range: -25 to +80℃ • Humidity Range: 35% to 80% RH • Accuracy: ±10% • Max Water Pressure: 2.0 MPa • Output duty cycle: 50% ±10% • Output rise time: 0.04µs • Output fall time: 0.18µs • Flow rate pulse characteristics: Frequency(Hz) = 7.5 * Flow rate (L/min) • Pulses per Liter: 450 • Cable Length: 15cm • 0.5” nominal pipe connections • 0.78” outer diameter • 0.5” of thread	YF-S201 is a Hall Effect water flow sensor. It sits in line with the water line and contains a pinwheel sensor to measure how much water has moved through it. The magnetic hall effect sensor outputs an electrical pulse with every revolution. Each pulse is approximately 2.25 milliliters

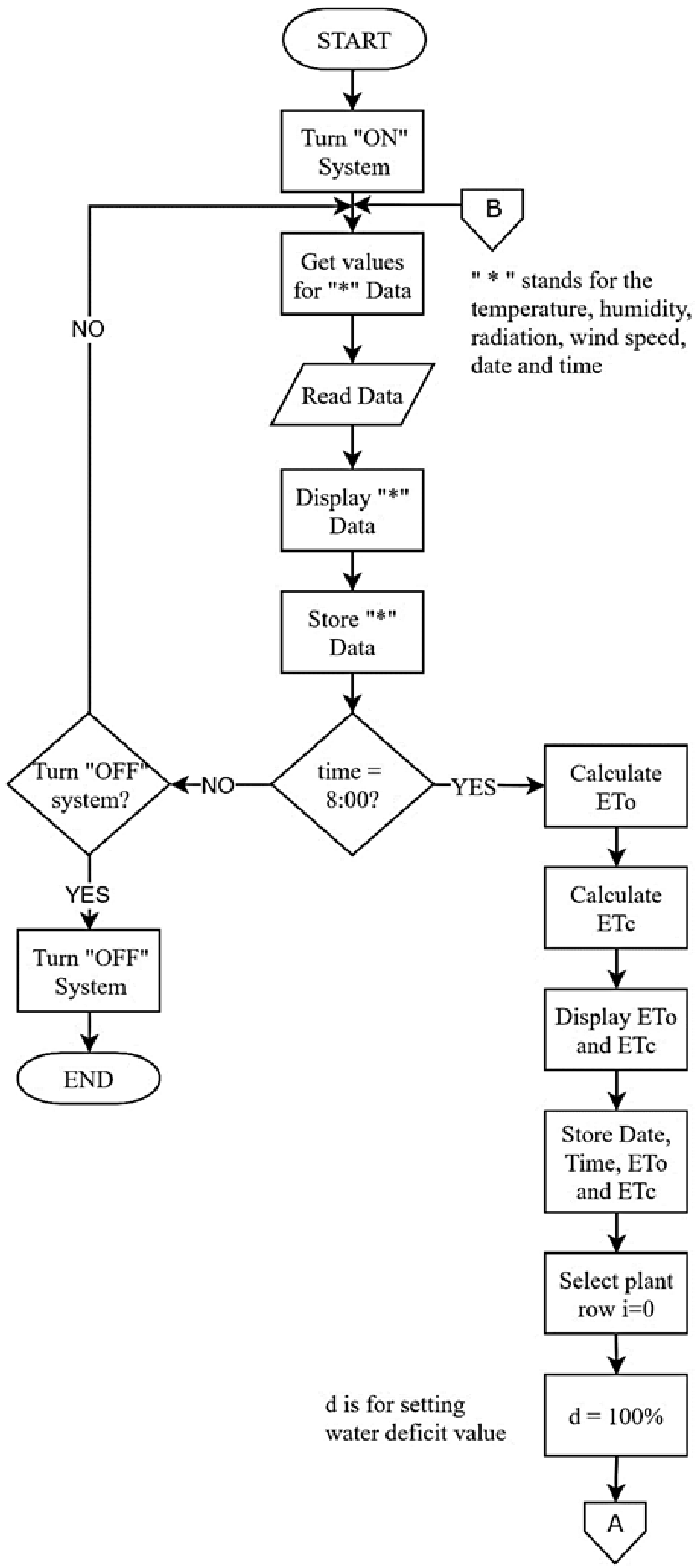
Table 3.2 Cont. of Hardware Components Listing

Component	Specification	Description
e-Gizmo SPDT Single Relay 	• Relay Model: GOODSKY RUDHSS-112D • Contact Configuration: SPDT • Coil Voltage: 12VDC • Coil Current: 37.5mA • Max Allowable AC Voltage: 240V • Max Allowable DC Voltage: 110V • Max Switching Current: 12A • Frequency: 50/60Hz • Driver: BC548 NPN Transistor • LED	e-Gizmo SPDT Single Relay consists of a built in driver (BC548 NPN transistor) that allows microcontrollers and logic devices to operate on the embedded GOODSKY RUDH-SS-112D relay. This is used to operate the solenoid valve.
Soleoid Valve 	• Input Voltage: 12V DC • Rated Power: 5W • Operation: Normally Closed • Pressure: 0.02 – 0.8 MPa • Port size: G3/4” • Fluid Temperature: 0 to 100℃ • Flow characterastics: 0.02Mpa>2L/min; 0.10Mpa>10L/min; 0.30Mpa>16L/min; 0.80Mpa>28L/min	A solenoid valve is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid. Generic solenoid valves has an input voltage of 12V and has a Normally Closed (NC) operation.

Table 3.3 Cont. of Hardware Components Listing

Component	Specification	Description
20x4 Character LCD 	• Number of Characters: 20 characters x 4 Lines • Viewing area: 77.0 x 26.5 mm, Active area: 70.4 x 20.8 mm • Supply Voltage For Logic: 5V • Supply Voltage of backlight: 3.84.2V (180mA) • Operating Temperature -20 to +70 °C	Generic 20x4 character LCD display with back light that can be interfaced to any Arduino microcontroller board.
Power Supply	• Input: 220-240V AC (60 Hz) • Output: 12 V DC	The 12V power supply will be used by all the devices connected to the system.

System Flowchart



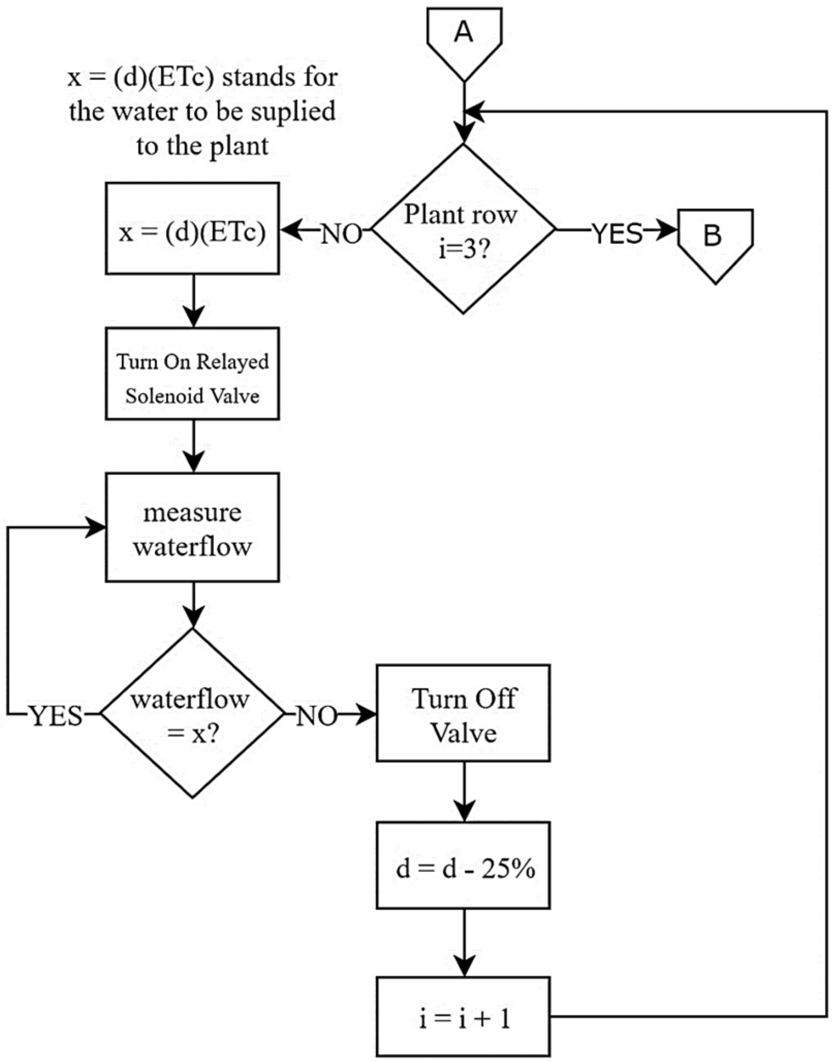


Figure 3.5 System Flowchart

As the system is turned on, it will get data from the API weather station and it will read and display by the system and store the data. The system will fetch data from the API weather station which contains meteorological data such as temperature, humidity, radiation, and wind speed. Next, the system will check if it has been running for 24 hours. This is because irrigation processes will be performed on a daily basis. The meteorological data will be used to compute for the Reference Crop Evapotranspiration (ET_o) and the Crop Evapotranspiration (ET_c). The crop reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) will be displayed in LCD and stored in microSD. The system will turn on the solenoid valve that will dispense the imposed irrigation rates to the crops. The system will measure the water flow rate and compares it to the imposed irrigation water flow rates to be supplied to the crop. If the water flow reaches the certain amount of water, the system will stop the irrigation.

Penman-Monteith Equation

The Penman-Monteith equation is recommended by the Food and Agriculture Organization (FAO) as a method in calculating the reference crop evapotranspiration (ET_o) and is summarized with this equation.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3.1}$$

where:

ET_0 = Reference ET (mm/day)

R_n = net radiation (MJ/m^2day)

G = Soil Heat Flux (MJ/m^2day)

γ = Psychrometric Constant (kPa/ ^oC)

T = Mean Daily Air Temperature at 2m Height (^oC)

U_2 = Wind Speed at 2m Height (m/s^2)

e_s = Saturation Vapour Pressure Deficit (kPa)

e_a = Actual Vapour Pressure Deficit (kPa)

Δ = Slope Vapour Pressure Curve (kPa/ ^oC)

The (average) daily maximum and minimum air temperatures in degrees Celsius (°C) are required. Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of ET_o will probably occur due to the non-linearity of the saturation vapor pressure - temperature relationship.

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \tag{3.2}$$

Where:

T_{mean} = mean daily air temperature, ºC

T_{max} = maximum daily air temperature, ºC

T_{min} = minimum daily air temperature, ºC

The average daily wind speed in meters per second (m / s) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ. The wind speed measured at heights other than 2 m can be adjusted according to the follow equation:

$$u_2 = u_h \frac{4.87}{\ln\left(67.8\, h - 5.42\right)} \tag{3.3}$$

Where:

u_2 = wind speed 2 m above the ground surface, m / s

u_h = measured wind speed z m above the ground surface, m / s

h = height of the measurement above the ground surface, m

For the calculation of evapotranspiration, the slope of the relationship between saturation vapor pressure and temperature is required.

$$\Delta = \frac{4098\left[0.6108 exp\left(\frac{17.27 * T_{mean}}{T_{mean} + 237.3}\right)\right]}{(T_{mean} + 237.3)^2} \tag{3.4}$$

Where:

Δ = Slope Vapour Pressure Curve, kPa / ºC

T_{mean} = mean daily air temperature, ºC

exp = 2.7183 (base of natural logarithm)

The psychrometric constant is the ratio of specific heat of moist air at constant pressure (Cp) to latent heat of vaporization. The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure. The psychrometric constant is kept constant for each location depending of the altitude

$$\gamma = 0.000665\, P \tag{3.5}$$

Where:

γ = Psychrometric Constant, kPa / ^{o}C

P = atmospheric pressure, kPa

The mean saturation vapor pressure is calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperatures. The mean saturation vapor pressure for a day, week, decade or month should be computed as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for that period.

$$e_{(T_{max})} = 0.6108exp\left[\frac{17.27\ T_{max}}{T_{max} + 237.3}\right] \quad (3.6)$$

$$e_{(T_{min})} = 0.6108exp\left[\frac{17.27\ T_{min}}{T_{min} + 237.3}\right] \quad (3.7)$$

$$e_s = \frac{e_{(T_{max})} + e_{(T_{min})}}{2} \quad (3.8)$$

Where:

E_{tmax} = saturation vapor pressure at the air maximum temperature, kPa

E_{tmin} = saturation vapor pressure at the air minimum temperature, kPa

T_{max} = maximum daily air temperature, ºC

T_{min} = minimum daily air temperature, ºC

Es = mean saturation vapor pressure, kPa

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \quad (3.9)$$

Where:

R_n – net radiation, MJ / m^2 day

R_{ns} = net solar or shortwave radiation, MJ / m^2 day

R_{nl} = net outgoing longwave radiation, MJ / m^2 day

$$R_{ns} = (1 - a)R_s \qquad (3.10)$$

Where:

R_{ns} = net solar or shortwave radiation, MJ / m^2 day

α = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop

R_s = the incoming solar radiation, MJ / m^2 day

$$R_{nl} = \sigma\left[\frac{(T_{max} + 273.16)^4 + (T_{min} + 273.16)^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left[1.35\frac{R_s}{R_{so}} - 0.35\right] \qquad (3.11)$$

Where:

R_{nl} = net outgoing longwave radiation, MJ / m^2 day

σ = Stefan-Boltzmann constant

T_{max} = maximum absolute temperature during the 24-hour period, K

T_{min} = minimum absolute temperature during the 24-hour period, K

e_a = actual vapor pressure, kPa,

R_s = the incoming solar radiation, MJ / m^2 day

R_{so} = clear sky solar radiation, MJ /m^2 day

Table 3.4 Stefan-Boltzmann constant, σ

T (°C)	σT_K^4 (MJ m^{-2} d^{-1})	T (°C)	σT_K^4 (MJ m^{-2} d^{-1})	T (°C)	σT_K^4 (MJ m^{-2} d^{-1})
1.0	27.70	17.0	34.75	33.0	43.08
1.5	27.90	17.5	34.99	33.5	43.36
2.0	28.11	18.0	35.24	34.0	43.64
2.5	28.31	18.5	35.48	34.5	43.93
3.0	28.52	19.0	35.72	35.0	44.21
3.5	28.72	19.5	35.97	35.5	44.50
4.0	28.93	20.0	36.21	36.0	44.79
4.5	29.14	20.5	36.46	36.5	45.08
5.0	29.35	21.0	36.71	37.0	45.37
5.5	29.56	21.5	36.96	37.5	45.67
6.0	29.78	22.0	37.21	38.0	45.96
6.5	29.99	22.5	37.47	38.5	46.26
7.0	30.21	23.0	37.72	39.0	46.56
7.5	30.42	23.5	37.98	39.5	46.85
8.0	30.64	24.0	38.23	40.0	47.15
8.5	30.86	24.5	38.49	40.5	47.46
9.0	31.08	25.0	38.75	41.0	47.76
9.5	31.30	25.5	39.01	41.5	48.06
10.0	31.52	26.0	39.27	42.0	48.37
10.5	31.74	26.5	39.53	42.5	48.68
11.0	31.97	27.0	39.80	43.0	48.99
11.5	32.19	27.5	40.06	43.5	49.30
12.0	32.42	28.0	40.33	44.0	49.61
12.5	32.65	28.5	40.60	44.5	49.92
13.0	32.88	29.0	40.87	45.0	50.24
13.5	33.11	29.5	41.14	45.5	50.56
14.0	33.34	30.0	41.41	46.0	50.87
14.5	33.57	30.5	41.69	46.5	51.19
15.0	33.81	31.0	41.96	47.0	51.51
15.5	34.04	31.5	42.24	47.5	51.84
16.0	34.28	32.0	42.52	48.0	52.16
16.5	34,52	32.5	42.80	48.5	52.49

Table 3.4 shows the Stefan-Boltzmann constant from the food and agriculture organization. Stefan-Boltzmann is the rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the power of four. The table shows the exact Stefan-Boltzmann constant based from the temperature. Since humidity and cloudiness play a major role, Stefan – Boltzmann use to correct in estimating the net outgoing flux of longwave radiation, R_{nl}.

$$R_{so} = (0.75 + 0.00002h)R_a \tag{3.12}$$

Where:

R_{so} = clear-sky solar radiation, MJ / m^2 day

h = station elevation above sea level, m

R_a = extraterrestrial radiation, MJ / m^2 day

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \tag{3.13}$$

Where:

R_s = solar or shortwave radiation, MJ / m^2 day

n = actual duration of sunshine, h

N = maximum possible duration of sunshine or daylight hours, h

R_a = extraterrestrial radiation, MJ / m^2 day

a_s+b_s = fraction of extraterrestrial radiation reaching the earth on clear days (n = N)

Crop Evapotranspiration (ET_c)

Crop evapotranspiration (ETc) can be calculated having the value of reference crop evapotranspiration (ET_o) and the crop coeeficient (K_c). The Solanum melongena have different crop coefficient (K_c) for its corresponding growth stages. The crop coefficient is 1.05 for the mid stage, and 0.90 for the end stage (FAO, 1999). Crop Evapotranspiration (ET_c) is determined by the crop coefficient approach whereby the effects of the various weather conditions are incorporated into the Reference Crop Evapotranspiration (ET_o) and the crop characteristics into the Kc coefficient (Allen et al, 1998). aSimply, the crop evapotranspiration (ET_c) is calculated by multiplying the reference crop evapotranspiration (ET_o), by a crop coefficient (Kc).

$$ET_c = K_c\, ET_o \tag{3.13}$$

Where:

ET_c = crop evapotranspiration, mm / day

K_c = crop coefficient (dimensionless)

ET_o = reference crop evapotranspiration, mm / day.

Experimentation

Table 3.5 Summary of Data Gathered Daily

Date	**Time**					**Water Used (L)**		
		Temperature	**Humidity**	**Radiation**	**Wind speed**	**100%**	**75%**	**50%**
Total Water Used								

Table 3.5 shows the daily data summary for the system. It shows the temperature, humidity, radiation and wind speed used by the system to calculate the Reference Crop Evapotranspiration (ET_o). The table also shows the water used for each rows of plants with different amount of water following the deficit irrigation watering strategy.

Effects of Deficit Irrigation Treatment in Plant Growth

In this experiment, the factors that determine plant growth are considered. This includes the height of the plant. These are measured per week

Table 3.6 Increase of Plant Height in weekly basis (watered with 100% ET_c)

Week	Height (cm)					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average Per Week
1						
2						
3						
4						
n						

Table 3.6 shows the increase of height of the plant per week on the row of Solanum Melongena that is fully watered with its daily water requirement. It means that the plant is watered with 100% daily water requirement.

Table 3.7 Increase of Plant Height in weekly basis (watered with 75% ET_c)

Week	Height (cm)					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Average Per Week
1						
2						
3						
4						
n						

Table 3.7 shows the increase in height of the plant per week on the row of Solanum Melongena with a 25% deficit irrigation. This means that the plants are watered with only 75% of the daily water requirement.

Table 3.8 Increase of Plant Height in weekly basis (watered with 50% ET_c)

Week	**Height (cm)**					
	Plant 1	**Plant 2**	**Plant 3**	**Plant 4**	**Plant 5**	**Average Per Week**
1						
2						
3						
4						
n						

Table 3.8 shows the increase of plant height per week on the row of Solanum Melongena with its half daily water requirement. This means that the plants are watered with only 50% of the daily water requirement.

Statistical Analysis of Plant Height

The growth of the plants watered with 100% ET_c will be compared to the plants watered with only 75% ETc and 50% ET_c. The proposed hypothesis is that with or without application of deficit irrigation (H_O: $\mu1 = \mu2$) the Solanum Melongena will have no significant difference in terms of plant height. The alternative hypothesis is that there is a significant difference in terms of plant height (H_A: $\mu1 \neq \mu2$). A two sample T-test will be used to compare the deficit irrigation applications. There will be a comparison in terms of the growth between plants being watered with 100% ET_c and 75% ET_c. There will also be a comparison between plants being watered with 100% ET_c and 50% ET_c.

Table 3.9 Number of Fruit Yield of Solanum Melongena

Date	Number of Bearings		
	100% Etc	**75% Etc**	**50% ETc**

Tables 3.9 shows the number of fruit yields of Solanum Melongena for the plants watered with 100% ET_c, 75% ET_c and 50% ET_c application of deficit irrigation scheme.

Statistical Analysis of Plant Fruit Yield

The growth of the plants watered with 100% ET_c will be compared to the plants watered with only 75% ETc and 50% ET_c. The proposed hypothesis is that with or without application of deficit irrigation (H_O: μ1 = μ2) the Solanum Melongena will have no significant difference in terms of plant fruit yield. The alternative hypothesis is that there is a significant difference in terms of fruit yield (H_A: μ1 ≠ μ2). A two sample T-test will be used to compare the deficit irrigation applications. There will be a comparison in terms of the growth between plants being watered with 100% ET_c and 75% ET_c. There will also be a comparison between plants being watered with 100% ET_c and 50% ET_c.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{3.14}$$

Where:

t = t-value

$\bar{X}_1$ and $\bar{X}_2$ = sample means of two sets

s^2 = sample variance

n_1 and n_1 = sample sizes

The calculated t-value is then compared to the critical t-value of 0.05 from the t-distribution table. If the calculated t-value is less than the critical t-value 0.05, the researchers reject the null hypothesis and therefore conclude that there is a significant difference with the measured values of plant watered with full water and the plant watered with less water. If the calculated t-value is greater than the critical t-value 0.05, the researchers do not reject the null hypothesis and therefore conclude that there is no significant difference with the measured values of plant watered with full water and the plant watered with less water. The values considered in the treatment will be the plant height and the crop yield of Solanum Melongena.

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