



UNIVERSITI PUTRA MALAYSIA

***IMAGE-BASED LEAF ANALYSIS FOR DETECTION OF SOIL WATER
STATUS IN SWEET CORN PRODUCTION***

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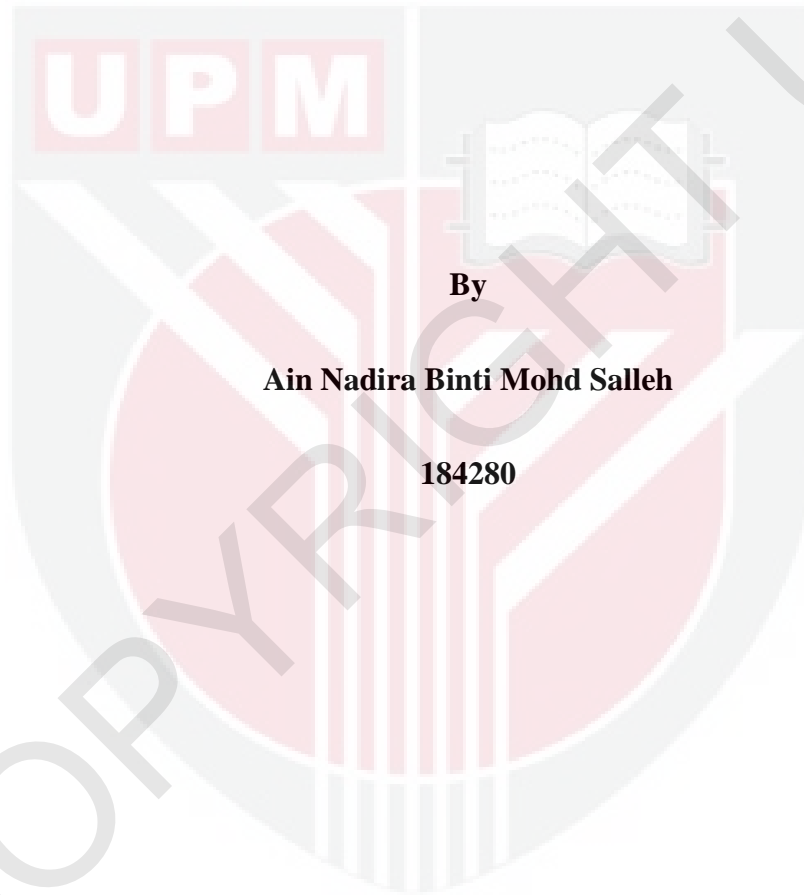
BACHELOR OF ENGINEERING
(AGRICULTURAL & BIOSYSTEM)

FACULTY OF ENGINEERING
UNIVERSITI PUTRA MALAYSIA

SERDANG, SELANGOR

2018/2019

**Image-based Leaf Analysis for Detection of Soil Water status in Sweet
Corn Production**



By

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Report submitted to the Faculty of Engineering, Universiti Putra Malaysia,

In fulfillment of requirement for the Bachelor of Engineering

(Agricultural and Biosystem)

July 2019

APPROVAL SHEET

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ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my research supervisor Dr. Rowshon Md Kamal for his valuable and patient guidance, enthusiastic encouragement and useful critiques during planning and development of this research work. His willingness to give his time generously has been very much appreciated.

I would also thank to Mr. Mazhar Iqbal, the Ph.D. student who has assist me in doing my research. Not forgotten to the staff of MARDI, Serdang who gave me the opportunity to take the sample on their sweet corn field.

I would like to extend my thanks to my supportive classmate who has always ready to give me a hand especially to Aimi Amira Binti Ab Halim. Thank you for the help, courage and strength that help me to cope with the tough weeks. Last but not least, I wish to thank to my parents and family for their support, love and non-stop encouragement throughout my research work. Thank you.

ABSTRACT

The detection of water stress in the plant is very important in agricultural production. The field capacity (FC) and permanent wilting point (PWP) which are important in irrigation scheduling can be estimated by some of the soil physical especially moisture content and chemical properties. Leaf physiological method and distillation method also can be done in detecting the plant moisture content. But, these methods are practically destructive, tedious, and expensive because of the instrument and sensor, time-consuming and also need a longer time to analyze the data for any decision, which is unsuitable for real-time water status assessment. In this research, the soil moisture content (MC), soil water tension (SWT), and leaves image were collected using TDR 350, tensiometer, and Android camera respectively. A relation between MC and SWT is plotted and it gives a strong correlation which is $R^2=0.9636$. This was actually the conventional method that we have in doing the irrigation scheduling. Therefore, an alternative approach has been done by doing the relation between soil MC and Dark Green Colour Index (DGCI). In this approach, the same MC as the conventional approach has been used in plotting the relation. The DGCI value was extracted using an algorithm that was developed in the MATLAB. Results indicate that DGCI value has a strong correlation with soil MC with R^2 of 0.9417. So, it shows that this method also can be used to detect water stress in sweet corn plant and it is much more easier which is only by using the Android camera, which is a device almost everyone would have it.

ABSTRAK

Pengesanan terhadap kekurangan air pada tumbuhan amat penting dalam pengeluaran produk pertanian. *field capacity* (FC) dan *permanent wilting point* (PWP) yang merupakan sangat penting dalam menganggarkan penjadualan pengairan boleh dianggarkan dengan beberapa ciri fizikal dan kimia. Kaedah fisiologi daun dan kaedah penyulingan juga boleh dilakukan dalam mengesan kandungan kelembapan. Tetapi, kaedah ini secara praktikalnya mampu merosakkan tumbuhan, remeh, dan mahal kerana instrumen dan sensornya, memakan masa dan juga memerlukan masa yang agak lama untuk menganalisis data untuk sebarang keputusan dilakukan, dimana ianya tidak sesuai untuk penilaian status air sebenar. Dalam kajian ini, kandungan kelembapan pokok (MC), ketegangan air tanah (SWT), dan gambar daun diambil menggunakan TDR 350, tensiometer, dan kamera telefon pintar masing-masing. Hubungan antara MC dan SWT telah diplotkan dan memberikan korelasi yang kukuh iaitu pada $R^2=0.9636$. Ini merupakan teknik konvensional. Oleh itu, pendekatan alternatif diambil iaitu dengan mengadakan hubungan antara MC dan *Dark Green Colour Index* (DGCI). Untuk pendekatan ini, MC yang sama seperti teknik konvensional telah digunakan. Nilai DGCI dianalisis menggunakan MATLAB. Hasil menunjukkan korelasi yang kukuh antara nilai DGCI dan MC iaitu pada $R^2=0.9417$. Oleh itu, ia membuktikan bahawa kaedah ini boleh digunakan untuk mengesan kekurangan air pada pokok jagung dan ianya lebih mudah iaitu dengan hanya menggunakan kamera Android, iaitu peranti yang hampir dimiliki oleh semua orang.

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LIST OF ABBREVIATIONS

MC	Moisture Content
SWT	Soil Water Tension
DGCI	Dark Green Colour Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-red
RGB	Red, Green, and Blue
HSI	Hue, Saturation, and Intensity
R ²	Coefficient of determination
FC	Field Capacity
AW	Available Water
PWP	Permanent Wilting Point

CHAPTER 1

INTRODUCTION

1.1 Overview

Water is vitally important for plants, which means it could be a factor that could affect the growth and development of a crop. The physiological and morphological structure of plants will get affected because of the deficiency of water. These will ultimately influence the quality, growth, and yield of the plants. In other word, this main environmental limitation that unfavorably affects crop production around the world is called as water stress. The sweet corn plant is very sensitive to water stress. Therefore, it is very crucial to have early detection of water stress on the sweet corn plant.

A lot of methods which are highly accurate to detect the plant moisture such as leaf physiological method and distillation method. There is also a way which is by knowing the daily soil moisture then it has to be analyzed with the plant moisture. But, this method is liable to the installation area, where it might won't represent spatial plant fluctuation for the entire field. Basically, these methods are practically destructive, tedious, and expensive because of the instrument and sensor, time-consuming and also

need a longer time to analyze the data for any decision, which is unsuitable for real-time water status assessment.

The leaf's reflectance characteristics will get affected, instead of the chemical properties and physiology, when there is water stress in the sweet corn plant. It can also change the structure of the leaves, including decreased cell turgor and cell structure. These can be distinguished with near infra-red (NIR) region. The structure of the canopy can change where there are changes in leaf angle such as the leaves is folding. Besides, water stress can also influence the spectral reflectance in the shortwave infrared region with strong absorption bands. Therefore, due to the strong absorption of moisture in the infrared band, a non-destructively method can be used to detect the water stress for the maize plant as it will be detected by the spectrometer.

In this study, we are going to develop a technique to detect the water stress in sweet corn plant non-destructively and faster. The technique is only by having the image of the sweet corn plant, we can already detect the water stress of it. For this purpose, the images of the sweet corn plant were collected from the field and also the daily soil moisture.

1.2 Problem Statements

Early water stress detection is incredibly important for proper irrigation scheduling and crop production. Proper recommendation of irrigation demand and scheduling is not only time consuming, tedious and expensive, but also takes a long time for data analysis and real-time decision making. Zhung et al., (2017) stated that the latest imaging

technique is carried out in detecting the early signs of crop water deficiency, which allow non-destructive and fast phenotyping in plants.

1.3 Aim and Objective

To develop a cost-effective and faster technique for determining the water stress of sweet corn based on the leaf-based image analysis and experimental field data.

These are the specific objectives:

1. To determine the relationship between soil moisture content (MC) and soil water tension (SWT) in the sweet corn field.
2. To determine the Dark Green Colour Index (DGCI) of sweet corn leaf using MATLAB code.
3. To derive the relationship between DGCI and MC to determine when to irrigate the crop.

1.4 Scope and Limitation

This study only focuses on finding the relationship between the DGCI value and soil MC of sweet corn plant using an Android camera and TDR 350 respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Stress in Sweet Corn Plant

When there is limiting of water supply to plant's roots and also intense of transpiration rate, plants will experience water stress. Water deficit, high soil salinity or drought would usually contribute to this situation. 'Physiological drought' is where the water does exist in the soil solution, but it couldn't be uptake by the plant. This condition usually occur when there is high soil salinity and when there are flooding and low soil temperature condition (S. Lisar et al., 2012). Therefore, the main environmental restraint that will untimely affect the production of agricultural crop around the world is water stress (Zhung et al., 2017).

Under the limiting soil moisture conditions, hydraulic and chemical signals are transmitted to the plant leaf through xylem pathways (Limpus, 2009). These would lead to the closure of stomatal and there would be a reduction of photosynthesis rate which called as physiological responses. Wang et al. (2015) evaluated that crop that is under

water stress would reduce the evapotranspiration rate, and another symptom such as stunted growth, leaf area reduction, and leaf wilting can be seen. It would also affect the nutritional development and the physiological of crops, where these could lead to decreased of biomass, quality of crops, and the yield production (Zhang et al., 2017a, 2017b; Madramootoo and Aladenola, 2014; Rossini et al., 2013;).

Crop water status would give a measure to a crop to the combined effects of soil evaporative demand, moisture availability, uptake capacity of the plant-root interface, and internal hydraulic resistance. Crop response towards water stress would rely on the conditions of the environment and also crop evapotranspiration needs. Soil moisture deficit which are from evapotranspiration losses must be replenished by irrigation (Ihuoma and Madramootoo, 2017). As defined by FAO-56, the irrigation water requirement for the well-watered crop is when the soil is under no limiting condition, the water loss through evapotranspiration of a disease-free crop (Allen et al., 1998). Having the measure of plant water status is very crucial for a better understanding of plant's adaptation towards water stress, the plant's response mechanism, and also for the crop production optimization through precision irrigation (Osakabe et al., 2014).

Sweet corn is very sensitive to water stress. Drought stress at different stages will give a big impact on the reproductive and vegetative growth of the sweet corn. Water stress would cause the decreasing of leaf area, leaf extension rate, leaf number, and plant height, ultimately there would be a serious loss in the production of the crop. Therefore, it is very necessary to have a precise detection of crop water stress for irrigation strategies and sustainable agriculture. (Zhung et al., 2017).

2.2 Soil Water Tension (SWT)

Irrigation scheduling can be done through monitoring and managing the soil water tension (SWT). Shock and Wang (2010) explained the definition of SWT as the force needed by the plant roots in extracting the water from the soil. In another words, it is the amount of work per quantity that need to be done by the external forces in transferring the water reversibly and isothermally from the standard state to soil at the point under consideration.

The SWT measurement is much more useful if the soil is uniform over large geographic expanses. Many types of field instruments used to measure the SWT, either directly or indirectly. For example, it can be done using tensiometers, gypsum blocks, heat dissipation sensors, granular matrix sensors, psychrometers, and other devices. But, these method is time consuming, tedious, expensive, and also takes a long time for data analysis and real-time decision making (Zhung et al., 2017).

2.3 Soil Moisture Content (MC) Concept

Solid particles and pores are the elements that does consist in the soil. Air and water can fill the pores. In soil moisture, there are three conditions can describe the soil, which are saturated, field capacity (FC), and permanent wilting point (PWP).

Saturated refers to a condition where the pore is totally filled with water. This point does refer to the maximum water holding capacity of the soil. While, FC is the water held in the pores after the gravitational water has drained away. The water remain is adequately bonded with the soil that has no longer drain. Practically, the water will

not drain when MC is at or below the FC. The water remain is actually the available water (AW) for the plant.

Permanent wilting point (PWP) is where the moisture condition were severely restricts the absorption of water by the plant. Any water from the soil couldn't be extract by the plant. If the MC achieve this level, the plant will die and could not be recover back (Oliveira et al, 2015)

2.4 Technique Used for Detection of Water Stress in Maize Plant

One way to detect the water stress in the crop is by knowing the soil moisture using the soil moisture sensor. But, the result would only give field measurement that is subject to the installation location, which may not valid for spatial plant variability within the whole field. Another way is by using leaf physiological methods. It can be detected by leaf area analysis, leaf stomatal conductance measurements, or stem water potential, respectively. In most cases, these techniques are practically destructive, which is limited under controlled laboratory environment, where the process would consume a long time and is not suitable for real-time water status assessment (Zhung et al., 2017).

Zhung et al. (2017) stated that the latest imaging technique is carried out to detect early signs of crop water deficiency, which allow fast and non-destructive phenotyping in plants. Few examples for this method are fluorescence, thermography and multispectral imaging. The photosynthetic apparatus of leaves will get affected directly under the water stress condition, where there would be an increase in chlorophyll fluorescence. There was a new flash-lamp induced chlorophyll fluorescence

imaging system, but the detecting of early stress in plants before visual symptoms was constricted only to the leaf area (Zhung et al., 2017).

There is a significant negative linear correlation between an empirical crop water stress index (CWSI) and leaf water potential determined by O'shaughnessy et al. (2011) by using digital infrared thermography. Thermal imaging is also applicable for phenotyping to screen water stress-tolerant maize varieties. In assessing the drought tolerant genotypes, a non-destructive measurement could be done by infrared thermography. But, thermography cannot detect the presymptomatic change in temperature caused by different environmental conditions, compared with fluorescence imaging.

Analyzing image in terms of hyperspectral also could give a great value to measurement, where the picture can be taken using a hyperspectral camera. Normalized difference index (NDVI) and Red Edge NDVI are some indices calculated from spectral bands which are highly correlated to water stress (Sims and Gamon, 2002). There is also a method which combining the multispectral image to detect early water stress in plants. Airborne Multispectral Infrared and Visible Imaging Spectrometer (MIVIS) data could estimate the water content through the Empirical and radiative transfer models. Basically, these techniques are almost non-invasive, non-destructive and can be applied for automation in determining the water stress in the plant. There is an unsupervised classification approach, which is by using simplex volume maximization (SiVM) that was applied to hyperspectral data for early drought stress detection in cereals. By using image-based analysis, these machine learning algorithms could recognize crop patterns effectively (Zhung et al., 2017). As a consequence, a sensitive and specific technique to

detect early symptoms of water stress in the crop is much needed in gaining sustainable agriculture.

2.5 Colour Indices

2.5.1 Visible Band

2.5.1.1 RGB

RGB is a colour model which comes with red, green and blue that will be added together numerous ways produce a broad array of colour. Table 2.1 is the RGB values for 100% amplitude and 100% saturated colour bars. RGB is basically for sensing, images display, and representation in the electronic system.

Table 2.1: 100% RGB Colour Bar

	Nominal Range	White	Yellow	Cyan	Green	Magenta	Red	Blue	Black
R	0 - 255	255	255	0	0	255	255	0	0
G	0 - 255	255	255	255	255	0	0	0	0
B	0 - 255	255	0	255	0	255	0	255	0

2.5.1.2 HSI

HSI is also a type of colour model in terms of hue, saturation, and sand intensity. Hue (H) refers to the purity of the colour such as pure red, yellow, and green. Saturation (S) refers to the measure of the pure colour is diluted by white light. The intensity is the

grey level of the pixels in a monochromatic image which is black and white. HSI is the best colour model for image processing function such as convolution, equalization, histograms, that will be operated by the manipulation of brightness value since “I” is dependent on RGB (Salwani, 2014). Figure 2.1 shows the RGB and HSI image.

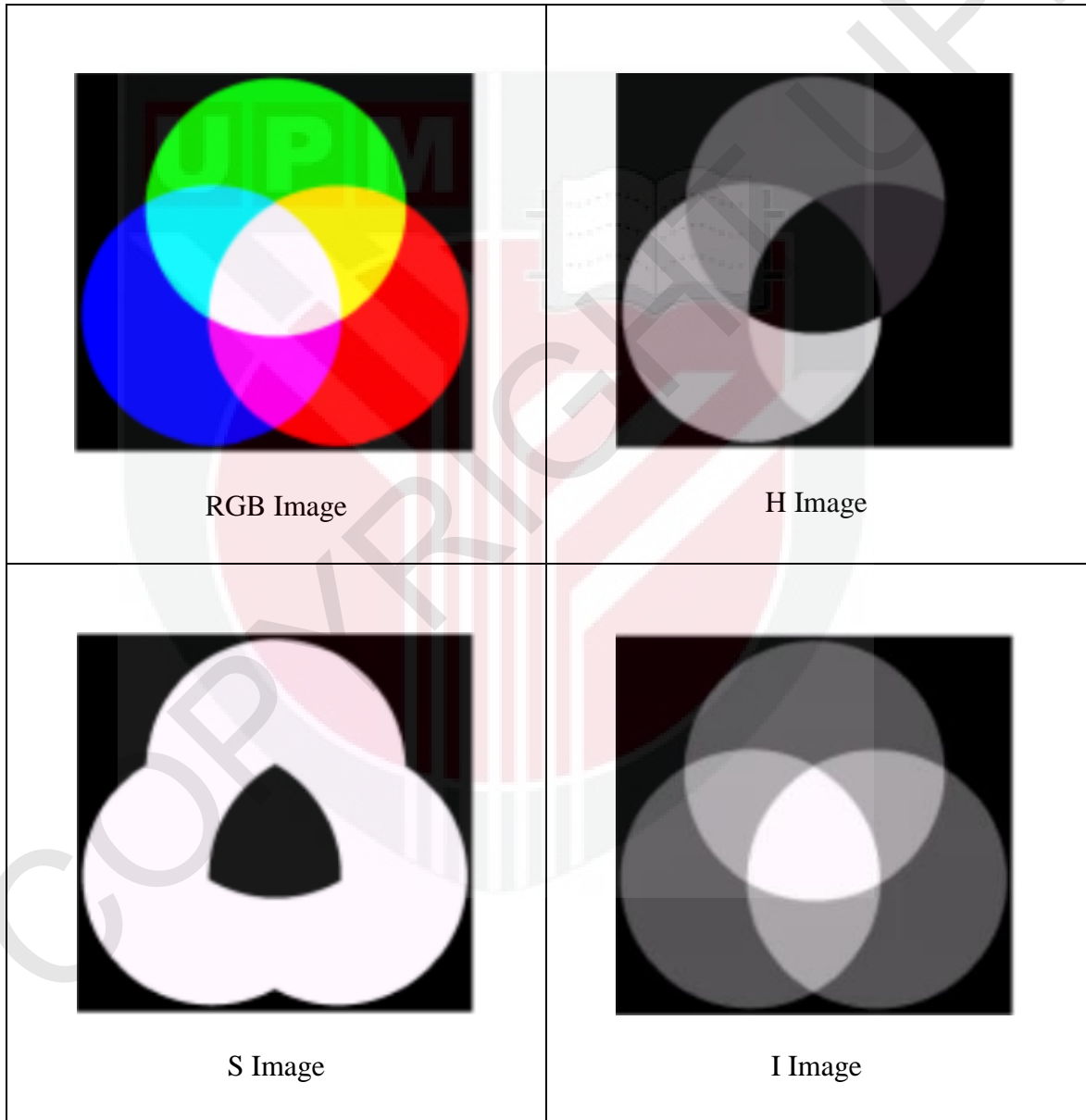


Figure 2.1: RGB and HSI Image

2.5.2 NIR Band

NIR is the small portion from infrared radiation (IR), which located between visible and microwave portions of the electromagnetic spectrum. NIR is in the wavelength of visible light which occupies the wavelength between (0.7 μm – 1.5 μm). Information that can be gained from NIR is crop stress, weed, and pest infections since NIR have a longer wavelength than visible light (Salwani, 2014). Therefore, the health of crop can be constantly monitored because of the wider range of reflectance between healthy and unhealthy crop within the NIR region.

2.5.3 Vegetation Indices

Water stress is one of the main reason for the loss in yield and quality. A crop that undergoes water stress will show the sign on their leaves that can be detected by the vegetation indices. Vegetation indices are widely used for the estimation of crop and vegetation variables by using visible and Near Infrared Regions (NIR) of the electromagnetic spectrum (Zulhaidi, 2004). Previously, vegetation indices based on a simple combination of visible and near-infrared reflectance, such as the normalized difference vegetation index (NDVI) and simple ration (SR) have been widely used by the community of remote sensing to monitor from space (Salwani, 2014).

2.5.3.1 Normalized Difference Vegetation Index (NDVI)

NDVI is a calculation according to several spectral bands of the photosynthetic output, which is the amount of green stuff in a pixel of the image. It calculates the amount of green vegetation in an area. For live green plant, it will absorb solar radiation in the photosynthetically active radiation (PAR) spectral region, which they use a source of energy in the process of photosynthesis (Larry, 1997). NDVI is calculated by using the formula below:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad (\text{Eqn. 1})$$

Red and NIR refer to the spectral reflectance measurement acquired in the red and near-infrared region respectively. NDVI varies between -0.1 and +1.0. For healthy vegetation, it will absorb most of the visible light that hits it, and a large portion of the NIR will be reflected. While unhealthy vegetation will reflect more visible light and less NIR. NDVI is related by many environmental factors such as topography and soil, which consist of soil fraction soil type and soil moisture. It also related to the atmospheric condition, vegetation association, rainfall, non-photosynthetic materials and others (Salwani, 2014).

2.5.3.2 Dark Green Colour Index (DGCI)

Another algorithm that can be used to analyse the vegetation greenness is by using DGCI. The result from the digital image that record spectral information of visible band

could give a high resolution image with a lower cost. The image will give 3 separated colour value which are Red, Green, and Blue value (RGB) (Prabowo, 2015).

Karcher and Richardson (2003) has proposed to make it simple the interpretation of the digital colour data by changing the RGB value into hue, saturation, and intensity (HSI) that is based on human interpretation. Before finding the HSI value, normalized red, green, and blue values must be calculated in terms of RGB. These can be done by using the formula:

$$r = \frac{R}{R + G + B}$$

$$g = \frac{G}{R + G + B}$$

$$b = \frac{B}{R + G + B}$$

$$r + g + b = 1$$

The R , G , and B can be simultaneous. Then, the HIS can be calculated as:

$$I = \frac{1}{3}(R + G + B)$$

$$S = 1 - \frac{3}{R + G + B} [\min(R, G, B)]$$

$$H = \cos^{-1} \left\{ \frac{\frac{1}{2} [(R - G) + (R - B)]}{[(R - G)^2 + (R - B)(G - B)]^{\frac{1}{2}}} \right\}$$

To find DGCI, the RGB values are converted into hue, saturation and intensity values using a method described by Karcher and Richardson (2003). DGCI is much more consistent compared to RGB in measuring the green colour of maize plant. But, Prabowo (2015) mention that many aspects can affect the performance of DGCI value such as camera quality, setting, and lighting. The DGCI value can be calculated by using the formula:

$$DGCI = [(H - 60)/60 + (1 - S) + (1 - I)]/3 \quad (\text{Eqn. 2})$$

The range of DGCI value will be from 0 (very yellow) to 1 (dark green).

CHAPTER 3

METHODOLOGY

Flowchart diagram shown in Figure 3.1 illustrates the step by step procedure for developing a leaf-based moisture content detection and for determining irrigation requirement in sweet corn production

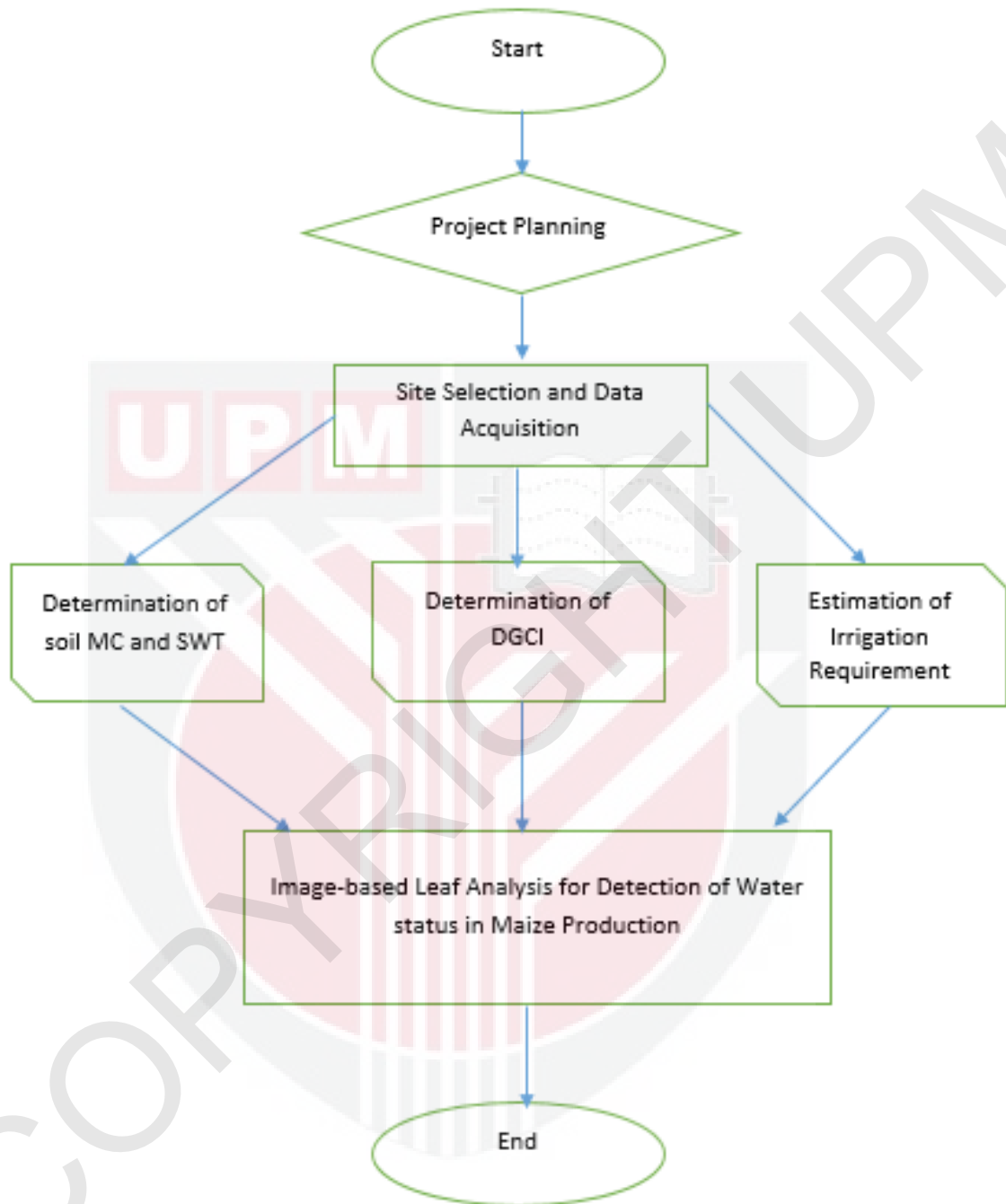


Figure 3.1: Step by step procedure for developing a leaf-based image irrigation requirement in sweet corn production

3.1 Study Area

The study was conducted at the MARDI Serdang, Selangor. The type of crop that has been planted and analyzed was sweet corn, *Zea mays* var. The type of soil here is dark and clay soil. The crop covered until 812m² which was divided into two subplots at 22m x 37m. The sweet corn has been planted in the early of September 2018 by the MARDI and was harvested in the middle of May. The data was collected on the early of October 2018 until in the middle of May. It was raining season during the data collection since it was at the end of the year, where Malaysia faced Northeast Monsoon from October to March. On this study, few samples of sweet corn were being studied, where the image of the leaves, soil moisture content, and the soil water tension was taken.



Figure 3.2: A typical view of a sweet corn experimental field at MARDI

3.2 Field Investigation of Soil

3.2.1 Moisture Content in Soil

The MC in soil was determined in terms of Volumetric Water Content (VWC) in percent. The daily MC was collected using a portable soil moisture sensor which is TDR 350 from FieldScout. The sensor checked the soil moisture to a depth of 12cm. The moisture determination was based on Standard VWC and Hi Clay VWC. The Standard mode is appropriate for most mineral soils, while High Clay mode is more accurate for soils with higher clay content (>27%). The image of leaves captured was at the same place where the soil moisture content is taken. The data was collected every day. Figure 3.3 shows the TDR 350 that has been used to collect the VWC data.



Figure 3.3: TDR 350



Figure 3.4: Taking the Soil MC

3.2.2 Soil Water Tension

The force needed for the plant's roots to gain water from the soil (to move water in the soil) is called as soil water tension (SWT). Usually, tension will be expressed in atmospheres, pascals, or bar. In this research, a tensiometer was used to determine the soil water tension. The SWT data is also collected everyday. It has been measured from the same point where the soil moisture content is taken. Figure 3.5 shows the tensiometer used to collect the SWT data.



Figure 3.5: Tensiometer for determining the tension in the field

3.3 To Determine the Dark Green Colour Index (DGCI)

3.3.1 Image Acquisition

The image of sweet corn leaves was taken by using the Android camera with 13 megapixels. The captured image of leaves was the crop where the VWC and SWT taken. This data was also taken daily. The time for the collected data was fixed at 11 am every day. Fixed timing can prevent the Android camera from being affected by the lighting while capturing the images.



Figure 3.6: The Sweet Corn Image Captured using Android

3.3.2 Image Analysis

An Android camera was used to acquire images. The acquired images were cropped and it has been analyzed. Each mean pixel value of its RGB was extracted using an algorithm that was developed using the MATLAB Software. The RGB value was also used to find the Hue (H), Saturation (S), Intensity (I) value. The value of DGCI is very important in this experiment, where it will become an indicator for irrigation scheduling. The coding is developed using MATLAB. DGCI is used instead of NDVI because NIR is needed in NDVI, yet NIR is not available in the smartphone. DGCI is calculated by using the formula:

$$DGCI \text{ value} = \frac{\left[\frac{H - 60}{60} + (1 - S) + (1 - I) \right]}{3}$$

Where,

$$H = \cos^{-1} \left(\frac{\frac{1}{2}(R - GG) + (R - B)}{[(R - G)^2 + (R - B)(G - B)]^{1/2}} \right)$$

$$S = 1 - \frac{3}{(R + G + B)} [\min(R, G, B)]$$

$$I = \frac{1}{3} (R + G + B)$$

3.4 Estimation in Irrigation Requirement using DGCI Application

The relationship between soil MC and DGCI value obtained from objective one and objective two respectively was derived. The relation between SWT and soil MC can be used to detect the Field Capacity (FC), Available Water (AW), and Permanent Wilting Point (PWP) where this could be as an indicator for irrigation scheduling. Therefore, the relation between the same soil MC and DGCI has indirectly indicated the FC point, AW point, and PWP point. By having these, the estimation in irrigation requirement using DGCI application is applied.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Conventional Approach for Irrigation Scheduling

Irrigation scheduling is very important in managing the crops to ensure an optimum yield is obtained. The irrigation must be definitely sufficient for the crops and must not be overwatering. Insufficient water could affect the plant while, overwatering can cause leaching. Therefore, irrigation scheduling is actually a process in particularizing the timing and duration of watering.

The conventional approach used for irrigation scheduling is by having the relationship between the soil MC and SWT. By having this relation, the field capacity, available water content, and permanent wilting point can be detected. These value would be an indicator to irrigate the plant.

4.1.1 Relationship between Soil MC and SWT

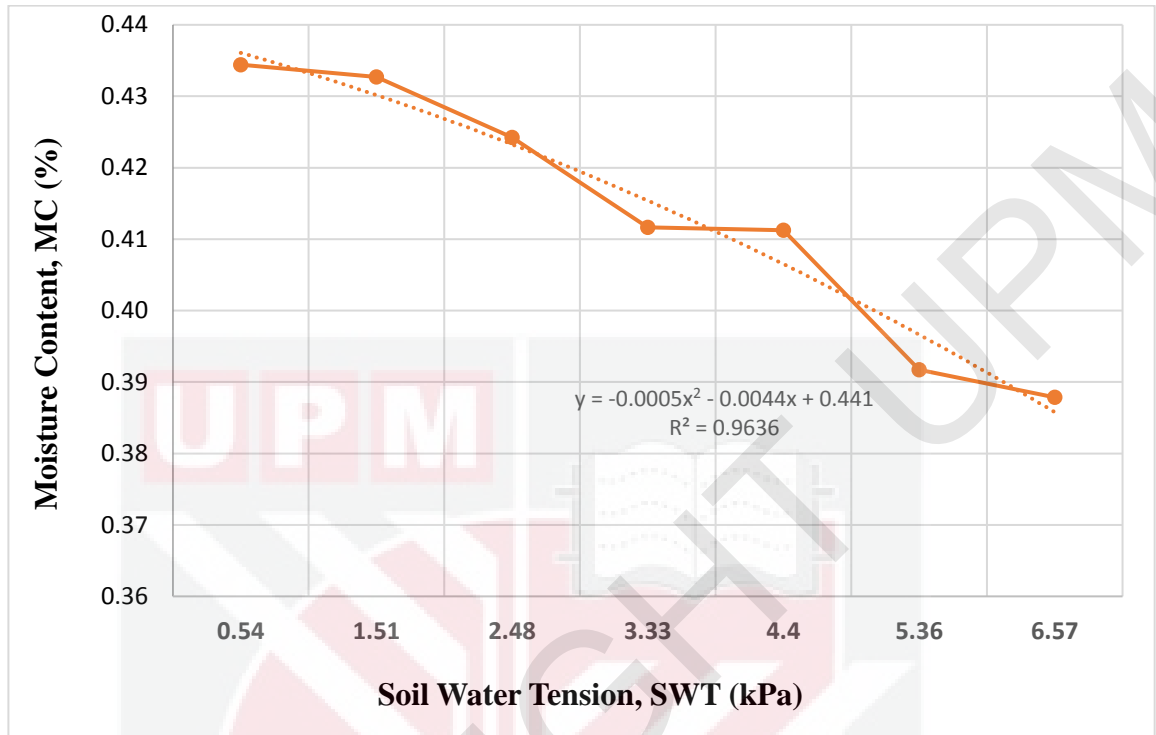


Figure 4.1: Relation between Soil Moisture Content and Soil Water Tension

The result from Figure 4.1 shows the relationship between soil MC and SWT. The horizontal axis represents SWT in kPa, while the vertical axis represents MC in percent. The result shows that MC and SWT has a strong correlation with the $R^2=0.9636$. This data is obtained from the clay type of soil. From the graph we can conclude that as the MC decreases, the SWT would increase.

Theoretically, FC is the amount of water held in the soil after the excess water (Gravitational Water) has been drained. Field capacity usually occurs at 1/10 atmosphere for coarse soil, while 1/3 atmosphere for heavy soil. PWP is a condition where the soil contains a very small amount of water, where it has caused the plant to become wilt and would not be able to recover back. This is because the root could not extract any water from the soil anymore. For PWP, it would usually occur at 1/15 atmosphere of tension. Lastly, Available Water (AW) is the amount of water content in the soil between the FC and PWP level. Figure 4.2 would give a clear vision upon this explanation.

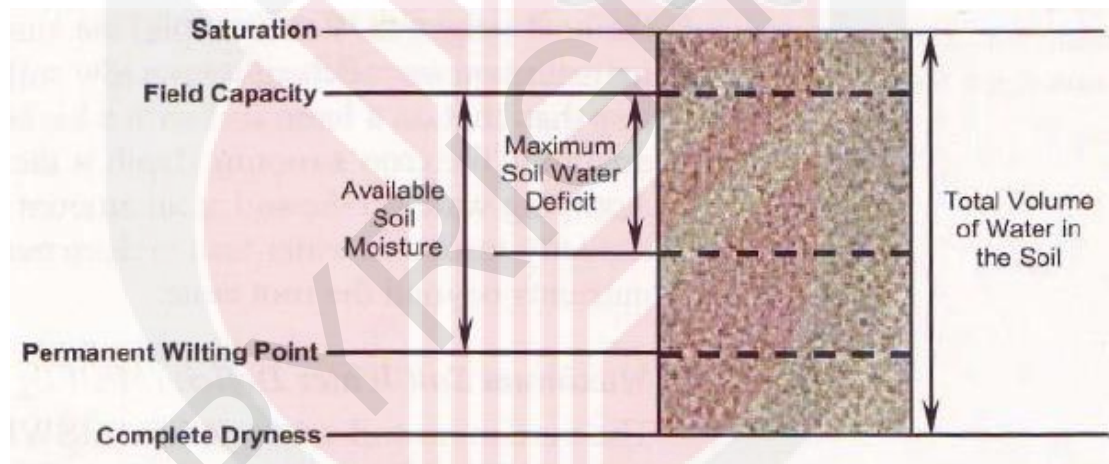


Figure 4.2: Water Level in Soil

But, the water level would be different for different texture and types of soil. Figure 4.3 and Table 3.1 shows the variations of moisture release curve and FC, AW, PWP value for different types of soils. The concept is just the same. So, the irrigation must be done after the FC point, but before the PWP point.

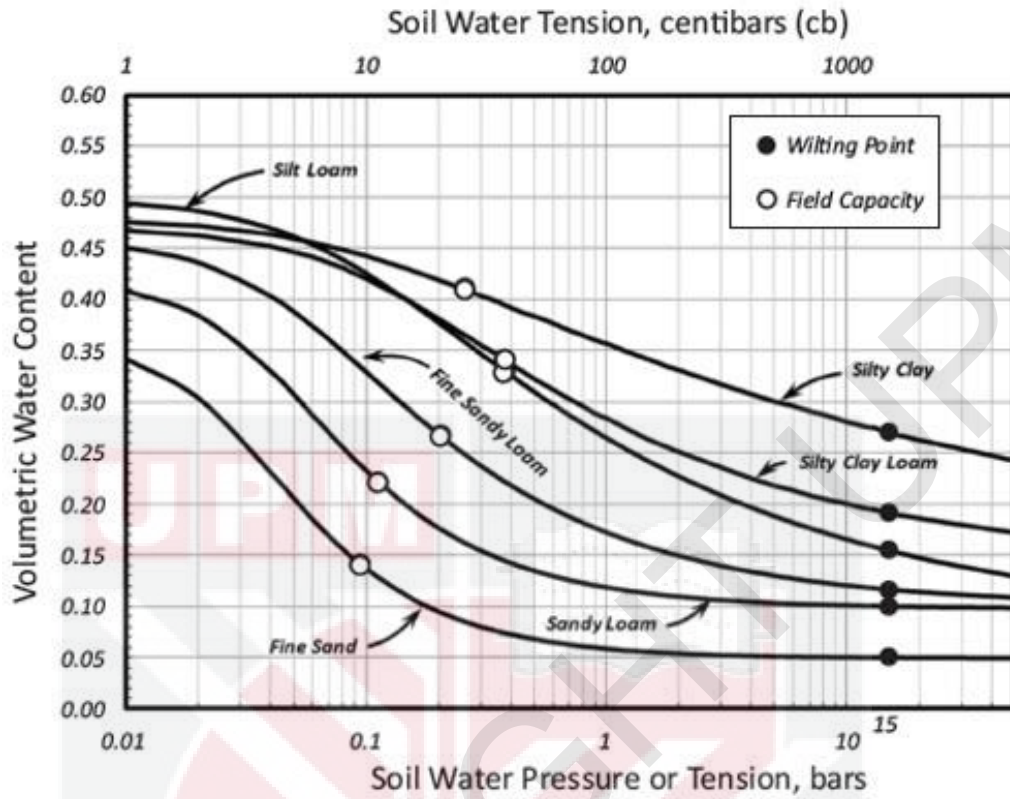


Figure 4.3: Moisture Release Curve for Different Types of Soil

Table 3.1: FC, PWP, and AW for different type soils, adapted from Keller and Bliesner
(1990)

Soil Type	Total Pore Space (%)	Moisture (% by weight)		Available Water (mm/m of soil)
		Field Capacity (%)	Permanent Wilting Point (%)	
		45	30	135
Clay	51-55	45	30	135
Clay Loam	47-51	40	25	120
Sandy Loam	40-47	28	18	120
Fine Sand	35-40	15	8	80
Sandy	32-42	8	4	55

Therefore, SWT is related to the stress experienced by the plant. The water needed by the plant has caused tension to the roots to extract more water from the soil. That is why irrigation schedule that is referred to the SWT can be related with the state of the plant. This method has required the users to have the tensiometer which is expensive and the approach also is quite tedious.

4.2 Modern Approach

4.2.1 Relationship between MC and DGCI Value

Figure 4.4 shows the relationship between MC and DGCI. The horizontal axis shows the DGCI value, while the vertical axis shows soil MC in the unit of %. There are two soil type modes in the TDR 350 that can be set on them. The Standard mode is appropriate for most mineral soils, while High Clay mode is more accurate for soils with higher clay content (>27%). The curve with the triangle legend shows for the High Clay mode, while the round legend refers to Standard mode. The same soil MC value as in the conventional method has been used in this method. From these curve, soil MC and DGCI value have a strong correlation for both in High Clay mode and Standard mode, with $R^2 = 0.8878$ and $R^2 = 0.9417$ respectively.

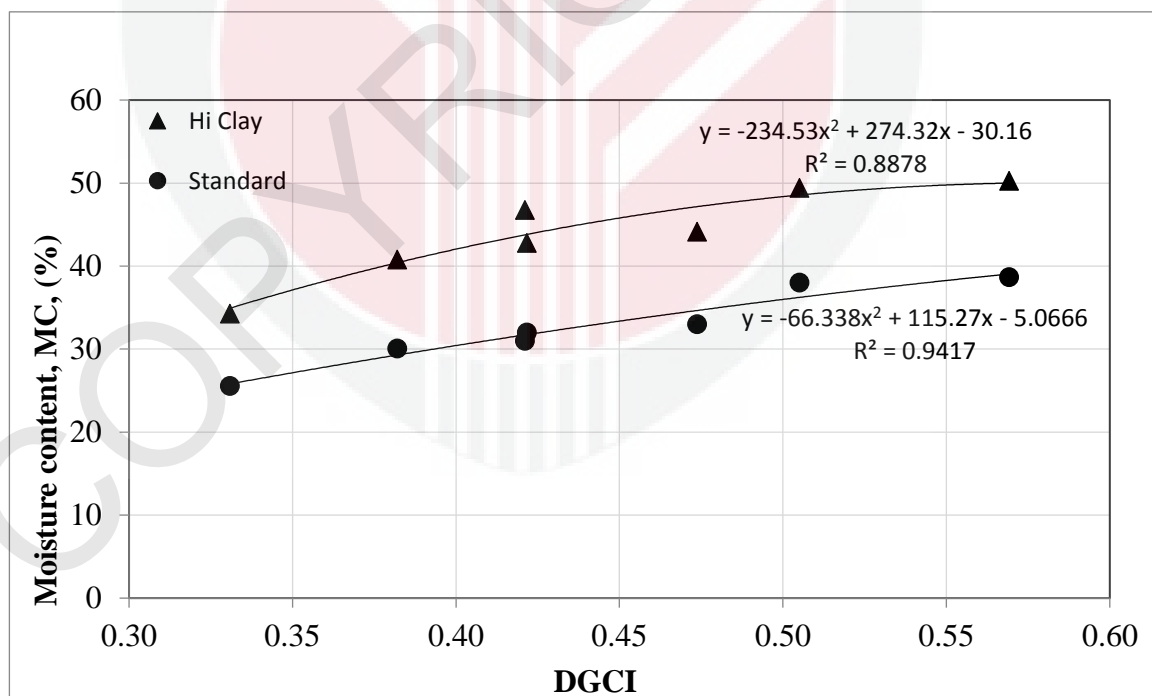


Figure 4.4: Relationship between MC and DGCI

From the graph plotted in Figure 4.4, we can conclude that the DGCI value increases as the soil MC increases. For this method, it was an alternative approach to replace the uses of the tensiometer. A camera from an Android is used in the data collection. Therefore, an analysis of images and soil moisture content is done in order to find the relation between them. The analysis is done to find the DGCI value that has been build the algorithm in the MATLAB. In this research, DGCI is used instead of NDVI. This is because NDVI require the value of NIR in its formula, where the Android camera doesn't have it. Therefore, DGCI is used since this formula didn't require the NIR value.

4.2.2 Daily DGCI Value

Result shown in Figure 4.5 shows the daily DGCI value. The value is quite fluctuating since it depends on the weather condition, if there is raining or did the crop just being irrigated. If the crop just being watered, then the DGCI value would be increased.

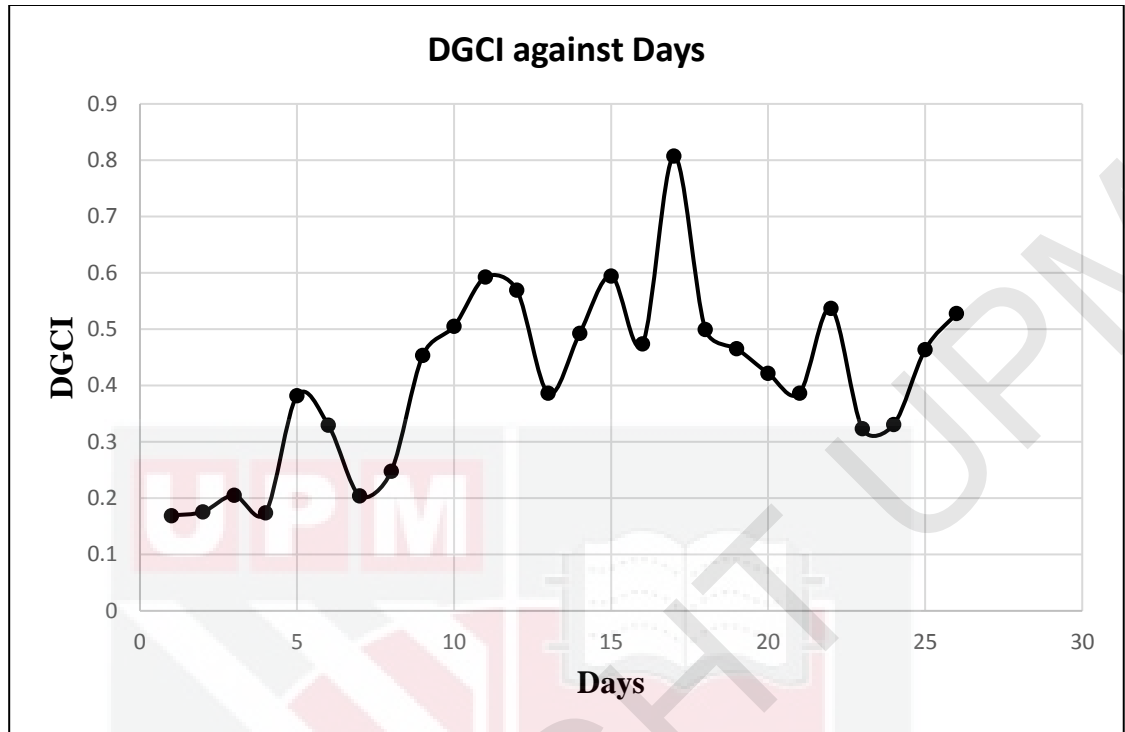


Figure 4.5: Daily Dark Green Colour Index (DGCI)

In this experiment, there is no specific water treatment condition prepared for the sample. The sweet corn plant itself didn't have any specific schedule for its irrigation. Therefore, an accurate data for this condition can't be prepared. But, from this graph, we can conclude that there are changes in the daily DGCI value, where it does relate to the soil condition and indirectly with the sweet corn plant's water status.

Table 4.1: Daily DGCI value

Day	DGCI
1	0.1692
2	0.1758
3	0.2051
4	0.1742
5	0.382
6	0.3295
7	0.2039
8	0.2477
9	0.4533
10	0.5051
11	0.5927
12	0.5692
13	0.3863
14	0.4926
15	0.5945
16	0.4738
17	0.8076
18	0.4995
19	0.4657
20	0.4217
21	0.3867
22	0.5373
23	0.3234
24	0.3308
25	0.4638
26	0.5278

4.3 Decision Making for Irrigation Scheduling

From the MC and SWT graph, the FC and PWP point can be determined. The irrigation needs to be done when the water level is in between these two points. Usually, the irrigation will be done when the moisture content is at 50%-60%. But, it still depends on the decision making made by the farmers and the interval and the evapotranspiration rate (ET_o) of the plant.

So, the presence of DGCI can give an alternative approach to the uses of tensiometer. The value of moisture content can be obtained from the DGCI value of the leaf. The irrigation scheduling would be related with the Net Irrigation Requirement (NIR) and Maximum Allowed Depletion (MAD). Therefore, DGCI value can be the indicator in this irrigation scheduling.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

All objectives of this project have been achieved successfully. The first objective was to determine the relationship between soil MC and SWT. Soil MC and SWT gives a strong correlation at $R^2=0.9636$. The SWT can give an indicator on when to irrigate (timing) and also the frequency for watering the plants. As we all know, the use of tensiometer is a conventional method in irrigation scheduling, where it is costly and tedious.

The second objective is to determine the DGCI value. The DGCI value was managed to be obtained from the captured image of corn leaves. The DGCI value is extracted from the image by using an algorithm that has been developed in the MATLAB. The DGCI value is important for the third objective purpose.

The third objective was to determine the critical MC to know when to irrigate using the DGCI approach. For this objective, a relation between soil MC and DGCI value has been done. The result showed a strong correlation between them at $R^2=0.9417$. By having this relation, the FC, AW, and PWP value which are the important

parameters in determining irrigation scheduling can be determined. Instead of detecting them using tensiometer, these value can be determined only by using an Android camera (image analysis). This method has led to the development of non-destructive, simpler, cheaper, and faster way to detect the water status of plant and also in irrigation scheduling.

5.2 Recommendation

It was suggested to capture the leaves image at many parts or angle. This is to ensure to have an accurate data, since every angle of capturing the image will give different input and lighting. Furthermore, it would be better if the soil condition can be controlled. These can be done by providing three conditions of water treatment: (a) well-watered treatment, (b) reduced watered treatment, and (c) drought stressed water treatment.

In the future, this method can be proceed with the development of application for detecting water status in the cell phone. By having this, everyone can download and use it. Indirectly, it could help the farmers or the users in monitoring their plant water status and also helps in their irrigation scheduling. In this research, the camera used is an Android camera. Means, this method would be applicable since almost everyone would have cell phone with an Android camera. For example, the farmers just only need to download the application and just capture the image of their crops to know the water status of their plant.

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APPENDIX

Appendix MATLAB Code for the extraction of DGCI value

```
%Read in image
img = imread('3.png');

% RGB color space
R = img(:,:,1);
G = img(:,:,2);
B = img(:,:,3);

MaxR = max (R(:));
MaxG = max (G(:));
MaxB = max (B(:));

MinR = min (R(:));
MinG = min (G(:));
MinB = min (B(:));

%Calculate mean of RGB
meanR = mean(R(:));
meanG = mean(G(:));
meanB = mean(B(:));

%Calculate SD of RGB
stdR = std2(R);
stdG = std2(G);
stdB = std2(B);

% %Accessing Pixel Values of RGB Image
% red_value = img(966,1288,1);
% green_value = img(966,1288,2);
% blue_value = img(966,1288,3);

% %Pixel info
% imshow (img);
% impixelinfo;
```

```

% size (img);

% %Converting RGB to HSI color spaces
% hsimg = rgb2hsi (img);
% figure (2), imshow (hsimg), title ('RGB to HSI');
%
% %Calculate mean of HSI
% H = hsimg(:, :, 1);
% S = hsimg(:, :, 2);
% I = hsimg(:, :, 3);
% meanH = mean(H(:));
% meanS = mean(S(:));
% meanI = mean(I(:));
%
% sprintf('Mean value of the hue, saturation and intensity is %d, %d,
%d', meanH, meanS, meanI)
%
% %Accessing Pixel Values of HSI Image
%
% hue_value = hsimg(966,1288,1);
% saturation_value = hsimg(966,1288,2);
% Intensity_value = hsimg(966,1288,3);
% sprintf('Value of the hue, saturation and intensity pixel is %d, %d,
%d', hue_value, saturation_value, Intensity_value)
%
% %Pixel info
%
% imshow (hsimg);
% impixelinfo;
% size (hsimg);

%Calculate Hue
maxRGB = meanG;
minRGB = meanB;
num = meanB - meanR;
% num2 = meanG - meanB;
denom = maxRGB-minRGB;
C = num/denom;
% C2 = num2/denom;
H = 60*(2+C);
% H2 = 60*C2;

```

```

%Calculate Saturation
S = denom/maxRGB;

%Calculate Brighthness
B = maxRGB/255;

%Calculate GMR
GMR = meanG - meanR;

%Calculate GDR
GDR = meanG/meanR;

%Calculate VI
VI = GMR/(meanG+meanR);

%Calculate DCGI
M = (H/60)-1;
DCGI = (M + (1-S) + (1-B))/3;

%Calculate NRI
NRI = (meanR/(meanR+meanG+meanB));

%Calculate NGI
NGI = (meanG/(meanR+meanG+meanB));

%Calculate YCbCr color spaces
Y = (0.257*meanR) + (0.504*meanG) + (0.098*meanB) +16;
Cb = ((-0.148*meanR) - (0.291*meanG) + (0.439*meanB) + 128);
Cr = (0.439*meanR) - (0.368*meanG) - (0.071*meanB) +128;

%// Concatenate data
A = [meanR; meanG; meanB; H; S; B; GMR; GDR; VI; DCGI; NRI; NGI; Y; Cb;
Cr];

%Open file to write
fileID = fopen('3.txt','w');

```

```

// Select format for text and numbers

fprintf(fileID, 'Max value of the red, green and blue is %d, %d, %d
\n', MaxR, MaxG, MaxB);
fprintf(fileID, 'Min value of the red, green and blue is %d, %d, %d
\n', MinR, MinG, MinB);
fprintf(fileID, 'Mean value of the red, green and blue are %.4f, %.4f,
%.4f \n', meanR, meanG, meanB);
fprintf(fileID, 'SD value of the red, green and blue are %.4f, %.4f,
%.4f \n', stdR, stdG, stdB);

% fprintf(fileID, 'Value of the red, green and blue pixel is %d, %d,
%d\n', red_value, green_value, blue_value);
fprintf(fileID, '%6s %6s %6s %6s %6s %6s %6s %6s %6s %6s %6s %6s %6s
%6s %6s %6s\n', 'meanR', 'meanG', 'meanB', 'H', 'S', 'B',
'GMR', 'GDR', 'VI', 'DCGI', 'NRI', 'NGI', 'Y', 'Cb',
'Cr');
fprintf(fileID, '%.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f
\t %.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f \t %.4f
\t %.4f \t %.4f \t %.4f\t %.4f\t %.4f\t %.4f\n',A);

fclose (fileID);
type ('3.txt');

```