ESTIMATION OF CASSAVA WATER REQUIREMENTS BY USING GEOSPATIAL DATA IN CHON BURI, THAILAND

CHANAPORN JANTAH

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE MASTER DEGREE OF SCIENCE
IN GEOINFORMATICS
FACULTY OF GEOINFORMATICS
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2022

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The Thesis of Chanaporn Jantah has been approved by the examining committee to be partial fulfillment of the requirements for the Master Degree of Science in Geoinformatics of Burapha University

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KEYWORDS: Crop Evapotranspiration, Crop coefficient, Reference crop evapotranspiration, Penman-Monteith, Geospatial data; Cassava

CHANAPORN JANTAH : ESTIMATION OF CASSAVA WATER REQUIREMENTS BY USING GEOSPATIAL DATA IN CHON BURI, THAILAND. ADVISORY COMMITTEE: XIAOLING CHEN, Ph.D., JIANZHONG LU, Ph.D. PHATTRAPORN SOYTONG, Ph.D. 2022.

Water is one of the most important factors in agriculture. Moreover, the plants have different water requirements depending on their species, climate, and soil condition. In this research, the estimation of the water requirement of cassava was from application of remote sensing by satellite image cassava cultivation areas in Bang Lamung District, Chon Buri Province, Thailand. To study the best correlation between vegetation indices obtained from Sentinel-2 satellite image and crop coefficients referenced by the Royal Irrigation Department (RID), with linear regression analysis. In addition, to calculate cassava evapotranspiration by the Penman-Monteith method. The vegetation indices are Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Soil-Adjusted Vegetation Index (SAVI), and Normalized Difference Red Edge index (NDRE) were evaluated in this study. The results showed that the vegetation index has correlated with the crop coefficient (Kc) of cassava as referenced by RID, divided into critical periods of crop water requirement for cassava according to the equation, the age range of 1-6 months (R2 = 0.82) is obtained from the equation Kc = -011 + (0.94*SAVI) and 7-12 months (R2 = 0.98) is obtained from the equation Kc = -3.21 + (-3.24*GNDVI) + (-3.16*NDVI) + (11.94*SAVI). The comparison of crop evapotranspiration estimated using Kc predicted from the vegetation index with ET calculated by using Kc referenced from the RID. Where crop evapotranspiration was calculated using crop coefficient from Kc predicted and was found to be 26.08 mm/day while the crop evapotranspiration value of cassava calculated using crop coefficient referenced by the Royal Irrigation Department was 25.81 mm./day. As a result, the estimated values were quite near to the real values with a Root Mean Square Error of 0.15 indicated that were of significant and reliable correlates.

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Chanaporn Jantah

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LIST OF ACRONYMS AND ABBREVIATIONS

CWR	Crop water requirements
ET	Crop Evapotranspiration
ETo	Reference evapotranspiration
Kc	Crop coefficient
SVIs	Spectral Vegetation Indices
NIR	Near-Infrared wavelength
Red	Red spectral bands
Green	Green wavelength
RedEdge	RedEdge wavelength
NDVI	Normalized Difference vegetation Index
GNDVI	Green Normalized Difference Vegetation Index
SAVI	Soil-Adjusted Vegetation Index
NDRE	Normalized Difference Red Edge index
PET	Potential Evapotranspiration
R^2	Coefficient of determination
RMSE	Root mean square error
RID	Royal Irrigation Department

CHAPTER 1
INTRODUCTION

Background and Problem Statement

The Eastern region of Thailand has become more economic importance as a newly developed area. There is an expansion of several sectors, including traveling, agricultural and industrial sectors from the capital city. Recently, the government has launched a flagship project called Eastern Economic Corridor (EEC) in 3 provinces, which are Chachoengsao, Chon Buri, and Rayong (Soytong, Janchidfa, Phengphit, & Chayhard, 2018). This mega project is starting to promote emerging markets and investment in these are which will contribute to the rapid growth of the population. As a result, an increase in water demand in all sectors in near future. In 2037 or 15 years from now, when this area is fully developed, water demand could increase as much as 1000 million m3 per year. A water shortage crisis might occur as well as conflicts between the manufacturing sectors and the agricultural sector (Water Spread Head, 2020).

One of the most crucial variables in agricultural production is water. In normal conditions, when plants receive adequate water, sufficient nutrients, proper soil, and climate condition, they can effectively grow by photosynthesis to produce and collect nutrients. Therefore, a plant must receive the proper amount of water in each growing stage. The cultivation which depends mainly on seasonal rainfall poses a risk of lack of water. For example, when a long period of discontinuous rain, the plant is severely deprived of water and unable to survive. Or excessive rainfall leads to flooding in the cultivated area they cannot maintain normal root conditions because of the flow rate of oxygen exchange. Therefore, water management based on good irrigation is important for plant cultivation. This includes enriching soil moisture for crop requirements as well as providing and transporting water depending on the suitability of each species of the plant (Chiemchaisri, 2007).

Cassava is one of the major plants which are economically important. As one of the top exporting counties in Asia, Thailand has a cultivation area of 8.9 million rai and produces 20.9 million tons of cassava. It is widely cultivated in many areas of Thailand because of several advantages. First, it does not depend on the seasonal and can be planted throughout the year. Second, it does not sensitive to drought conditions compared to other types of plants. Third, can grow in soil with low fertility. Finally, can be harvested all year as a convenience and sold at a reasonable price. However, growth and production rates may decrease over time, particularly during long periods of drought. Thus, the availability of water during periods of rainfall depletion would ensure optimum growth, improve disease tolerance, and continuous starch collection at the root (Pipatsitee, Prasertkul, et al., 2018), (Pipatsitee, Eiumnoh, et al., 2018). Chonburi Province is located in the Eastern Economic Corridor (EEC). The cultivated cassava in several area provinces. According to the Office of Agricultural Economics, in 2017-2020 Bang Lamung, Chonburi Province consisted of 37,008 rai 35,462 rai 33,872, and 34,609 rai of cassava, respectively (Office of Agriculural Economics, 2021). Furthermore, the provincial development plan for 2018-2022 (revised 2020) stated that one of the most important area-based requirements is the issue of water resource management, which are insufficient water for the expansion of each sector, such as the industrial, travel, and agricultural sectors. Therefore, estimating water requirements based on plant species is critical for water resource management in agricultural areas.

To estimate crop water requirement, traditionally, it is necessary to survey and collect data in the field by the direct method using the specialized equipment called "Lysimeter" (Irrigation Development Institute, 2011), (Irrigation Water Management Division, 2011a) to calculate crop evapotranspiration. By this method, researchers can estimate the volume of water loss by calculating the water used by the plant at each stage of growth. Therefore, require high cost, intensive labor, and difficulties in processing (Wullschleger, Meinzer, & Vertessy, 1998). Nowadays, the application of satellite image and remote sensing technology has increasingly been adopted for crop coefficient to estimate water requirements. There are several advantages, including surveying's ability to obtain area-based data with high resolution and precision, reducing the financial burden, and reducing surveying time and labor. Therefore, appropriate for monitoring plant activity in large agricultural areas. This study is primarily concerned with estimating water requirements by cassava to investigate the relationship between Vegetation Index; Normalized Difference vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Soil-Adjusted Vegetation Index (SAVI) and Normalized Difference Red Edge index (NDRE) with Crop coefficient (Kc) referenced from the Royal Irrigation Department (RID). The linear regression and multiple regression equations are used to calculate crop evapotranspiration by multiplying crop coefficients retrieved from the vegetation index of Sentinel-2 satellite image with reference crop evapotranspiration (ETo) values. The result of this study is expected to improve guidelines for developing the application of remote sensing technology and satellite imagery for estimating geospatial crop water requirements. Additionally, can be used as supporting data for effectively planning and managing water resources in a specific cassava cultivated area for each growing stage effectively according to availability of water.

Research Objectives

1. To apply the Sentinel-2 satellite image in determining the crop coefficient (Kc).
2. To find the best correlation between the vegetation index and the cassava crop coefficient.
3. To study the estimation of water requirement for cassava with vegetation index from Sentinel 2 satellite image.

Scope of work

Scope of the study

This study was conducted by sampling 80 cassava plots in the Bang Lamung district of Chon Buri province. Selected from land type usability announced by the Land Development Department in year 2020 (Land Development Department, 2020) excluding the area of island, urban, built-up land, forest area, water resource, and other agricultural areas. The area of cassava in Bang Lamung district, Chon Buri province is shown in Figure 1.

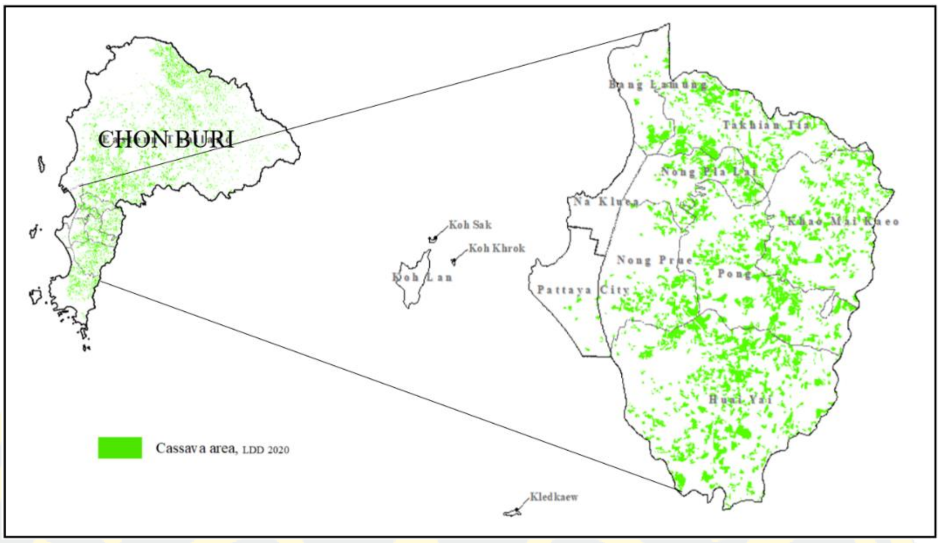


Figure 1 Cassava cultivation areas in Chon Buri Province

Scope of the content

In this study, to estimate crop water requirements using Sentinel-2 satellite data by using the Penman-Monteith equation. Investigating the relationship between the vegetation index of cassava and the crop coefficient (Kc) referenced from the Royal Irrigation Department (RID). Crop evapotranspiration was calculated using linear regression and multiple regression equations by multiplying crop coefficients retrieved from Sentinel-2 satellite image's vegetation index with reference evapotranspiration (ETo) values from 8 stations covering the study area. The expected result is the amount of cassava water required in the area.

Conceptual Framework

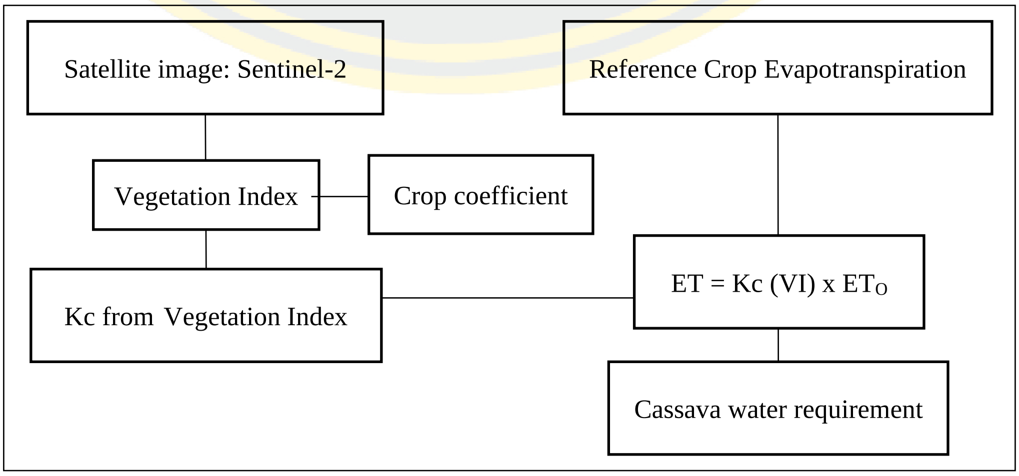


Figure 2 Conceptual framework of the method adopted in the research

CHAPTER 2
LITERATURE REVIEW

General Background

Chonburi Province is situated in the eastern part of Thailand. And partly includes the eastern coast of the Gulf of Thailand. The total area of the province is 4,363 square kilometers or 2,726,875 rai. In this study, was Bang Lamung District, which is one district of Chonburi Province. The coordinates of the Bang Lamung district lie between 12° 46′ 22.81″ and 13° 5′ 17.57″ Latitude and between 100° 57′ 18.04″ and 101° 6′ 6.88″ Longitude with an area of about 727 square kilometers or 469,021 rai. The district is also in the southwest of Chonburi Province, which is about 45 kilometers from the Mueang, Chon Buri District and 142 kilometers from Bangkok. There is a border with adjacent areas as follows:

...North ··connect with Sriracha district

...East ···connects with Pluak Daeng district, Nikhom Phatthana district, and Ban Chang District (Rayong Province)

...South ··connects to Sattahip District

...West ···connects to the Gulf of Thailand

Figure 3 The boundary of Bang Lamung district

According to ten years of statistical data collected by meteorological stations in Chonburi Province from 2008 to 2017 (Climate Information Services, 1951-2009), this area has a Tropical Monsoon Climate, which is characterized by frequent rainfall and drought alternately. The weather in this area is warm throughout the year due to it is close to the sea (the Gulf of Thailand). Furthermore, it was also influenced by the monsoon, which arrives from the northeast during the winter and the southeast during the summer. The average annual rainfall is 1,358.72 mm, with an average of 125 rain days. The lowest temperature is 18.3°C, and the highest is 37.22°C. Average annual temperature is 29°C, and the relative humidity is 72.36 percent. From February to October, the relative humidity increased, peaking at a high of 78.40 percent in September. Since November, the relative humidity has decreased, with the lowest average relative humidity in December being 64.90 percent (Thai Metrorological Department, 2017), (Thai Metrorological Department, 2018).

Moreover, the agricultural water balance for the analysis of the optimal crop season period was computed in CROPWAT, which can be examined as the relationship between average monthly rainfall and average monthly potential evapotranspiration (PET) using Penman-Monteith. According to the graph (Figure 4), the best period to cultivate is when the amount of rainfall remains above the 0.5 ETo line (Thai Metrorological Department, 2017).

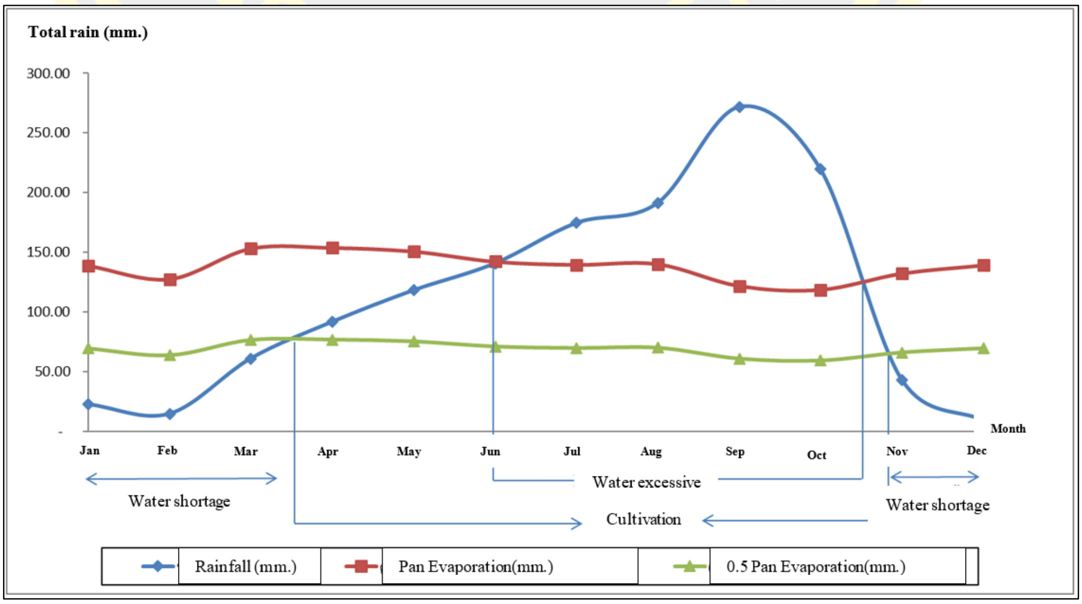


Figure 4 Water balance for agriculture in Chonburi Province

Figure 4 shows the suitable period for plant cultivation is between mid-March and October, which is the period of the rainfall value exceeding 0.5 of the total potential evapotranspiration. Because the soil is totally water-absorbing, it is adequately humid for cultivation until November. Even with a slight amount of rainfall, the plants can use the sufficient moisture in the soil. Therefore, this period is suitable for plant cultivation using rainwater.

Significantly, the Bang Lamung district is important for the economy of the province. This area is the tourism center because it is located near the sea, and it has famous cities such as Pattaya city. Meanwhile, the rural areas are located outside the central city, which is mostly in the agricultural area (Figure 5) (Water Crisis Prevention Center, 2021).

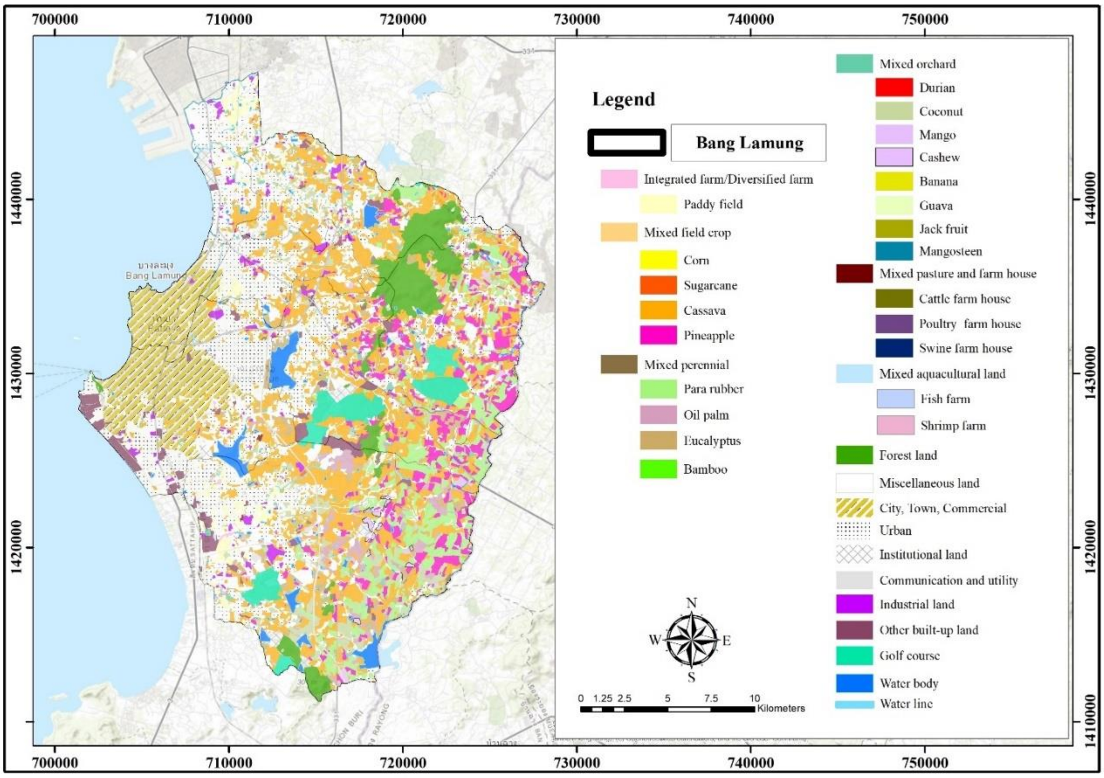


Figure 5 Land use of Bang Lamung, 2020

According to the Office of Agricultural Economics (Office of Agriculural Economics, 2021), most of the cassava cultivation area was found to be in Bang Lamung district, Phanat Nikhom district, and Ban Bueng district, respectively, as shown in Table 1 (Land Development Department, 2020).

Table 1 Land use of cassava by districts of Chon Buri during the year 2017-2020

Districts (Amphoe)	Area (Rai)			
	2017	2018	2019	2020
Mueang Chonburi	524	210	708	1,377
Bang Lamung	37,008	35,462	33,872	34,609
Ban Bueng	28,479	24,161	22,082	23,894
Phanat Nikhom	18,934	23,963	27,514	28,396
Phan Thong	42	45	15	36
Si Racha	22,515	20,042	17,689	18,521
Sattahip	7,963	6,821	3,575	8,301
Nong Yai	15,086	13,838	15,350	15,559
Bo Thong	15,973	14,637	14,801	13,121
Ko Chan	10,234	10,145	9,023	9,204

Sentinel-2 satellite image data

The Sentinel-2 satellite image data was provided by the European Space Agency (ESA) and can be downloaded from the website at https://scihub.copernicus.eu/. The Sentinel-2 spacecraft is a twin satellite comprising the Sentinel-2A (launched in 2015) and Sentinel-2B (launched in 2017) systems (European Space Agency, 2020b). The Multispectral Instrument (MSI) system provided 13 MS frequency bands, with four bands at 10 m, six bands at 20 m, and three bands at 60 m spatial resolution. Figure 6 shows the mission specification of the twin satellites is in the same orbit, which was phased at 180°, enabling a revisit frequency at the Equator of every 5 days, and the orbital swath width is 290 kilometers.

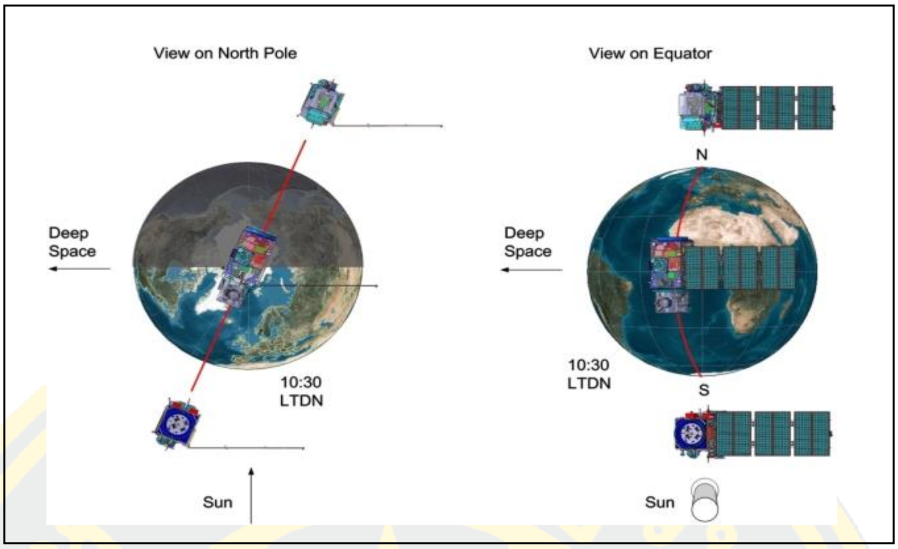


Figure 6 The Twin-Satellite SENTINEL-2 Orbital Configuration (courtesy Astrium GmbH)

Sentinel was developed to support applications such as agriculture, resource exploration, disaster management, and water resource management. The resolution of sentinel-2 is shown in the Table 2 (European Space Agency, 2020b), (European Space Agency, 2020a).

Table 2 Spectral bands for the Sentinel-2 sensors

Bands	**Description**	**Sentinel-2A**		**Sentinel-2B**		**Spatial resolution (m)**
		Central wavelength (nm)	**Bandwidth (nm)**	**Central wavelength (nm)**	**Bandwidth (nm)**	
Band 1	Ultra-blue (Coastal and Aerosol)	442.7	21	442.2	21	60
Band 2	Blue	492.4	66	492.1	66	10
Band 3	Green	559.8	36	559.0	36	10
Band 4	Red	664.6	31	664.9	31	10
Band 5	Vegetation red edge	704.1	15	703.8	16	20
Band 6	Vegetation red edge	740.5	15	739.1	15	20
Band 7	Vegetation red edge	782.8	20	779.7	20	20

Table 2 Spectral bands for the Sentinel-2 sensors (continuous)

Bands	Description	Sentinel-2A		Sentinel-2B		Spatial resolution(m)
		Central wavelength (nm)	Bandwidth (nm)	Central wavelength (nm)	Bandwidth (nm)	
Band 8	Near Infrared (NIR)	832.8	106	832.9	106	10
Band 8A	Narrow NIR	864.7	21	864.0	22	20
Band 9	Water vapour / Short Wave Infrared (SWIR)	945.1	20	943.2	21	60
Band 10	SWIR – Cirrus / Short Wave Infrared (SWIR)	1373.5	31	1376.9	30	60
Band 11	Short Wave Infrared (SWIR)	1613.7	91	1610.4	94	20
Band 12	Short Wave Infrared (SWIR)	2202.4	175	2185.7	185	20

Crop and water requirement

Crop evapotranspiration

Crop water requirement, also known as evapotranspiration or consumptive usage; ET (Irrigation Development Institute, 2011), (Kositsakulchai, 2009) is the amount of water used by a plant, including water loss because of transpiration and evaporation. Transpiration is the process by which plants uptake water from the soil, distribute it to their stems, and lose it to the atmosphere through their stomata. There are several related factors (Spiliotopoulos & Loukas, 2019), such as solar radiation, temperature, sunlight, and wind speed. Whenever evaporation is the procession by which water evaporates as a vapor into the atmosphere, its rate depends on the type of surface. There are also many factors related to the rate of evaporation, for example

(R. G. Allen, 2006), method of irrigation, soil property, type of plant, and method of cultivation. Therefore, it can be summarized that factors affecting crop water requirement are mainly related to climate factors, plants, environmental factors, and management-related factors, as shown in Figure 7 (Muhammad Hassani, 2018).

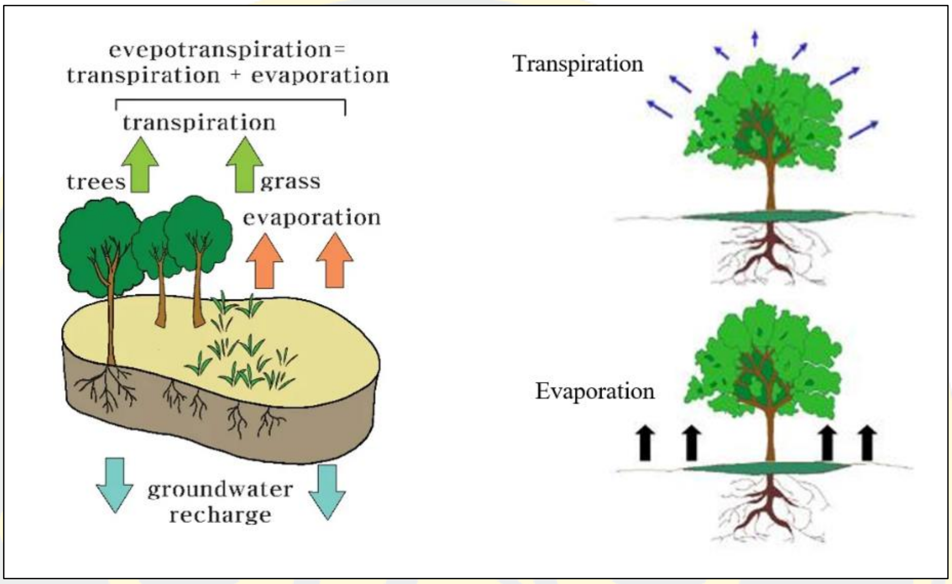


Figure 7 The process of Evapotranspiration

Generally, crop water requirements can be estimated by the direct method. For example, measuring from the plot of plants and the lysimeter obtains an accurate result. However, it might be practically unsuitable because it cannot be used in the other cultivation areas that do not have this equipment or in areas with different environmental conditions. Thus, assessing crop water requirements by the application of climatic data is widely used. Since the assessment of crop water requirement in a specified area can be calculated from reference crop evapotranspiration (ETo) and crop coefficient (Kc), which were obtained from calculating climatic parameters in that area by using the specified formula, multiplied with the crop coefficient, which depends on crop type and species (Irrigation Development Institute, 2011), as shown in Figure 8 (Food and Agriculture Organization of the United Nations, 2020).

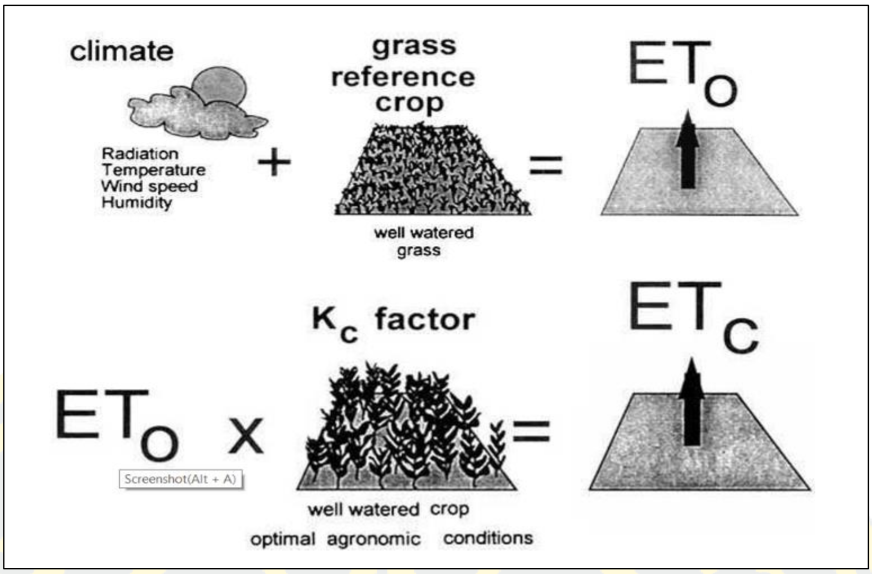


Figure 8 Reference crop evapotranspiration (ETo) and crop evapotranspiration under standard (ETc)

The method or equation, which is well-known and has been widely used for calculating consumption water or crop water requirements is the method that is accredited by Food and Agriculture Organization of the United Nations (FAO) (R. Allen, Pereira, Raes, & Smith, 1998). In Thailand, the Royal Irrigation Department has adopted the Penman Monteith calculating method, which obtains high accuracy of results compared to the results from the direct method (Irrigation Water Management Division, 2011a), (Pereira, Allen, Smith, & Raes, 2015). Therefore, the assessment of crop water requirements for a specified crop type is calculated by the following equation (2-1) (R. G. Allen, 2006), (Zotarelli, Dukes, Romero, Migliaccio, & and Morgan).

$$ET = Kc * ETo \qquad (2\text{-}1)$$

When ET = Evapotranspiration

Kc = Crop Coefficient

ETo = Reference Crop Evapotranspiration

Reference Crop Evapotranspiration

Reference Crop evapotranspiration (ETo) is the principle or reference value for calculating the amount of water loss from cultivating areas covered by plants. Thus, the soil is moisture enough for the requirement of plants and the area is large enough that external factors would not affect the evaporation of plants. Several methods of calculation using climatic data exist, depending on the scale and accuracy of the data. There are seven popular equations, namely 1) Modified Penman, 2) E–pan, 3) Penman-Monteith, 4) Blaney-Criddle, 5) Thornthwaite, 6) Hargreaves, and 7) Radiation (Irrigation Water Management Division, 2011b).

This study uses a method of calculation by Penman-Monteith in which it included the geographic and climatic factors following the FAO-56 guidelines (R. Allen et al., 1998). This method obtains high accuracy with actual crop water requirements compared to other equations. The equation is as follows (Equation 2-2) (Richard G., Luis S., Raes, & Smith, 1998), (R. G. Allen, 2006):

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)} \qquad (2\text{-}2)$$

Where ETo = reference crop evapotranspiration (mm d^{-1})

R_n = net radiation at crop surface (MJ m^{-2} d^{-1})

G = soil heat flux (MJ m^{-2} d^{-1})

T = average temperature (^{0}c)

Δ = slope vapor pressure curve (kPa $^{0}c^{-1}$)

γ = psychometric constant (kPa $^{0}c^{-1}$)

U_2 = windspeed measured at 2m height (m s^{-1})

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure deficit (kPa)

(e_s-e_a) = saturation vapour pressure deficit (kPa)

900 = conversion factor

Crop coefficient

Crop coefficient (Kc) is the coefficient of water utilization by the plant, which depends on the type and growth stage of the plant as it is a fixed value obtained from the relation between crop water requirement in situ measured by the Lysimeter and the calculated value of reference crop evapotranspiration following Equation 2-3:

$$Kc = ET/ETo \qquad (2\text{-}3)$$

The crop coefficient is useful for agricultural areas where crop water requirements have not been investigated. It can be used to estimate agricultural water requirements when calculated using climate data (Irrigation Water Management Division, 2011a). Each crop has a unique Kc, which may be calculated using differential equations. As a result, it is critical to select carefully Kc before applying the appropriate ETo and calculating the correct ET value (Royal Irrigation Department, 2011).

Spectral Vegetation Indices

Spectral Vegetation Indices (SVIs) were created by integrating data from many spectral bands into a single value. Simple algebraic formulas, or SVIs, are typically used to boost the vegetative signal through remotely sensed data. It gives an estimate of the number of green plants that are alive and green. The concept behind SVIs is to take advantage of the distinct spectral fingerprints of green plants compared to other Earth components (Center for Coastal Physical Oceanography, n.d.). In the visible (VIS) and near-infrared (NIR) wavelengths, green leaves display a distinct spectral reflectance pattern. Blue and red areas have relatively little reflection, whereas green areas have slightly higher bumps. As a result, the leaves seem green when seen normally. Green leaves have a substantially higher spectral sensitivity in the NIR than in the visible. Other materials, such as bare soil, sand, rock, concrete, or asphalt, often reflect light when the wavelength shifts from visible to near infrared. Most SVIs compare the reflectance of red and near-infrared light. NIR reflectance is sensitive to the mesophyll structure of leaves, while red reflectance responds to chlorophyll. The more NIR reflectance, the green vegetation present is evident in the pixels or scene of the photograph. NIR reflectance, on the other hand, shows that a scene or pixel is largely made up of bare soil or other non-green components, and as shown is Figure 9.

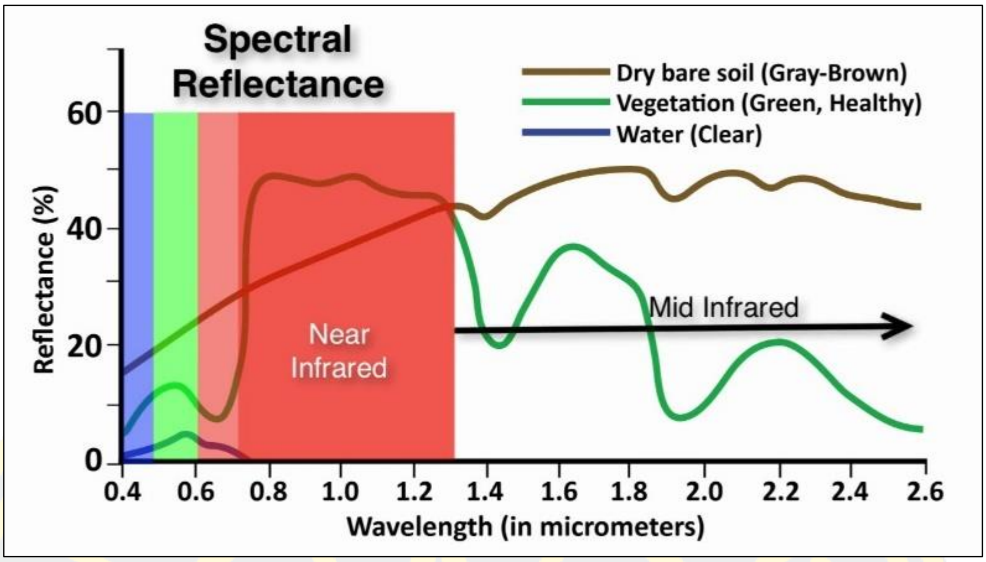


Figure 9 Spectral Reflectance Curves of Remote Sensing

Vegetation Index

The satellite data of multi-band is used to calculate the principle of crop data validation. The method for creating data for the vegetation index has been selected in order to demonstrate crop type in the study area. The difference in vegetation indexes will highlight certain features. In this study, the vegetation indices were selected as follows:

Normalized Difference vegetation Index

The Normalized Difference Vegetation Index (NDVI) is a standard vegetation index that can show differences in biomass intensity. Rouse et al., 1974 (Rouse, Haas, Schell, & Deering, 1974) developed it using data from two bands, which are proportionately near-infrared (NIR) and red. The calculated value ranges from -1 to 1. In areas with a high density of plants, NDVI is close to one, whereas in areas with bare soil or water, NDVI is close to 0 value (Carlson & Ripley, 1997). This is because the reflectance occurs at a NIR wavelength less than the red. NDVI can be used as a quantitative tool and algorithm for mapping object classification between plants and non-plants, plant density, and the abundance of plants for monitoring, tracking, and predicting agricultural products (Auravant, 2021), as well as drought assessment and mapping the risk area of forest fire. As a result, NDVI has been widely adopted by several studies. The NDVI is computed from the ratio of NIR and RED spectral bands as:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (2\text{-}4)$$

Where: NIR = The reflectance in Near Infrared wavelength

Red = The reflectance in Red wavelength

Green Normalized Difference Vegetation Index

The Green Normalized Difference Vegetation Index (GNDVI) is an index of the "greenness" of plants or photosynthesis. It is a chlorophyll index and is used in the next stage of development (Auravant, 2021). As it saturates more slowly, NDVI is one of the most widely used vegetation indices to determine water and nitrogen absorption in crops. The value defined by this index also ranges from -1 to 1, and a value between -1 and 0 correlates with the presence of water or bare soil. This index is mainly used at the intermediate and final stages of the cultivation cycle. GNDVI is the green vegetation index that uses the near-infrared (NIR) and the green band of the electromagnetic spectrum. The green light wavelength is the sum of the amount of energy reflected in the near-infrared (NIR) wavelength and the amount of energy reflected in the green spectrum (Gitelson, Kaufman, & Merzlyak, 1996). GNDVI was more sensitive to changes in chlorophyll in crops than NDVI and had a higher saturation point. That can be used in dense tented crops or advanced stages of development, while NDVI is suitable for the early estimation of plant vigor. which can calculate GNDVI from the following equation (2-5):

$$GNDVI = (NIR - Green)/ (NIR + Green) \quad (2\text{-}5)$$

Where: NIR = The reflectance in Near Infrared wavelength

Green = The reflectance in Green wavelength

Soil-Adjusted Vegetation Index

The Soil-Adjusted Vegetation Index (SAVI) was used to mitigate the effect of soil luminance. Huete, (Huete, 1988) added soil-adjusting factor L to the NDVI equations to correct the effect of soil noise (soil color, soil moisture, regional soil variability), which affects the results, and SAVI is the best index used to characterize vegetation in arid regions (Ayu Purnamasari, Noguchi, & Ahamed, 2019). The distribution between vegetation and bare land can be calculated from the following Equation (2–6):

$$SAVI = (1 + L) * (NIR – Red)/ (NIR + Red +L) \qquad (2\text{-}6)$$

Where: NIR = The reflectance in Near Infrared wavelength

Red = The reflectance in Red wavelength

The correction factor is L, and values range from 0 to 1. When L = 0 and tree densities are very high, soil reflectance is high; when L = 1 and vegetation is scattered, soil reflectance is high. To adapt to most situations, they typically set L to 0.5 (Huete, 1988).

Normalized Difference Red Edge index

Normalized Difference Red Edge index (NDRE) is a method for determining the amount of chlorophyll in plants. As a result, it should be utilized to determine whether the growing plant is healthy. Other indexes are less effective at this point. Values calculated using the near-infrared (NIR) frequency range and the red-edged band between visible red and NIR represent this. By combining these bands, the NDRE becomes highly sensitive to the wavelengths of light reflected by chlorophyll. Low levels of chlorophyll in crops, such as starvation plants, may be shown a problem. Plant pests and agricultural damage (Carlson & Ripley, 1997), which is between -1 and 1, with -1 and 0.2 indicating bare soil or a developing crop, and 0.6 to 1 are good values indicating healthy, mature, ripening crops (Earth Observing System, n.d.). The health index considers more than just the chlorophyll content of the canopy’s outer layer. However, it can penetrate deeper into the shade than NDVI (Aerobotics, 2021), (Auravant, 2021). The NDRE equation as (2-7):

$$NDRE = (NIR - RedEdge) / (NIR + RedEdge) \qquad (2\text{-}7)$$

Where: NIR = The reflectance in Near Infrared wavelength

RedEdge = The reflectance in RedEdge wavelength

Spatial Interpolation

Interpolation is the process of predicting, destroying, or predicting a cell in raster data based on a limited sample of data. This approach can be used to predict observed values based on geography.

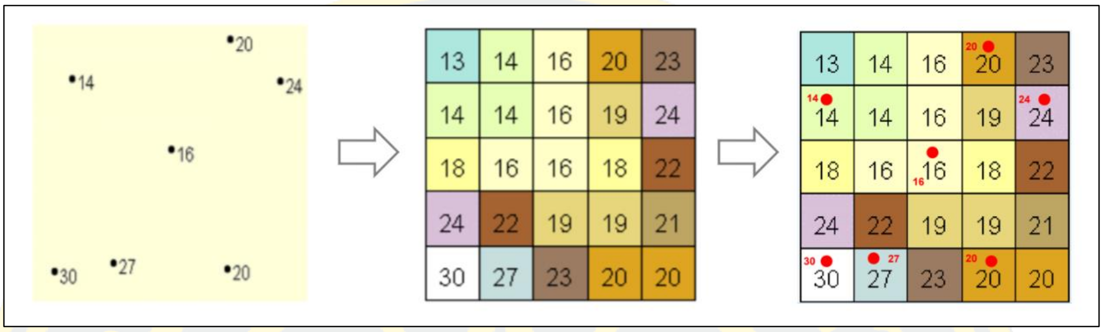


Figure 10 Interpolation predicts values for cells in a raster

The reference crop evapotranspiration (ETo) data was calculated from weather data obtained from the weather station. Therefore, ETo data from multiple stations is used to estimate spatial data to cover the study area by (Yensakulsuk & Chayakula, 2020) referred to (Hodam, Sarkar, Marak, Bandyopadhyay, & Bhadra, 2017), their used 32-year average monthly meteorological data for 131 sites in India to conduct a spatial data calculation of reference crop evapotranspiration. The results revealed that the Inverse Distance Weight (IDW) spatial estimate approach provided the most accurate results.

In this study, the Inverse Distance Weight method was used to estimate the spatial data of the reference crop evapotranspiration. The Inverse Distance Weight method was based on the principle of approximate location. There will always be a spatial relationship to calculate the value at the desired location. The position nearest to the station is of greater importance than the farthest point. Thus, the approximation of the unknown point by the linear sum of the known values weighted the point to be limited by distance. As shown in Figure 11 (Mitas & Mitasova, 1999), the nearest known point is the most important or weighted in the estimation of that unknown point.

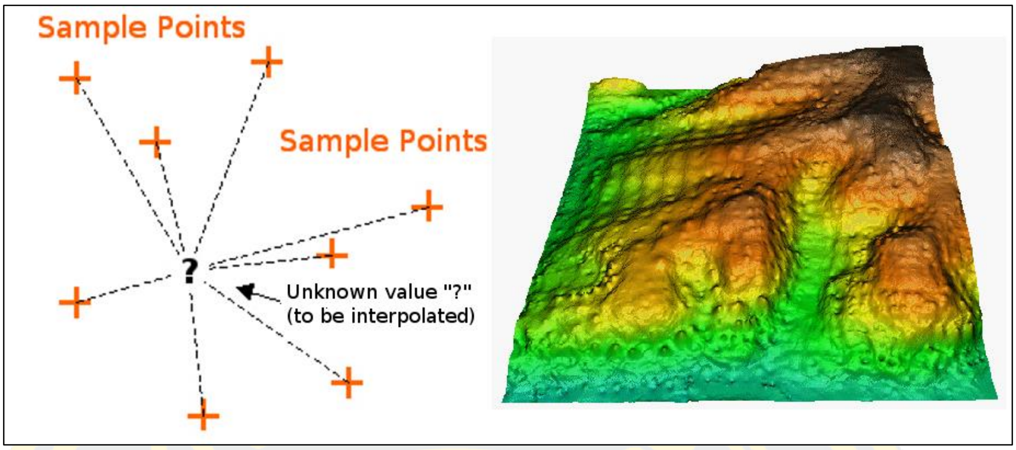


Figure 11 Inverse Distance Weighted interpolation based on weighted sample point distance (left). Interpolated IDW surface from elevation vector points (right)

The Inverse Distance Weighted method is calculated as in Equation (2-8) (GISGeography, 2022).

$$z_p = \frac{\sum_{i=1}^{n} \left(\frac{z_i}{d_i^p} \right)}{\sum_{i=1}^{n} \left(\frac{1}{d_i^p} \right)} \qquad (2\text{-}8)$$

Where: Z_p = Value of known point

Z_i = Distance to know point

n = A user selected exponent (often 1,2 or 3)

d_{ip} = Distance from known point

Regression Analysis

Regression analysis is a statistical approach for investigating the relationship between two known variables, referred to as independent variables and denoted by the symbol x. This can be used to calculate the value of another variable known as the dependent variable, which is denoted by the symbol y, and it is used to investigate the relationship between two variables in order to determine which is an independent variable and which is a dependent variable. The relationship between the two variables can have any shape, including a straight line or a curve (Chansuwan, 2021).

A simple linear regression analysis was used in this study, which can show the relationship in linear equations or linear equations as an analysis of the relationship between the dependent variable (Y), in this case, the crop coefficient, and the variable plant (X), which is the average vegetation index in each training area. Equations (2–9) and Figure 12 illustrate the sample regression equations from a simple linear regression study.

$$y = a + bx \tag{2-9}$$

Where y is the dependent variable, x is the independent variable, a is the slope of the line and b is the y-intercept, as shown Figure 12 (Chansuwan, 2021).

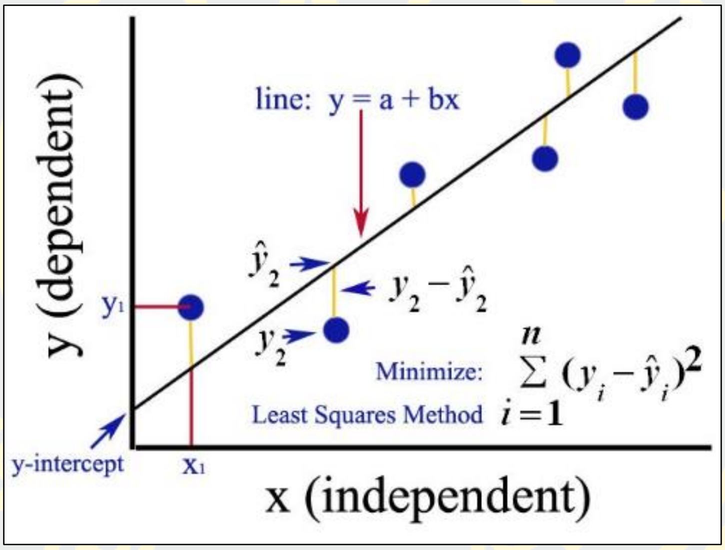


Figure 12 Simple linear regression

Whether the regression consequence can accurately depict the relationship between two variables remains to be seen. The R-Squared (R^2) value, the value of the Coefficient of determination, ranges from 0 to 1, which can be interpreted in terms of 0% to 100%, with a higher percentage indicating that the model can theoretically compute values that are very close to the observed values. When the model accurately explains 100% of the variation, the calculated values are equal to the observed values, and the observed data values are on the straight line of the math model (Charoenhirunyingyos, 2018) referred to (Solution Center Minitab, 2020).

In addition, several linear regression attempts were made to model the relationship between two or more explanatory variables and response variables by optimizing the linear equations for the observed data. This can be done with the use of multiple regression. Simple linear regression is supplemented by multiple regression. The value of two or more variables are used to predict the values of a variable. The dependent variable is the variable that needs to be predicted. (Or, in certain cases, outcomes, objectives, or criteria variables) (Takemura, 2021), where simple linear regression uses a single independent variable to predict the value of the dependent variable. Multiple linear regression, where two or more independent variables are used to predict the value of a variable based on the difference between the two, is the number of independent variables.

Accuracy assessment

An accuracy assessment can be evaluated by determining the error of the result. By comparing the crop coefficient (Kc) obtained from the mean vegetation index of 80 cassava samples plots with the Kc obtained from the Royal Irrigation Department, And a comparison of crop evapotranspiration (ET) calculated using the crop coefficient derived from the mean vegetation index with crop evapotranspiration calculated using the crop coefficient obtained from the Royal Irrigation Department each month using the percentage difference as in Equation 2-10 and then accuracy for statistical discrepancies as indicated in Equations 2-11, where the disparity of the result was estimated using the square root of the Root Mean Square Error (RMSE). The best model is the one with the lowest RMSE value. In other words, the lower the RMSE, the better. If 0 indicates that the model predicts the “y” value correctly 100 percent of the time, the model can be trained (Yensakulsuk & Chayakula, 2020), (Dalla Marta et al., 2019).

$$\text{Percentage Difference} = \left| \frac{(\text{Experimental Value} - \text{Theoretical Value})}{\text{Theoretical Value}} \right| * 100 \quad (2\text{-}10)$$

When Experimental Value = Values obtained from satellite data

Theoretical Value = Value referenced from the RID

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \qquad (2\text{-}11)$$

When RMSE = Root Mean Square Error

$\hat{y}i$ = Crop coefficient (Kc) obtained from Vegetation Index

yi = Crop coefficient (Kc) referenced from the RID

Cassava

Cassava is one of most important economic crops in Thailand. It can be cultivated the whole year and has plantations spread throughout the country. Because it is simple to grow, the plant is drought resistant and can thrive in a variety of soil conditions. The majority is planted during the rainy season (March to May) 65 percent of the time, with the remainder planted after the rainy season or during the dry season (November to February) 20 percent of the time, and the remainder planted between June and October. Planting at the beginning of the rainy season yields more fresh tubers than planting at other times of the year. However, if the soil is sandy, planting during times of drought will provide the most dried tubers. Farmers' planting decisions are influenced by the following factors.

(1) Soil preparation: earlier cultivation in the rainy season, when rainfall is low, allows for adequate soil preparation. Weeds will be considerably reduced provided users spend the time properly preparing for the soil. Loamy soil is suitable for rooting, and cassava receives rain throughout the growing period. After the cassava has emerged at the end of the season or during the dry season, there will be a period of 2-3 months of rain, causing the cassava to stop growing. However, planting has the advantage of fewer weeds to manage.

(2) The types of soil: it can be planted all year if the soil is sandy, although many farmers prefer to plant it during the rainy season, as in Rayong and Chonburi provinces. However, if the soil is clay, it is common to plant in the early wet season. Because plowing produces big lumps of soil in a dry season, the cassava logs will dry up before they grow into plants.

(3) Cultivars of Cassava: if gathered during the rainy season, native cassava cultivars have a low starch content and are difficult to transport. As a result, they are planted throughout the growing season for harvesting and transportation during the dry season, resulting in high quality and low cost. However, new types have emerged recently. A large percentage of starch was produced. Therefore, it can be planted throughout the year to ensure that the produce is distributed uniformly.

There are five growth stages of cassava: 1) the budding phase lasts 5 to 15 days; 2) the tissue formation stage of leaves and roots, which lasts from 15 days to 3 months, with the first month being the most challenging because the leaf tissue is not fully established. Cassava growth during this time is not due to photosynthesis. After 2 to 3 months, starch will begin to accumulate in the roots from the food deposited in the cassava plant; 3) stem and leaf growth stage from 3 to 6 months. Cassava will have the most efficient photosynthetic area during the 4 to 5-month period, and starch synthesis at the roots will continue in parallel; 4) the food-accumulating period of the cassava plant, 6–10 months of age, due to the plant's lack of growth. Lignin accumulates in the plant, making it grow stronger. To prevent water loss, several of the lower leaves will fall, and the rate of food accumulation at the roots will rise; and 5) the dormancy period lasts 10 to 12 months, during which time productivity remains stable (Alves, 2002). Cassava is harvested between the ages of 8 and 18, but most commonly at the age of harvesting. The optimum is 12 months after planting.

Cassava requires a regular rainfall of 1,000–1,500 millimeters per year. That can grow in areas that receive less than 800 millimeters of rainfall per year or have a dry season of 4 to 6 months. Although cassava can grow in droughts, tuber production is expected to decrease as the water shortage continues (Pipatsitee, Eiumnoh, et al., 2018). The critical period for cassava water deficiency was 1 to 5 months after planting, which is when the tuber and roots are forming. According to research, the presence of a repeat for two months can reduce the production of potatoes.

Therefore, cassavas should be watered adequately for the first 5 months after planting to provide enough root growth for food storage throughout the dry season and increased output. Cassava should indeed be planted in irrigated areas at the start of the rainy season to get enough water.

CHAPTER 3
MATERIALS AND METHODS

The estimation of Cassava water requirement is gathering and analyzing spatial data to calculate further water cassava evapotranspiration. In order to know the evapotranspiration of cassava according to the growing age, to be able to find the water require of cassava in Bang Lamung District further.

Materials

Software and Hardware

(1) SNAP 8.0

(2) ArcGIS 10.5

(3) Google Earth Pro

(4) Microsoft Office 365

(5) Computer laptop

Data collection

The data that was used in the investigation, as shown Table 3.

Table 3 Data collected for this study

Descriptions	Data sources	Period	Data Types
Sentinel-2 Satellite Image	Copernicus Open Access Hub	Jan. 2020 to Dec. 2021	Raster file
Land use	Land Development Department, Thailand	2018 to 2020	Vector file
Crop Coefficient	Irrigation Water Management Information, Royal Irrigation Department, Thailand		Word file
Reference Crop Evapotranspiration	Irrigation Water Management Information, Royal Irrigation Department, Thailand	30 years (1991-2020)	Word file

Data from satellite images

This study has compiled image data from the European Space Agency (ESA) Sentinel-2 satellite, a twin satellite comprising Sentinel-2A and Sentinel-2B Multispectral Instrument (MSI) systems with 12-bit radiometric resolution and a work surface of 10x10 meters. by using Level-2A which is Product with Radiometric Correction and Atmospheric Correction was performed and the recording was repeated every 5 days. There is also the World Geodetic System 1984 (WGS1984) reference ground system and the Universal Transverse Mercator (UTM) Zone 47 North coordinate system. It contains 52 low-cloud images from January 2020 to December 2021, covering the study area of Bang Lamung District, Chonburi, Thailand. And can be obtained from the Sentinel Hub data service system (https://www.sentinal-hub.com/explor/eobrower).

Land use

This study area was the cassava cultivation area in Bang Lamung District. Chonburi with a total cassava cultivation area of approximately 90,576,000 square kilometers or 56,610 rai, courtesy of the shape file, referring to area data from the Department of Land Development in 2020. The study included 80 cassava plots in total.

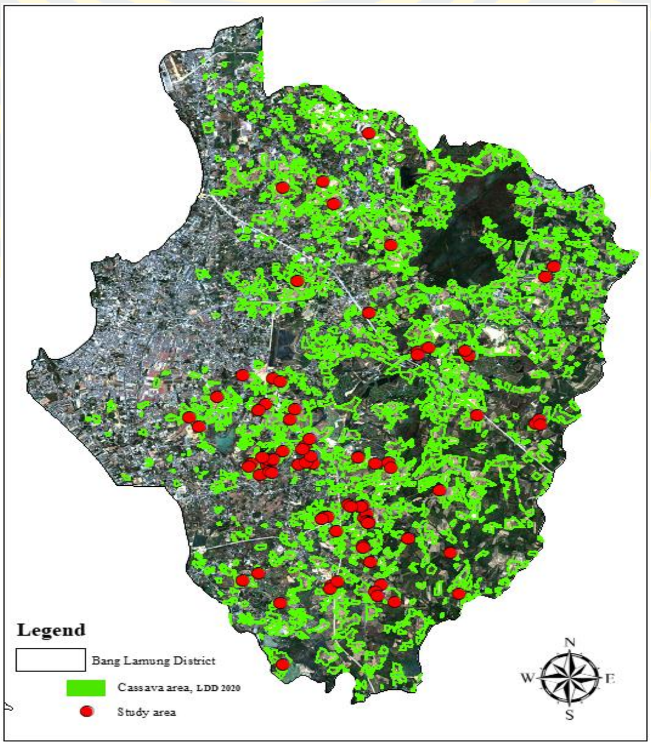


Figure 13 Land use; cassava in Bang Lamung, 2020

Crop coefficient data

Data on cassava crop coefficients This is information gathered from research investigations on crop evapotranspiration throughout the duration, from the start of cultivation to harvesting, at irrigation water consumption experiment stations located in various areas, which have different climatic conditions to analyze the crop coefficient (Kc). By calculating the correlation between the reference crop evapotranspiration (ETo) and the crop evapotranspiration obtained from the experiments in the lysimeter tank according to the equation of Penman-Monteith (Irrigation Water Management Division, 2012), which can download information from the website http://water.rid.go.th/hwm/cropwater/CWRdata/Kc/kc_en.pdf. The Kc values are divided according to the age of the plants for 12 months, as shown in Table 4 and Figure 14.

Table 4 Crop coefficient of cassava

Month	1	2	3	4	5	6	7	8	9	10	11	12
Kc	0.28	0.29	0.32	0.34	0.50	0.72	0.99	1.13	1.01	0.79	0.58	0.42

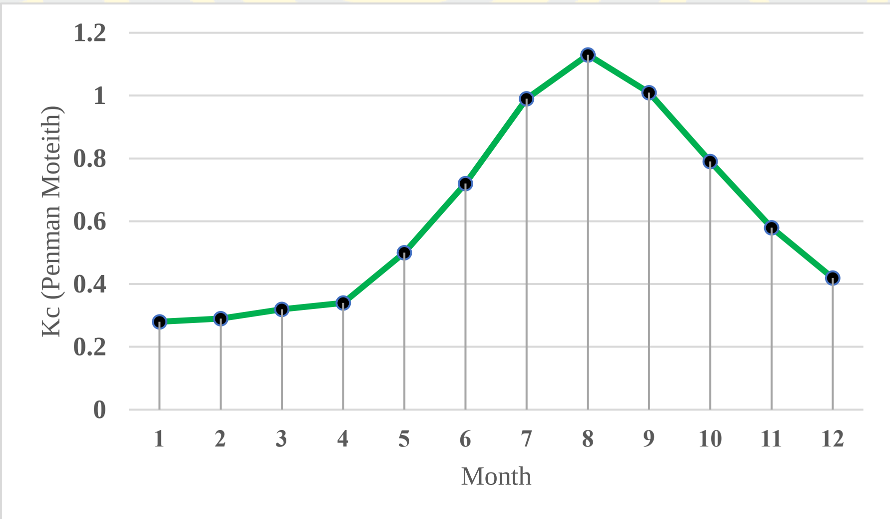


Figure 14 Crop Coefficient (Kc RID) of Cassava by Penman-Monteith

Reference Crop Evapotranspiration data

Reference Crop Evapotranspiration (ETo) is statistical data by the Royal Irrigation Department’s irrigation water use section over 30 years, from 1981 to 2010, to determine the average climate, namely air temperature, air’s relative humidity, wind speed, and daylight hours. Reference Crop Evapotranspiration (ETo) was calculated by applying the Penman-Monteith method according to the FAO-56 manual.

The reference crop evapotranspiration (ETo) data is obtained by the Irrigation Development Institute, the Royal Irrigation Department. To compile average values of climate conditions that affect evapotranspiration for 30 years from 1981 to 2010, such as air temperature, relative humidity, wind speed, and sunlight hours, were then calculated for reference crop evapotranspiration (ETo) by the Penman-Monteith method according to the FAO-56 manual (Irrigation Water Management Division, 2011b). Which, ETo data is available for download on the website http://water.rid.go.th/hwm/cropwater/CWRdata/ETo/ETo_PenMon_2011.pdf. Currently, the latest data has been updated for the years 1991-2020 from the Irrigation Department. As indicated in Table 5 and Figure 15, data on Reference Crop Evapotranspiration (ETo) were obtained from all 8 weather monitoring sites that covered the study area in Bang Lamung District.

Table 5 Monthly Reference Crop Evapotranspiration

Station	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CHACHOENGSAO	3.31	3.81	4.09	4.46	4.17	3.82	3.51	3.59	3.52	3.51	3.46	3.25
CHONBURI	3.64	4.21	4.46	4.88	4.36	3.94	3.94	3.53	3.45	3.45	3.76	3.54
KO SICHANG	3.49	3.98	4.47	4.84	4.42	4.03	3.84	3.82	3.69	3.58	3.70	3.35
LAEM CHABANG	3.27	3.59	3.96	4.38	3.70	3.61	3.55	3.56	3.45	3.09	3.28	3.25
PHATTHAYA	3.53	3.90	4.20	4.64	4.08	3.78	3.62	3.53	3.38	3.39	3.36	3.30
SATTAHIP	3.27	3.59	3.92	4.30	3.61	3.57	3.49	3.02	3.36	3.04	3.31	3.22
HUAI PONG AGROMET.	3.37	3.79	4.09	4.42	4.04	3.79	3.52	3.64	3.42	3.35	3.37	3.40
RAYONG	3.49	4.07	4.50	4.82	4.27	3.90	3.74	3.76	3.61	3.65	3.72	3.38

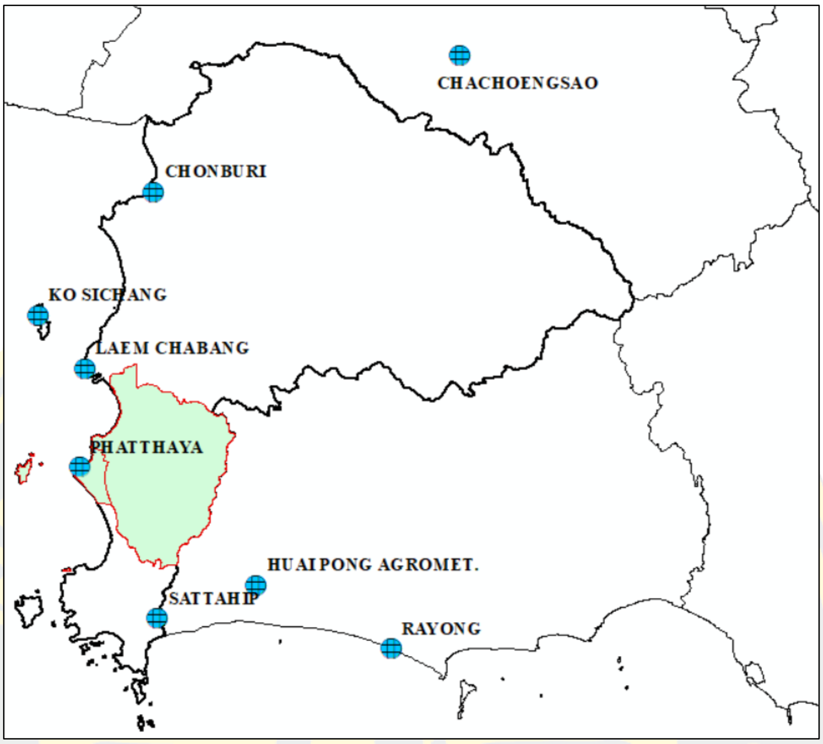


Figure 15 Position of meteorological stations in the study area

Method

The study uses Sentinel-2 satellite images from January to December 2020-2021 to calculate the Vegetation Index, NDVI, GNDVI, SAVI, and NDRE. To layer stacking and find the average value of each index in the study cassava training area used. The index average data was then constructed by plotting time series to see the cassava growth state (Ayu Purnamasari et al., 2019) and refer to the local growing season using Google Earth. After obtaining the average data, from the start of cultivation through harvesting, the vegetation index in cassava plots was measured. Then developing crop coefficient data in a geographical model using a linear regression analysis method. And determine the most correlated indices for further crop evapotranspiration. As indicated in Figure 16, there are techniques for conducting research.

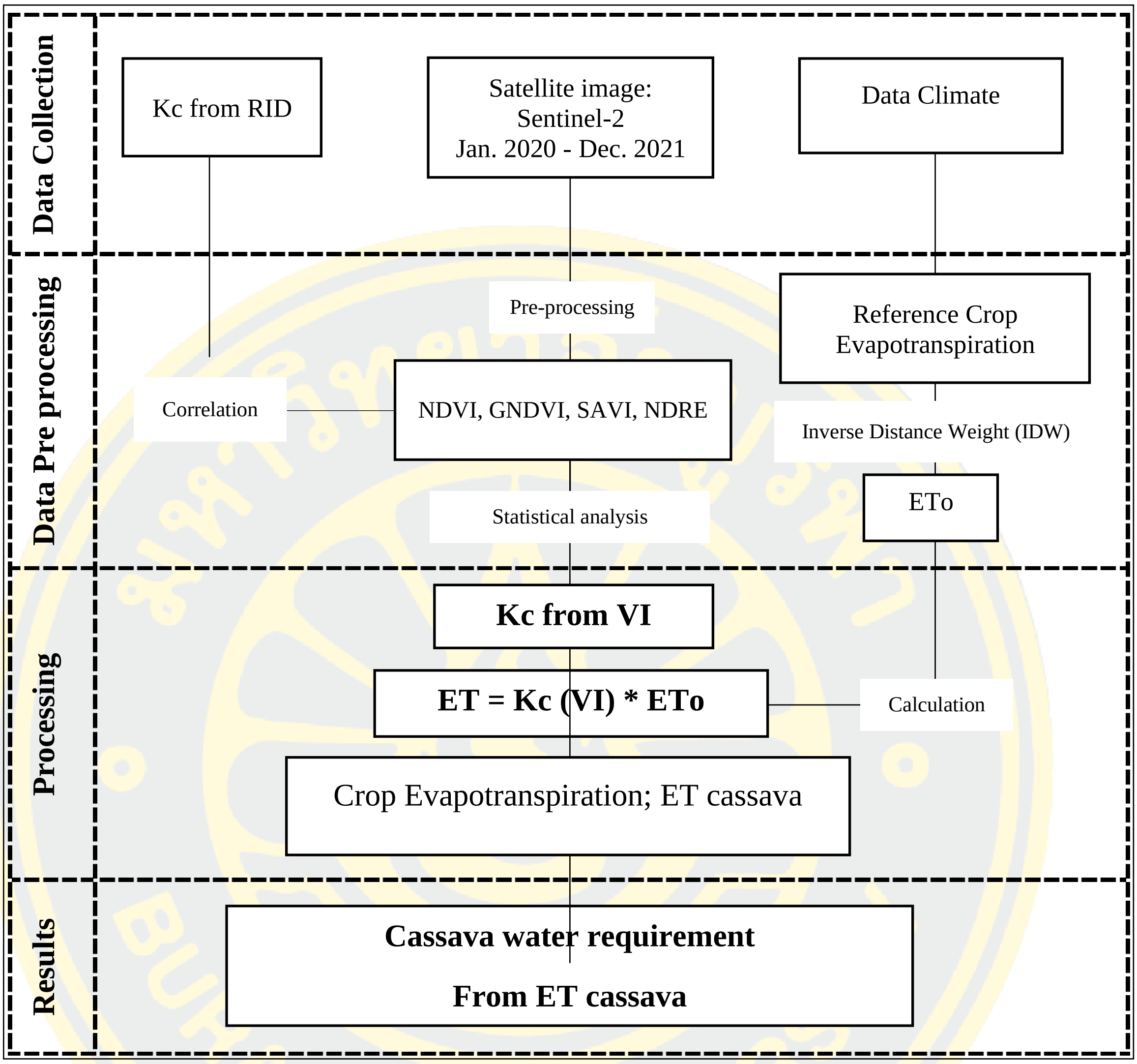


Figure 16 Methodology flowchart

Procedure for research

Preparation of satellite image data and vegetation index data

Download Sentinel-2 Level-2A satellite imagery from January 2020 to December 2021, and then use the band of quality cloud confidence to filter out the clouded areas. The cloud area, which was discovered, was removed to use as a mask. The cloud cover area exceeds 100, indicating that the cloud area should be removed. Where values less than 100 are preserved, values greater than 100 must be replaced by 1, and then use the cloud split image to calculate the vegetation index, as shown in Figure 17.

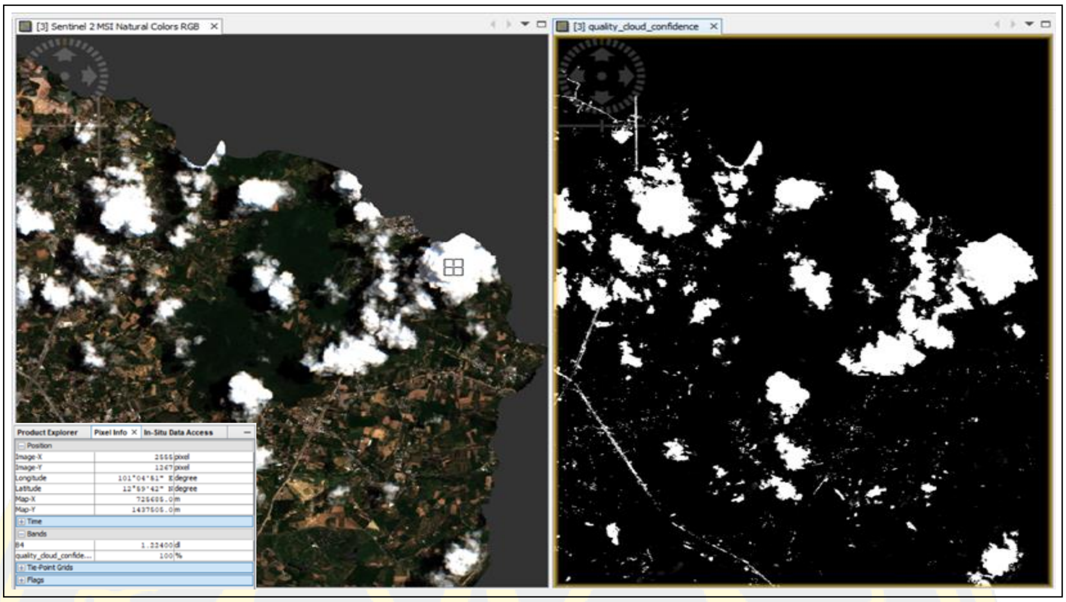


Figure 17 The Sample of training areas with cloud mask

Calculation of vegetation index

The vegetation index was calculated using surface reflectance values from Sentinel-2 satellite image data in the Green Light Wavelength (Band 3), Red Light Wavelength (Band 4), Rededge Wavelength (Band 5), and Near Infrared (Band 8) (Chalermpong, 2017). In this investigation, all four indicators were used, namely:

The Normalized Difference Vegetation Index (NDVI) is the ratio of near-infrared wavelengths (B8), with the red wavelengths (B4). The NDVI ranges from -1 to 1, with 0 indicating no vegetative cover. A positive value, such as 0.1-0.7, represents vegetation cover, while a negative value represents water area (Tucker, 1979).

$$NDVI = (B8 - B4)/ (B8 + B4) \quad (3\text{-}1)$$

Green Normalized Difference Vegetation Index (GNDVI) is a frequency band to determine the ratio between the reflectance difference in the near-infrared frequency band (B8) and the green vegetation-frequency (B3) absorption proportional to the sum of reflectance in the near-infrared frequency band, values in the range of -1 to 1 (Gitelson et al., 1996), (Gabri., 2019).

$$GNDVI = (B8 – B3) / (B8 + B3) \quad (3\text{-}2)$$

Soil-adjusted vegetation index (SAVI). This index is a transition method that reduces the influence of soil brightness on the vegetation spectral index. where NIR is the near-infrared wavelength (B8) and Red wavelength (B4) and L is constant = 0.5 (Huete, 1988).

$$SAVI = (1+0.5) (B8 - B4)/ (B8 + B4 + 0.5) \quad (3\text{-}3)$$

Normalized Difference RedEdge Index (NDRE). This value is represented by a value calculated using the near-infrared (NIR) frequency range (B8) and the red-edged range (B5) between the visible red Rededge (B5) and NIR (B8), values in the range of -1 to 1 (Carlson & Ripley, 1997)

$$NDRE = (B8 – B5)/ (B8 + B5) \quad (3\text{-}4)$$

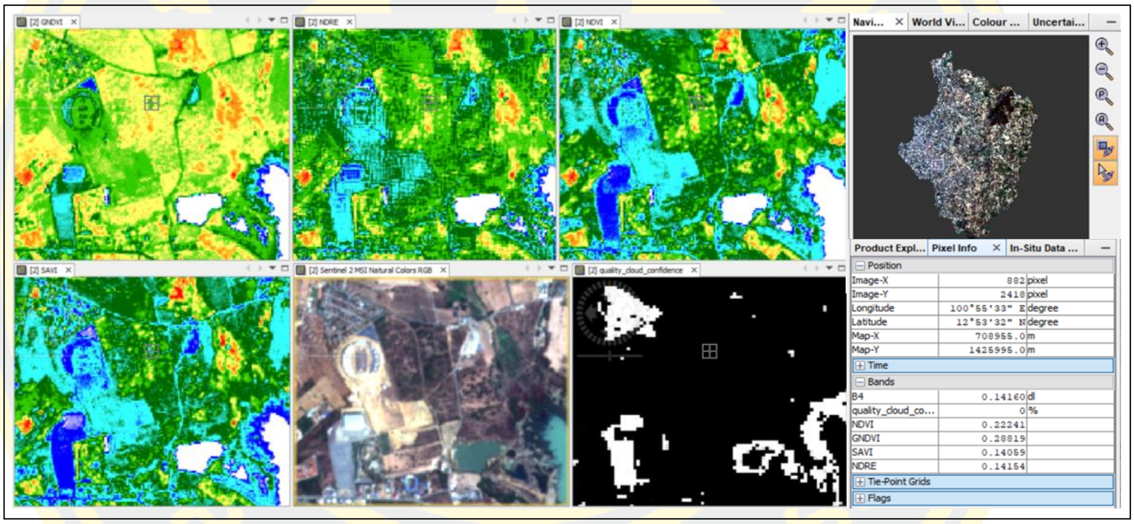


Figure 18 A sample of vegetation index calculation by SNAP

Sampling crop areas for the study

The number of samples and sampling methods used in this study were determined by (Congalton & Green, 2008). The appropriate number of samples depends on the size of the area. When the study area is less than 1 million acres and less than 12 data layers, the data layers should use at least 50 samples. Alternatively, if the area is large and there are more than 12 data layers, should be used at least 75 samples. To have a statistical representative with characteristics of normal distribution. In this study, the researcher chose the number of cassava plots in a total of 80 samples. The sample data is distributed throughout the cassava-cultivated area using a simple random sampling method. By using a Google Earth image survey of cassava plantations between 2020 and 2021. Then, the satellite image data that has been calculated vegetation index is overlaid with layer stacking to monitor the growth of cassava according to cultivation. The mean data for each index of cassava sample plots grown from the initial stage of cultivation to the 12-month near-harvest were used to develop the relationship between the vegetation index and the Kc reference by the Royal Irrigation Department (Alves, 2002), (Abdullakasim, 2017).

The most of research utilizes NDVI to collect phenology and other plant growth-related data. The assumptions for the growth of cassava were as follows (Kasetsart University, 2021): For 1-3 months during the budding stage, leaf tissue and root tissue were forming, and the NDVI value was less than 0.4 because the leaf area per unit was not high. In the growth stage on stem and leaves between the 3rd-6th months, the NDVI rises more than 0.4, Accumulation of food on cassava tuber 6-10 months, some lower leaves reduce water loss, the NDVI value reduce.

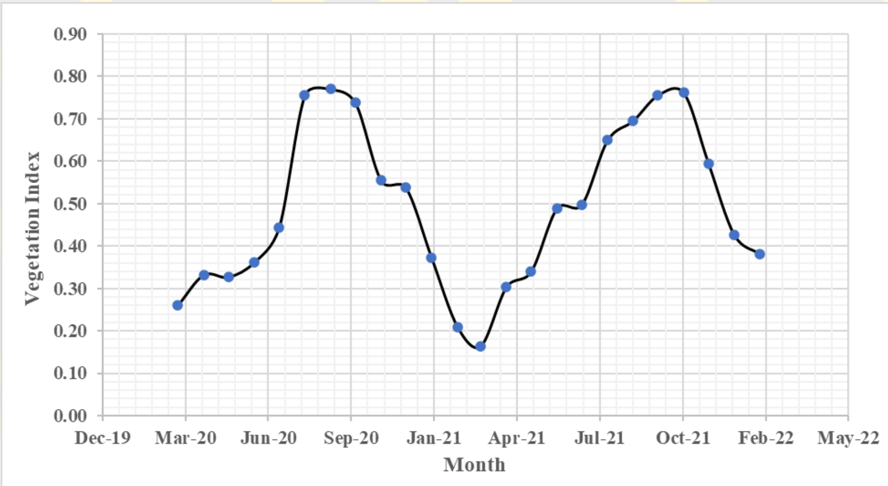


Figure 19 The sample time series of cassava area in Bang Lamung, Chon Buri, Thailand

Relationship Between Crop Coefficient and Vegetation Index

By linear regression analysis method will be used to find the relationship between the cassava crop coefficient referenced by the Royal Irrigation Department and the mean vegetation index data of the cassava sample plots from Sentinel-2 satellite images from prediction the start of planting to the harvesting period. The study uses the sample training in Bang Lamung District Chonburi, the start of cultivation is in March 2020 and the harvesting period is in February 2021.

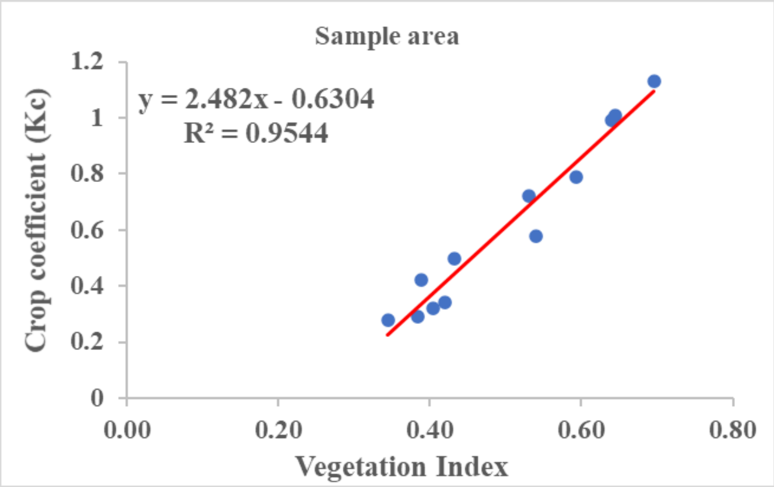


Figure 20 The sample correlation between the vegetation index and crop coefficient by Royal Irrigation Department

Furthermore, simple linear regression statistical calculations. Multiple linear regression analysis is also required for multi-variate correlation. To determine the correlation between the variables, it implements the same method as linear regression. As the result, the nearer the decision coefficient (R-Square) is to 1, the greater the relationship between the X and Y values. The average of the five vegetation indices is calculated at this point. The crop coefficients were correlated using sample plots received from Sentinel-2 satellite images. The model for calculating the crop coefficient from the index for estimating water usage was then the regression equation with the highest R-Squared value.

Spatial value Reference Crop Evapotranspiration

The monthly data for reference crop evapotranspiration (ETo) is calculated using the Penman-Monteith method. The evapotranspiration was used to create 8 stations. The Inverse Distance Weight (IDW) approach is used to create a spatial assessment for each station. Set the image point size equal to the photo data each month, every 12 months, to cover the study area. The satellite Sentinel-2 is 10 x 10 meters in size.

Crop Evapotranspiration

The crop Evapotranspiration calculation is calculated from a sample of 80 cassava trainings. Multiplying the crop coefficient (KC) by the range of monthly cassava growth with the Reference Crop Evapotranspiration (ETo) value of the cultivated area. For that period where the plant coefficient (Kc) is the value obtained from the development of the relationship the highest correlation, between the index value and the Kc referenced by the Royal Irrigation Department and the Reference Crop Evapotranspiration (ETo) calculated by the method Penman-Monteith.

Accuracy assessment

This study was using the results validation method to calculate the percentage difference between the crop coefficient (Kc) derived from the index of all 80 cassava crop samples and the crop coefficient (Kc) referenced by the Royal Irrigation Department. At each month, the calculated percentage difference between crop evapotranspiration values and the Root Mean Square Error (RMSE). The crop evapotranspiration values were calculated each month using the Kc values prescribed by the Royal Irrigation Department and the Kc values received from the index 80 cassava crop samples, with the degree of difference in the results determined by the Root Mean Square Error.

CHAPTER 4

RESULTS AND EXPERIMENTS

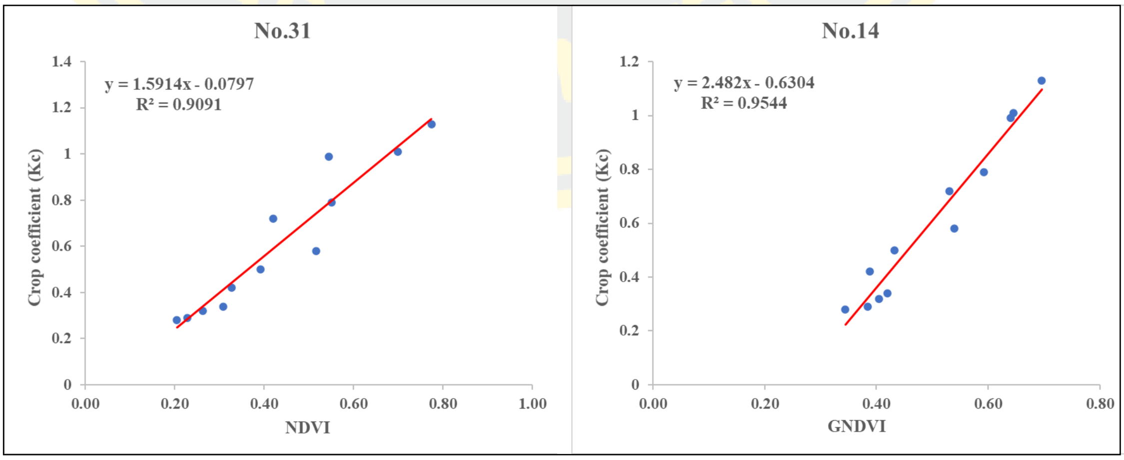
In this study, a total of 80 cassava sample plots were used as a sample group to study the estimation of crop water requirement throughout the growing season. The results are as follows.

Correlation of crop coefficient and vegetation index

The results of analyzing statistical relationship dependent variables are defined among the crop coefficients referenced by the Royal Irrigation Department. Having four vegetative index values as independent variables, which were analyzed using multiple linear regression equations.

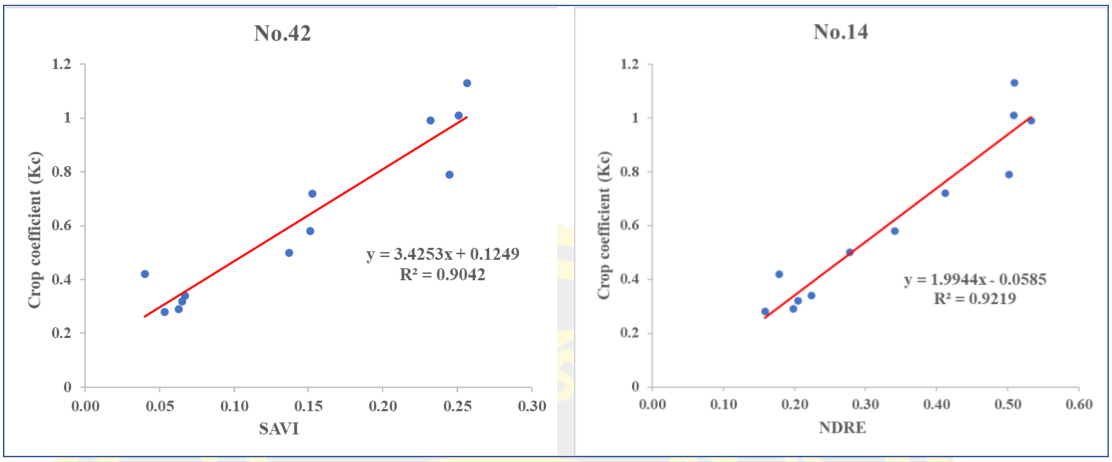
Table 6 Correlation equation of crop coefficient and vegetation index

Data	Equation	R^2	RMSE
1	Kc NDVI = 1.5914 NDVI – 0.0797	0.91	1.06
2	Kc GNDVI = 2.482 GNDVI – 0.6304	0.95	0.75
3	Kc SAVI = 3.4253 SAVI + 0.1249	0.90	1.09
4	Kc NDRE = 1.9944 NDRE – 0.0585	0.92	0.99



(a) (b)

Figure 21 Correlation between Vegetation Index NDVI (a), GNDVI (b), and Crop coefficients



(c) (d)

Figure 22 Correlation between Vegetation Index SAVI (c), NDRE (d), and Crop coefficients

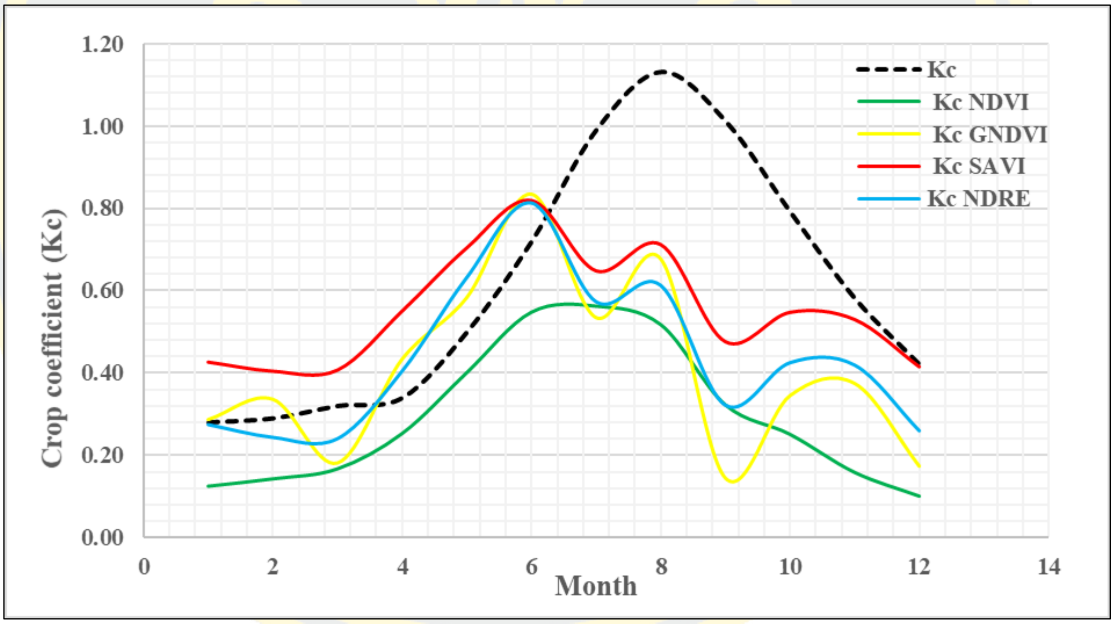


Figure 23 Comparison correlation of vegetation index and crop coefficient referenced by the Royal Irrigation Department

The results of the crop coefficients assessment using the vegetation index of 80 cassava sample plots were compared to the Royal Irrigation Department's reference crop coefficients. It was discovered that after the 6 months during the 7th to 12th month the cultivation area does not correspond to the cultivation period. As a result, the statistical correlation between Kc RID with Kc mean from vegetation index was investigated using multiple regression and R^2. Which the table 7 shows GNDVI, SAVI, and NDRE divided by the critical period of water deficiency impacting water cassava and consistency of the graph.

Table 7 Equation to predict the water crisis of cassava

Growth stage	Prediction equation	R^2
1-12 Month	Kc = -2.64+(2.86*NDVI) + (-1.80*GNDVI) +(11.69*SAVI) + (-9.34 NDRE)	0.65
1-6 Month	Kc = -0.11 + (0.94*SAVI)	0.91
7-12 Month	Kc = -3.21 + (-3.24*GNDVI) + (-3.16*NDRE) + (11.94*SAVI)	0.98

Estimation of Crop Coefficients

The results of an estimation of the crop coefficient (Kc) obtained from Kc predicted compared with the crop coefficient (Kc) referenced by the Royal Irrigation Department, as shown in Figure 24, showed that the lowest crop coefficient was 0.27. The highest value was 1.12, and the mean was 0.62, with an R-Squared value of 0.98.

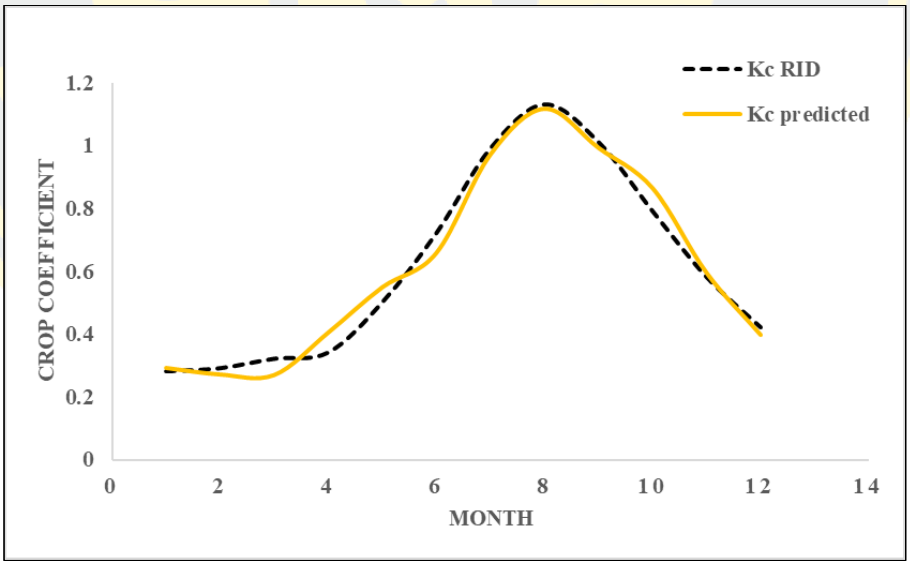


Figure 24 Comparison of crop coefficients predicted by the vegetation index with crop coefficients reference from the Royal Irrigation Department

The graph in Figure 24 compares the mean crop coefficient (Kc) obtained from each vegetation index of the 80 cassava crop samples with the crop coefficient (Kc) used by the Royal Irrigation Department. When considering monthly, the predicted crop coefficients were shown substantially correlated. Which could be described as follows:

- The Kc value obtained from the Kc predicted was greater, at 0.29 in the first month, during which the cassava was in the germination stage and established stage.
- The Kc obtained from the Kc predicted was lower, with a value of 0.27 in the second month, during which the cassava was in bud.
- The Kc obtained from the Kc predicted was less than 0.27 in the 3rd month during which the cassava was in the canopy stage
- The Kc obtained from the Kc predicted was higher, at 0.41 in the 4th month, during which the cassava was in the canopy stage.
- The Kc obtained from Kc predicted was higher, at 0.55 in the 5th month, during which the cassava was in the canopy stage to the tuber expansion stage.
- The Kc values obtained from Kc predicted were lower, at 0.66 in the 6th month, during which the cassava was in the canopy expansion stage to the tuber expansion stage.
- The Kc obtained from Kc predicted were lower, at 0.97, and 1.12 in the 7th-8th month, respectively, during which cassava was in the stage of tuber enlargement, weight accumulation, and starch accumulation.
- The Kc obtained from Kc predicted was lower, 0.99, 0.86 in the 9th-10th month, respectively, during which cassava was in tuber size, weight accumulation, and starch accumulation.
- The Kc values obtained from the Kc predicted were lower, at 0.60, and 0.40 in the 11th-12th month, respectively, during the period in which the cassava was in the dormant stage of stem growth and was ready for harvest.

In conclusion, when considering from the figure 24, reveals that the Kc value in the early planting stage is low, then the Kc value tends to gradually increase according to the growth sequence of the cassava. The Kc predicted value was obtained from the vegetation index of the plot. The samples with the highest accuracy, as shown in Figure 23, showed that the Kc predicted of cassava in the 4-5th month was during the period when cassava was in the canopy stage. It is consistent with the Kc value referenced by the Department of Education. And in the 6th-9th month, it is the period when the cassava is in the tuber growth stage and the Kc predicted value obtained from the index is the highest during the 10th-12th month when the cassava begins to enter the dormancy or stem growth stops and leaves were discarded; the Kc predicted values obtained from the index were lower and tended to decline accordingly.

Estimated crop evapotranspiration

Estimated results of crop evapotranspiration (ET) calculated using crop coefficient (Kc) predicted obtained from the vegetation index. Compared with the crop evapotranspiration (ET) value calculated using crop coefficient (Kc) referenced by the Royal Irrigation Department. As shown in Figure 24, from the results obtained, it was found that the quantitative value of crop evapotranspiration (ET) minimum of 1.07 mm/day, a maximum of 3.69 mm/day, and an average of 2.17 mm/day.

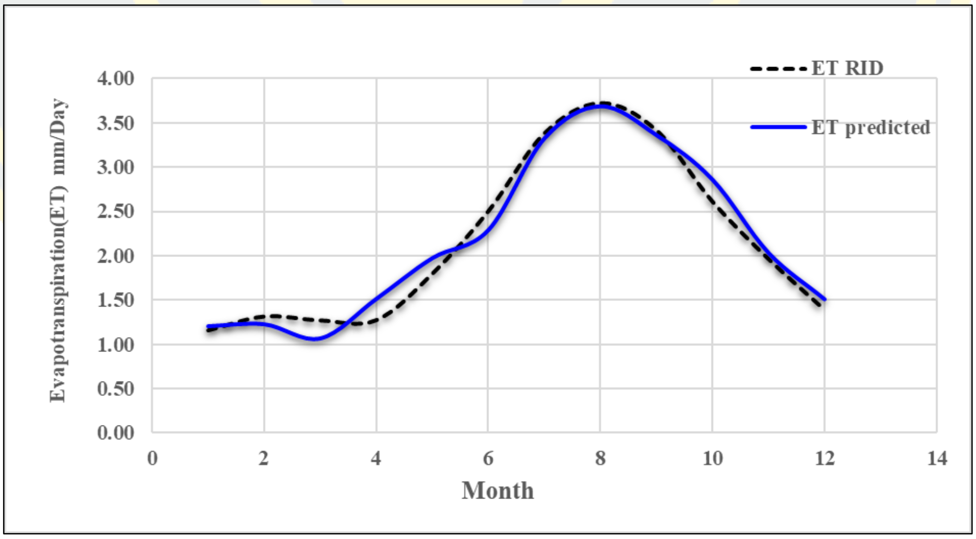


Figure 25 Comparison of ET estimated with predicted Kc with Mean ET calculated by Kc from the Royal Irrigation Department

According to the graph displaying the comparison between the average value of crop evapotranspiration (ET) determined using the crop coefficient (Kc) predicted obtained from the vegetation index and the value of crop evapotranspiration

(ET) derived using the Royal Irrigation Department's Kc value when considering monthly observed in a sample of 80 cassava sample can be described as follows:

- During the first 1-3 months, the cassava was in the germination stage and established. The ET value calculated using Kc predicted obtained from the vegetation index is lower, with a value of 1.21, 1.23, and 1.07, respectively.
- During the 4th-6th months of the canopy stage, the ET value calculated using Kc predicted obtained from vegetation index were less than on the 6th month and were higher at 1.52, 1.98, and 2.29 on the 5th-6th month respectively.
- During the 7th-10th month, during the cassava tuber enlargement stage, ET values calculated using Kc predicted obtained from the vegetation index were higher in the 10th month and were less than those at 3.33, 3.69, and 3.36, respectively.
- During the 11th-12th months of dormancy (growth stopped, leaf dropping), ET values calculated using Kc predicted obtained from the vegetation index were higher than 2.03 and 1.15, respectively.

The average crop evapotranspiration (ET) value was computed using Kc projected from the vegetation index, and ET was calculated using the Royal Irrigation Department. The germination and maturation time for cassava is 1-3 months, hence the ET by Kc predicted value is low at this stage. The period for starch accumulation and cassava tuber enlargement is 6-10 months, during this period, the crop evapotranspiration will gradually increase in relation to the stage of growth. Crop water requirement, the value rises in steps with the eighth month being the peak of growth and high-water requirement. And during the 11th-12th month, when the yield is constant till harvesting, crop water requirement tends to steadily decrease until the harvesting season.

Furthermore, when considering the average crop evapotranspiration throughout the growing season of the sample of 80 cassava, representing an area of approximately 373.94 rai or 598,304 square meters, it was found that the crop water consumption (ET) calculated using Kc predicted was 26.08 mm./day and accounted for the volume of crop water requirement 116,968 cubic meters, while the crop evapotranspiration (ET) calculated using Kc referenced by the Royal Irrigation Department was 25.81 mm./day and accounted for 115,757 cubic meters of crop water requirement, with a percentage difference of 1.05.

Accuracy assessment results

The comparison results of the percentage difference of Kc referenced from Royal Irrigation Department with Kc value predicted from 80 samples of cassava plots as shown in Table 8, and the comparison result of percentage difference of mean ET calculated using Kc referenced by Royal Irrigation Department and ET calculated using Kc predicted from the 80 cassava plot samples were shown in Table 9 and the square root of squared error was calculated as shown in Table 10.

Table 8 Compare the percentage difference between Kc RID and Kc predicted

Month	Kc RID	Kc predicted	Percentage difference
1	0.28	0.29	4.00
2	0.29	0.27	-6.00
3	0.32	0.27	-16.00
4	0.34	0.41	19.00
5	0.50	0.55	10.00
6	0.72	0.66	-9.00
7	0.99	0.97	-2.00
8	1.13	1.12	-1.00
9	1.01	0.99	-2.00
10	0.79	0.86	9.00
11	0.58	0.60	3.00
12	0.42	0.40	-5.00

Table 9 Compare the percentage difference of ET RID with ET by Kc predicted

Month	ET RID	ET predicted	Percentage difference
1	1.16	1.21	-4.00
2	1.31	1.23	7.00
3	1.27	1.07	19.00
4	1.27	1.52	-16.00
5	1.80	1.98	-9.00
6	2.50	2.29	9.00
7	3.39	3.33	2.00
8	3.73	3.69	1.00
9	3.42	3.36	2.00
10	2.61	2.86	-9.00
11	1.96	2.03	-3.00
12	1.39	1.51	-8.00

Table 10 Root Mean Square Error

Information	RMSE
Kc from the vegetation index predicted	0.04
ET from Kc predicted	0.15

CHAPTER 5
DISCUSSION AND CONCLUSION

Discussion

The spatial vegetation coefficients were developed in this study using a linear regression analysis method to establish the correlation between the vegetation index from satellite images and the vegetation coefficient. Which the correlation equation for predicting crop coefficients revealed that the correlation curve with linear regression method that used one variable to predict, resulted in variability and instability in predicting crop coefficients. Subsequently, stepwise multiple linear regression using multiple variables was analyzed to predict different growth stages of Kc from NDVI, GNDVI, SAVI and NDRE for each growth stage, these were divided by cassava water demand range, which SAVI index correlates with cassava life span 1-6 months. As that is a modified index to reduce soil reflection, the decision coefficient of equation R2 = 0.91. Where GNDVI, NDRE, and SAVI were related to cassava ages 7-12 months, the decision coefficient of equation R2 = 0.98 from the predicted crop coefficient that was found to be consistent in the same direction.

Calculating the crop evapotranspiration by method Penman-Monteith From the predicted crop coefficient multiplied by the ETo value of the study area, it was found that the crop evapotranspiration of cassava was similar to the crop evapotranspiration calculated from the Kc value, referring to the Royal Irrigation Department. According to the accuracy results, the percentage difference was within the acceptable range. Including the calculation of the square root of the mean square error (RMSE), the error is close to zero. It demonstrated the accuracy of applying remote sensing technology based on satellite imagery for spatial measurement of crop evapotranspiration (Chansuwan, W, 2021). According to the results of the study, cassava had not been planted and harvested at the same time in the plots of the study area. The analysis of the Vegetation Index at 12 months revealed unusual values because this study was conducted in non-irrigated areas. Further studies on farmland in irrigated areas as a database should be conducted in order to gather the most consistent data.

Conclusion

The determination of crop water requirements for addition to traditional methods, it can be used to predict crop coefficients, the correlation between Kc and the vegetation index was calculated using satellite images that can be used as a model to monitor crop evapotranspiration conveniently and quickly in specific area. Since the data in the model is open asses that is simple to access and process. The remote sensing can be used to monitor spatial levels by satellite image. It has the benefit of the ability to investigate cover to a wide area, and cultivation data can be continuously monitored due to the orbital re-imaging of the sensinel-2.

In this study, the spatial vegetation coefficient method of cassava (Kc cassava) was applied to determine the cassava evapotranspiration (ET cassava) by the method of using the vegetation index to find the correlation with the crop coefficient (Kc RID). Then calculated the water requirement of cassava that found it was a consistent value. The Kc values were obtained from the Kc predicted equations of the indices NDVI, GNDVI, SAVI, and NDRE. The RMSE values for the calculated predicted Kc throughout the growing season, divided from the growth periods of 1-6 months, and 7-12 months, were 0.65, 0.91, and 0.98, respectively. However, it was considered that the ETc predicted values computed using those equations for the sample plot of cassava which were between 1.07 and 3.69 (Total 26.08), these values were consistent in the same direction as the values of ETc RID of the value between 1.16-3.39. (Total 25.81), the results of estimated casava evapotranspiration from RMSE method were 0.15. Therefore, the geographic ETc of cassava in Bang Lamung District, Thailand revealed that crop evapotranspiration can be applied in a variety of disciplines. In addition to irrigation in water supply management and allocation of irrigation water, land development. Furthermore, in the field of agricultural extension services, there are multiple areas where the general information in this segment can be applied in future developments.

Suggestions

1) In this study, the estimation of cassava water requirement outside of irrigated areas was investigated. Which is an agricultural area depending on rainfall, there is no definite management of irrigated areas. In the irrigated area, the additional study should be carried out on the cultivated area. To determine cassava’s water evapotranspiration throughout the whole growing season.

2) According to the first recommendation, the data collected was used for processing and study in this study. It is the data for the year of drought in 2019. This could cause satellite data to fluctuate depending on the features of plants that have been damaged by natural disasters, along with a consequence of crop rotation. As a result, comprehensive data validation is not feasible; that seems to be, there ought to be field record data with each time to cover the growing season, such as cassava cutting before harvesting or having problems with plant diseases or cultivating out of season or in a different manner than usual.

3) With the cloud filtering system of Sentinel-2 satellite data, there are still a lot of discrepancies. Because only the top clouds are filtered by cloud mask data. Furthermore, there could be an issue in the cloudy area’s implementation. Blue band factors should be incorporated in additional research, and perhaps other ways to modify cloudy data should be investigated to obtain precise data.

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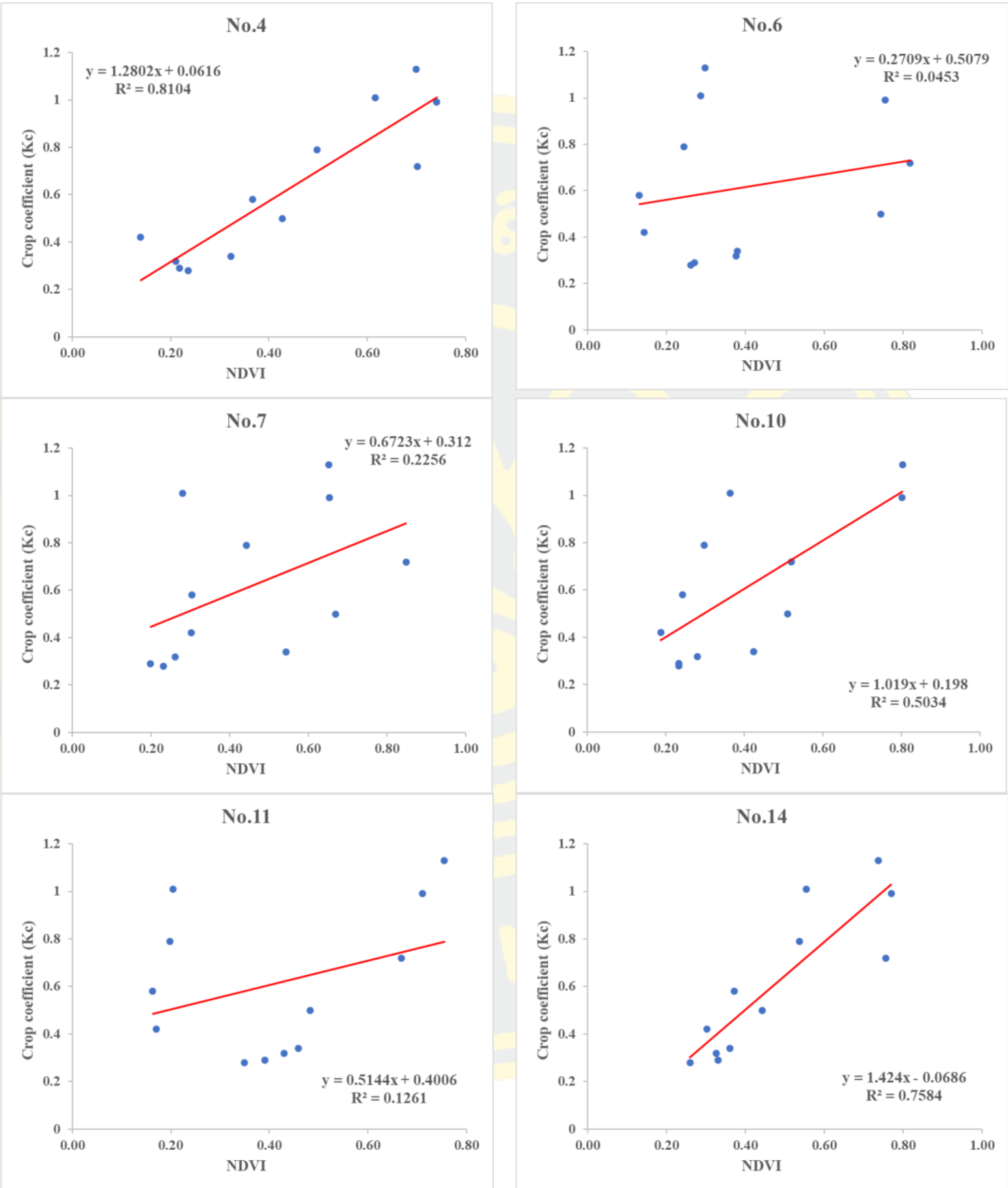
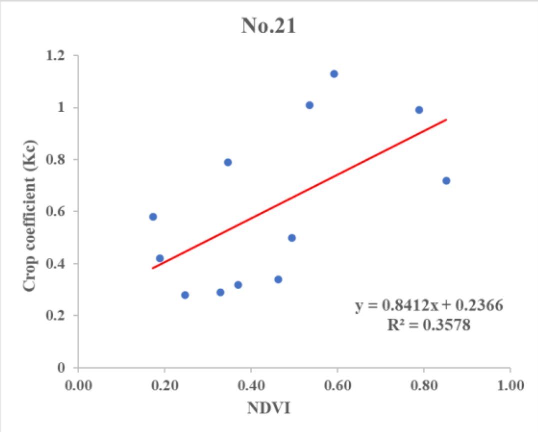
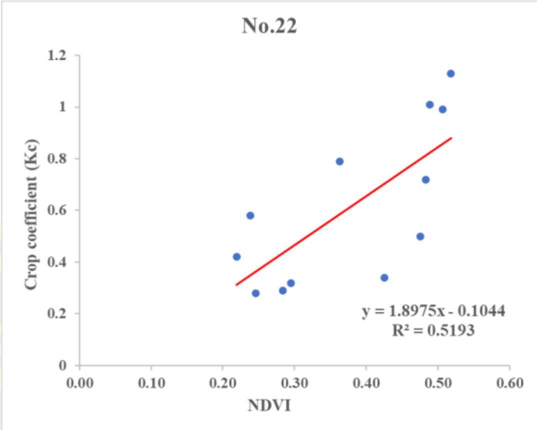
APPENDICES

Figure I-1 The Correlation of NDVI with Crop coefficient cassava by RID




No.21
Crop coefficient (Kc)
NDVI
y = 0.8412x + 0.2366
R² = 0.3578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Crop coefficient (Kc)
NDVI
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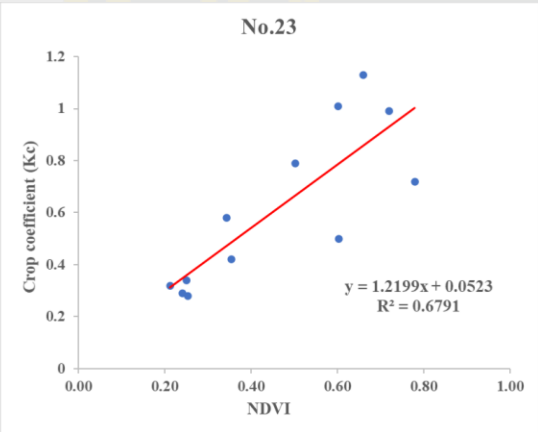
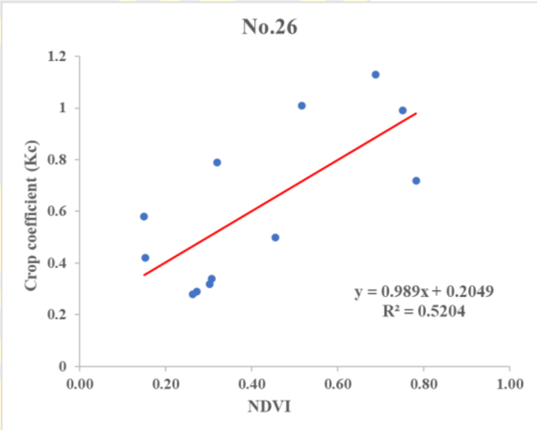
R² = 0.5193


No.23
Crop coefficient (Kc)
NDVI
y = 1.2199x + 0.0523
R² = 0.6791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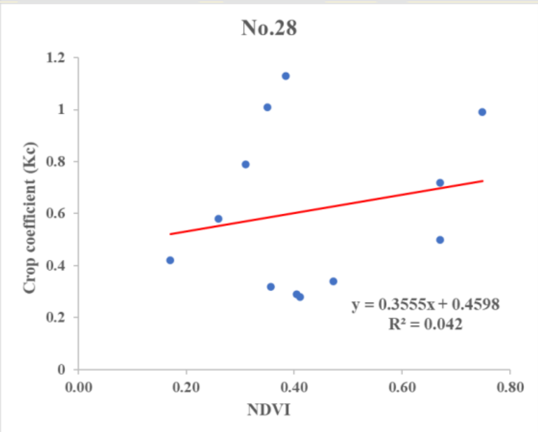
Crop coefficient (Kc)
NDVI
y = 0.989x + 0.2049
R² = 0.5204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Crop coefficient (Kc)
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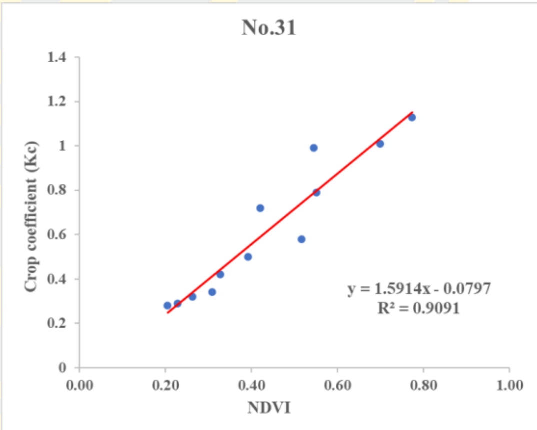
R² = 0.042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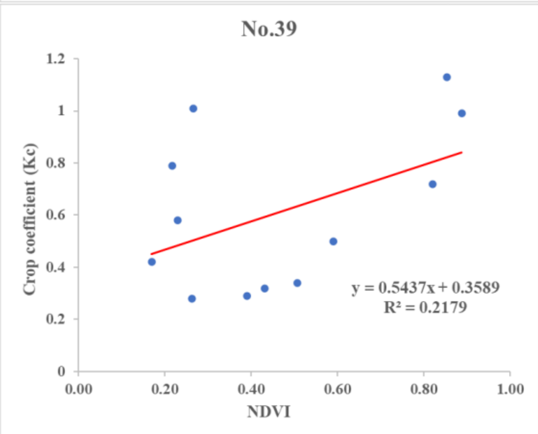
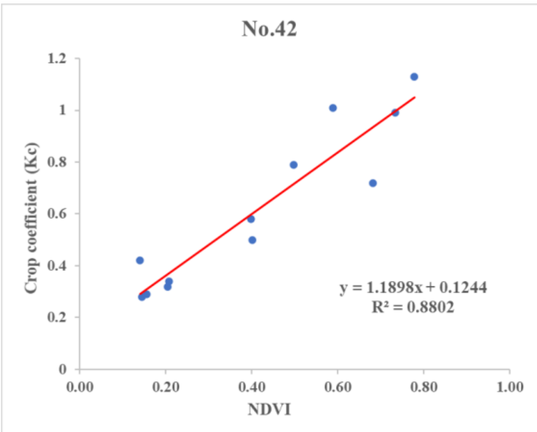
Crop coefficient (Kc)
NDVI
y = 1.5914x - 0.0797
R² = 0.9091


No.39
Crop coefficient (Kc)
NDVI
y = 0.5437x + 0.3589
R² = 0.2179


No.42
Crop coefficient (Kc)
NDVI
y = 1.1898x + 0.1244
R² = 0.8802

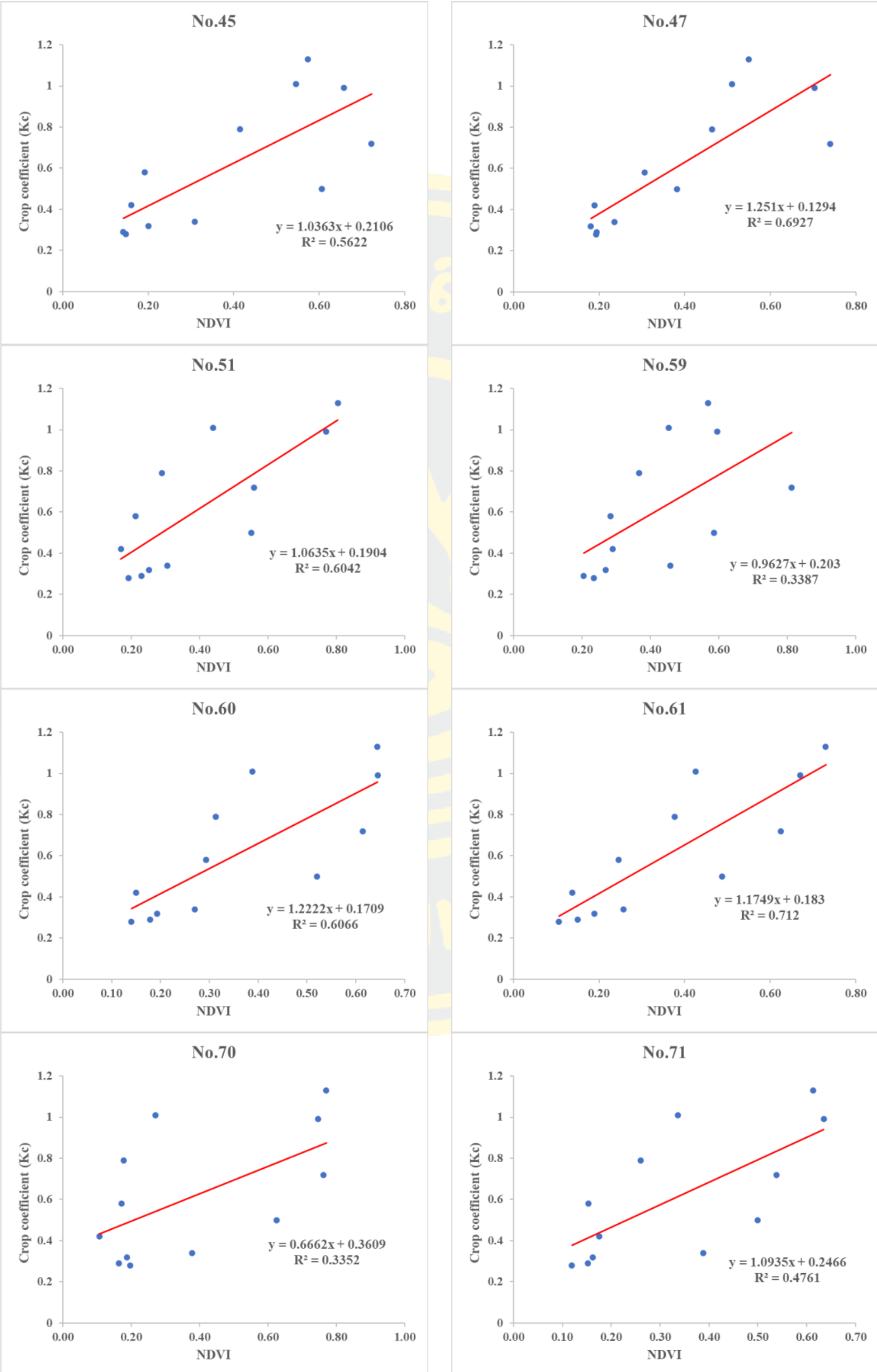
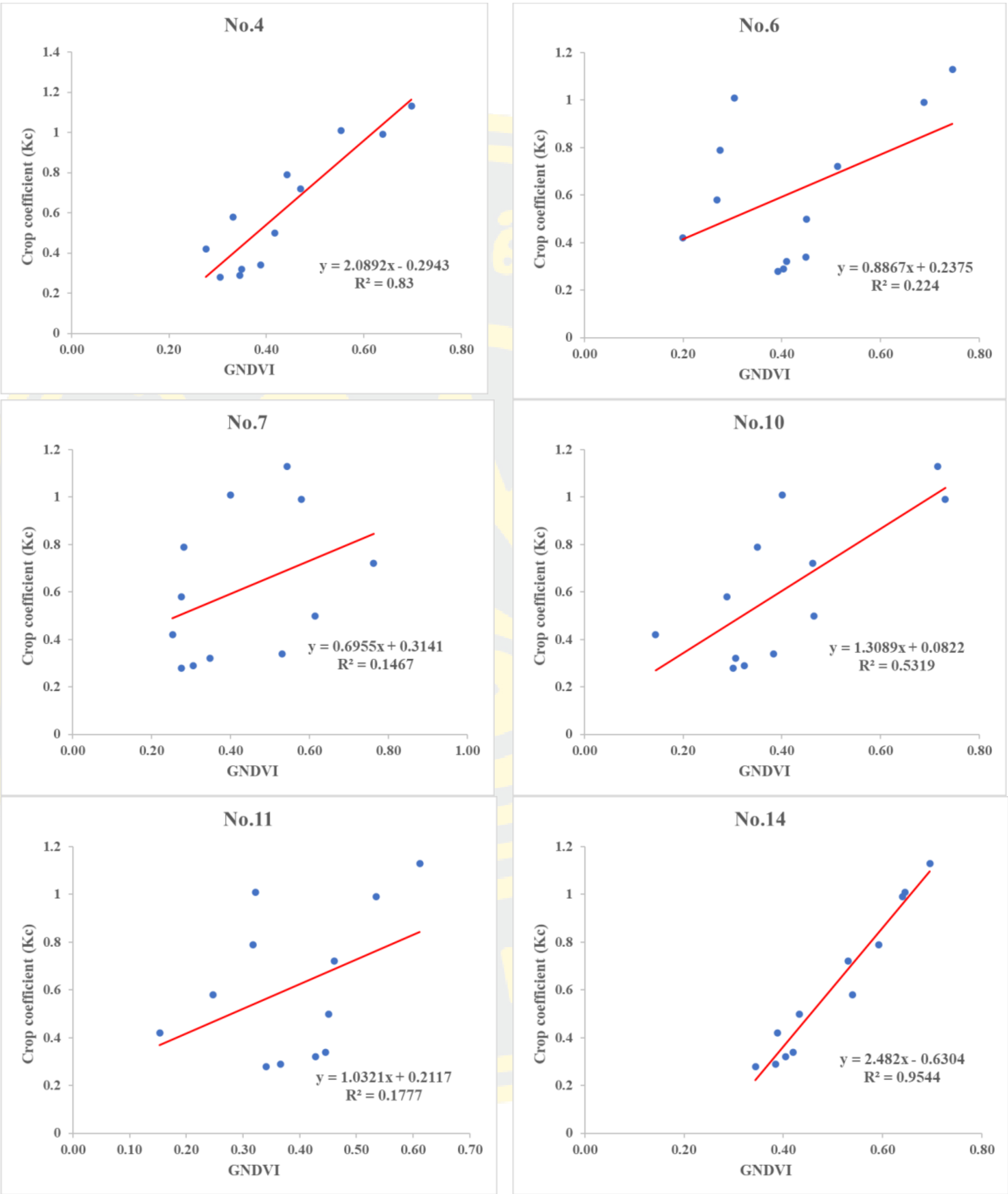
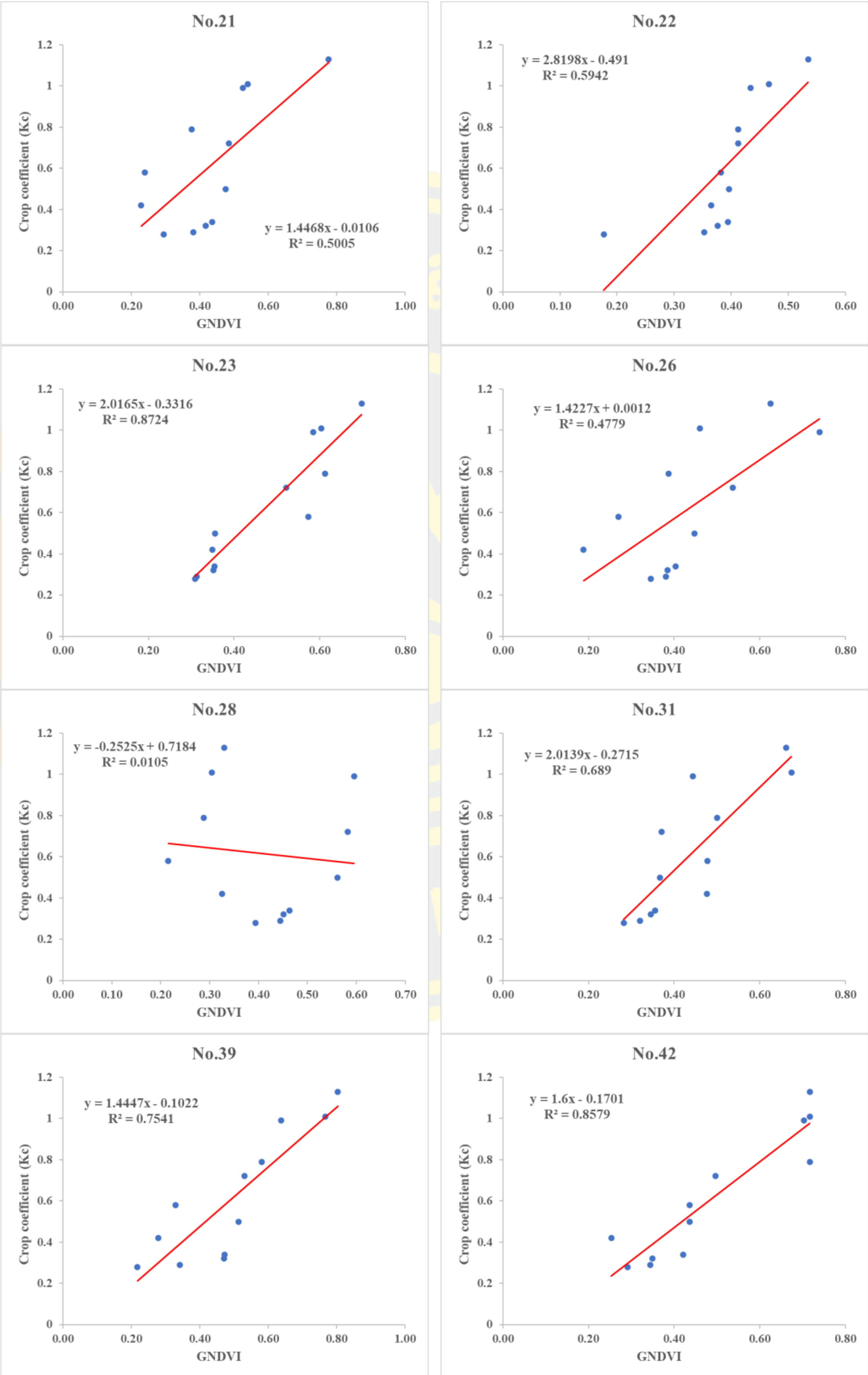
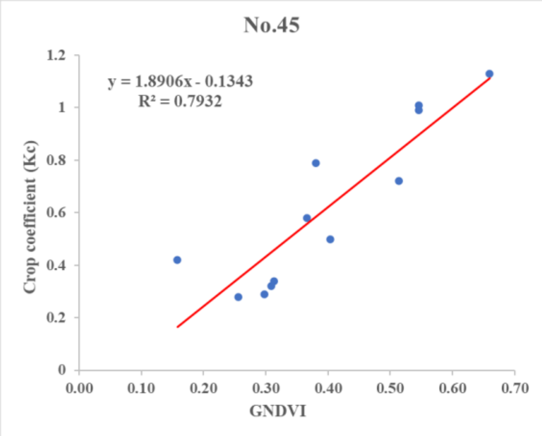
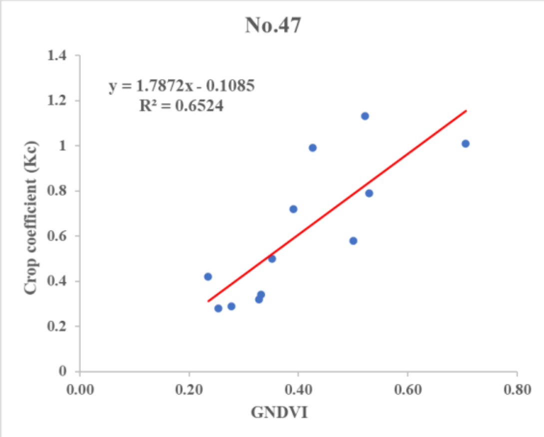

No.45
y = 1.0363x + 0.2106
R² = 0.5622
No.47
y = 1.251x + 0.1294
R² = 0.6927
No.51
y = 1.0635x + 0.1904
R² = 0.6042
No.59
y = 0.9627x + 0.203
R² = 0.3387
No.60
y = 1.2222x + 0.1709
R² = 0.6066
No.61
y = 1.1749x + 0.183
R² = 0.712
No.70
y = 0.6662x + 0.3609
R² = 0.3352
No.71
y = 1.0935x + 0.2466
R² = 0.4761
Crop coefficient (Kc)
NDVI

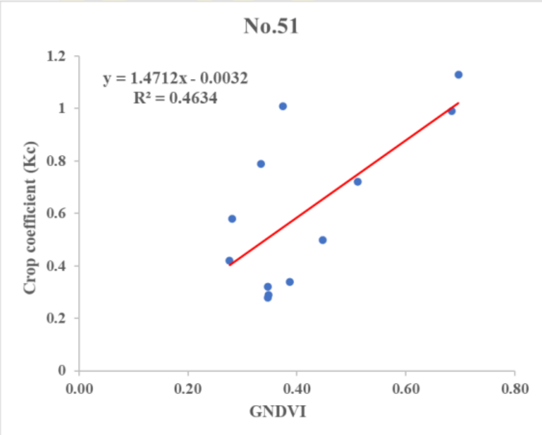
Figure I-2 The Correlation of GNDVI with Crop coefficient cassava by RID

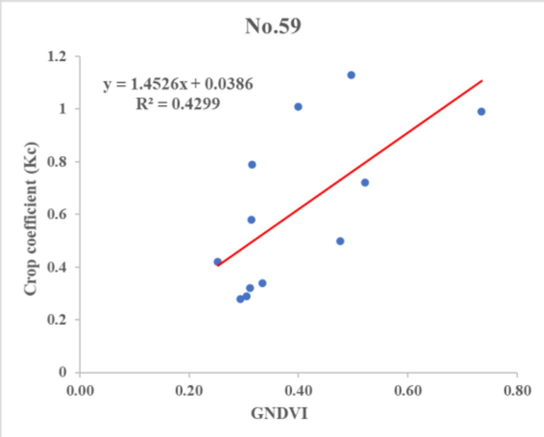


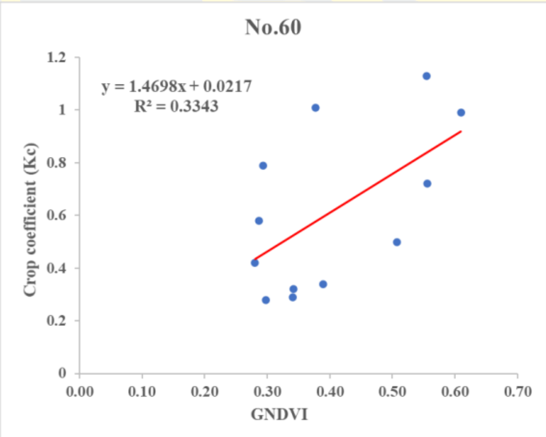

No.21
y = 1.4468x - 0.0106
R² = 0.5005
Crop coefficient (Kc)
GNDVI
No.22
y = 2.8198x - 0.491
R² = 0.5942
Crop coefficient (Kc)
GNDVI
No.23
y = 2.0165x - 0.3316
R² = 0.8724
Crop coefficient (Kc)
GNDVI
No.26
y = 1.4227x + 0.0012
R² = 0.4779
Crop coefficient (Kc)
GNDVI
No.28
y = -0.2525x + 0.7184
R² = 0.0105
Crop coefficient (Kc)
GNDVI
No.31
y = 2.0139x - 0.2715
R² = 0.689
Crop coefficient (Kc)
GNDVI
No.39
y = 1.4447x - 0.1022
R² = 0.7541
Crop coefficient (Kc)
GNDVI
No.42
y = 1.6x - 0.1701
R² = 0.8579
Crop coefficient (Kc)
GNDVI

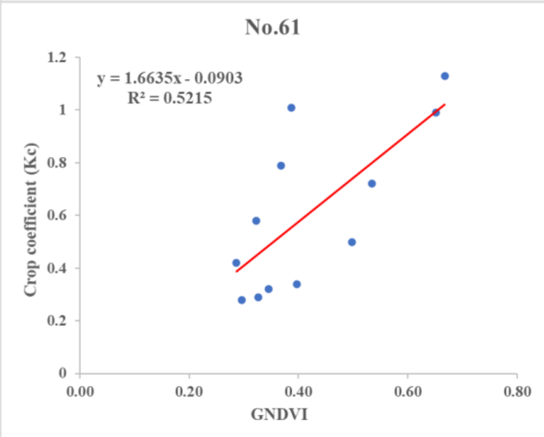

No.45
y = 1.8906x - 0.1343
R² = 0.7932
Crop coefficient (Kc)
GNDVI

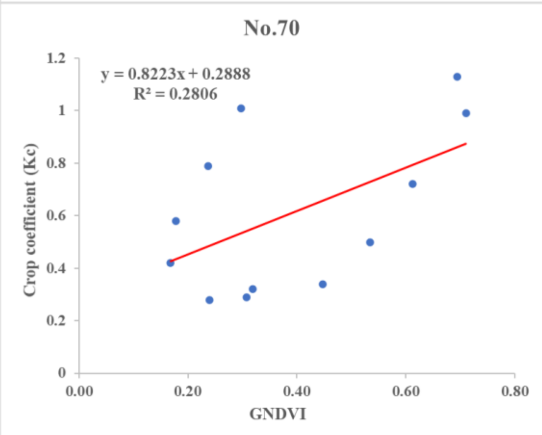

No.47
y = 1.7872x - 0.1085
R² = 0.6524
Crop coefficient (Kc)
GNDVI

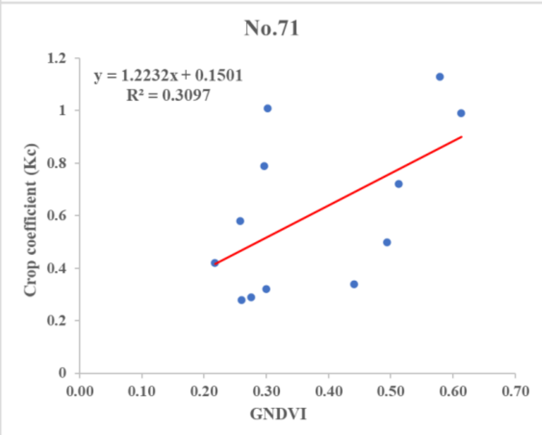

No.51
y = 1.4712x - 0.0032
R² = 0.4634
Crop coefficient (Kc)
GNDVI


No.59
y = 1.4526x + 0.0386
R² = 0.4299
Crop coefficient (Kc)
GNDVI


No.60
y = 1.4698x + 0.0217
R² = 0.3343
Crop coefficient (Kc)
GNDVI


No.61
y = 1.6635x - 0.0903
R² = 0.5215
Crop coefficient (Kc)
GNDVI


No.70
y = 0.8223x + 0.2888
R² = 0.2806
Crop coefficient (Kc)
GNDVI


No.71
y = 1.2232x + 0.1501
R² = 0.3097
Crop coefficient (Kc)
GNDVI

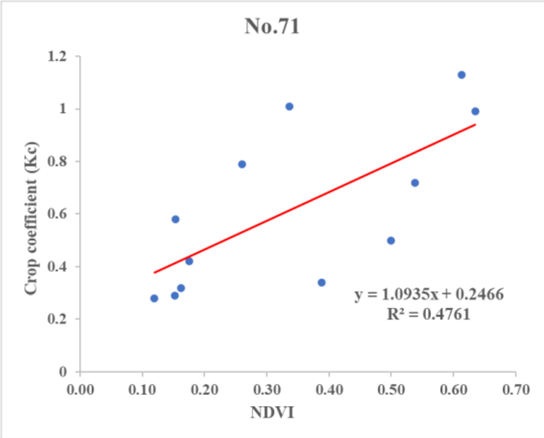
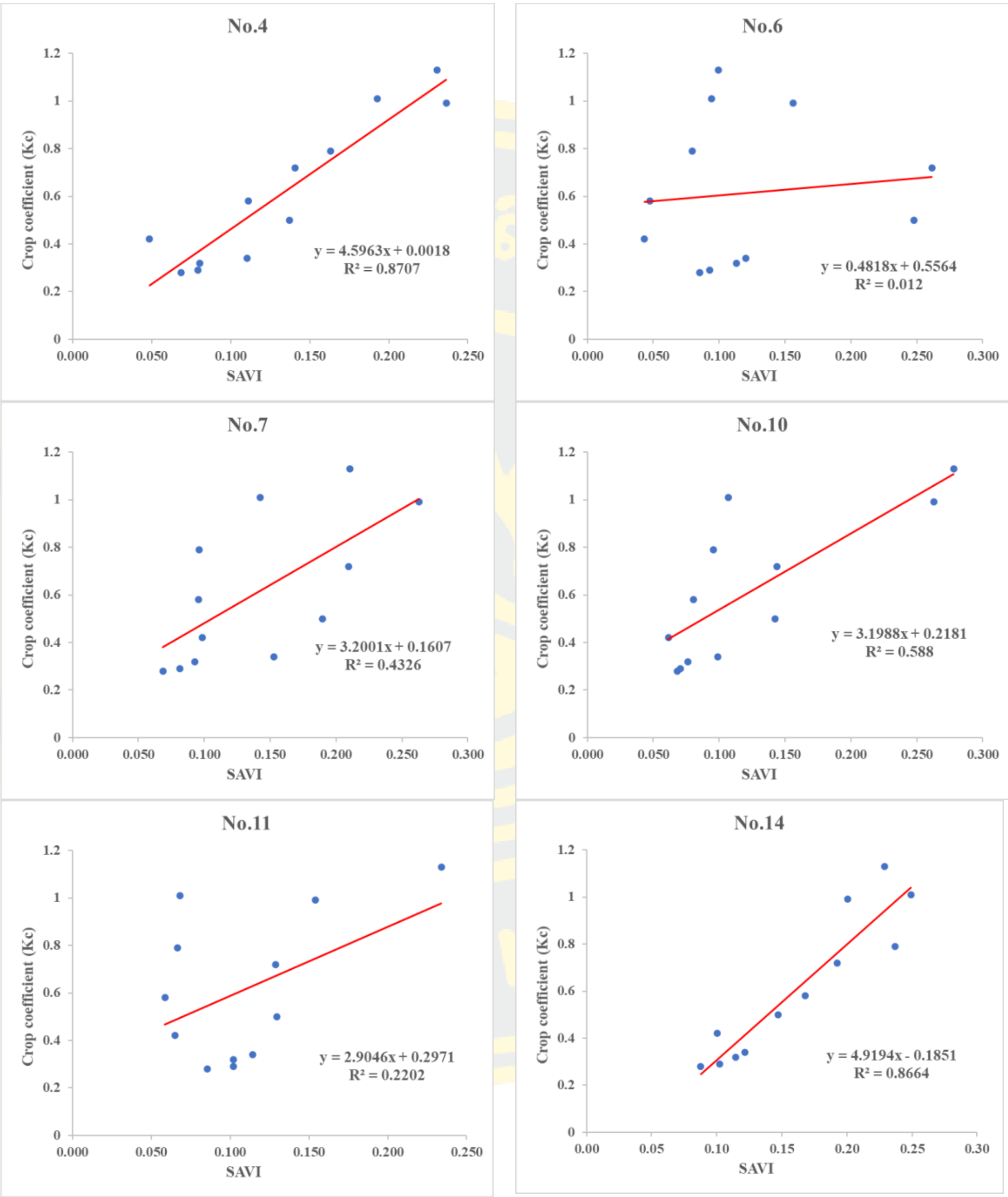
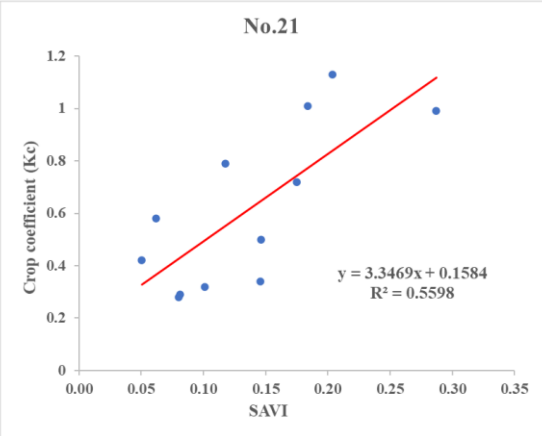
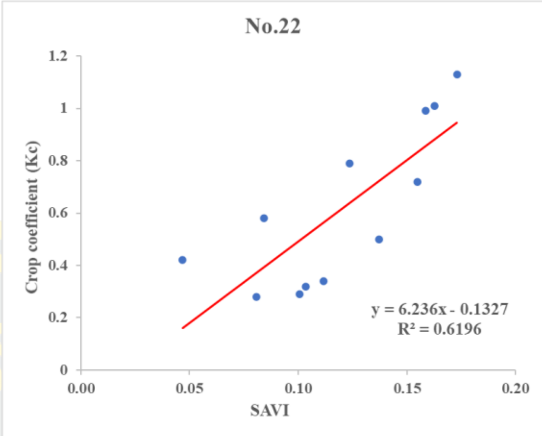
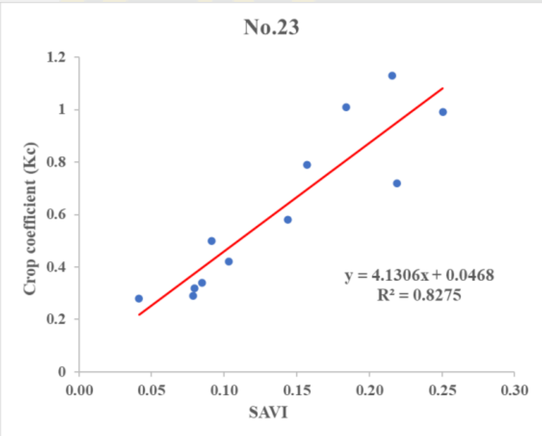

No.71
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
NDVI
y = 1.0935x + 0.2466
R² = 0.4761

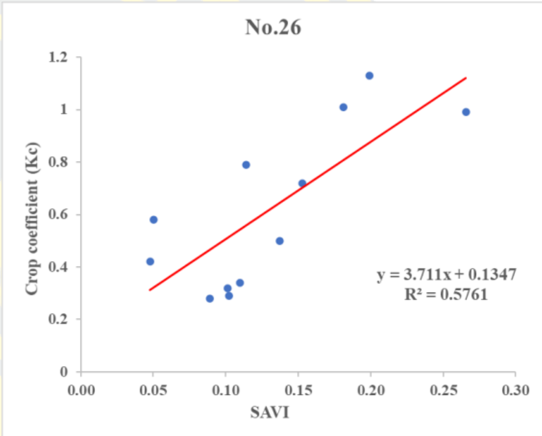
Figure I-3 The Correlation of SAVI with Crop coefficient cassava by RID

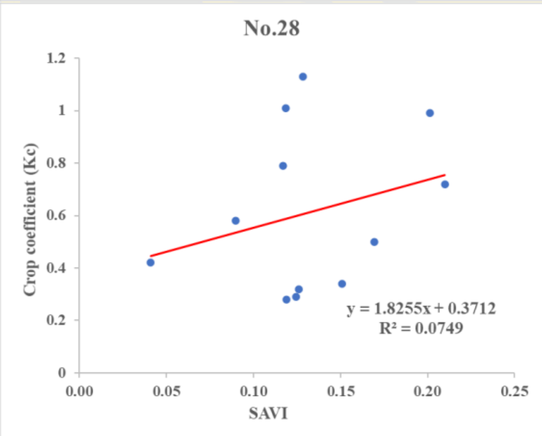


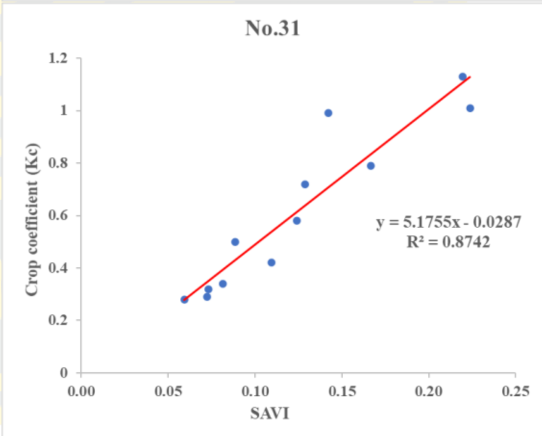

No.21
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 3.3469x + 0.1584
R² = 0.5598
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
SAVI

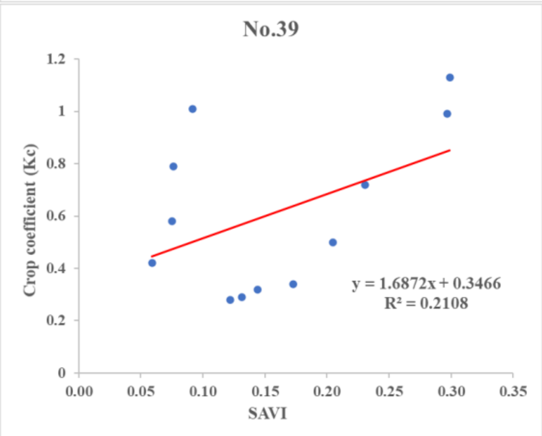

No.22
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 6.236x - 0.1327
R² = 0.6196
0.00
0.05
0.10
0.15
0.20
SAVI

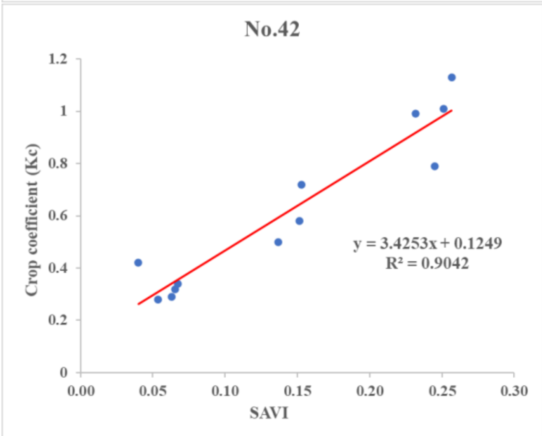

No.23
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 4.1306x + 0.0468
R² = 0.8275
0.00
0.05
0.10
0.15
0.20
0.25
0.30
SAVI


No.26
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 3.711x + 0.1347
R² = 0.5761
0.00
0.05
0.10
0.15
0.20
0.25
0.30
SAVI


No.28
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 1.8255x + 0.3712
R² = 0.0749
0.00
0.05
0.10
0.15
0.20
0.25
SAVI


No.31
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 5.1755x - 0.0287
R² = 0.8742
0.00
0.05
0.10
0.15
0.20
0.25
SAVI


No.39
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 1.6872x + 0.3466
R² = 0.2108
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
SAVI


No.42
Crop coefficient (Kc)
1.2
1
0.8
0.6
0.4
0.2
0
y = 3.4253x + 0.1249
R² = 0.9042
0.00
0.05
0.10
0.15
0.20
0.25
0.30
SAVI

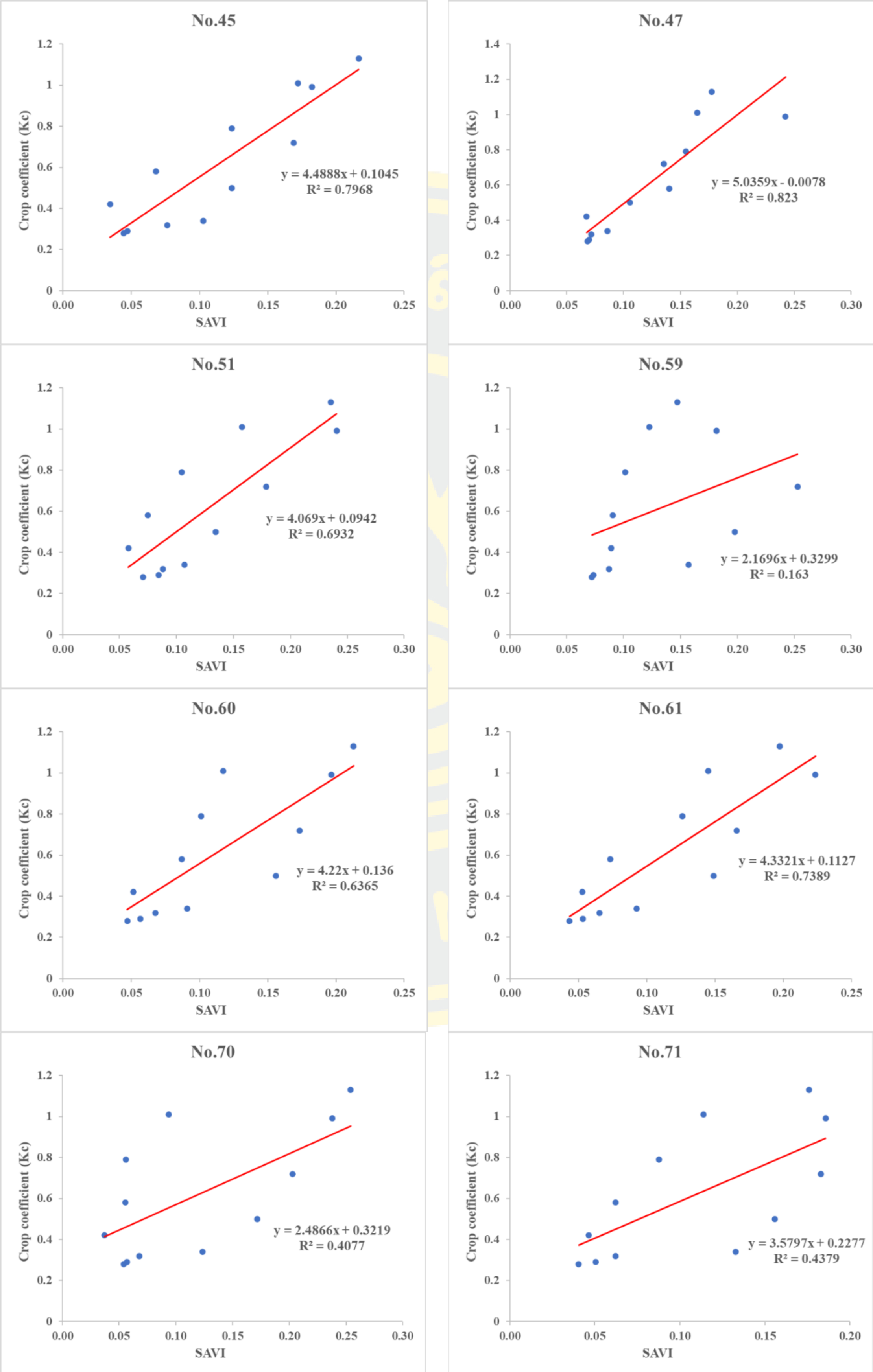
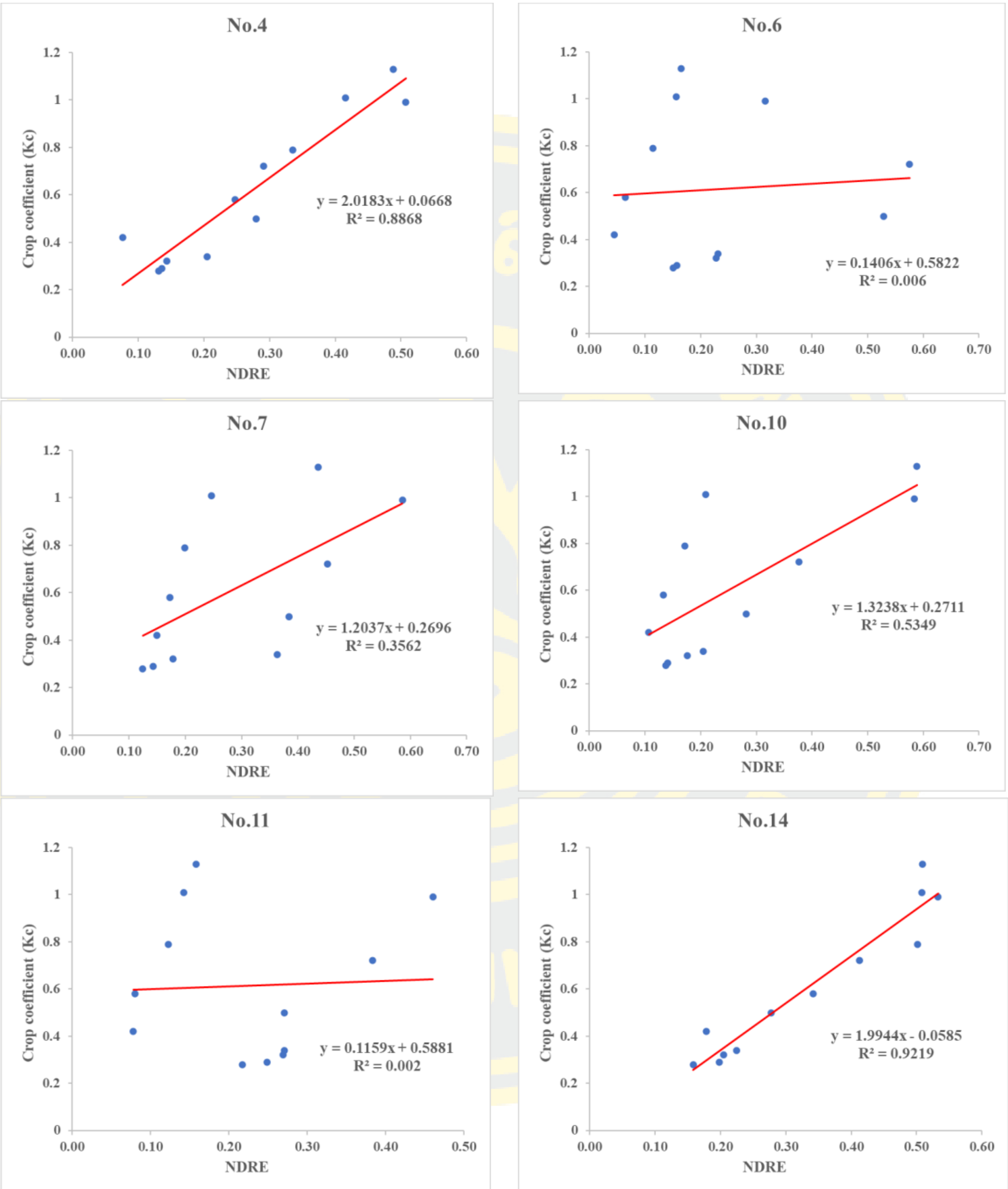
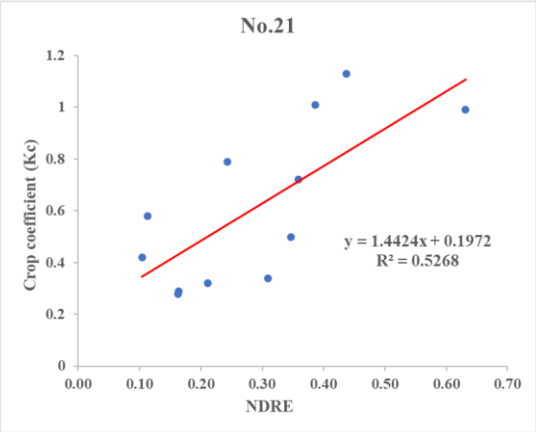
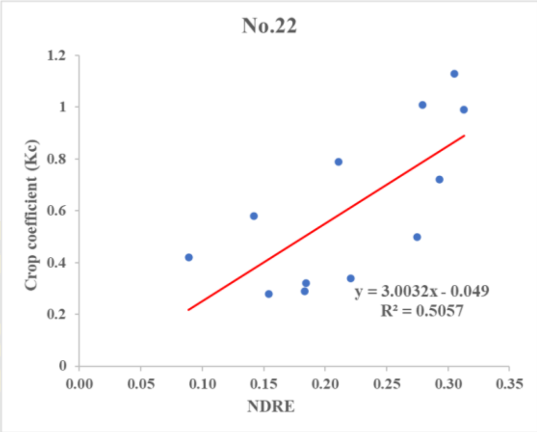
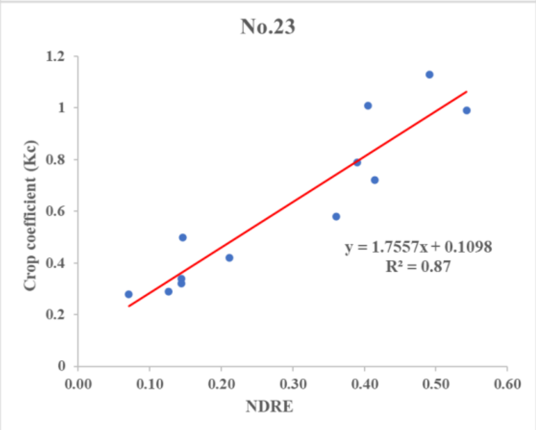

No.45
Crop coefficient (Kc)
SAVI
y = 4.4888x + 0.1045
R² = 0.7968
No.47
Crop coefficient (Kc)
SAVI
y = 5.0359x - 0.0078
R² = 0.823
No.51
Crop coefficient (Kc)
SAVI
y = 4.069x + 0.0942
R² = 0.6932
No.59
Crop coefficient (Kc)
SAVI
y = 2.1696x + 0.3299
R² = 0.163
No.60
Crop coefficient (Kc)
SAVI
y = 4.22x + 0.136
R² = 0.6365
No.61
Crop coefficient (Kc)
SAVI
y = 4.3321x + 0.1127
R² = 0.7389
No.70
Crop coefficient (Kc)
SAVI
y = 2.4866x + 0.3219
R² = 0.4077
No.71
Crop coefficient (Kc)
SAVI
y = 3.5797x + 0.2277
R² = 0.4379

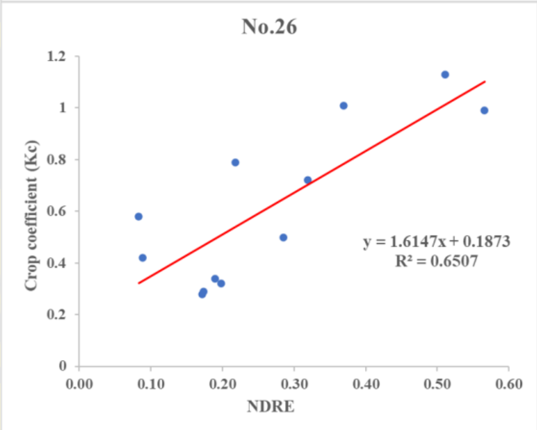
Figure I-4 The Correlation of NDRE with Crop coefficient cassava by RID

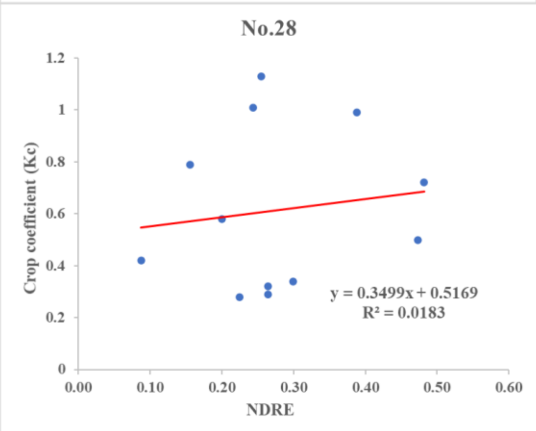


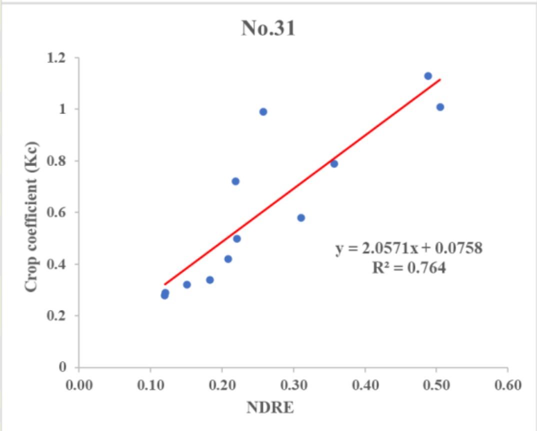

No.21
Crop coefficient (Kc)
NDRE
y = 1.4424x + 0.1972
R² = 0.5268

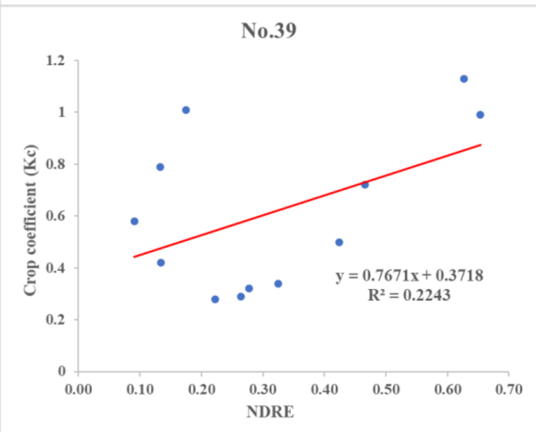

No.22
Crop coefficient (Kc)
NDRE
y = 3.0032x - 0.049
R² = 0.5057

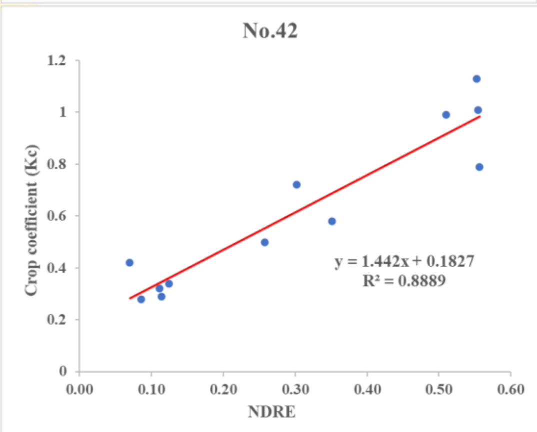

No.23
Crop coefficient (Kc)
NDRE
y = 1.7557x + 0.1098
R² = 0.87

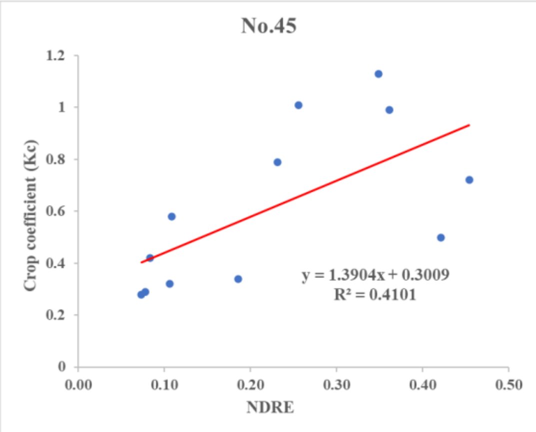

No.26
Crop coefficient (Kc)
NDRE
y = 1.6147x + 0.1873
R² = 0.6507

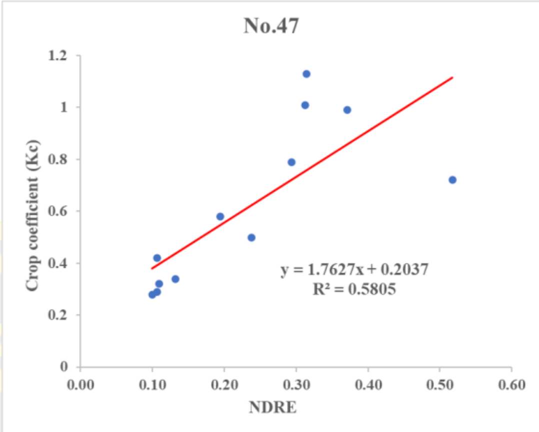

No.28
Crop coefficient (Kc)
NDRE
y = 0.3499x + 0.5169
R² = 0.0183

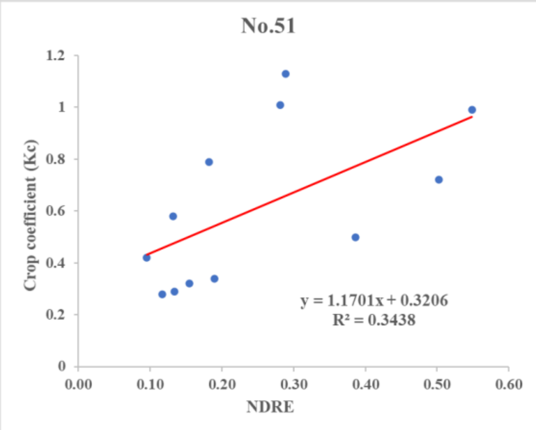

No.31
Crop coefficient (Kc)
NDRE
y = 2.0571x + 0.0758
R² = 0.764

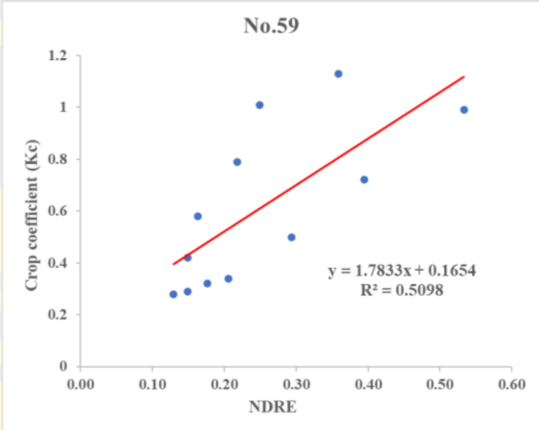

No.39
Crop coefficient (Kc)
NDRE
y = 0.7671x + 0.3718
R² = 0.2243

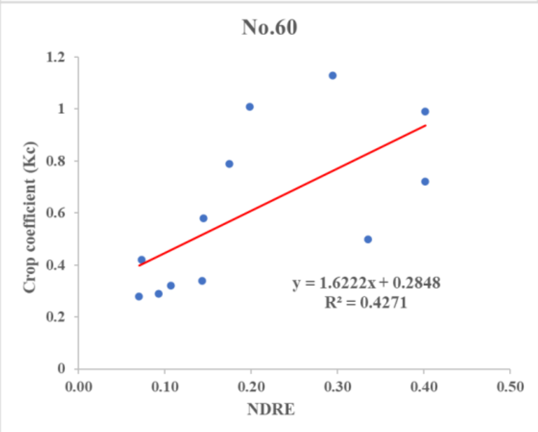

No.42
Crop coefficient (Kc)
NDRE
y = 1.442x + 0.1827
R² = 0.8889

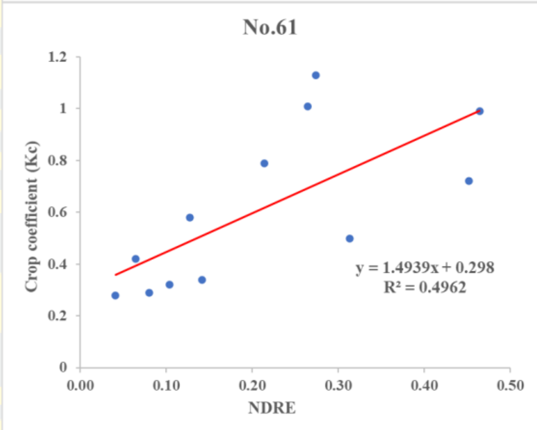

No.45
Crop coefficient (Kc)
y = 1.3904x + 0.3009
R² = 0.4101
NDRE

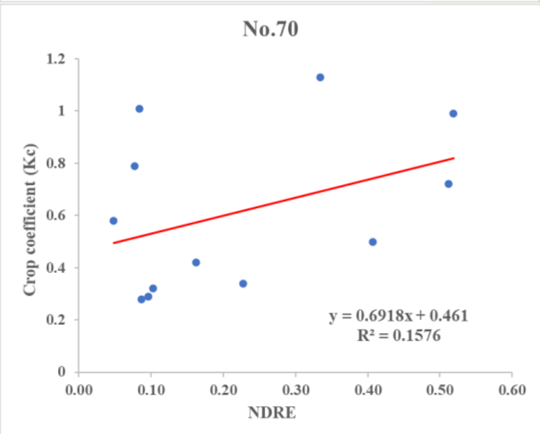

No.47
Crop coefficient (Kc)
y = 1.7627x + 0.2037
R² = 0.5805
NDRE


No.51
Crop coefficient (Kc)
y = 1.1701x + 0.3206
R² = 0.3438
NDRE


No.59
Crop coefficient (Kc)
y = 1.7833x + 0.1654
R² = 0.5098
NDRE


No.60
Crop coefficient (Kc)
y = 1.6222x + 0.2848
R² = 0.4271
NDRE


No.61
Crop coefficient (Kc)
y = 1.4939x + 0.298
R² = 0.4962
NDRE


No.70
Crop coefficient (Kc)
y = 0.6918x + 0.461
R² = 0.1576
NDRE

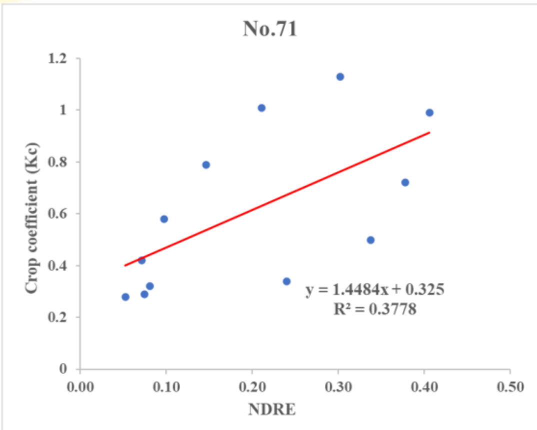

No.71
Crop coefficient (Kc)
y = 1.4484x + 0.325
R² = 0.3778
NDRE

Table I-1 The Percentage difference between Kc RID with Kc predicted and RMSE

The percentage difference between the crop coefficient (Kc) values calculated using the Kc obtained from the Kc predicted was compared with the quantity value Kc values based on the Royal Irrigation Department. Monthly, the start of planting to the harvesting stage of the 80-cassava sample and the R-square of the Root mean square error (RMSE) have a minimum of 0.45 (No.43) and a maximum of 1.84 (No.39), shown in Table I-1.

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
1	0.42	0.31	0.23	0.62	0.69	0.93	2.14	-0.37	0.72	0.09	-0.57	-0.21	0.84
2	0.31	0.30	0.31	0.36	0.44	0.68	1.25	-0.15	-0.53	0.15	0.47	-0.86	0.87
3	0.20	0.25	0.37	0.46	0.52	0.76	1.09	1.42	2.34	3.27	1.88	-0.62	0.65
4	0.23	0.26	0.27	0.36	0.45	0.46	4.27	3.91	3.05	2.47	0.96	-0.87	0.99
5	0.27	0.24	0.27	0.41	0.82	0.84	2.67	-0.35	-0.27	1.60	1.78	1.04	0.77
6	0.28	0.31	0.37	0.39	0.80	0.85	1.43	-0.60	0.65	0.28	-0.86	-0.73	1.04
7	0.23	0.27	0.31	0.50	0.62	0.68	5.30	3.74	2.04	0.66	0.75	1.03	1.03
8	0.26	0.26	0.38	0.44	0.65	0.58	0.95	2.71	1.31	1.00	0.69	-0.04	0.39
9	0.33	0.27	0.37	0.46	0.80	0.63	0.53	-0.76	-0.79	0.84	0.75	0.90	0.94
10	0.23	0.23	0.25	0.33	0.47	0.47	4.83	5.47	0.70	0.51	0.23	-0.01	1.22
11	0.28	0.34	0.34	0.38	0.42	0.42	1.39	5.37	-0.41	-0.40	-0.37	0.20	0.98
12	0.44	0.34	0.30	0.48	0.81	0.55	1.10	3.63	2.45	2.00	0.40	1.10	0.53
13	0.35	0.35	0.11	0.42	0.66	0.42	-1.49	0.39	1.44	1.97	2.25	1.36	0.85
14	0.29	0.34	0.38	0.40	0.48	0.63	2.72	3.78	4.78	4.46	2.33	0.57	1.20
15	0.41	0.28	0.24	0.43	0.83	0.73	-0.58	0.84	-0.14	1.24	2.94	1.26	0.79
16	0.33	0.32	0.18	0.37	0.39	0.57	1.85	0.27	0.18	0.06	-0.42	0.81	0.75
17	0.34	0.28	0.42	0.58	0.84	0.79	0.97	-0.22	-0.12	0.56	0.28	0.69	0.78
18	0.40	0.30	0.29	0.48	0.74	0.59	0.00	1.43	-0.20	0.17	0.60	0.54	0.67
19	0.31	0.31	0.22	0.35	0.78	0.88	0.10	4.45	-0.30	-0.57	-0.94	0.15	1.10
20	0.13	0.13	0.10	0.12	0.15	0.49	0.43	1.63	-0.66	0.80	1.10	0.48	0.63
21	0.27	0.27	0.33	0.48	0.48	0.57	6.32	2.70	2.84	1.11	-0.32	-0.72	1.31
22	0.27	0.33	0.34	0.37	0.45	0.51	2.37	2.66	2.55	1.33	0.04	-1.27	0.69
23	0.14	0.26	0.26	0.28	0.30	0.71	4.91	3.29	2.57	1.48	1.16	0.70	0.89
24	0.27	0.21	0.18	0.27	0.50	0.65	0.03	3.20	1.14	2.43	3.04	0.34	0.73
25	0.15	0.15	0.17	0.43	0.20	0.89	2.39	0.38	-0.83	0.01	0.85	-0.78	0.88
26	0.29	0.34	0.33	0.36	0.45	0.50	4.95	2.79	3.03	1.00	-0.80	-0.65	1.06
27	0.35	0.27	0.14	0.21	0.39	0.63	0.99	1.93	-0.15	0.47	0.61	0.27	0.51
28	0.39	0.41	0.41	0.49	0.55	0.68	3.36	1.66	1.39	1.64	0.63	-1.36	0.67
29	0.32	0.33	0.28	0.38	0.82	0.49	1.71	1.89	-0.58	1.80	1.11	3.12	0.73
30	0.34	0.28	0.36	0.40	0.64	0.69	1.59	0.00	-1.22	-1.21	-1.33	-0.73	1.22
31	0.20	0.24	0.24	0.27	0.29	0.42	1.84	3.57	3.65	2.35	0.82	0.55	0.69

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
32	0.30	0.27	0.14	0.33	0.60	0.76	1.66	2.52	0.17	-0.32	-0.81	0.26	0.77
33	0.42	0.31	0.26	0.34	0.68	0.94	3.27	4.48	2.36	3.54	1.75	-0.45	0.99
34	0.23	0.19	0.14	0.43	0.80	0.76	0.11	-0.64	-1.08	-0.27	0.59	0.07	1.05
35	0.19	0.17	0.28	0.52	0.32	0.15	-0.22	0.31	1.66	1.66	0.46	0.82	0.66
36	0.29	0.28	0.26	0.44	0.48	0.59	1.34	-0.30	-1.30	0.71	2.71	0.22	0.95
37	0.39	0.36	0.44	0.51	0.53	0.90	3.94	5.46	0.56	0.06	-0.45	-0.19	1.18
38	0.43	0.41	0.55	0.53	0.63	0.95	3.83	5.82	0.47	-0.01	-0.50	-0.10	1.23
39	0.40	0.43	0.47	0.56	0.67	0.75	6.28	5.92	-1.00	-0.91	0.01	-0.64	1.84
40	0.33	0.28	0.19	0.35	0.52	0.92	2.25	5.23	-1.27	1.35	1.37	-0.23	1.06
41	0.32	0.26	0.19	0.37	0.39	0.73	2.26	4.14	-1.36	1.27	1.15	-0.60	0.94
42	0.18	0.21	0.22	0.22	0.45	0.50	3.87	4.70	4.47	4.22	1.95	-1.13	1.37
43	0.41	0.39	0.30	0.41	0.47	0.65	1.31	2.50	2.67	2.46	0.44	-0.20	0.45
44	0.19	0.16	0.25	0.50	0.35	0.72	-1.00	0.07	-0.01	0.41	0.17	-0.78	1.02
45	0.15	0.16	0.25	0.34	0.41	0.55	2.84	3.90	2.75	1.37	-0.45	-1.07	0.78
46	0.32	0.30	0.33	0.28	0.18	0.71	1.20	4.03	1.25	3.04	2.91	-0.40	0.86
47	0.23	0.23	0.24	0.28	0.35	0.44	5.63	2.86	1.73	1.96	1.77	-0.06	0.96
48	0.37	0.38	0.50	0.57	0.83	0.74	1.57	4.60	0.11	1.68	2.03	0.12	0.80
49	0.34	0.34	0.20	0.52	0.63	0.67	0.77	0.06	1.61	2.57	2.73	0.82	0.65
50	0.27	0.29	0.16	0.36	0.40	0.53	-0.91	2.73	1.95	2.24	2.18	0.47	0.69
51	0.23	0.28	0.29	0.35	0.44	0.58	4.17	4.75	2.62	0.90	0.01	-0.56	0.95
52	0.33	0.31	0.32	0.43	0.63	0.71	1.46	0.33	0.96	2.36	1.91	0.56	0.52
53	0.25	0.24	0.19	0.33	0.50	0.54	-1.12	-1.11	-0.41	-0.58	-0.24	0.15	1.21
54	0.30	0.28	0.34	0.43	0.73	0.77	2.25	3.28	-1.19	1.23	3.30	0.43	0.90
55	0.23	0.23	0.31	0.33	0.49	0.46	1.26	3.31	-0.75	2.21	2.06	1.07	0.71
56	0.29	0.26	0.47	0.49	0.17	0.64	0.30	2.57	-0.36	1.91	1.91	0.86	0.63
57	0.55	0.39	0.52	0.61	0.68	0.92	1.37	4.43	1.19	2.18	2.72	1.09	0.75
58	0.26	0.22	0.23	0.40	0.62	0.54	0.57	0.93	-0.26	1.84	3.93	-1.04	0.97
59	0.24	0.24	0.29	0.51	0.64	0.82	1.65	1.55	1.22	0.72	0.45	0.63	0.27
60	0.16	0.19	0.23	0.30	0.51	0.57	3.08	4.26	1.23	0.92	0.47	-0.75	0.74
61	0.15	0.18	0.22	0.31	0.49	0.54	3.85	3.33	2.13	1.58	-0.17	-0.69	0.77
62	0.34	0.19	0.15	0.28	0.49	0.78	2.49	2.52	1.04	1.41	0.66	1.05	0.29
63	0.29	0.22	0.17	0.18	0.26	0.85	2.67	2.20	2.24	2.96	4.15	1.90	0.87
64	0.20	0.16	0.14	0.14	0.25	0.84	2.76	5.83	2.30	3.12	3.94	1.26	1.27
65	0.43	0.33	0.24	0.61	0.74	0.94	-0.48	-0.24	0.09	1.68	1.17	1.02	0.79
66	0.26	0.22	0.21	0.67	0.83	0.99	2.02	5.31	1.76	2.05	1.12	0.94	0.85
67	0.24	0.25	0.19	0.45	0.65	0.80	1.03	3.25	0.71	1.15	0.45	-0.15	0.52
68	0.24	0.24	0.24	0.54	0.67	0.56	0.55	3.92	1.28	1.72	0.22	0.52	0.59
69	0.17	0.19	0.19	0.18	0.16	0.42	2.28	1.95	-1.19	-0.35	0.68	1.22	0.78
70	0.18	0.19	0.22	0.41	0.56	0.66	4.07	5.36	0.88	-0.45	-0.17	-1.26	1.15
71	0.14	0.17	0.21	0.43	0.51	0.60	2.60	2.64	1.29	0.44	-0.33	-0.75	0.64
72	0.30	0.25	0.23	0.41	0.61	0.83	-1.01	0.84	-0.55	0.67	0.09	1.00	0.88

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
73	0.30	0.30	0.18	0.44	0.79	0.95	1.90	2.71	2.50	3.60	4.79	0.54	1.04
74	0.33	0.33	0.34	0.53	0.56	0.15	-0.35	3.07	1.84	2.73	3.06	0.55	0.78
75	0.44	0.23	0.23	0.49	0.91	0.47	5.61	1.65	-1.48	0.07	1.63	0.65	1.18
76	0.45	0.23	0.22	0.51	0.84	0.48	5.55	1.94	-0.88	0.49	1.71	1.79	1.16
77	0.46	0.37	0.36	0.48	0.55	0.58	5.72	0.58	-1.10	-0.02	1.16	1.43	1.18
78	0.28	0.27	0.19	0.30	0.47	0.60	0.55	2.74	3.15	2.65	2.08	1.99	0.60
79	0.31	0.25	0.16	0.25	0.41	0.51	0.49	1.24	3.49	3.43	2.30	0.04	0.77
80	0.27	0.34	0.18	0.47	0.67	0.94	1.02	1.27	-0.38	0.48	1.38	1.46	0.61
Average	0.29	0.27	0.27	0.41	0.55	0.66	1.93	2.37	0.82	1.24	1.03	0.21	

Table I-2 Percentage difference between ET RID with ET by Kc predicted and RMSE

The percentage difference between the Crop evapotranspiration (ET) values calculated using the Kc obtained from the vegetation index was compared with the quantity value. Crop evapotranspiration (ET) calculated using Kc values based on the Royal Irrigation Department monthly from the start of planting to the harvesting stage of the 80 cassava sample and the root mean square error (RMSE) have a minimum of 0.99 (No.62) and a maximum of 4.66 (No.42), shown in Table I-2.

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
1	1.75	1.42	0.91	2.32	2.47	3.25	4.65	-2.32	0.74	-1.14	-2.74	-2.14	2.84
2	1.25	1.36	1.23	1.34	1.59	2.31	2.20	-1.12	-2.67	-1.01	-0.05	-3.70	2.96
3	0.83	1.11	1.46	1.73	1.85	2.60	1.70	4.04	5.37	7.69	4.10	-3.24	2.22
4	0.94	1.18	1.05	1.35	1.61	1.57	10.68	9.00	7.25	5.54	1.82	-4.21	3.37
5	1.11	1.09	1.09	1.56	2.96	2.95	5.91	-2.46	-2.04	2.98	3.98	1.56	2.59
6	1.17	1.39	1.48	1.48	2.90	2.96	1.97	-4.37	0.46	-0.64	-3.87	-3.78	3.53
7	0.95	1.23	1.22	1.87	2.22	2.38	14.12	8.97	4.13	0.89	0.95	1.73	3.51
8	1.07	1.21	1.50	1.67	2.34	2.03	1.11	5.71	2.33	1.50	0.76	-1.40	1.34
9	1.38	1.22	1.48	1.72	2.89	2.21	-0.30	-3.67	-3.32	0.88	0.93	1.05	3.16
10	0.93	1.06	1.00	1.22	1.67	1.63	12.29	13.47	0.56	0.02	-0.71	-0.95	4.11
11	1.17	1.52	1.34	1.41	1.53	1.48	3.68	10.45	-2.35	-2.39	-2.42	-0.69	3.27
12	1.81	1.56	1.20	1.79	2.94	1.96	1.86	8.53	5.60	4.24	0.13	2.04	1.80
13	1.46	1.57	0.45	1.57	2.40	1.51	-4.80	-0.67	2.46	3.88	4.78	2.52	2.89
14	1.18	1.50	1.48	1.49	1.71	2.15	7.06	8.85	11.80	11.01	4.97	0.07	3.99
15	1.69	1.28	0.96	1.63	2.99	2.57	-2.28	2.74	-1.90	1.99	6.75	2.39	2.70
16	1.36	1.44	0.73	1.39	1.41	2.03	3.65	-0.95	-0.81	-1.32	-2.54	1.05	2.52
17	1.41	1.28	1.66	2.17	3.05	2.81	1.39	-2.23	-1.66	0.07	-0.48	0.61	2.60
18	1.67	1.38	1.15	1.81	2.68	2.08	-1.16	2.33	-1.33	-0.66	0.10	0.19	2.28
19	1.29	1.41	0.88	1.31	2.83	3.10	-0.63	10.52	-1.74	-2.79	-4.30	-1.35	3.72
20	0.54	0.59	0.38	0.43	0.54	1.62	0.02	2.91	-2.56	1.11	2.08	0.32	2.16
21	1.09	1.21	1.31	1.77	1.71	1.95	17.20	5.42	6.55	1.88	-1.99	-3.33	4.50
22	1.09	1.48	1.33	1.36	1.60	1.71	5.35	5.31	5.33	2.02	-1.50	-5.59	2.45
23	0.58	1.17	1.03	1.05	1.08	2.46	12.81	7.56	5.78	2.91	2.11	0.90	3.03
24	1.10	0.96	0.72	0.99	1.78	2.24	-1.39	7.16	2.11	5.41	6.94	-0.29	2.46
25	0.62	0.70	0.65	1.59	0.73	3.06	5.26	-0.59	-2.97	-0.97	0.98	-4.02	3.01
26	1.20	1.51	1.30	1.34	1.61	1.70	12.39	6.78	7.24	1.39	-3.52	-3.07	3.62
27	1.45	1.20	0.55	0.80	1.41	2.16	1.61	3.74	-1.27	0.18	0.52	0.00	1.74
28	1.62	1.85	1.65	1.85	2.00	2.40	7.74	3.50	2.95	2.89	1.14	-5.74	2.45

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
29	1.35	1.51	1.12	1.44	2.96	1.73	3.89	4.36	-2.37	3.89	2.85	8.20	2.66
30	1.44	1.29	1.47	1.49	2.30	2.43	2.95	-1.49	-4.22	-4.42	-4.88	-3.57	4.15
31	0.83	1.11	0.99	1.02	1.06	1.49	3.57	8.56	8.88	5.18	1.35	-0.13	2.32
32	1.26	1.25	0.56	1.23	2.17	2.68	3.40	6.19	-0.46	-2.07	-3.89	-0.87	2.63
33	1.77	1.41	1.05	1.27	2.46	3.31	8.46	10.82	5.37	8.35	3.76	-2.79	3.35
34	0.94	0.87	0.54	1.61	2.91	2.72	-1.09	-3.01	-3.80	-1.80	0.27	-1.24	3.52
35	0.79	0.76	1.11	1.94	1.15	0.54	-2.16	-0.92	3.26	3.22	0.46	1.09	2.24
36	1.18	1.25	1.02	1.63	1.71	2.03	2.43	-2.44	-4.21	0.82	5.92	-0.77	3.18
37	1.60	1.63	1.73	1.92	1.90	3.10	9.50	13.45	0.68	-1.00	-2.73	-2.10	3.96
38	1.78	1.83	2.16	1.99	2.27	3.28	9.07	14.16	0.30	-1.30	-2.97	-1.88	4.12
39	1.65	1.94	1.86	2.11	2.39	2.59	16.83	14.41	-5.46	-4.65	-1.75	-3.10	6.21
40	1.35	1.25	0.77	1.31	1.87	3.18	5.08	12.64	-4.08	2.68	2.77	-2.07	3.56
41	1.32	1.17	0.75	1.38	1.39	2.54	4.92	9.76	-4.37	2.48	2.28	-3.36	3.20
42	0.74	0.95	0.86	0.84	1.61	1.73	9.45	11.35	11.12	10.26	4.61	-4.88	4.66
43	1.69	1.75	1.17	1.54	1.69	2.26	2.22	5.14	5.75	5.08	0.12	-1.81	1.56
44	0.78	0.72	1.00	1.87	1.26	2.49	-3.89	-1.51	-1.11	-0.32	-1.04	-3.71	3.49
45	0.62	0.72	1.00	1.26	1.46	1.91	6.42	8.13	5.32	2.42	-2.92	-4.15	2.71
46	1.32	1.35	1.30	1.05	0.66	2.45	2.29	9.59	1.77	7.25	7.37	-1.92	2.91
47	0.94	1.05	0.94	1.06	1.25	1.55	13.96	6.00	2.58	3.67	2.68	-1.56	3.29
48	1.53	1.72	2.00	2.14	2.99	2.59	3.23	11.13	-0.46	3.59	4.80	-0.79	2.69
49	1.42	1.56	0.81	1.94	2.25	2.32	1.14	-1.05	3.32	5.72	6.36	1.09	2.20
50	1.13	1.33	0.62	1.36	1.45	1.83	-3.24	6.30	4.31	4.87	4.58	0.06	2.35
51	0.96	1.25	1.15	1.31	1.57	2.00	10.58	9.51	5.94	1.12	-1.21	-3.20	3.23
52	1.34	1.40	1.25	1.59	2.27	2.43	2.84	-0.70	1.30	5.07	4.13	0.45	1.74
53	1.03	1.08	0.73	1.22	1.80	1.87	-3.84	-4.19	-2.23	-2.82	-1.86	-0.93	4.05
54	1.22	1.24	1.31	1.60	2.59	2.62	4.97	7.73	-3.91	2.49	7.80	0.18	3.01
55	0.93	1.03	1.23	1.22	1.74	1.56	2.22	7.20	-2.83	5.09	4.81	2.11	2.38
56	1.20	1.15	1.83	1.84	0.62	2.17	-0.35	5.67	-1.67	4.27	4.34	1.44	2.12
57	2.26	1.72	2.03	2.25	2.42	3.11	2.91	10.67	2.38	4.72	5.90	1.95	2.47
58	1.08	1.00	0.92	1.48	2.23	1.89	0.11	1.19	-1.90	3.58	9.37	-4.45	3.37
59	0.99	1.11	1.15	1.92	2.32	2.87	3.99	3.33	2.16	1.02	-0.03	0.64	0.92
60	0.66	0.87	0.91	1.13	1.84	1.98	7.04	9.12	1.89	1.28	-0.01	-3.98	2.58
61	0.61	0.82	0.87	1.15	1.76	1.89	9.24	6.25	4.56	2.83	-1.89	-3.91	2.68
62	1.41	0.87	0.59	1.05	1.75	2.72	5.30	5.45	1.65	2.53	0.90	1.70	0.99
63	1.20	1.01	0.69	0.68	0.95	2.96	6.12	5.15	5.11	6.84	10.23	4.35	3.01
64	0.84	0.72	0.55	0.53	0.89	2.94	6.25	14.49	5.21	7.36	10.04	2.50	4.27
65	1.76	1.49	0.96	2.30	2.67	3.29	-1.91	-2.11	-0.97	3.15	1.96	1.79	2.66
66	1.08	1.02	0.85	2.50	3.00	3.45	4.78	13.07	3.82	4.46	2.39	1.65	2.85
67	1.00	1.14	0.75	1.69	2.35	2.78	1.87	7.12	0.83	1.73	-0.06	-2.11	1.79

No.	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	RMSE
68	0.99	1.09	0.95	2.04	2.41	1.96	0.18	8.84	2.32	3.34	-0.37	0.19	1.97
69	0.69	0.85	0.76	0.67	0.58	1.46	4.80	3.80	-3.92	-2.02	0.49	2.59	2.65
70	0.75	0.87	0.90	1.52	2.02	2.32	9.97	11.48	0.49	-2.51	-1.88	-4.07	3.91
71	0.57	0.78	0.83	1.63	1.84	2.09	5.87	5.19	2.46	-0.11	-2.25	-3.70	2.26
72	1.23	1.15	0.92	1.53	2.20	2.91	-3.65	0.72	-2.52	0.59	-0.75	1.73	2.97
73	1.24	1.36	0.74	1.67	2.84	3.34	4.17	6.38	5.67	8.49	12.02	0.66	3.55
74	1.36	1.53	1.35	1.98	2.03	0.53	-2.11	6.98	3.81	6.02	7.12	0.41	2.66
75	1.83	1.02	0.92	1.85	3.26	1.65	14.01	3.65	-4.76	-0.68	3.33	0.77	4.05
76	1.87	1.02	0.88	1.93	3.00	1.68	14.01	4.43	-4.21	-0.08	3.52	4.06	4.00
77	1.90	1.68	1.45	1.79	1.99	2.02	14.31	0.57	-3.72	-1.05	1.75	2.84	4.05
78	1.15	1.22	0.75	1.13	1.68	2.11	0.70	6.14	7.32	5.73	4.20	4.33	2.08
79	1.28	1.12	0.63	0.95	1.49	1.79	0.62	2.50	8.28	8.02	5.07	-1.45	2.60
80	1.12	1.54	0.72	1.77	2.41	3.32	1.41	2.16	-2.42	-0.25	2.06	2.53	2.07
Average	1.21	1.23	1.07	1.52	1.98	2.29	4.36	5.15	1.23	2.27	1.75	-0.60	

BIOGRAPHY

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