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Estimation of Crop Evapotranspiration of Satsuma (*Citrus reticulata* Blanco) by Normalized Difference Vegetation Index in Nueva Vizcaya, Philippines

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ABSTRACT

Evapotranspiration has a major impact on agricultural productivity particularly in maintaining soil moisture level and sustaining plant health. Crop coefficient (Kc) is an important component for evaluating crop evapotranspiration (ETc) as it incorporates crop characteristics and average effects of evaporation from the soil. This study estimated the crop evapotranspiration of Satsuma in Malabing, Kasibu, Nueva Vizcaya using Kc values from remotely sensed NDVI data. Three neighboring areas with an area of one hectare were selected for the vegetative, early fruiting, and mature fruiting stages. Satellite imagery from Landsat 9 was used in determining NDVI values which are significant in the estimation of Kc values. It was found that the computed Kc values of citrus for the vegetative stage in all the three phases (initial, mid, and late) were 0.41, 0.46, and 0.48, respectively. The Kc values for the early fruiting were 0.47 (initial), 0.45 (mid), and 0.46 (late) and for the mature fruiting stage the values were 0.65(initial), 0.58 (mid), and 0.63 (late) which follows the trend of the FAO Kc values that decrease in the mid phase. The estimated crop evapotranspiration using these Kc values shows that the highest for the vegetative stage is in the month of August and May for both early and mature fruiting stage, while the lowest ETc values were recorded in the month of January for the vegetative and December for both early and mature fruiting stage. Thus, these computed Kc values provide a site-specific value needed for the computation of crop water requirement and irrigation scheduling for citrus production in Kasibu, Nueva Vizcaya, Philippines.

Keywords: *citrus, crop coefficient, crop evapotranspiration, normalized difference vegetation index, remote sensing*

INTRODUCTION

Citrus has been identified as one of the top high-value crops in the Philippines, with Cagayan Valley as one of the major citrus-producing regions, where Kasibu, Nueva Vizcaya is located (Antonio et al. 2011). The Municipality of Kasibu is one of the leading producers of citrus in the country, a municipality nestled between mountain ranges in the province of Nueva Vizcaya, with approximately 1,200 ha of land devoted to citrus production, primarily Satsuma mandarin (*Citrus reticulata* Blanco), Ponkan mandarin (*Citrus reticulata*), pomelo (*Citrus maxima*), Calamadarin oranges (*Citrus microcarpa*) and oranges such as Hamlin, Perante, and Valenca varieties. About 500 farmers tend 400,000 citrus trees in the municipality (Antonio et al., 2011).

In the study of Bitog (2007), it was highlighted that more than 50% of the citrus growers in Kasibu depend on rainfall as their source of water for their crops and did not practice irrigation from other sources. Citrus growers who have access to irrigation applied irrigation water in their area by means of hose. Irrigation water was applied only during flowering and fruit development stages at least once or twice a week until stage completion, which resulted to an average production per harvest season of 120-139 kg/tree as compared to the average production of citrus growers that did not practice irrigation which at 100-119 kg/tree. Thus, there is a need to estimate crop evapotranspiration of citrus for proper irrigation scheduling in Kasibu to maximize the yield of citrus.

Knowledge of citrus crop evapotranspiration (ETc) is important in scheduling irrigations, optimizing crop production, and modelling ET and crop growth. The ability to measure, estimate, and predict citrus crop water requirement through ET can result in satisfying the water needs of crops and improving water use efficiency. With increasing demand for water resources from competing sectors, great emphasis has been placed on water use efficiency in irrigated fields (Hatfield et al. 2001). The quantification of crop ET can be indirectly estimated by multiplying the reference evapotranspiration (ETo) and Kc.

Reference evapotranspiration can be derived using the FAO Penman- Monteith (Allen et al. 1998) and the crop coefficient values are from the published Kc values for different crops by the United Nations Food and Agriculture Organization (FAO). This method has been widely used because it gives satisfactory results under various climate conditions across the world (Bodner et al. 2007).

Accurate estimation of crop water requirements is crucial. According to Allen et al. (1998) and Kamble et al. (2013) crop coefficient varies in space and time and it is linked to the crop type, phenological cycles, soil, and to the climate of the area. However, database of crop coefficients for different crops of varying agroclimatic conditions is not available, it is essential to have a localized crop coefficient for accurate estimation of water use under specific climatic conditions (Abebe et al., 2021).

With advances in remote sensing, as discussed in the study of Gonzales et al. (2018) crop coefficients can be associated with spectral reflectance of Vegetation Indices (VIs) such as Normalized Difference Vegetation Index (NDVI) which provides an alternative for estimating localized Kc values because remotely sensed NDVI is an indication of photosynthetic activity, a higher NDVI values means a greater level of photosynthetic activity as reported by Tucker et al. (1991).

An increase in crop coefficient caused by higher temperature results in a decrease in soil water and a decline of NDVI, while dense vegetation induces more evapotranspiration and lowers the land surface temperature; or the transpiring canopy is cooler (Sellers 1985; Tucker 1979). Thus, remotely sensed NDVI been used extensively for vegetation monitoring, crop yield assessment, and drought detection.

This study was carried out to estimate the crop evapotranspiration of citrus for the three growth stages (vegetative, early fruiting, and mature fruiting stages) using crop coefficient based on remotely sensed NDVI data at Kasibu, Nueva Vizcaya, Philippines.

MATERIALS AND METHODS

Study Area

The study was carried out in barangay Malabing Valley, Kasibu, Nueva Vizcaya (**Figure 1a**) with 16^{o} 34' 27" N latitude and 121^{o} 37' 65" E longitude which is the center of citrus production within the municipality. The area is characterized by annam clay loam and has an annual temperature of 22.74^{o}C. and it is -4.48% lower than Philippines average.

The selected areas for different growth stages (**Figure 1b**) have an approximate area of one hectare. Three growth stages (vegetative, early fruiting, and mature fruiting stage) used in this study were based on the farmers' practice of the area that the vegetative stage is one to three years, early fruiting stage starts as early as three to five years, and the mature fruiting stage (peak productivity stage) is five to ten years.

A B

Figure 1. Location of the study; a) Kasibu, Nueva Vizcaya; b) area for each growth stages.

Agroclimatic Data

The province of Nueva Vizcaya falls under two types of climates: Type II and Type III. The northwest part of the province experiences Type II which means no dry season and minimum monthly rainfall occurs during March to May. Moreover, a very pronounced maximum rain period from December to February. The Eastern part falls under Type III with no pronounced maximum rainfall period, with a short dry season lasting only from 1-3 months, either during the period of December to February or March to May.

The average annual temperature in Kasibu for a typical day ranges from a high of 25.6^{o}C to a low of 17.34^{o}C with an annual temperature of 22.74^{o}C. July is the wettest month where it receives an average precipitation of 292.48 mm, while February is recorded as the driest month with an annual precipitation of 41.5mm. Kasibu typically receives about 166.78 millimeters of precipitation and has 239.29 rainy days (65.56%) annually, while it has 125.71 days with no rain 34.44%, (*Weather and Climate of Kasibu*, 2020). These variations in temperature and rainfall for the different months in Kasibu affect the growth and water requirements of citrus, as this crop is sensitive to water stress (Ningomban, 2022).

Normalized Difference Vegetation Index (NDVI)

Satellite imagery from Landsat 9 instrument was used in estimating NDVI values. Landsat 9 imagery was extracted and accessed through Google Earth Engine which contains a catalog of different satellite imagery including data such as surface reflectance from Landsat 9 OLI-2/TIRS-2. Pixels of the entire study area were selected and extracted from NDVI maps for each season. Normalized Difference

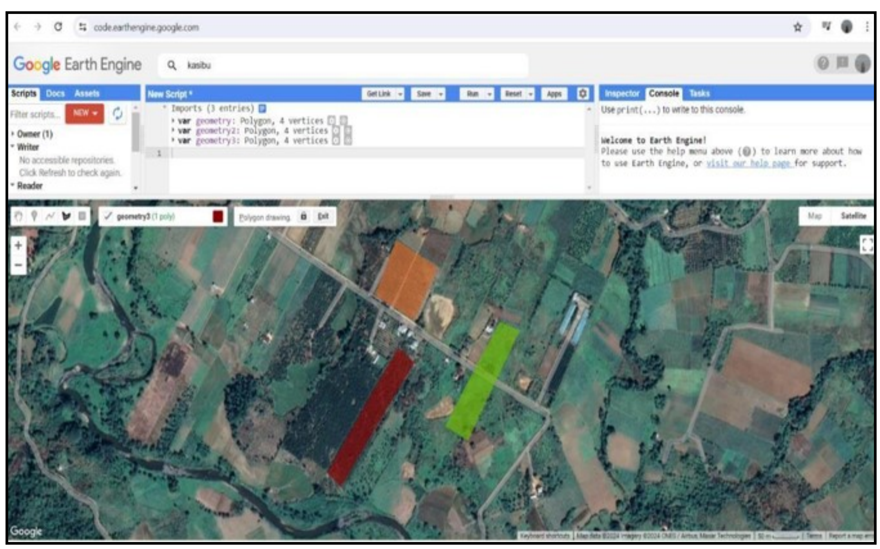

Figure 2. Generating Google Earth Engine using Landsat 9 at Malabing, Kasibu, Nueva Vizcaya.

Vegetation Index values were estimated based on hyperspectral narrow bands using **Equation 1** developed by Rouse et al. (1974):

$$NDVI = \frac{NIR-R}{NIR+R} \qquad \textit{Equation 1}$$

Where *NIR* is the near-infrared band reflectance and *R* is the red band reflectance value. NDVI is good in measuring plant vigor or greenness with a value ranging from – 1.0 to 1.0 (dela Torre et al., 2021).

NDVI values range between – 1 and + 1, where the water presents negative values, and dense canopy presents high positive values. NDVI is a simple numerical index to assess the presence of live green vegetation. The higher the NDVI, the higher the fraction of live green vegetation present in the scene. The process of running satellite data from Google Earth Engine with the use of Landsat 9 is shown in **Figure 2** where the green, orange, and red polygons indicate the vegetative, early fruiting, and mature fruiting stage, respectively.

Crop Coefficient (Kc) Estimation

Raster images from Landsat 9 for the period of January 2023 to January 2024 were loaded to GRASS QGIS for the computation of Kc values using the raster calculator for the different growth stages of citrus. The methods proposed by Brunsell and Gillies (2002) to obtain the Kc values were used in the study where Kc is computed based on the fraction of vegetation cover and fraction between the emissivity of bare soil and a full canopy as shown in **Equation 2**:

$$Kc = \left(\frac{(NDVI - NDVI_0)}{NDVI_{max} - NDVI_0}\right)^2 \qquad \textit{Equation 2}$$

where $NDVI_0$ is the NDVI value corresponding to bare soil, and $NDVI_{max}$ is the value corresponding to full vegetation. The gathered minimum value of NDVI considering the bare soil of the selected area which is used in all stages. The collected NDVI maximum values depend on the highest vegetative cover value accumulated on a specific area of each citrus stage.

Furthermore, the mean values of NDVI were based on the overall mean average of each stage considering the precise value of NDVI from Google Earth Engine.

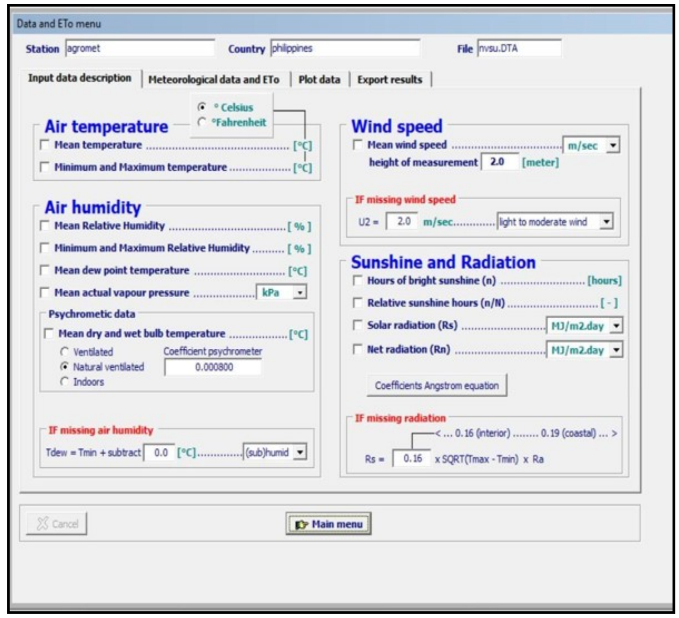

Figure 3. FAO ETo calculator software.

Reference Crop Evapotranspiration (*ET_0*)

The reference crop evapotranspiration (*ET_0*) was computed using the FAO *ET_0* Calculator Software (*ET_0* Calc). The software requires weather parameters (**Figure 3**) such as air temperature, air humidity, wind speed, and solar radiation. These data were gathered from the NVSU PAGASA-AGROMET Station.

Crop Evapotranspiration (ETc)

The monthly crop evapotranspiration for the different growth stages of citrus were computed by multiplying the reference evapotranspiration in millimeters per day by crop coefficient, an approach presented by Allen et al. (1998) as shown in **Equation 3**.

$$ET_c = Kc \ x \ ETo \qquad \textit{Equation 3}$$

RESULTS AND DISCUSSION

Crop Coefficient Values

The computed crop coefficient (Kc) values of satsuma citrus based on remotely sensed NDVI values obtained from Landsat 9 in three stages (vegetative stage, early fruiting stage, and mature fruiting stage) were shown in **Tables 1-3**, respectively. The Crop coefficient values for the three stages were divided into three phases that are initial, mid, and late with 150 days, 120 days, and 90 days respectively, corresponding to the length of crop development stages in a year. This classification is based on the Food and Agriculture Organization (FAO) of the United Nations Irrigation and Drainage Paper No. 56. The vegetative stage (**Table 1**) shows that there is an increasing trend from initial to late as compared to the FAO Kc values that there is a decrease at the mid. This resulted in a low correlation of 0.25 between estimated Kc values and FAO Kc values. In the early fruiting stage (**Table 2**) and mature fruiting stage (**Table 3**) the Kc values follow the trend of the FAO Kc values that there is a decrease at mid, resulting in a strong correlation of 0.75 and 0.94, respectively.

Table 1. Comparison of the computed K_c values to FAO Kc Values for vegetative stage.

Length of Crop Development Stage	Crop Coefficient (Kc)		
	NDVI	Computed Kc	FAO Kc
Initial (150 days)	0.330	0.41	0.5
Middle (120 days)	0.345	0.46	0.45
Late (95 days)	0.350	0.48	0.55
Correlation			0.25

Table 2. Comparison of the computed K_c values to FAO Kc Values for early fruiting stage.

Length of Crop Development Stage	Crop Coefficient (Kc)		
	NDVI	Computed Kc	FAO Kc
Initial (150 days)	0.300	0.47	0.65
Middle (120 days)	0.295	0.45	0.6
Late (95 days)	0.297	0.46	0.65
Correlation			0.75

Table 3. Comparison of the computed K_c values to FAO Kc Values for mature fruiting stage.

Length of Crop Development Stage	Crop Coefficient (Kc)		
	NDVI	Computed Kc	FAO Kc
Initial (150 days)	0.355	0.65	0.7
Middle (120 days)	0.340	0.58	0.65
Late (95 days)	0.350	0.63	0.7
Correlation			0.94

The decreasing trend of Kc values in mid for both early fruiting and mature fruiting stage is due to the crop transpiration and soil evapotranspiration (FAO). The result of this study is in agreement with the findings of Petillo and Castel, 2007 that there is a seasonal trend in the Kc values which is minimum in summer and maximum in winter. In this study the mid is from May to September, which corresponds to the summer months while the months that fall in late (October to December) and initial (January to mid-May) experience wet season conditions.

Crop Evapotranspiration (ETc) of Citrus

A monthly calculation for crop evapotranspiration (ETc) in all growth stages of citrus given the gathered monthly ETo was presented in **Table 4**. The estimated monthly ETo values using the FAO calculator shows that the highest value of 4.43 mm/day is the month of May and lowest which is 2.05 mm/day is January. The result is affected by the climatic factors like temperature, relative humidity, wind speed, and sunshine duration.

The maximum computed ETc for the vegetative stages falls in the month of August with 2.02 mm/day, while the early fruiting stage and mature fruiting stage falls in the month of May with 2.09 mm/day and 2.90 mm/day, respectively. The increase in the ETc values during these months is a result of the higher temperature and low rainfall that took place during that month. The lowest computed ETc values for vegetative stage falls on January with 0.84 mm/day, and for the early fruiting stage and mature fruiting stage fall on the month of December with 0.96 mm/day, and 1.32 mm/day, respectively. This results from the low temperature recorded in this month coupled with an increase in rainfall.

The crop evapotranspiration values were gathered to monitor the required water consumption of satsuma

Table 4. Mean monthly ETc for the different growth stages of citrus.

Month	Mean Monthly ETo (mm/day)	Mean monthly ETc (mm/day)		
		Vegetative	Early Fruiting	Mature Fruiting
January	2.05	0.84	0.97	1.34
February	2.95	1.21	1.39	1.93
March	3.69	1.52	1.74	2.41
April	4.06	1.67	1.92	2.66
May	4.43	1.82	2.09	2.90
June	4.35	2.01	1.96	2.54
July	4.2	1.94	1.90	2.46
August	4.38	2.02	1.98	2.56
September	3.73	1.72	1.68	2.18
October	3.05	1.46	1.40	1.92
November	2.40	1.15	1.10	1.51
December	2.10	1.01	0.96	1.32
October	3.05	1.07	0.85	0.95
November	2.40	0.84	0.67	0.74
December	2.10	0.74	0.59	0.65

citrus in selected areas in all stages. It is highlighted in the review of Wanniarachchi, (2022) that the accurate estimation of evapotranspiration is important because understanding and quantifying the processes governing clarifies the uncertainties in the behavior of the hydrologic cycle with the changing climate. The calculated average monthly crop evapotranspiration can be used in irrigation scheduling in Kasibu, which refers to when to irrigate, how frequent and what is the amount of water to be applied in citrus crops since crop evapotranspiration is numerically equal with crop consumptive use.

SUMMARY AND CONCLUSION

This study aimed to assess the performance of remotely sensed NDVI values in determining the crop coefficient (kc) of the different growth stages (vegetative, early fruiting, and mature fruiting stage) of satsuma citrus. This study was conducted in Barangay Malabing, Kasibu, Nueva Vizcaya.

In each growth stage, a selected citrus production area approximately one (1) hectare was considered. The remotely sensed NDVI values obtained have resulted in crop coefficient values lower than the FAO Kc values for all the growth stages of citrus. This lower Kc values estimated from remotely sensed NDVI values have been affected by factors such as uncontrolled water supply, uneven slope, and weed growth during the growth of each citrus stage greatly which greatly affects the vegetation cover of the area being studied.

However, analysis shows that there is a positive correlation between the computed and the FAO Kc values with coefficient of correlation of 0.25, 0.75, and 0.94 for the vegetative, early fruiting and mature fruiting stages, respectively. These findings suggest that Kc values derived from remotely sensed vegetation indices are a valuable tool for accurately quantifying crop water consumption at the field scale.

The crop coefficients generated from vegetation indices provide a better estimate of ETc than the generalized dual crop coefficient method of Food and Agriculture Organization of the United Nations Irrigation and Drainage Paper No 56 as they reflect actual crop growth conditions and capture the spatial variability among different fields. Thus, the localized crop coefficient can be utilized by the citrus farmers in Kasibu in quantifying the crop evapotranspiration of the citrus for proper irrigation scheduling. This study can also be used as a basis for conducting similar studies regarding crop evapotranspiration estimation for different crops.

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