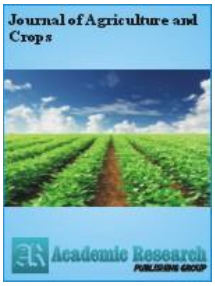

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Relationship between Tobacco Crop Evapotranspiration and the Normalized Difference Vegetation Index

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Abstract: Monitoring crop consumptive water use by applying recent remote sensing techniques has become a topic of research interest in water resources management and planning. In irrigated agriculture, conventional methods of estimating water use are costly. This study aims at estimate the relationship between tobacco crop evapotranspiration (ET_{crop}) and the normalized difference vegetation index (NDVI) during the crop development stage at Chedgelow irrigated farm in Zimbabwe. Tobacco ET_{crop} was estimated as a product of reference evapotranspiration (ET_o) and crop coefficient (K_c). The Penman-Monteith model was applied to estimate ET_o using climate data from Kutsaga research station, some 2 km away from the farm. K_c values were extracted from FAO tables. Five cloud-free MODIS images for the month of October in 2000, 2001, 2002, 2003 and 2007 were processed extract the NDVI values using ILWIS GIS. The results show significant ($p = 0.000$) differences between tobacco NDVI values over the years studied. The results also show a strong and significant positive relationship ($r^2 = 0.8061$, $p = 0.047$) between ET_{crop} estimated using Penman Monteith model and NDVI. Research findings show that satellite derived NDVI is a good and reliable predictor of tobacco crop water evapotranspiration. Therefore, remotely sensed NDVI can be used to monitor crop water use in irrigated tobacco fields in areas where resources do not permit field measurements.

Keywords: Evapotranspiration; Irrigation; NDVI; Relationship; Tobacco; Chedgerow.

1. Introduction

Monitoring crop water use has been a topic of interest in the field of irrigation and water resources planning due to increasing competition for fresh water among different users. Irrigated agriculture produces more than 40% of the world's cash and food crops. About two thirds of the world population depends directly or indirectly on it for livelihood [1]. Although irrigated agriculture accounts for 69% of world's freshwater withdrawal, the sector increasingly compete for limited water supplies. Irrigation faces stiff water competition from environmental demands, recreational, municipal, industrial and domestic activities. Thus, continued environmental and regulatory constraints on water supplies are anticipated as the effects of population growth, climate change and declining water conveyance infrastructure continue to evolve. To address these challenges, there is a need to provide new sources of information on crop water use to growers, to enhance their ability to efficiently manage available irrigation water supplies [2].

Crop water use, also known as evapotranspiration (ET), is the water used by a crop for growth and cooling purposes. Evapotranspiration is weather dependent as well as soil, water and plant dependent. It is a process in which the plant extracts water from the soil for tissue building and cooling purposes. Its variability at critical growth stages is important for irrigation scheduling to avoid stressing crops [3, 4].

Nevertheless, ET is one of the most important but difficult water balance element to estimate. Quantifying ET from irrigation projects is vital for water rights management, water resources planning and regulation. Crop evapotranspiration (ET_{crop}) can be estimated using empirical methods [5-7], field measurements [8], and remote sensing techniques [9]. However, the use of empirical methods and field measurements is often sophisticated, expensive, time consuming, and most farmers lack knowledge and skills to apply the techniques [10]. Traditionally ET from agricultural fields has been estimated by multiplying weather based reference ET by crop coefficients (K_c) determined according to crop type and crop growth stage. However, there are some concerns with regards to whether the crops grown compare with the conditions represented by the K_c values, especially in areas where water is limiting. In addition, it is difficult to predict the correct crop growth stage dates for large populations of crops and fields [3, 7].

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Recent developments in satellite remote sensing have enabled crop models to accurately estimate ET and K_c for large fields [9]. Satellite remote sensing images provide alternative sources of good quality data. Recent remote sensing approaches such as the Surface Balance Algorithms for Land (SEBAL) have been widely used to estimate ET in irrigated farms [9, 11]. Thus, use of remote sensing offers a simple, cost effective and quick reliable way to estimate crop ET or crop water use at farm level [12].

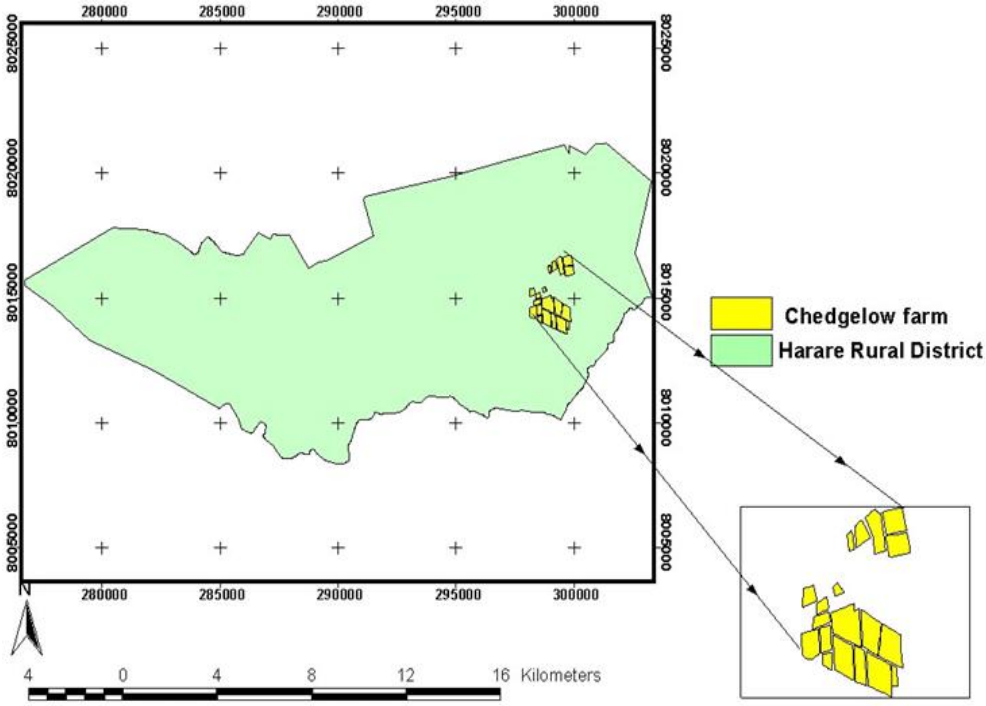
The objective of this study was to determine whether there is significant relationship between tobacco crop evapotranspiration (ET_{crop}) estimated using the Penman-Monteith model and normalized difference vegetation index (NDVI) at Chedgelow farm in Harare. It was hypothesized that a significant relationship would allow the use of NDVI as a proxy for crop ET. Thus, farmers can rely on crop NDVI during irrigation scheduling.

2. Materials and Methods

2.1. Study Area

Chedgelow farm occupies an area of 592 ha of land. The farm is 16 km away from Harare city centre in Harare rural district. Winter wheat, tobacco, horticulture and floriculture crops are grown under irrigation. Horticulture and florticulture take place in green house conditions. Tobacco is grown in 18 fields occupying 70 ha under irrigation. Maize is grown annually under rainfed conditions. Other activities are in the farms include game ranging, livestock farming and forestry. Figure 1 shows the location of Chedgelow farm in Harare rural district.

Figure-1. Location of Chedgelow farm in Harare district



The farm receives an average of 800 mm of rainfall annually and experiences an average annual temperature of 26°C. Soils are primarily derived from granite parent material. The farm has heavy textured clay soils and sandy clay loams supporting wooded grassland. Natural grasses growing in the area include the *Cynodon dactolon* and *Hyperenia filipendula*. It is dominated by *Jubernadia globifora*, *Brachstegia speciformicis*, *Parinari curatifolia Pinus piñata*, *Eucalyptus* and *Cypress* tree species. The *Pinus piñata*, *Eucalyptus* and *Cypress* are exotic trees which are used as wind breaks [13].

2.2. Data

The mean monthly minimum and maximum temperature, wind speed, relative humidity, and duration of sunshine data for October 2000, 2001, 2002, 2003 and 2007 were obtained from Kutsaga tobacco research station located 2 km from Chedgelow farm. Information on farm cropping pattern which includes crops grown, rotation cycles, harvesting and planting dates, and irrigation information were obtained from the farm manager.

Fields were digitized from an aerial photograph acquired in August 1996. The aerial photograph was georeferenced using UTM WGS84 Zone 36S and orthorectified to give real world coordinates using a digital elevation model (DEM) of Chedgelow farm.

Five cloud free TERRA/MODIS images for 18 October 2000, 17 October 2001, 18 October 2002, 16 October 2003, and 17 October 2007 with a spatial resolution of 250 x 250 m were obtained from the lads web site (www..nasa.gov): Extraction of binary files was performed for the red (band 1) and near infrared (band 2) of

MODIS. A subset image for the farm was created for better visualization, while georeferencing was done using UTM WGS84 Zone 36S.

2.3. Estimation of NDVI

The NDVI is an algorithm which is used to estimate plant biomass or greenness [3]. It is affected by stages of crop growth, moisture content and soil background or colour. In addition, NDVI is an important variable for indirectly monitoring ET over large areas, thus, has great potential for agronomical applications. Thus, when ET_{crop} is optimum, there is less water stress, hence, maximum evapotranspiration occurs and biomass production increases [14, 15]. Therefore, when evaporative demand is met, there is an increase in carbon dioxide uptake and increase in photosynthetic activity, which leads to high biomass production.

NDVI is calculated from band 1 (red, R) and band 2 (near infrared, NIR) of the MODIS images in ILWIS GIS using the formula [3, 16]:

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

The values of NDVI range from –1 to 1 with high values corresponding to high vegetative biomass and primary production. In this study, NDVI values for all images were extracted from tobacco fields by overlaying NDVI from each image on Chedgelow field boundaries.

2.4. Estimation of Reference Evapotranspiration

Reference evapotranspiration (ET_o) is the loss of water from an extended surface of a short green crop, completely shading the ground, with uniform height, and with adequate status in the soil profile [6, 15]. In this study, the Penman-Monteith model was used to estimate ET_o because it has been shown to give best results, as it utilizes almost all meteorological parameters [14]. Meteorological data comprising mean maximum and minimum temperature, relative humidity, total wind run, sunshine duration and wind speed were collected from Kutsaga research station which is 2 km from Chedgelow farm. ET_o (in mm) was computed using Penman-Monteith equation [6, 17]:

$$ET_0 = C(W * R_n) + ((1 - W) * f(U) * (e_a - e_d)) \quad \text{............................ (2)}$$

Where: R_n = net radiation (mmday^{-1})
R_n = difference between incoming short wave radiation and net long wave radiation (mmday^{-1})
(e_a-e_d) = vapour pressure deficit
f (U) = wind function in km day^{-1} measured at 2 m height
W = temperature and altitude dependent weighing factor
C = adjustment factor for the ratio U day/U night

2.5. Estimation of Crop Coefficient

The crop coefficient (K_c) at the crop development stage was obtained from FAO tables [14]. This stage is from the 21st day after crop emergence and is reached when the crop reaches 10% to 80% ground cover after crop emergence [8]. Table 1 illustrates the K_c values for tobacco used in this study.

Table-1. Kc for tobacco crop

Crop growth stage	Development	Mid-season	Late-season	Harvest	Total
K_c value	0.7-0.8	1.0-1.2	0.9-1.0	0.75-0.85	0.85-0.95

Source: [14]FAO (1999)

Using Table 1, for each crop growth stage, the first figure (lowest) is considered if humidity high (RH mean > 70%) and wind speed low (U < 5m/sec) while the second figure (highest) is considered under low humidity (RH min < 20%) and strong wind (> 5m/sec).

2.6. Estimation of ET_{crop}

Crop evapotranspiration, ET_{crop} refers to evapotranspiration (ET) of a disease free crop in a large field under optimal soil conditions for water and nutrients aimed at full production potential under a given crop environment. ET_{crop} was calculated as a product of K_c and ET_o [6, 14]:

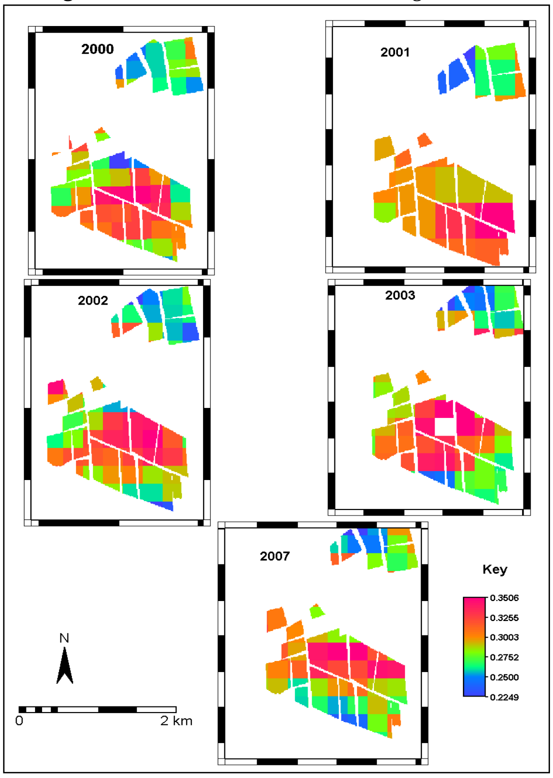
$$ET_{crop} = ET_0 \times K_c \quad \text{.. (3)}$$

3. Results

3.1. Variations of Tobacco NDVI Values over the 5 Seasons

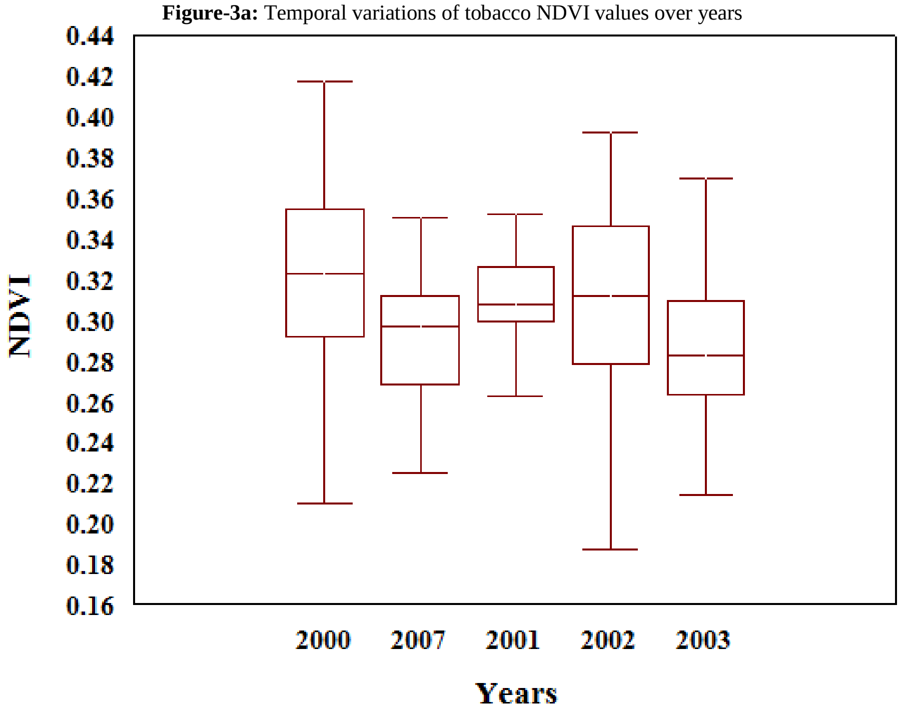
Figure 2 shows tobacco NDVI values for October 2000, 2001, 2002, 2003 and 2007.

Figure-2. NDVI values of tobacco at Chedgelow farm



In order to determine whether there were significant variations among tobacco NDVI values for the 2000, 2001, 2002, 2003 and 2007 crop development stages, box plots were constructed. Figure 3a shows box plots illustrating significant ($p = 0.000$) tobacco NDVI differences among the seasons.

Figure-3a: Temporal variations of tobacco NDVI values over years

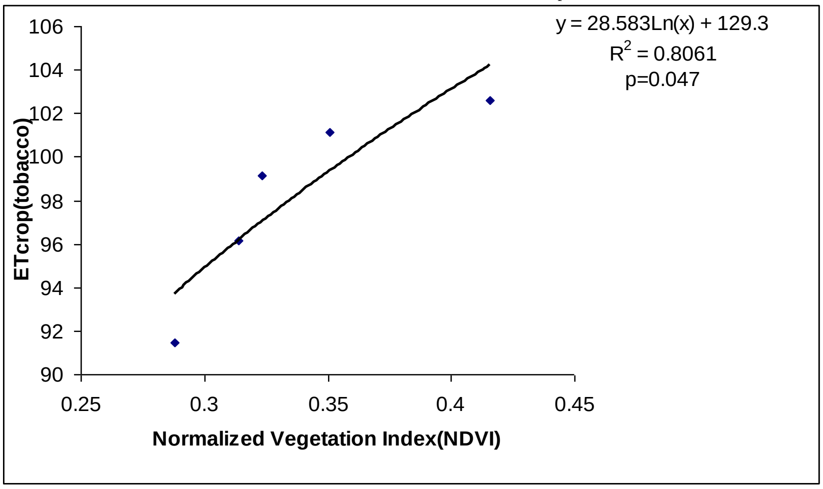


The results show significant ($p < 0.05$) differences among tobacco NDVI values over the 5 years. The differences in NDVI could have been caused by different tobacco varieties grown in these fields. Thus, even if crop growth stages are uniform, the NDVI may not necessarily be the same because different tobacco varieties differ in their greenness. Thus, the results show that NDVI is a good index for measuring vegetation biomass as low values correspond to low biomass and high values correspond to high biomass.

3.2. Relationship between ET_{crop} and NDVI

Figure 3b shows a strong and significant positive logarithmic relationship (r^2 = 0.8061, p = 0.047) between ET_{crop} and NDVI for the tobacco crop.

Figure-3b. Relationship between ET_{crop} and NDVI



The results shown in Fig. 3 indicate a significant positive relationship between ET_c and NDVI meaning that an increase in biomass production leads to an increase in crop consumptive water use. This means that NDVI can be used to predict greener vegetation at each crop development stage during the entire cropping season. Therefore, NDVI is a good indicator of the available biomass and evapotranspiration in tobacco fields at each crop development stage.

4. Discussion

Responsible water resources management calls for accurate information that will allow farmers, landowners, and government officials to make good decisions that can ultimately save money, increase agricultural production, and protect water resources for the future. In irrigated agriculture, effective management of irrigated crop water use or ET is the key principle to achieving sustainable agriculture. Knowledge about the amount of water used by crops acts as a guide in exploring appropriate scientific practices for improving crop water use. However, due to increased competition for fresh water among users, monitoring the consumptive use of water is becoming a challenge. While obtaining field measurements of hydrologic parameters is very important to advance research in the field of hydrology, obtaining extensive datasets of ground measurements is generally too costly and labour intensive.

The results of this study indicate that a significant positive relationship between ET_{crop} estimated using the Penman Monteith model and NDVI values derived from MODIS data. This implies that NDVI data derived from MODIS satellite imagery can be used to define crop health under conditions of unrestricted water availability to the crops. The advantage of estimating relationship between NDVI and ET is that it eliminates the need for identifying each crop and determining its acreage. It requires the general knowledge of the dominant crops are and of their growth stages at the time of data acquisition. Also required are crop coefficients relating to the crops in the area. Doorenbos and Kassam [5] devised guidelines for selecting coefficients that take into account crop characteristics, time of planting, stage of crop development and general climatic conditions. However, extension of this methodology to non-irrigated fields requires an understanding of the effect of decreasing water availability on NDVI values derived from spectral crop data.

5. Conclusion

This study aimed at investigating the relationship between irrigated tobacco crop use or evapotranspiration (ET_{crop}) and normalized difference vegetation index (NDVI) at Chedgelow farm in Harare rural district. Climate data were collected from Kutsaga research station near the farm while crop data were collected from farm records. Five cloud free MODIS images for the month of October 2000, 2001, 2002, 2003 and 2007 were processed to extract the NDVI values in ILWIS GIS.

ET_{crop} was estimated as a product of reference evapotranspiration (ET_o) and crop coefficient (K_c) during the crop development stage in the month of October 2000, 2001, 2002, 2003 and 2007. The Penman-Monteith model was applied to estimate ET_o while crop coefficient (K_c) values were extracted from standard FAO irrigation tables. The results showed significant (p = 0.000) differences among tobacco NDVI values over the years studied. This study developed a simple positive and significant logarithmic regression model (Y=28.58LnX+129; r^2 = 0.8061, p = 0.047) to establish a general relationship between NDVI from moderate resolution satellite data (MODIS) and the ET_{crop} estimated using Penman-Monteith model.

Based on the research findings, it is clear that NDVI is a good and reliable predictor of tobacco crop water use or evapotranspiration. Therefore, remotely sensed NDVI can be used to monitor crop water use on irrigated tobacco fields in areas where resources do not permit field measurements. This implies that farmers can integrate NDVI data in their day-to-day water schedules when irrigating crops.

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