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Early maize yield forecasting in the four agro-ecological regions of Swaziland using NDVI data derived from NOAA's-AVHRR

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Abstract

In Swaziland, maize (*Zea mays* L.) yield and production fluctuate from year to year mainly due to rainfall variability. Such fluctuations result in food insecurity, and therefore, forecasting of crop yields prior to harvest is required for early intervention in case of a deficit. The Normalised Difference Vegetation Index (NDVI) data derived from NOAA-Advanced Very Resolution Radiometer (AVHRR) has been used in several countries to forecast crop yields. The objective of the current study was to evaluate the potential usefulness of the NDVI in forecasting maize yield in Swaziland, and also to identify the best time for making a reliable forecast. Regression results showed that the NDVI can be used effectively to forecast maize yield in three of the four agro-ecological regions of the country. The models developed for each agro-ecological region accounted for 5, 61, 68 and 51% of maize yield variability in the Highveld, Middleveld, Lowveld and Lubombo Plateau, respectively. The best time for making an accurate forecast was found to be from the third dekad of January through to the third dekad of March depending on the agro-ecological region. Maize production forecasts using the developed models can be made at least 2 months before harvest, which would allow food security stakeholders enough time to secure maize imports in case of a deficit.

Keywords: Maize; Yield forecast; Food security; NDVI; NOAA-AVHRR

1. Introduction

Maize (*Zea mays* L.) is the staple crop in Swaziland. About 90% of the maize is grown as a rain-fed crop (without irrigation) by small-scale farmers in the Swazi Nation Land (SNL). Over the past years, maize production has fluctuated from year to year mainly due to rainfall variability. The fluctuation in production leads to lost income due to reduced yields and most of all threatens the food security of the country.

Since maize plays a substantial role in the food security of the country, it is important that timely accurate maize production estimates are provided to the government and other food security stakeholders for timely intervention in case of a deficit. Since 1987,

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the National Early Warning Unit (NEWU) of the Ministry of Agriculture and Co-operatives (MOAC) has been using the Food and Agriculture Organisation (FAO) developed water balance model to forecast maize production in the country. The model is based on a cumulative water balance established over the whole growing season for the given crop and established for successive periods of 10 days. The water balance is the difference between precipitation received by the crop and the water lost by the crop and the soil (FAO, 1986). The water retained by the soil and available to the crop is also taken into account in the calculation. The water balance model explains 45, 55, 61 and 83% of the maize yield variability in the Highveld, Middleveld, Lowveld and Lubombo Plateau, respectively. The disadvantage with this model is that it assumes that crop yield is affected only by moisture level, which in reality is not the case. Besides moisture, there are other factors that determine crop yields such as solar radiation, temperature (Muchow et al., 1990), soil fertility, pests and crop management. Moreover, for this model to give reliable yield forecast there is a need to have a good, reliable network of rainfall stations throughout the country and rainfall data has to be acquired at least every 10 days. Due to the apparent limitations of the water balance model, there is a need to develop and/or use other models that incorporate different variables in order to complement the water balance model.

In the recent years, many studies have been conducted to establish the relationship between the Normalised Difference Vegetation Index (NDVI) derived from NOAA-Advanced Very Resolution Radiometer (AVHRR) and crop yields. For example, Mkhabela and Mkhabela (2000) studied the relationship between NDVI and cotton yield in the Lowveld of Swaziland and found that there is a positive linear correlation ($R^2 = 0.70$) between cotton yield and cumulative maximum NDVI. The authors concluded that in Swaziland cotton yield and consequently production could be effectively estimated using NDVI. Similar results were reported by Quarmby et al. (1993) in Greece.

Meanwhile, Lewis et al. (1998) found that maize production in Kenya could be estimated using NDVI data. Quarmby et al. (1993), Hayes and Decker (1996), Unganai and Kogan (1998) and Baez-Gonzalez et al. (2002) also reported that maize production could be estimated accurately early in the season (before harvest) using NDVI data in Greece, the USA cornbelt, Zimbabwe and Mexico, respectively. All the above mentioned authors reported that crop production forecasts could be made 1–2 months before harvest which gives governments, NGO's and other food security stakeholders enough time to secure food imports in case of a deficit. Knowledge of crop condition prior to harvest can be beneficial in planning for anomalies in production through international trade (Hayes and Decker, 1996; Bastiaanssen and Ali, 2003). In addition, other studies have shown that there is a correlation between NDVI and cumulative monthly rainfall (Groten, 1993; Di et al., 1994) and between Sea Surface Temperature (SST) anomalies and NDVI anomalies (Myneni et al., 1996; Verdin et al., 1999).

The NDVI is based on properties of green vegetation to reflect the incident solar radiation differently in two spectral wavebands observed by the AVHRR sensor: visible 0.58–0.6 μm (Channel 1) and near-infrared 0.725–1.1 μm (Channel 2). The presence of chlorophyll pigment in green vegetation and leaf scattering mechanisms cause low spectral reflectance in Channel 1 and high reflectance in Channel 2, respectively. Reflectance values change in the opposite direction if vegetation is under stress (Kogan, 1994). Hence, the NDVI measures vegetation vigour and greenness (Tarpley et al., 1984) and is calculated as follows:

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

where NIR and R represent the reflectance of the near infrared (Channel 2) and the red (Channel 1), respectively. The NDVI is unit-less, with values ranging from −1 to +1. Healthy green vegetation normally has the highest positive values while surfaces without vegetation, such as bare soil, water, snow, ice or clouds usually have low NDVI values that are near zero or slightly negative. Stressed vegetation or vegetation with small leaf area has positive but reduced NDVI values (Kogan, 1994; Hayes and Decker, 1996). A typical NDVI temporal profile for healthy green vegetation rises as plant cover increases during spring, reaches a peak during summer and declines during autumn (Baez-Gonzalez et al., 2002).