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# Evaluating the sequential masking classification approach for improving crop discrimination in the Sudanian Savanna of West Africa

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Classification of remotely sensed data to reveal the spatial distribution of crop types has high potential for improving crop area estimates and supporting decision making. However, remotely sensed crop maps still demand improvements as e.g. variations in farm management practices (e.g. planting and harvesting dates), soil and other environmental factors cause overlaps in features available for classification and thus confusion in error matrices. In this study, a variant of the sequential masking classification technique was applied to multi-temporal optical and microwave remote sensing data (RapidEye, Landsat, TerraSAR-X) to improve the accuracy of crop discrimination in West Africa. This approach employs different sets of multi-temporal images to sequentially classify individual crop classes. The efficiency of the sequential masking approach was tested by comparing the results with that of a one-step classification, in which all crop classes were classified at the same time. Compared to the one-step classification, the sequential masking approach improved overall classification accuracies by between 6% and 9% while increments in the accuracy of individual crop classes were between 4% and 19%. The McNemar's statistical test showed that the observed differences in accuracy of the two approaches were statistically significant at the 1% significance level. The findings of this study are important for crop mapping efforts in West Africa, where data and methodological constraints often hinder the accurate discrimination of crops.



## 1. Introduction

Efficient agricultural monitoring systems rely on accurate and timely information on crop area statistics (GEOSS, 2009). This information is crucial input for a wide range of biophysical and economic models such as crop production forecasting (Blaes et al., 2005) and estimations of irrigation water requirements (Conrad et al., 2013; Van Niel and McVicar, 2004). The output of these models aid in formulating effective agricultural policies and ultimately improves food security assessments. In addition, observed inter-annual differences in the cultivated area of different crop types may help in gauging farmers' response to changing climate and assist in formulating adaptation measures to climate change and variability.

Over the past thirty years, numerous researchers have demonstrated the use of remote sensing technology for providing crop area estimates (McNairn et al., 2009). The large area coverage and regular acquisition of satellite imagery makes remotely sensed data cost effective and a reliable source for regular agricultural monitoring than conventional field based methods (Okhimamhe, 2003). However, crop discrimination from satellite images must be conducted to an acceptable accuracy to ensure that extracted crop area estimates are reliable (Blaes et al., 2005; GEOSS, 2009). For instance, variations in management practices (e.g. planting dates), soil and other environmental factors challenge accurate mapping. As a result the same crop class can exhibit different spectral or microwave response patterns over time, which in turn complicates its identification or discrimination from other crops, which may interfere due to temporal overlap of the recorded signals (Blaes et al., 2005; Peña-Barragán et al., 2011). This situation is further aggravated in rainfed agriculture dominated areas like West Africa, where the small-scale cultivation of numerous crops leads to remarkable cropping calendar overlaps (Forkuor et al., 2014).

Previous studies have shown that the sequential masking classification technique is a promising approach to improve the above mentioned challenges (Ban and Howarth, 1999; Ehrlich et al., 1994; Turker and Arikan, 2005; Van Niel and McVicar, 2004). Based on standard photo-interpretation procedures, the classification

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technique firstly classifies the most distinct or easily separable class, then proceeding to sequentially classify the remaining classes based on the ease or difficulty in discriminating them (Ehrlich et al., 1994; Estes et al., 1983). By classifying single crops at a time, the sequential masking approach ensures that the best obtainable classwise accuracy for each crop is achieved (Ehrlich et al., 1994; Van Niel and McVicar, 2004). In addition, classification of single crops at a time reduces confusion between certain dominant crops and other classes (Van Niel and McVicar, 2004). Consequently, this technique produces better classification accuracies compared to one-step classifications where all crop classes of interest are classified at the same time (hereinafter referred to as "one-step classification"). Ehrlich et al. (1994), for example, compared the results obtained from a sequential masking classification approach to a one-step classification (maximum likelihood) for discriminating four major crops (small grains, soybeans, sugar beet and corn) in the Regione del Veneto, Italy. They found that the sequential masking approach generally produced better results than the one-step approach and improved the classwise accuracy (user's accuracy) of soybeans and sugar beet by 9% and 22% respectively. Van Niel and McVicar (2004) also showed that the implementation of a sequential masking classification to classify four major crops in Australia increased classification accuracy by between 6% and 12% compared to a one-step multi-date classification. Similarly, Turker and Arikan (2005) observed an improvement of 10% in overall classification accuracy when the results of a sequential masking classification technique was compared to a one-step classification approach.

Although all these studies followed the general principles of sequential masking classification (i.e. classifying one crop at a time), some studies used different terminologies to describe the process. Van Niel and McVicar (2004), for example, described the process as "iterative multi-date classification". Based on initial single date classifications, they selected the best single date image for classifying individual crop types and iteratively classified the respective crops based on the selected image. Other studies also used single date images (e.g. Ehrlich et al., 1994) or their transformations (e.g. principal component, Turker and Arikan, 2005) to classify single crops in a sequential masking classification scheme.

Despite the reported advantages, sequential masking approaches are still underexplored. For instance, using combinations of multi-temporal data sets to sequentially classify single classes has not been tested yet. Moreover, previous studies have only been conducted on optical data in regions with reduced or negligible atmospheric disturbances. Sequential masking approaches applied to multi-sensor data in regions in which quasi-permanent cloud cover necessitates the use of synthetic aperture radar data for successful crop discrimination have not been investigated.

This study aims at enhancing classification accuracy of multi-sensor crop mapping in West Africa using a sequential masking classification technique. To account for the high spatial heterogeneity in the patchy landscape of West Africa (Cord et al., 2010), high spatial resolution optical and SAR data were selected. The approach was implemented in two watersheds in the Sudanian Savanna. In its implementation, an analysis was first conducted to determine the best image time-series (out of all available time-series) for discriminating individual crop classes, after which they were sequential classified based on the pre-determined time-series. Results of the sequential masking classification were compared to a one-step classification approach to ascertain whether the sequential masking approach achieved an improvement in the discrimination of crops in the study watersheds. The statistical significance of the differences in accuracy derived from the two classification approaches was evaluated using the McNemar's statistical test (Foody, 2004; de Leeuw et al., 2006).

## 2. Study area

The study was conducted in two watersheds – Vea in northern Ghana (301 km$^2$) and Dano in south western Burkina Faso (580 km$^2$) (Fig. 1). Both watersheds fall in the Sudanian Savanna agro-ecological zone, described as having the potential to become the bread basket of Africa (Dixon et al., 2001). Agriculture is mainly rainfed, while dry season cultivation is done on a limited scale, where irrigation water is available (normally around small reservoirs). Both watersheds have a uni-modal rainfall distribution, with an average annual rainfall of between 900 and 1000 mm, although inter-annual and intra-seasonal variability are high (Sivakumar and Gnoumou, 1987; Yilma, 2006). Irrigation schemes in both watersheds allow for dual season cultivation (in the irrigation command area). The terrain is flat in both sites, with average slope of less than 5°. Fig. 1 shows the schematic view of the two watersheds while Table 1 presents further information on them.

Due to frequent inter-cropping of certain crop types and similarities in their structure and cropping calendar, they were grouped into a single class (crop group) in this study. The two main crop groups considered are (1) "cereals", which represents millet or sorghum or their intercropping and (2) "legumes", which is made up of groundnuts and bambara beans. Thus, four crop classes were mapped in both watersheds respectively: cereals, legumes, rice and maize in Vea (Ghana), and cereals, cotton, maize and rice in Dano (Burkina Faso). Cereals and legumes are the dominant crops in Vea while maize is a minority crop. In Dano, cotton, maize and cereals are dominant. Due to the application of fertilizer on cotton fields, some farmers usually implement a cotton–cereals/maize–cotton rotation based system in which cereals/maize benefit from residual effects of cotton fertilizer (Ouattara et al., 2011).

A cropping calendar considered in this study was derived based on field surveys conducted between July and September 2013 (Fig. 2). The long "land preparation and planting" period for most crops is indicative of the subjective decisions of farmers concerning land preparation and planting dates. Generally, cereals are cultivated earlier in Vea (especially as early maturing millet), while legumes and maize are cultivated later than cereals (a month or two). In Dano, the cultivation of all crops starts at the onset of the rains (mostly in June), which could lead to high overlaps in the cropping calendars of the respective crops.

## 3. Satellite and reference data

Multi-temporal data of 2013, recorded by two optical sensors (RapidEye and Landsat 8) and a SAR sensor (TerraSAR-X; TSX) were used in this study. Tables 2 and 3 detail the acquisition dates of the various images used in the Vea and Dano watersheds, respectively.

RapidEye and TerraSAR-X data were obtained from the RapidEye and TerraSAR-X Science Archive teams of the German Aerospace Center (DLR), while Landsat 8 was downloaded from the United State's Geological Survey's GLOVIS website (http://glovis.usgs.gov/). The RapidEye data has five spectral channels (blue, green, red, rededge and near-infrared (NIR)) and a high spatial resolution of 5 m (i.e. orthorectified, level 3A) (Tyc et al., 2005). Dual polarimetric TerraSAR-X data acquired in the StripMap (SM) mode with a high spatial resolution of approximately 6–7 m (Werninghaus and Buckreuss, 2010) was employed to ensure optimal integration with the RapidEye data. VV and VH polarizations were selected due to their proven usefulness for crop mapping in previous studies (McNairn et al., 2009). Incidence angle of the TSX images ranged between 43° and 45°. Six, out of the eleven, spectral channels of the Landsat 8 data (Irons et al., 2012) were