MAPPING CULTIVATED AREA IN WEST AFRICA USING MODIS IMAGERY AND AGROECOLOGICAL STRATIFICATION

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ABSTRACT

To predict and respond to famine and other forms of food insecurity, different early warning systems are using remote analyses of crop condition and agricultural production, using satellite-based information. To improve these predictions, a reliable estimation of the cultivated area at national scale must be carried out.

In this study, we develop a methodology for extracting cultivated domain based on their temporal behaviour as captured in time-series of moderate resolution remote sensing MODIS images. We also used higher resolution SPOT and LANDSAT images for identifying cultivated areas used in training. We tested this methodology in Senegal and Mali at national scale. Both studied areas were stratified in homogeneous areas from an ecological and a remote sensing point of view, to reduce the land surface reflectance variability in the dataset in order to improve the classification efficiency. A spatiotemporal (K-means) classification was finally made on the MODIS NDVI time series, inside each of the agro-ecological regions

For Senegal, we obtained an updated map of crop area with a better resolution than the USAID map (which is 1 km resolution) and with a nomenclature more specific of the Senegal region than suggested in the POSTEL map.

For Mali, the results showed that MODIS data set can provide a completely satisfactory representation of the cultivated domain in one FEWS zone, in combination with external data. Results at national scale are being processed and will be presented at the conference.

Index Terms— Crop area, MODIS, Stratification, Senegal, Mali.

1. INTRODUCTION

The northern fringe of sub-Saharan Africa is a region that is considered particularly vulnerable to climate variability and change, and food security remained there a major challenge. To address this issue, major international research efforts are being deployed, coordinated by the ongoing project AMMA (African Monsoon Multidisciplinary Analyses). Its aim is to better understand the West African Monsoon and its variability, and to improve the predictions of the impacts of this variability on West African societies. One of the preliminary stages necessary for analyzing such impacts on agriculture and food security is a reliable estimation of the cultivated domain at national level, a scale compatible with climate change studies. For that purpose, different early warning systems such as FEWS and JRC-MARS use global land cover maps but they are generally focused on large ecosystems, and are not suitable for fragmented and heterogeneous African landscapes.

The opportunity of using satellite remote sensing for agricultural statistics has been explored by the research community as well as by national departments of agriculture during the last few decades [1]. In Africa, existing global land cover maps have arisen from different initiatives such as the GLC2000 [2] or the POSTEL global land cover maps [3] but generally they are more focused on ecosystems than on agricultural systems. In the Sub-Saharan Africa countries, operational land cover mapping systems are restricted by the cost of high resolution images. Yet, the monitoring of vast ecosystems at national or continental scales typically resorts to low-resolution free images [e.g. 4; 5], but the pixel size of these images is generally too coarse for the identification of fields, especially in fragmented landscapes. Nevertheless, recent moderate-resolution sensors, such as MODIS/TERRA, with spatial resolutions as low as 250 m, offer new possibilities in the study of agricultural lands. With this increase in spatial resolution, the detection of groups of fields can now be considered. The low and medium spatial resolutions do not, by themselves, provide a completely satisfactory representation of the landscape but are compensated for by a large coverage area and by an excellent temporal resolution.

This brings us to the question whether moderate-resolution satellite data, in combination with external data (thematic maps, statistics, etc.) can provide a correct assessment of the distribution of the cultivated domain at country level. It is expected that more consistent information on vegetation would allow monitoring Sahelian rural landscapes with better continuity, thereby providing relevant information for early warning systems.

In this study, we develop a methodology for extracting cultivated areas based on their temporal behavior as captured in time-series of moderate resolution remote sensing images. We applied this methodology in Senegal at national scale and tested its applicability to a FEWS zone (Koutiala) located in Bani catchment in Central Mali.

2. MATERIALS AND METHODS

2.1. Study area

Senegal and Mali are respectively the two westernmost countries of West Africa around Latitude 14°N. Both countries display a South – North climatic gradient that ranges from subtropical to semi-arid, and which extends further north to arid and desertic in the case of Mali. As for other West African countries along the same latitudinal belt, food security relies on an adequate supply of rainfall during monsoon season. They can therefore be considered representative of the Sudano-Sahelian zone, where a strong dependence on rainfed agriculture implies vulnerability to major changes due to climate and human activities, and hence require specific attention.

2.2. Data

MODIS TERRA Vegetation Indices

Amongst MODIS products, we selected the 'Vegetation Indices 16-Day L3 Global 250m SIN Grid' temporal syntheses for our study. For Senegal, 46 MODIS 16-days composite NDVI images (MOD13Q1/V04 product, 250 m spatial resolution) were acquired for 2004 and 2005 and NDVI time series were generated. These products include a NDVI quality band (QB). Although MODIS images have already been radiometrically corrected, we noticed some radiometric defects and noises. For dates with a Vegetation Indices Usefulness Index value in the QB data set lower than "good" quality, NDVI values were replaced by linearly interpolated values from the two closest surrounding dates with "good", "high", or "perfect" quality. The required set of tools was developed with IDL (Interactive Data Language) programming language. This interpolation considerably improved the NDVI temporal profiles, eliminating abnormal drops and smoothing the profiles.

Landsat ETM+ orthogeocover data

Twelve Landsat ETM+ Orthogeocover images were used to cover Senegal. They were directly downloaded in GeoTIFF format in the UTM WGS84 Zone 28N projection from the http://glovis.usgs.gov/ website. No conversion of format or projection was thus necessary. Their acquisition dates are in September, October, November 1999, 2000 and 2001.

A set of ten Landsat ETM+ Orthogeocover images were used to cover Bani catchment in Mali. They come from the Landsat image bank that was put at the disposal of the scientific community free of charge by NASA (http://glcf.umiacs.umd.edu). Their acquisition dates are in October, November, December, January, 1999, 2000, 2001 and 2002. These images were classified in order to provide seven land cover classes according to methods described in [6] and [7]. For this study, the land cover map was simplified to a two-classes map (crop/non crop).

SPOT 5 data

One SPOT image included in the FEWS zone of Koutiala was used. The acquisition date is November 2007.

2.3. Methods

Stratification

Several studies have shown that image classifications of very heterogeneous areas lead to much confusion between different natural environments [8]. To reduce confusion, a stratification of the territory into homogeneous areas, mixing remote sensing with previous knowledge from various disciplines is usually carried out. Land surface reflectance variability is reduced in the dataset, thus improving classification efficiency. Each stratified region can be classified separately and the results subsequently combined to cover the whole of the study area.

Stratification of Senegal into 16 agro-ecological zones was carried out using an iterative process. First, we used various thematic maps (soil, vegetation, climatology, etc.) to perform an initial delimitation based on different criteria (relief, geology and soil, vegetation, rainfall and growing season duration, ethnic groups and population density, agricultural and animal production). This delimitation was then refined with the help of NDVI temporal profiles obtained from MODIS images and high-resolution Landsat ETM+ images.

For Mali, we used the FEWS livelihood zones map, and stratified the country into 10 agro-ecological zones, as shown in Figure 1.

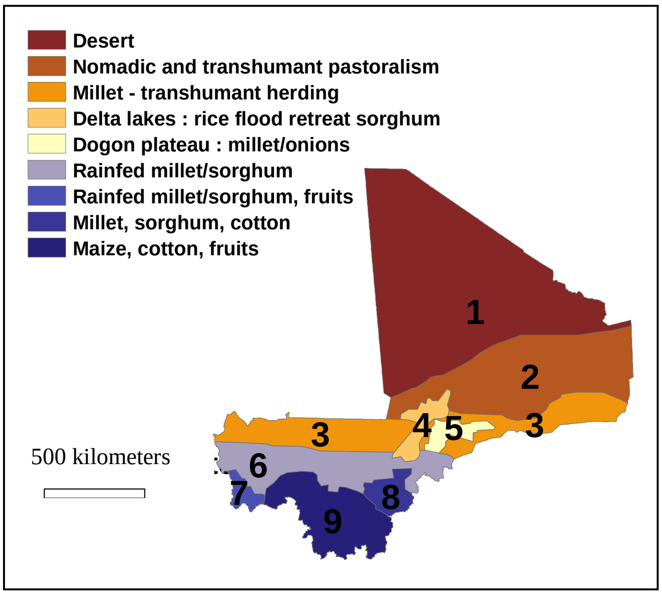

Figure 1: FEWS livelihood zones map for Mali country

Classification

The MODIS time series dataset can be seen as a collection of ‘temporal pixels’, each characterised by its own temporal profile. These pixels have to be classified and given a spatial representation, expressing the phenological evolution of different types of vegetation cover. Inside each of the agro-ecological regions, a spatiotemporal (K-means) classification was made on the MODIS NDVI dataset. This method would group pixels having similar temporal behaviours. The initial number of classes for each agro-ecological region varied between 20 and 40 depending on the heterogeneity of the region.

Interpretation

For Senegal, the initial 20 to 40 classes of each agro-ecological region were grouped into only three classes: “crops”, “crops mixed with natural vegetation” and “other”. We considered as “crops” all the classes constituted by more than 80% of crops, and as “mixed crops” classes constituted by about 50% of crops. The grouping was done by analysing the typical temporal profiles of the initial classes and interpreting the latter using high-resolution Landsat ETM+ images where cultivated domain could be identified.

For Mali, the initial 20 classes of the considered FEWS zone were grouped into two classes: “crops” and “other”. The low spatial resolution of the MODIS images does not allow us to visually distinguish crop zones because plots are not discernible. We identified the cultivated area using the high resolution SPOT image of Koutiala.

3. RESULTS AND DISCUSSION

3.1. Senegal

The map of the cultivated domain in 2005 is presented in Figure 2. Altogether, the results appear consistent at national scale, with the large agricultural areas correctly identified. However, a closer look at the results showed that accuracy was not uniform everywhere. The method seems more effective in regions where the cultures present important phenological differences with the surrounding vegetation, like for example, in Casamance, where crops are found in valleys and surrounded with tree savannas, whose phenological behaviour is extremely different from that of the crops.

The resulting map was compared with the only available map of the cultivated domain at national scale, which dates back to 1986 [9]. Although not from the same year, we can observe that, at that scale, the spatial distribution of cultivated area is very similar. However, if the two maps are analysed more closely and compared with high-resolution images, we can observe that the present map contain more detailed information. Another way of confronting this map to independent information was to compare it with official crop statistics. A good correlation was obtained ($R^2 = 0.81$) when the mapped crop surfaces were summed for 32 administrative divisions and compared with cereal crop area, as assessed by Institute of Agricultural Research of Senegal in 2005.

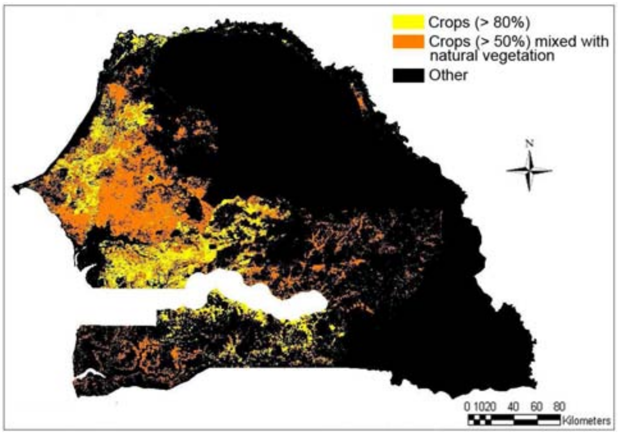

Figure 2: Cultivated area in Senegal.

3.2. Mali

For Mali, large agricultural areas were once more correctly identified. However, since agricultural plots are generally smaller than 0.5 ha in Mali, about twelve plots have to be grouped together to make up a ‘pure’ crop pixel. But most often, the plots are grouped in islands around villages or at the bottom of small valleys. And, most often, the plots are mixed with natural vegetation. The resulting pixels are mixed pixels, and we had to sort the classes into three categories (‘crop’ classes, ‘crops mixed with natural vegetation’ classes and ‘other’ classes), as it was done for Senegal.

The resulting map was compared to one classification of the Bani catchment [6] [7], made from Landsat data set in 2000 and showing 37% of crop area for the FEWS zone of Koutiala. From MODIS, we obtained a cultivated domain of 44% for the same zone. Although not from the same year, we can notice than the spatial distribution of crops is similar (Kappa=66%) (fig. 3). The classification from MODIS can bring more imprecision due to the image resolution, but considering that this method will be applied at national scale, the result is very satisfying and promising.

		MODIS		
		Non crop	Crop	Total
LANDSAT	Non crop	**3053238**	1632484	4685722
	Crop	925688	**1975414**	2901102
	Total	3978926	3607898	7586824
	Producer accuracy	**77%**	**55%**	
	Kappa	**66%**		

Figure 3: confusion matrix

4. CONCLUSION

A correct assessment of the distribution of the cultivated domain at country level can therefore be reached by a comprehensive stratification of the study area and moderate-resolution satellite data, in combination with external data.

First results have been very encouraging. The cultivated domain can be separated from other land-cover types on the basis of its temporal behaviour. This constitutes a satisfactory improvement in the mapping of the cultivated domain; an annual update, at minimal cost, will then be possible. Moreover, tools developed in this study can be reused for other regions.

5. ACKNOWLEDGMENTS

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