High Spatial and Temporal Resolution FORMOSAT-2 Images: First Results and Perspectives for Land Cover Mapping of Semi-arid Areas (Marrakech/Al Haouz plain)

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Abstract — The knowledge of land cover is a prerequisite for efficient agricultural water management and sustainable development of semi-arid areas. Remote sensing is the only feasible mean of providing this information with a consistent space and time basis. In this context, the objective of this communication is to present a first analysis of high resolution and high repetitivity FORMOSAT-2/RSI images. The work is performed from a time series of FORMOSAT-2 images acquired over the semi-arid Tensift-Marrakech plain during the 2005/2006 agricultural season. The main characteristics and the processing of these data are firstly presented. NDVI space time variations are analysed for the dominant land classes over an irrigated area where cereal and non irrigated lands are dominant. Finally, the first results obtained using a decision tree with criteria applied on NDVI time series averaged by fields are discussed.

I. Introduction

Irrigated agriculture makes a major contribution to food security, producing nearly 40% of food and agricultural commodities on 17% of cultivated lands (FAO 2002). Efficient agricultural water management is especially important in semi-arid areas where resources reach full exploitation or are overexploited. The design of tools that provide with regional estimates of water balance and crop yield may help the sustainable development of these areas. In this context, the knowledge of land cover is a prerequisite. Remote sensing information, in concert with GIS technologies, may form the information base upon which sound planning decisions can be made, while remaining cost-effective ([1],[2]).

Data acquired in the solar spectral domain have been the most intensively investigated. Until now, they have been acquired either by high spatial resolution systems with a moderate time revisit capacity (around 15 days, e.g. Landsat-TM, SPOT-HRV) or by large field-of-view sensors that observe the entire Earth every day at a much lower spatial resolution (250m to 1km, e.g. SPOT-VEGETATION, TERRA-MODIS). Launched in May 2004, FORMOSAT-2/RSI is the first and only satellite sensor able to provide daily images at a high spatial resolution.

One of the first time series of FORMOSAT-2 images has been acquired over the semi-arid Tensift/Al-Haouz plain, the pilot site of the SudMed programme ([3],[4]). The objective of this communication is to present the first results derived from these data for mapping the land cover of an irrigated area located 40 kilometers East of Marrakech. Despite the area is mainly cropped with cereals, there is a large variability as the agricultural practices are very heterogeneous and partly traditional. This variability makes difficult the use of classification methods based on statistical consistency between observations and typical signatures of thematic classes (e.g. maximum likelihood). Here the analysis is based on NDVI time series and a decision tree. The availability of numerous images allows identifying refined criteria to discriminate the main land classes of the area of interest.

II. Space Time Characteristics and Processing of Formosat-2 Images Acquired over the Tensift/Marrakech Plain

FORMOSAT-2 has been launched by the National Space Organization of Taiwan (NSPO, http://www.nspo.org.tw/). It is operational since May 2004 onto a sun-synchronous orbit, with onboard the Remote Sensing Instrument (RSI). RSI provides high spatial resolution images (8m in the multispectral mode for nadir viewing) in 4 narrow spectral bands ranging from 0.45 µm to 0.90 µm (blue, green, red and near-infrared). Unlike other systems operating at high spatial resolution, FORMOSAT-2/RSI observes a particular area every day with the same viewing angle. However, it only surveys a part -about the half- of the Earth.

The FORMOSAT-2/RSI images presented in this study were collected from November 2005 to July 2006 with a nominal time step of 4 days, for a total of 60 images during the 9-month period ([5], [6]). All images were acquired with an off-nadir angle of 18°±1°, viewing to the west across track. The scenes are 24km to 27km long, centred around 7°35'W x 31°40'N, 40 km East of Marrakech. Figure 1 provides the dates and cloud coverage of these acquisitions. The cloud coverage was determined by visual examination of each image and we only kept the 26 images that were totally cloud-free. It can be seen on figure 1 that some failures or conflicts

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in the programming occurred end-of-January, beginning-of-February, beginning- and end-of-April, and mid-June. Due to the programming conflicts and high cloudiness, no data were available between mid-January and the beginning of March.

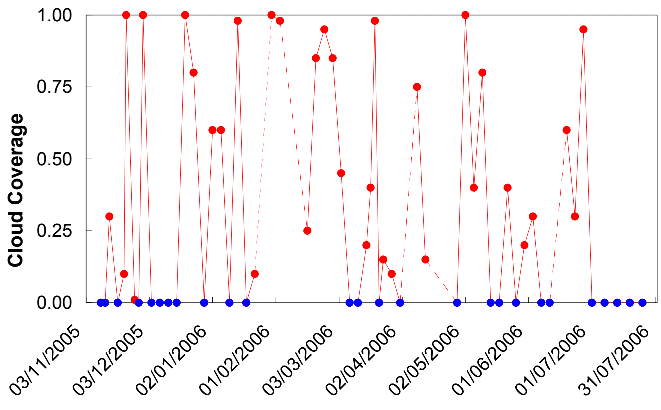

Fig.1. Dates and cloud coverage of FORMOSAT-2/RSI images. Blue dots highlight the data kept in this study. Dotted lines indicate gap in acquisition compared to the nominal planning.

SPOT-Image provided us with level 1A images. The images were superimposed together using an autocorrelation algorithm, geolocated against a set of GPS ground control points and resampled using Lambert North Morocco projection, with a sampling interval of 8m. Atmospheric correction was performed using the SMAC code ([7]) and data collected by CIMEL sun photometers installed in the vicinity of the region of interest. This processing results in a time series of cloud-free images of surface reflectances, from which the Normalised Difference Vegetation Index (NDVI) was computed.

III. Region of Interest

FORMOSAT-2/RSI images include the eastern part of the Tensift plain and the surrounding 'Jbilet' hills and foothills of High-Atlas mountains, in Central-Morocco ([5],[6]). The climate in the plain is of semi-arid continental type with low and irregular rainfall around 240mm/year in contrast of a high evaporative demand around 1500mm/year. On the South in the High-Atlas mountain range, precipitation is up to 600mm/year, supplying several large irrigated areas in the plain.

The region of interest is an irrigated area presented in Fig. 2. The area is managed by a regional public agency (ORMVAH) that is in charge of the distribution of dam water. It is largely dominated by cereal, mostly wheat, then barley. The others land classes includes sugar beet, olive trees, forage (mainly alfalfa) and fruit/vegetable. This site was documented in [8], [9] and [10] from data collected on wheat fields during the 2002/2003 and the 2003/2004 agricultural seasons. The experiment that took place in this area ([5],[6]) allowed to collect the land cover type over more than 400 fields as detailed in table 1. Despite the land use is rather simple, a lot of disparity may exist for a same crop type. In particular for cereal, the farmers do not go along the same technical itinerary and there is a large heterogeneity in crop calendar as well as irrigation and fertilisation schedules. The data collected during the 2005/2006 season shows the following agricultural practices: sowing occurs from mid-November to mid-January, the number of irrigation range from 0 to 4 and the quantity of fertilisers varied from 0 to 400 kg/ha. As a result, crop yield is very variable, from about 0.5 to 5 t/ha. The non irrigated class also includes a wide range of vegetation type (colza, oat, grass) and density, with scarce vegetation on the areas that remains non cropped during several years and rather dense vegetation on fallows which serves as natural forage in case of favourable rainfall.

Table I.
Land use type and sampling

Type	Samples	Type	Samples
sugar beet	4	non irrigated	123
cereal	280	Alfalfa	1
cereal/forage	5	Melon	5
broad bean	6	Olive tree	3

IV. Analysis and Classification of NDVI Time Series

In Figure 3, we compare two NDVI time series obtained over a non irrigated area and an irrigated wheat fields. This figure first allows to illustrate the quality of the FORMOSAT NDVI time series: the seasonality of the vegetation clearly appears and the mean curves are very smooth since the directional effects are strongly limited (no change in viewing angle). The wheat fields experienced two irrigations and was invaded by wild colza and oat, resulting in a poor yield (0.5-1 t/ha). This figure also highlights how large is the heterogeneity within the two plots. In the non cropped area, the in-field NDVI variation ranges from ±0.2 around average values during the growing season (days 364 to 456), indicating the juxtaposition of areas with scarce (NDVI~0.3) and dense (NDVI~0.6) vegetation. The wheat field heterogeneity is also large (±0.1 at the maturity period). As a result, it can be noticed that the dynamics of wheat crops, though irrigated, are sometimes the same as that of the non irrigated vegetation (the difference between seasonal minimal and maximal values of NDVI is about 0.6 in both cases). This example shows the difficulty of distinguishing non irrigated from irrigated area through a pixel analysis. In this objective it seems more effective to consider the NDVI time course averaged at the field level. Looking at the time courses of average NDVI in figure 3, it appears possible to separate the two classes. This is particularly visible around day 500, since the senescence is delayed for wheat plants compared to non-irrigated vegetation.

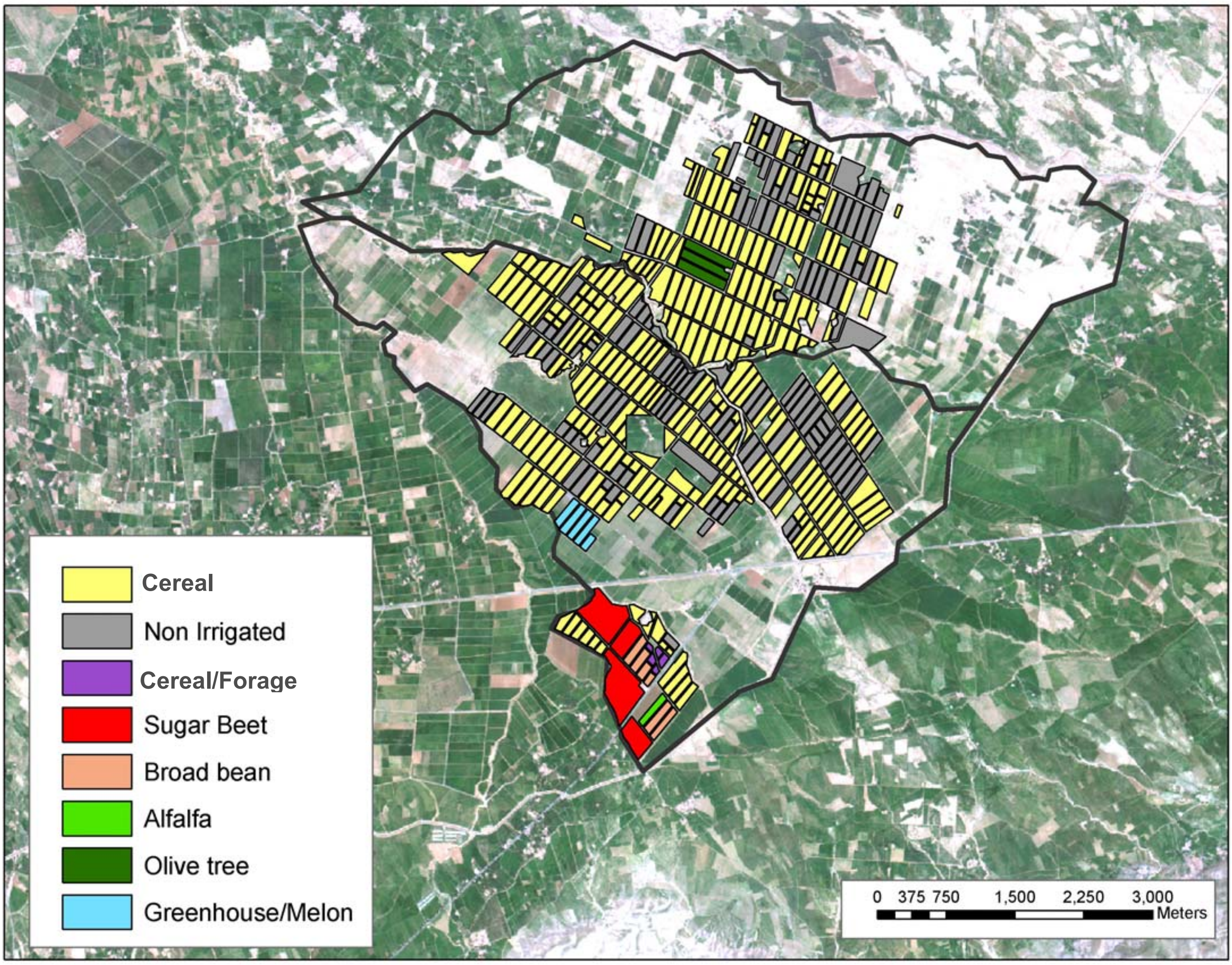

Fig.2. Irrigated area of interest and land cover presented on a FORMOSAT image acquired on March 22, 2005 ('true-color' composite image).

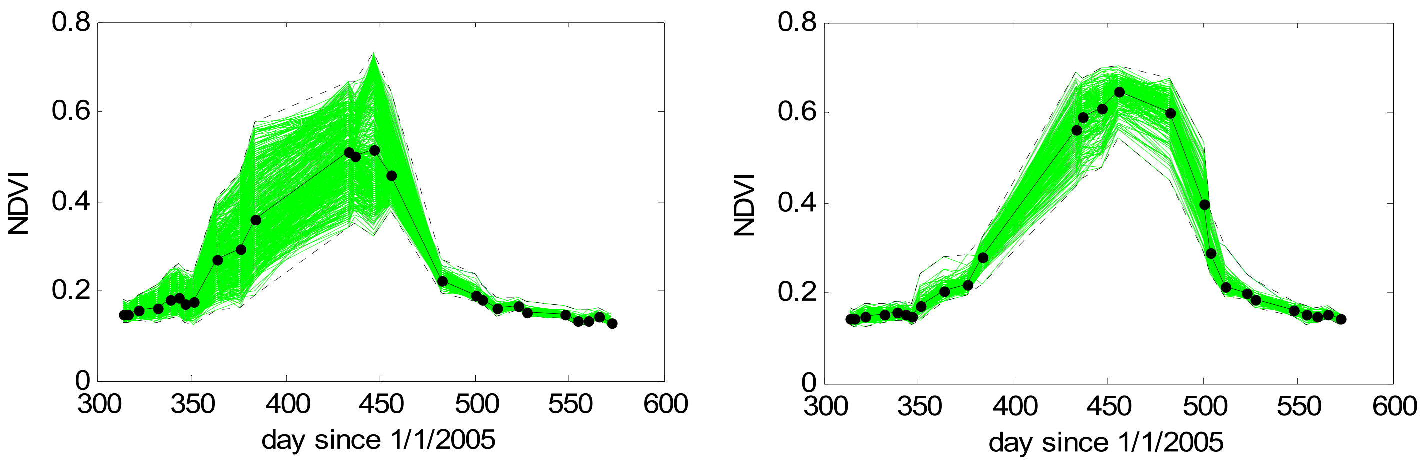

Fig.3. Examples of NDVI time series on two plots : non-irrigated (left) and wheat (right). The NDVI time courses obtained on all the pixels (8m resolution) are displayed in green, with minimum and maximal value in dotted lines. Average values are represented by the black curves

This first analysis is extended to other fields and land classes from the NDVI seasonal courses presented in figure 4. In this figure, each curve corresponds to one NDVI profile derived over each of the fields delimited in figure 2. Here again, we can notice the large heterogeneity of vegetation phenology and recovering within the non irrigated class as well as the cereal class. NDVI time courses appear more regular within the other classes, but the sampling is limited to some fields at the South of the irrigated area (see fig.2). The analysis of the NDVI profiles displayed in figure 4 allows to identify and to illustrate some specificities in the signatures of each land class:

- Alfalfa always display high NDVI values, with some very high values before cutting,
- The NDVI dynamics is limited for olive trees,
- Amongst the annual plants, there is a hierarchy of NDVI values at the beginning of the season, with the cereal used as forage displaying the highest NDVI values, followed by broad bean (day 364), then spring cereal and non irrigated areas,
- The senescence occurs later for irrigated areas (first on cereal then on sugar beet and melon) than for non irrigated areas.

These qualitative findings, which have to be generalised, are at the basis of the decision tree we built to discriminate these eight classes (Fig. 5). The confusion matrix associated to the classification obtained by applying this decision tree on mean NDVI time series (plot scale) is presented in table 2. Some mismatches occur between the different annual crops and in few cases between irrigated and non irrigated areas. The overall accuracy is nevertheless excellent, around 95%.

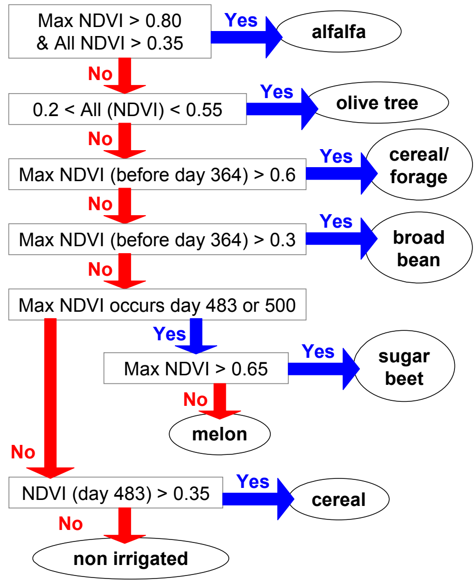

Fig.5. decision tree used to discriminate the 8 land cover classes from their mean NDVI time series (plot scale).

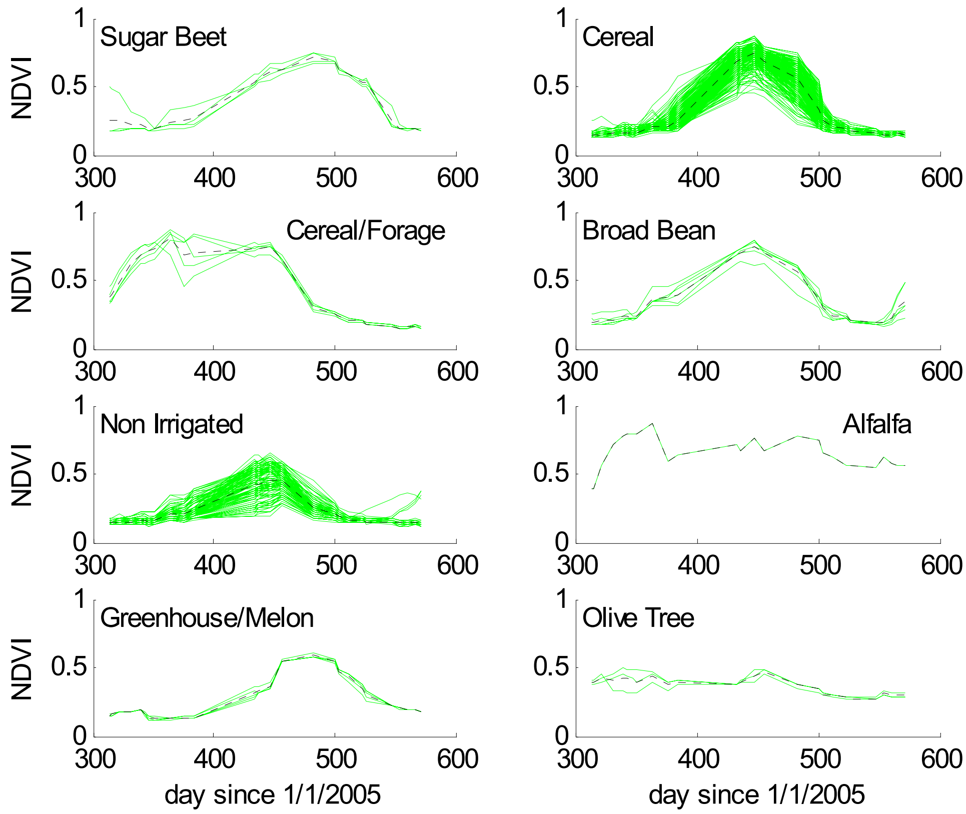

Fig. 4. NDVI time series on the 8 land classes. The time courses of NDVI averaged for each field of study are displayed in green, with the average time courses in black.

This first analysis confirms the interest of high spatial resolution and high repetitivity satellite data for the mapping of land cover. When compared to the previous analysis we performed based on a set of 8 Landsat-TM images acquired during the 2002-2003 agricultural season ([11]), it appears possible to gain both accuracy and refinement in the identification of land cover based on the analysis of FORMOSAT-2/RSI time series of images. This information will serve to benchmark different land cover mapping algorithms applied at various spatial, temporal or categorical scales, i.e. for various types and groups of land cover categories ([2]). In particular it will be used as a reference to validate regional applications based on coarse spatial resolution data ([12],[13]). However, the sampling is limited since the region of interest is mainly cropped with cereals. These preliminary results should now be confirmed and generalised using a second data set which have collected over the entire FORMOSAT images.

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TABLE 2.
CONFUSION MATRIX RESULTING FROM DECISION TREE. THE CELLS INDICATE A NUMBER OF PLOTS.

ground truth / estimate	sugarbeet	cereal	cereal/ forage	broad bean	non irrigated	alfalfa	melon	olive tree
sugarbeet	2	1	0	0	0	0	0	0
cereal	0	263	0	0	6	0	0	0
cereal/forage	0	0	5	0	0	0	0	0
broad bean	2	3	0	6	3	0	0	0
non irrigated	0	12	0	0	114	0	0	0
alfalfa	0	0	0	0	0	1	0	0
melon	0	1	0	0	0	0	5	0
olive tree	0	0	0	0	0	0	0	3