SEASONAL AND ANNUAL VARIATIONS OF SUGARCANE WITHIN-FIELD VARIABILITY, AS OBSERVED IN SPOT TIME SERIES

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ABSTRACT:

At the field scale, crop spatial variability is related to multiple factors that are time-dependant. In this paper, we analyzed the within-field variability of a sugarcane crop at two different time-scales, season and year, and try to relate this variability to cropping and environmental factors.
A series of fifteen SPOT4 and SPOT5 images were acquired in 2002 and 2003 over Gardel sugarcane estate in the French West Indies (Guadeloupe). The study was focused on a 6.5 ha field of rainfed sugarcane. The fifteen images of the field were individually classified using an equal count algorithm in order to enhance spatial patterns independently of the crop growth.
At the season scale, the inside-field growth pattern depends on the phenological stage of the crop and the cropping operations. At the year scale, NDVI maps around the peak of vegetation reveals a stable pattern for 2002 and 2003, despite very different rainfall amounts, but with inverse NDVI values. This inversion can be directly linked to the topography, and consequently to the water conditions of the plant. Through that example, we concluded that the pattern of vigor occurrence within fields can help to diagnose growth anomalies.

INTRODUCTION

Precision farming aims to improve crop production efficiency and reduce environmental pollution by adjusting production inputs to the specific conditions within each area of a field. Therefore, the delineation of iso-yield zones is the primary information for precision farming (Doerge, 1999). However, to optimize the inputs and cropping calendar, it is necessary to determine the causes of the spatial variability of the crop vigour.

Crop spatial variability is related to multiple factors that can be permanent or time-dependant. The main permanent factors of variability are linked to the substrate, like the topography or the soil type and depth (Wiegand et al., 1996). The time-dependant factors are anomalies in planting or emergence or weather conditions (annual variations) or plant disease, weeds development, severe climatic events or irrigation system dysfunction (seasonal variations). Theses permanent and time-variable factors generally interact leading to complex spatio-temporal patterns of crop vigour (Machado et al., 2002).

In remote sensing, broad bands vegetation indices like NDVI have been largely used to delineate management zones (e.g. Yang & Everitt, 2002; Wiegand et al., 1998), but they typically lack diag-nosis capability for identifying a particular type of stress or for determining why biomass is at a certain level. According to Pinter et al. (2003), historic imagery could be combined with crop calendars, heat units, precipitation records and yield monitor data to develop maps showing areas that are prone to water stress, nutrients deficiency or pest problems under a particular environ-mental scenario. To our knowledge, fine time series of satellite remote sensing data have been little studied so far in that direction, mainly because data were not available.

In this study, our working hypothesis is that the analysis of the seasonal and annual dynamics of NDVI spatial patterns can help to establish a diagnosis on crop conditions. To test this hypothesis, we analyzed the within-field variability at two different time-scales, seasonal and annual, and try to relate this variability to cropping (crop calendar and plant phenology) and environmental (topography and climate) factors. This analysis is based on a sugarcane field NDVI from a time series of fifteen SPOT images acquired in the French West Indies (Guadeloupe) in 2002-2004.

1 METHODS

1.1 *Crop material and study site*

Sugarcane (Saccharum officinarum L.) is a semi-perennial tall grass with fibrous stalks 2 to 6 meters tall. After the harvest of the plant crop (aged 18 to 24 months), buds on the leftover underground stubbles germinate again and give rise to another crop. This crop is then harvested at about 12-month intervals for up to four years or more, before being renewed due to decreasing yield.

The study site is located in Gardel Estate (16°18' 24" N; 61°20' 29" W), a planter-miller Estate growing rainfed sugarcane in the French West Indies (Guadeloupe). The site is a 6.5 ha field planted in 2000, and harvested in 10 June 2002, 30 Apr. 2003 and 9 June 2004.

The closest climatic station from Sahara field is Boisvin, less than 2 km far. The recorded rainfall were respectively 1185 mm and 1905 mm for the 2002-03 and 2003-04 growing seasons (from June to May) for an average annual rainfall of 1325 mm (1977-2000 period) on Gardel area.

1.2 *Data acquisition*

A time series of 15 cloud-free images (13 SPOT5 images and 2 SPOT4 images) were acquired in 2002-2004 over Gardel Estate (Guadeloupe). The images were acquired at 20 m and 10 m resolution respectively for SPOT4 and SPOT5 satellites (red and near infrared bands), in raw format (level 1a) with no geometric pre-processing.

The Sahara field Digital Elevation Model (DEM; Figure 1) was extracted from the Guadeloupe IGN TOPO® Data Base.

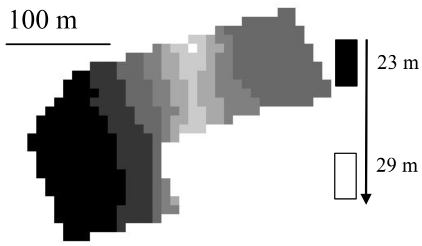

Figure 1. The Digital Elevation Model of Sahara field (Source: IGN TOPO® Data Base).

1.3 *Image processing*

SPOT images were orthorectified using the SPOT geometric model provided by ERDAS IMAGINE™ software. For the process, we used the 10 m resolution DEM and thirty control points scattered over the whole island. The control points were extracted from aerial orthophotos (ORTHO® DB, IGN). The images registration error was less than 10 m (less than 1 SPOT pixel).

In order to have absolute NDVI values for time analysis, the digital counts were converted to reflectances, and to minimize the radiometric residual effects due to varying irradiance conditions, we used the Normalized Difference Vegetation Index (NDVI; Rouse et al., 1974) calculated with the TOA reflectances in the Near Infrared and the Red bands.

Subset NDVI images corresponding to the boundaries of Sahara field (minus a buffer zone of 20 m) were created from the time series. To help visualize and summarize field spectral data, the field NDVI values were aggregated into five discrete categories. The aggregation was done according to the equal count (quintiles) or equal-area classification, where approximately the same number of observations (20% of the total) is put into each class. This technique permits to focus on crop spatial variability, independently of the crop growth stages.

2 RESULTS

2.1 *Environmental data*

The satellite time series is spread over two cycles of sugarcane growth with different climatic conditions (Figure 2). The 2002-2003 cycle shows a rainfall deficit of 140 mm compared to the 24 years average rainfall, with deficit records at the end of the rainy season (Nov. and Dec.). On the opposite, the rainfall of the 2003-2004 cycle has a surplus of 580 mm compared to the 24 years average with surplus peaks of 116 mm (Oct.) and 327 mm (Nov.) due to severe rainfall events.

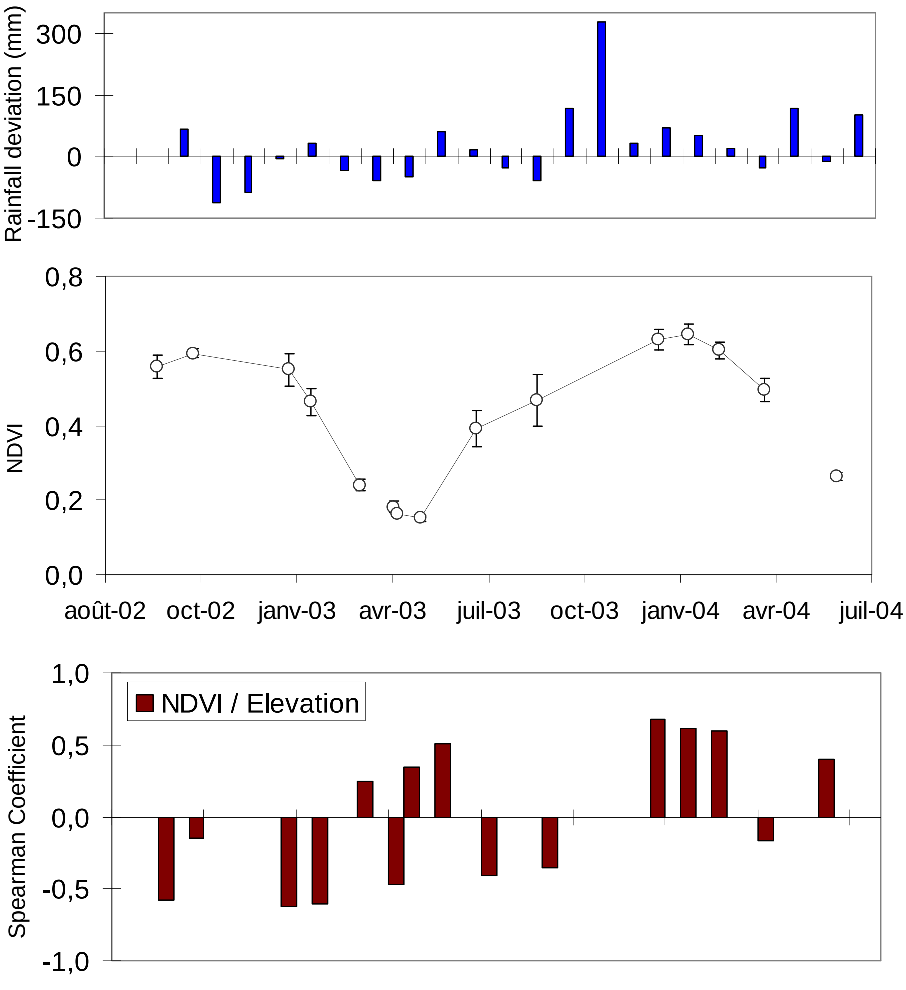

Figure 2. a) Boisvin monthly rainfall deviation from average over 24 years (1977-2000) at Gardel Estate, b) mean and standard deviation of Sahara field SPOT NDVI, c) Spearman coefficient be-tween NDVI and elevation at pixel scale.

2.2 *NDVI time series of sugarcane*

Figure 2 shows the evolution of the mean NDVI of Sahara field throughout the two growing cycles. After harvest, in May and June 2003, when there are only crop residues present on the soil, the value of the NDVI is low, between 0.15 and 0.2. The NDVI then increases rapidly as the vegetation re-grows and reaches its maximum at the end of the rainy season, with values between 0.7 and 0.8, typical of a fully developed dense green canopy. When there is no water stress, as in 2003-04, the NDVI remains stable or decreases slowly during the maturation phase due to a decline in leaves chlorophyll and change in the canopy architecture (Almeida et al., 2006). On the opposite, in case of severe water stress as in 2002–03, after reaching its maximum value the NDVI can decrease all the way down to 0.25 mainly due to the severe senescence of the leaves.

2.3 *Seasonal variations of NDVI patterns*

Inside-field growth pattern depends on the phenologic stage of the crop and the cropping operations. Figure 3 shows equal-population classes of Sahara field NDVI for each acquisition date during two consecutive growing cycles. During the growth stages (images 7, 8 and 15), the within-field spatial variability is erratic; at this stage, the vegetation cover is partial and the background (cane residues, weeds …) is still visible. From the end of the growing stage and to the initial maturation phase (images 1, 2, 3, 4, 11, 12 and 13), the pattern of the inside-field variability stabilizes. The crop is then fully developed and soil is no longer visible. On 30 April 2003 (image 6), the within-field variability map displays stripped patterns, characteristic of the harvest in progress.

However, in this time series, some images display unexpected growth patterns – 24 Oct. 2002 (image 2) and 12 Apr. 2004 (image 14) - that could not be explained by the acquisition conditions. For 24 Oct. 2002, a heavy rainfall two days ago could explain the change in growth pattern by changes in the crop architecture.

2.4 *Annual variations of NDVI patterns*

Around the peak of vegetation growth (images 1,2,3,4 for 2002-03; images 11,12,13 for 2003-04), the within-field NDVI patterns are similar for both crop cycles, but the values of the classes are inversed. This unexpected feature can be attributed to the interaction between topography and climatic conditions. The analysis of the relief of the field (Figure 1) indicates that during the dry year (2002/03), the NDVI is maximal in the low part of the field, while in the rainy year (2003/04), the NDVI is maximal in the high part of the field. In the same way, during the wet year, the NDVI is minimal in the low part of the field, while in the rainy year (2003/04), the NDVI is minimal in the high part of the field. This observation is confirmed by the correlation values obtained between elevation and NDVI at the pixel scale (Figure 2); negative values are obtained for the dry year, while positive values are found for the wet year. The best correlations are obtained with the images acquired around the peak of vegetation growth (between Nov. and Feb.), except for the two outliers (24 Oct., 2002 and 12 Apr., 2004).

3 DISCUSSION AND CONCLUSIONS

The main added values of satellite or aerial imagery over traditional systems remains its capacity of providing objective and spatially explicit observations of crop vigor variability throughout the cropping cycle. The dynamics of the spatial variability can be used to establish a diagnosis on crop conditions, as the spatial variability expresses itself at different time scales according to the driving factors. In this paper, we analyzed the within-field variability of a sugarcane crop at two different time-scales, seasonal and annual, and related this variability to cropping (crop calendar and plant phenology) and environmental (topography and climate) factors.

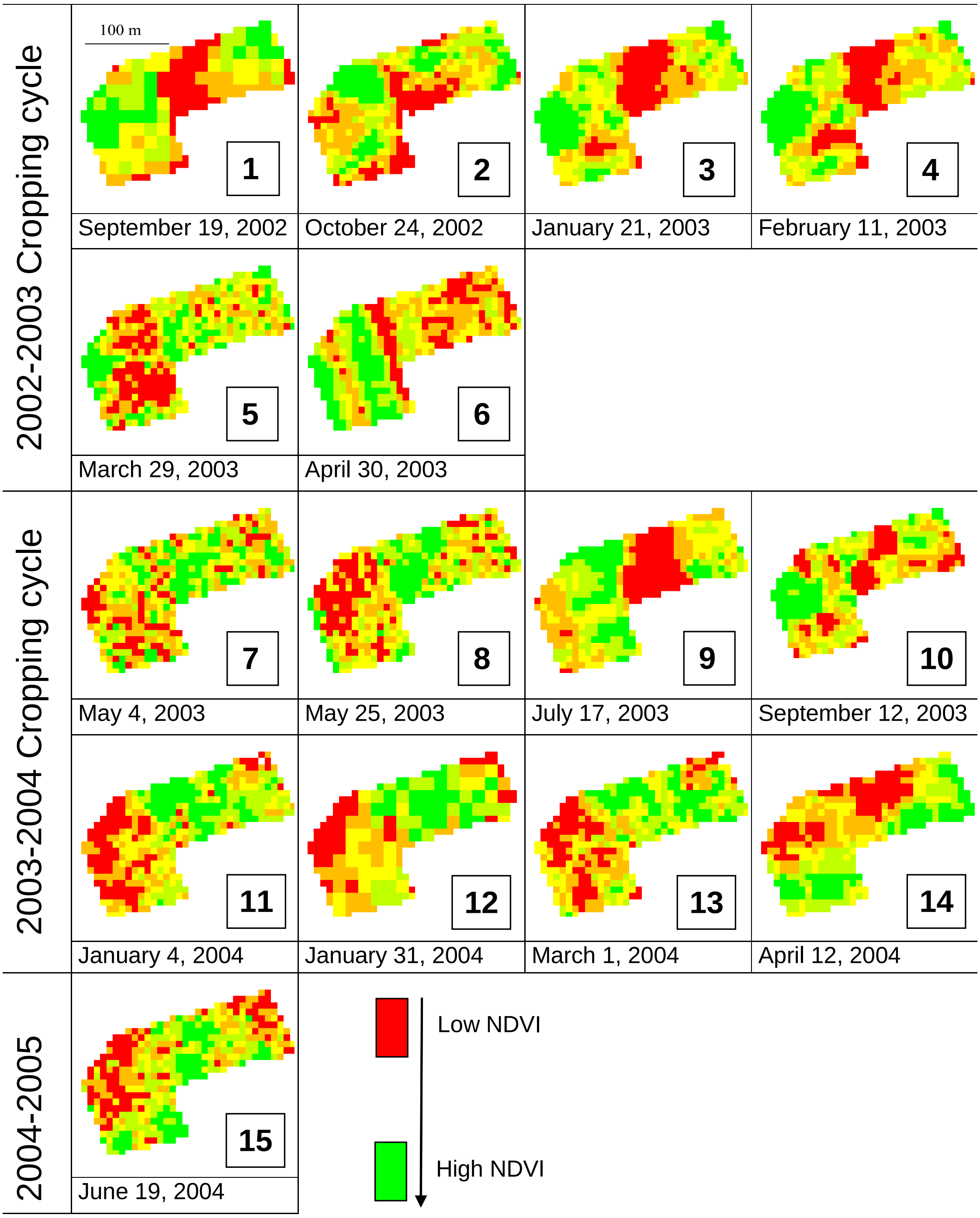

Figure 3. Sahara field images of equal-classified NDVI, for 2 crop cycles 2002-03 and 2003-04 (plus 2004).

At the season scale, the inside-field growth pattern depends on the phenological stage of the crop. At the early growth stages, the pattern within-field spatial variability is erratic and then stabilizes when the crop is then fully developed and the soil no longer visible. This result is consistent with Yang & Everitt (2002) who showed using a series of five airborne images that the images taken around peak vegetation development produced the best relationship with yield. However, some dates are outliers exhibiting different spatial patterns. Our hypothesis is that specific climatic events could be strong enough to change momentarily the architecture of the crop.

At the year scale, averaging the NDVI maps around the peak of biomass, we found a stable pattern for both years, but with very different NDVI values. These potential yield variations can be directly linked to the topography, and consequently to the water conditions of the plant, with limited water stress during the dry year in the low part of the field, and water logging during the rainy year. The influence of the topography was previously shown by Marques Da Silva & Alexandre (2005) who proposed topographical indexes to help in site-specific management for delineating areas where crop yields are more sensitive to extreme water conditions.

To conclude, in this paper we showed through an example how the pattern of vigor occurrence within fields could provide hints for growth anomalies diagnosis. We also showed that single images are usually not sufficient for the diagnosis of crop conditions or predictions, and the time feature of the variability, combined either with or without environmental information, could lead to a better understanding of crop conditions.

Image time series applications for supporting decision-making in crop management should develop shortly, thanks to the launch of a new generation of satellite systems (Formosat, Venµs…) with high spatial and temporal resolutions and the development of light airborne systems.

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