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Potential and limitations of multispectral satellite imagery for monitoring degraded pastures in the tropical savannas

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Through examples from the authors and others, we discuss the potentials and limitations of multispectral satellite imagery to monitor degrading pastures. Here, the broad term "degradation" means the change of pasture conditions that reduces the profitability of livestock activities, affecting pasture quality and/or quantity. Possible causes are the inadequate fertilization or nutrient recycling, soil compacting, overgrazing, undergrazing, poor drainage, pests, rainfall regime changes and, in the case of cultivated pastures, invasion by weeds (Rincón, 1999). Mapping of degrading pastures is important to help focus special management practices, technical assistance, incentives for rehabilitation or alternative options, or to make decisions about the construction or maintenance of infrastructure related to pastoral activities, such as wells and roads.

Combinations of multispectral images allow us to take advantage of the distinct spectral "behaviour" of different land surface types. For instance, vegetation's chlorophyll causes a high reflectivity in the near-infrared portion of the electromagnetic spectrum and high absorption (low reflectivity) in the red. The most widely used vegetation indices, such as the NDVI, are calculated from the image bands corresponding to these portions of the spectrum. Their values increase with green phytomass, but they show an asymptotic relationship with parameters such as Leaf Area Index (Baret and Guyot, 1991). When vegetation cover becomes dense, they "saturate" and become insensitive to an increase in phytomass. Image color composites, obtained by assigning different image bands to the red, green and blue guns of the computer screen, almost always include the near infrared and red bands, usually with the medium infrared band when it is available. The presence and concentration of green vegetation can then be visually appreciated by the intensity of the color to which the near infrared band is assigned.

Vegetation indices can be measured regardless of the spatial resolution of the images, since the necessary channels exist on high and lower resolution multispectral images acquired by meteorological satellites like NOAA (AVHRR sensor) or the SPOT-4 satellite (Vegetation sensor). However, there is a tradeoff between repetitivity and spatial resolution, as we can see in table 1, which only portrays medium and low resolution images (high resolution images pose, at the moment, a very high cost limitation for agricultural applications). With images spaced in time, we miss the variability of the conditions. However, with low resolution images, having a pixel spacing of about 1 km (each pixel covers 100 ha), the images become useful only to visualize processes at smaller scales (covering very large areas). Even large pastoral plots, community lands and villages are usually indistinguishable. These images are suitable to monitor climate-induced degradation of pastoral lands, but not anthropically induced. However, low-resolution images have shown to be very useful for policy-making, especially in the African Sahel. The processing of large quantities of images can be simplified by calculating weekly, monthly or annual maximums of vegetation indices. Justice et al., 1985 studied the phenology of global vegetation from weekly maximums of the NDVI calculated from AVHRR images. Fry and Dudgeon, 1990, have mapped the density of healthy vegetation from monthly maximums of NDVI in Australia. In the Kanem prefecture of Chad, the pastoral hydraulic program is prioritizing the rehabilitation of pastoral wells in function of the biomass ranges of vegetation, categorized using annual maximum values of the NDVI computed for 1998 and 1999 (Begué and De Wispeleare, in Forigiani et al. 2001). Medium resolution images have also been used in the Sahel for the assessment of desertification. They present the advantage of allowing the mapping of landforms and vegetation formations, although for the latter, extensive field data is necessary for definition of classes. Landforms are useful to distinguish some sometimes spectrally similar classes (De Wispeleare, 1990).

The case of the South American tropical savannas and Central African savannas is somewhat more complicated than the African Sahel, often classified as dry savannas. In the latter, we find very extensive areas of native grasslands with shrubs, the grass layer dominated by annual plants. The productivity of these annual plants depends mostly on rainfall during the rainy season and not so much on management, whereas for perennial native plants, it depends greatly on management. Cloud cover is also less important, facilitating the acquisition of time series of cloud-free images. In South America's tropical savannas (Brazilian *Cerrados*, Colombian, Venezuelan and Bolivian *llanos*), large but often discontinuous areas of native grass and shrubland have been converted to cultivated pastures. Most of the pasture species introduced originate from Africa. Cultivated pastures often co-exist with crops that, in certain growth stages, exhibit similar spectral responses to theirs. Rainfall is higher, reducing the number of cloud-free images that can be acquired over the year. In South America's tropical savannas, agronomists and farmers are mostly concerned with the degradation of their cultivated pastures, while in Africa, native pastures dominate. In cultivated pastures, the detection of degradation by weed invasion poses a great challenge to Remote Sensing.

Three different experiments have recently been initiated in the Brazilian *Cerrados* and Colombian *llanos.* In an experiment in Uberlândia, Minas Gerais, Brazil, scientists from the Universidade Federal de Uberlândia and EMBRAPA-Cerrados analyze the potential of remotely sensed data to discriminate three different degradation levels (low, intermediate and high levels) in the *Brachiaria decumbens*, the most common cultivated pasture type in the Brazilian *Cerrado* biome. The plan is to acquire three Landsat images from the wet, end of wet and dry seasons (November, March, and August, respectively). The team is also gathering % green cover, biomass, Leaf Area Index and radiometric data during the satellite overpasses. Preliminary wet season, radiometric analysis have indicated that there is a real possibility to spectrally discriminate the three levels of degradation, mainly based on the amount of green biomass existing in each degradation level. In another experiment conducted in the sate of Mato Grosso do Sul, scientists from JIRCAS and EMBRAPA-CNPGC are analyzing the possibility of using Remote Sensing images to target the dissemination of agropastoral systems as options to rehabilitate degraded pastures. This study uses a series of Landsat TM and ETM images acquired between 1985 and 2000 to derive a map of pasture degradation processes for the district of Campo Grande. It places a strong emphasis on the temporal behaviour of the spectral response of each location, in order to characterize the evolution of the degradation processes and to quantify them. Landscape ecology methods, the use of pattern and texture, are being studied to produce indicators of the spatial distribution of phytomass decline and weed invasion. The location and intensity of degradation will be used to decide which rehabilitation method to recommend and/or implement.

Through a study in the Colombian llanos, scientists from CORPOICA and CIAT examine the possibility of using Landsat TM and SPOT imagery as a support to managing pastures in villages and farms. CORPOICA's experimental farms in La Libertad and Carimagua, where the evolution of conditions are known for each plot, are used as control sites. Additional applications with small communities that manage communal range land have been initiated in Puerto Guadalupe, Humapo and La Victoria, the latter two being part of the same indigenous reserve. Satellite images can advantageously support monitoring efforts by local stakeholders who have knowledge of the local production systems, and who have the possibility of ground-checking any conclusions from the images. Infestations by spittlebug or locust, or pasture death caused by root putrefaction, can be fairly obviously detected. A lower than expected vegetation index (or vegetation-related colour on the image) can indicate fertility loss or soil compaction. In any case, the cause and nature of the degradation must be verified in the field. Moreover, it is important to consider the pasture's management in any diagnosis made from satellite images. If not, recently grazed plots of a rotating management practice could be mistakenly identified as degraded in comparison to resting plots. In environments of intensely managed cultivated pastures, even more so when other crops are also present, policy-makers should not expect remote sensing specialists to produce maps of degraded pastures over extensive areas. Radar images could eventually complement multispectral images in the optical domain for the ground cover mapping, especially when cloud cover is an issue (Beaulieu et al., 1999).

Table 1: Potentials and limitations of medium resolution and low resolution products

Type of images	**Potentials**	**Limitations**
Medium resolution images, for example • SPOT HRV (pixel spacing 20m, repetitivity 26 days, very much shortened by the possibility of pointing the sensor and using any one of the 3 satellites still in orbit) • Landsat ETM+ (pixel spacing 28.5m, repetitivity 16 days)	• Sensitivity to green fytomass • Farmers and technicians can see individual plots when they are large enough, and thus relate image characteristics to management • Possibility of identifying degraded areas within plots • Can be used as management tool by farmers and farm managers • Facilitate the identification of vegetation type, especially if landforms are integrated into the interpretation or classifications	• We miss the variability of conditions because of low repetitivity (recently grazed pastures could be mistaken for degraded) • We strongly depend on the knowledge of management practices • Distribution to the end-users or those that can validate conclusions requires organization • We still don't know of methods to reliably detect weed invasions • Cloud over can limit the acquisition of data during the growing season • The cost of the images is relatively high
Low resolution images: • NOAA AVHRR (pixel spacing 1km, 2 acquisitions/day) • SPOT-4 Vegetation (pixel spacing 1 km, 1 acquisition/day)	• Sensitivity to green phytomass but at a more regional scale • Suitable for departmental, regional or continental scale studies • High repetitivity allows to detect areas that show a consistently low fitomass throughout the year	• With such a low resolution, pastures and other uses are mixed; unsuitable for diagnosis on very heterogeneous uses • Not suitable as management tool for farmers or local technicians • Cloud over can limit the acquisition of data during the growing season

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