Quantitative Estimation of Woody Vegetation in the Sudano-Sahelian Region. A Textural Approach Applied in a Region of Burkina Faso

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ABSTRACT

The quantitative estimation of vegetation from satellite remote sensing data is generally carried out using a purely spectral approach. The idea is to establish correlations between measured radiations or their combinations, vegetation indices for example, and parameters characterising the vegetal cover such as the overlapping amount relative to the soil or Leaf Area Index. However, the influence of some covers on spectral indices in precise seasons is a cause of doubtful results. In the Sudano-Sahelian region, during the rainy season, the spectral signature of the herbaceous stratum in a savanna with trees is predominant for the calculation of the vegetation index. This makes the spectral approach doubtful at this vegetation stage. Another element which might characterize the state of vegetal cover and will be complementary to its spectral information, is its spatial arrangement or its texture. High resolution satellite data reinforce this idea and allow the distinction between different textures of a cover: a black spot on panchromatic Spot data represents a tree or a group of trees. Thus two different overlapping areas are presented according to two different textures and the hypothesis will be that “there exists a relation between the overlapping density of trees and their spatial arrangement”. The idea is to quantify this arrangement thanks to the calculation of textural parameters derived from co-occurrence matrices (example: contrast, entropy), and to test their correlations with other parameters characterising the vegetal cover.

STUDY AREA AND DATA USED

The study area is situated in the region north of the town of Bobo-Dioulasso in Burkina Faso. In general, the natural vegetation is made up of more or less dense tall woody units and savanna including all sub-types from wooded to grass-covered. Many plant species are represented and there is an important inter-annual variability in climate (Defourny 90, [Ref. 3]).

Data used are:
- Aerial photographs at a scale of 1:20 000 (1987)
- SPOT panchromatic (October 1990)
- Cartography of the woody biomass based on Landsat-TM data calculated from the vegetation indices (November 1987) (calculated and verified by P. Defourny).

TECHNICAL HYPOTHESES

The visual analysis of texture of vegetal covers using high resolution SPOT panchromatic data showed that it is possible to define differences in density in the wooded cover. In fact, a black spot on a panchromatic SPOT image represents a tree or more precisely its crown and the spatial disposition of several of these spots adds texture to the cover. Thus, the grouping of an important number of these spots indicates high density and their small number indicates low density.

Our first hypothesis is that “a relationship exists between the density of cover and its spatial arrangement”. To represent quantitatively this arrangement on the satellite image, we began from a second hypothesis: “Local variations of gray levels are all the more important when the density of cover is high”, (see fig. 1). The idea is to measure local variations using textural parameters ex-
tracted from matrices of co-occurrence of gray levels calculated on the satellite image and to test their correlation with the vegetal cover measured from classic aerial photographs (1:20 000 scale).

The parameters that were chosen for these measurements correspond to the contrast, to the entropy, to the local homogeneity and to the moment of inverse differences. They seem to be ideal for the quantification of local variations of gray levels, for in fact the first two parameters measure the degree of disparity of the pixels and the last two measure their homogeneous aspect. (see fig. 1).

**METHODOLOGY**

The relationships between the percentage of the surface covered and the spectral data combined with textural data were established using a supervised approach, as follows:

a) About thirty test sites were chosen using aerial photographs. Each site was chosen using visual determination of different textures in order to obtain different kinds of vegetal cover.

**Remark:** In the case of test sites having the same cover but presenting different textures, it is sufficient to take into account one of these sites representing this type of cover.

b) The percentage of the covered surface was measured using an automatic digital method developed by P. Defourny (1990 [Ref. 3]). It consists of digitally scanning the photograph in 256 gray levels followed by an interactive discrimination on the image between covered and bare surfaces.

A remark is necessary concerning the shadow cast by a tree: the interpretation of the surface thus shadowed as being a covered surface leads to an overestimation of the biomass. A detailed photointerpretation plan was therefore established for each site in order to take into account only those surfaces effectively covered by vegetation.

c) About twenty images were processed for texture in order to quantify the spatial arrangement of each of the sites chosen. These images correspond to a combination according to the four principal directions (0°, 45°, 90°, 135°) and their average for the disparity parameters (contrast and entropy) and the parameters of homogeneity (second angular moment and the inverse differential). The matrices of corresponding co-occurrence were calculated by scanning a window (3x3) of size and convolution according to a uniform distance.

The choice of the 3x3 neighbourhood was determined according to the average diameter of the crown of a tree which is 5.6m. A large crown could represent a SPOT panchromatic pixel (10 m), a larger neighbourhood size would neglect important local variations for this study. This statement was checked by an analysis of textural images produced by synthetic images and corresponding to different neighbourhood sizes. A distance equal to one therefore allows the localisation of local variations between two contiguous pixels. A larger distance would be appropriate for periodically regular textures, which is not the case for the test region.

d) Simple and multiple regression measurements were calculated and two approaches were tested. A first purely textural approach relies on correlation measurements between the percentage of cover and texture

*Fig. 1 - Textural analysis of vegetal cover (a black spot represents the crown(s) of a tree(s))
measurements only. The correlation coefficients not being sufficient to construct the regression model, the second approach was tested by integrating spectral information with the preceding measurements.

This last approach greatly improved the relationships between the percentage of cover, texture and spectral information, which thus allowed the elaboration of the model in question.

In this second case, the integration of spectral information avoided this confusion and considerably improved the determination coefficient, which brings us to the second approach.

**FIRST APPROACH: TEXTURAL**

In the first place, a purely textural approach was tested. This consists in measuring the correlation, by simple regression, between the percentage of cover measured on the ground and the average values of the textural indices extracted from the matrices of co-occurrence of gray levels. The correlation matrices of the textural parameters is presented (fig. 1a and fig. 1b).

Although the correlations calculated are not important, with one slight exception concerning the contrast parameter, this approach allowed us to make decisive statements concerning this experiment (see remarks (1) and (2) below).

**Remarks**

(1) Certain test sites upset the correlation calculations; they correspond to different colour of the soil background: in fact, "the variations of gray levels between a light coloured ground and a black spot are more important than those between dark-coloured ground and a black spot" (see fig. 2). Due to this fact, certain test sites were eliminated, those remaining all having the same ground colour.

(2) Those sites representing an entirely enclosed forest are considered as being a homogeneous zone from the moment that there are no important variations of gray levels. Therefore these sites were eliminated and the correlations (fig. 2a and fig. 2b) are appreciably greater, but when passing to the calculation of regression the improvement was not so important: for example, for the contrast parameter calculated in the horizontal direction, the coefficient of determination passed from $R^2 = 0.208$ to $R^2 = 0.499$. These sites were therefore not eliminated.

**SECOND APPROACH: SPECTRAL AND TEXTURAL APPROACH**

A textural parameter was chosen to build the new model, which corresponds to the contrast which presented more important correlations than the other parameters. The correlation matrix of mean contrast values and the SPOT panchromatic radiometric values is presented in figure 4. X1 = %cover, percentage of cover X2 = pan1fen, mean panchromatic values X3 = conf301, mean contrast values calculated for a window size 3x3, in a horizontal direction and according to a uniform distance.

Although the correlation gives slightly better results, the regression measurements are less important than those of contrast; the determination coefficient passed from $R^2 = 0.88$ for the contrast parameter and $R^2 = 0.75$ for local variance.

The relations are narrower, thus a multiple regression model was elaborated, its equation is the following:

\[
\text{rec} = 0.11\text{con} - 7.82\text{pan} + 456.47
\]

where rec: %cover con: values of mean contrast
pan: mean radiometric values of the SPOT panchromatic image

With a correlation coefficient of $R^2 = 0.884$, which is quite sufficient for estimating the percentage of cover from these parameters.
**Remark:** A possible influence of the shadow cast by trees on the spectral signature of the cover is negligible in our case, since the satellite data were acquired at a time when the sun was practically at its zenith (11h 08mn), which eliminates the importance of the shadow cast at this time. This statement is only true if the ground is relatively flat, which is the case in the test area, otherwise a tree at an angle casts longer or eventually shorter shadows.

**CARTOGRAPHY OF THE PERCENTAGE OF COVER**

The test zone presents three very different colours of soil: very light-coloured soils corresponding to cultivated land, dark-coloured soils with ridges and uncultivated light-coloured soils.

The regression model elaborated was based on sites hav-

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*Fig. 2 - Correlation matrices between the percentage of cover and textural parameters.*
Fig. 3 - Local variations of gray levels for different colours of soils. (Variations between a black spot and a light coloured soil are more important than between a black spot and a dark soil).

Matrice de corrélation pour les variables : $X_1 \ldots X_3$

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Fig. 4 - Correlation matrix for the parameters: $X_1 \ldots X_3$.

Fig. 5 - Cartography of the wood biomass obtained from SPOT panchromatic data.
Burkina Faso, October 90. Cartography of the percentage of woody vegetation cover (from 0% to 100%) on uncultivated soils.
ing light-coloured soils, thus only the surface of these soils was mapped for its percentage of cover. The remaining soil surfaces (very light-coloured soils and dark-coloured soils) is very insufficient to take into account the number of training areas statistically acceptable in order to construct a reliable regression model.

A first classification according to soil type allowed the separation of three colours of soil, and after having applied the regression model on the light-coloured soils (by masking the others), an interactive thresholding (cutting to the right of regression) gave us the different cover classes. Only SPOT panchromatic data were used for the whole processing chain. The result is presented in figure 5.

**VERIFICATION OF THE CARTOGRAPHY**

The validation of this cartography was made from the cartography of the woody biomass carried out in the same region, but using the vegetation indices obtained from Landsat-TM data (cartography performed and verified using ground truth measurements by P. Defourny 1990), and using a systematic non-aligned sample grid applied on the two cartographies. In a general manner, the two estimations correspond well with the exception of a few points where validation was not possible because of the difference in scale of the two resolutions (Landsat-TM has a resolution of 30 m while SPOT panchromatic has a resolution of 10 m).

**INTRODUCTION OF ANOTHER INDICATOR OF TEXTURE MEASUREMENT LOCAL VARIANCE**

In fact, another parameter similar to that of contrast, but calculated more rapidly for a large scene, would be the local variance. A visual analysis of the contrast and local variance images from synthetic images gives similar results for the two parameters. Correlation measurements gave the results presented in figure 6.

![Fig. 6 - Correlation matrices between the parameters X1, X2, X3, X4.](image)

\[
\begin{array}{c|cccc}
\text{X1 = %cover, percentage of cover} & \text{X2 = pan11en, mean panchromatic values} & \text{X3 = conf301, mean contrast values calculated for a 3x3 window, in a horizontal direction and according to a uniform distance} & \text{X4 = var, variance calculated in the 3x3 neighbourhood.} \\
\end{array}
\]

**CONCLUSION**

This study allowed the demonstration of the contribution of textural information in determining the quantity of woody biomass using remote sensing data. It would be interesting to introduce textural images representing the quantification of the spatial arrangement of cover as a supplementary dimension in a GIS (Geographic Information System), and this in order to resolve the problems of quantification of woody vegetation in particular, and to give more information on the state of the vegetal cover in general, by filling certain gaps in the information obtained from the spectral signature of the vegetal cover.

However, the conditions of application of the method proposed, due to the influence of the soils on texture measurements (local variations of gray levels), are not negligible. A stratification according to the colour of soils is proposed to deal with this problem. For each strata a regression model can be elaborated according to the methodology presented.

The stage dealing with the measurement of the percentage of cover could be made less fastidious by using the shadow correction models which exist (a model has been created by P. Defourny for the Sudano-Sahelian regions (Defourny, 1992), which it would be interesting to exploit.

On the other hand, the calculations of the matrices of co-occurrence of gray levels are reputed for being time-consuming due to the great number of gray levels of the image they require, some authors have proceeded by reducing the number of these gray levels, which has not been done in our case. Using powerful machines, this would not be a problem. For example, for an image 512x512 having 256 gray levels, the extraction of four textural parameters, using a window 3x3, according to a given distance and direction, requires 88mn 46s on a micro VaxII 630 but 79s on a Convex C230.

For this study, the contrast parameter could be replaced by simple local variance which can be calculated more rapidly, but which proved not so accurate as regards cover measurements. Nevertheless, since this experiment is only an estimation of the biomass and not an exact measure-
ment, it is in our interest to choose the contrast parameter which presents the best correlations with the cover measurements and this in order to arrive at the most accurate measurement possible.

ACKNOWLEDGEMENTS

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