USE OF SPOT SATELLITE IMAGES FOR THE INVENTORY AND FOLLOW-UP OF LIGNEOUS RESOURCES IN THE SAHEL (*)

Catherine Mering
Christine Jacqueminet

O.R.S.T.O.M.
Unité de télédétection, L.I.A.
70-74, route d'Aulnay
93140 Bondy, France

ABSTRACT

In the present study, the spatial resolution of SPOT images is used to estimate the ligneous vegetation cover of grazing areas in the Sahel and for characterizing in quantitative terms the different forms of spatial organization. The method has been tested in the Oursi region, north of Burkina Faso.

The Sahelian vegetation is characterized by a discontinuous texture : in the Oursi region, it is organized in isolated groves on dune constructions and in strips in the interdune spaces. On SPOT images, groves and strips appear respectively as subcircular spots and dark strips of varying size, orientation and spacing. The variations of the ligneous cover are perceptible through the changing shapes of the spots and the strips.

The satellite image is processed by different techniques such as automatic classification according to spectral criteria and morphological set transformations applied to binary images.

Once the image is classified, the area covered with ligneous vegetation is evaluated and the spatial organization of spots and strips is characterized by means of morphological parameters such as their size distribution and their relative distribution with respect to the bare areas. We thus obtain quantitative descriptors of the texture, that may serve to compare different types of ligneous cover.

The method using completely reproducible techniques may also serve to estimate the ligneous resources of other Sahelian grazing grounds.

1. PRESENTATION OF THE STUDIED AREA AND PROBLEMATICS

The Oursi region is located to the North of the Burkina Faso (1) in a semi-arid environment (2) (see figure A). On this vast peneplain, we find deposits of long dune bars oriented E-W, and separated by wide interdune plains, covered with aeolian sand deposits, on which crust surfaces show locally. The formation of bars has increased the endoreism (3) by obstructing the drainage network. Owing to these bars, we find numerous permanent or semi-permanent ponds located to the South of the dune system. The vegetation belongs to the *wooded steppe* type. It includes a loose shrub stratum with the following main species : *Balanites aegyptiaca, Combretum glutinosum, Pterocarpus luscens, Guiera senegalensis* and a herbaceous stratum mainly composed of annual short cycle species (*Cenchrus biflorus, Schoenfeldia gracilis, Aristida mutabilis*). The density of herbaceous, wood and shrub cover is quite variable. As a general rule, it is higher in areas remote from ponds and villages.

The Oursi population comprises sedentary people, settled near the permanent pond of Oursi, who cultivate millet on sandy soils, and nomads

* Paper destined to the Proceedings of the 22th E.R.I.M. Symposium for Remote Sensing, October 20-26, 1988, Abidjan, Ivory Coast.

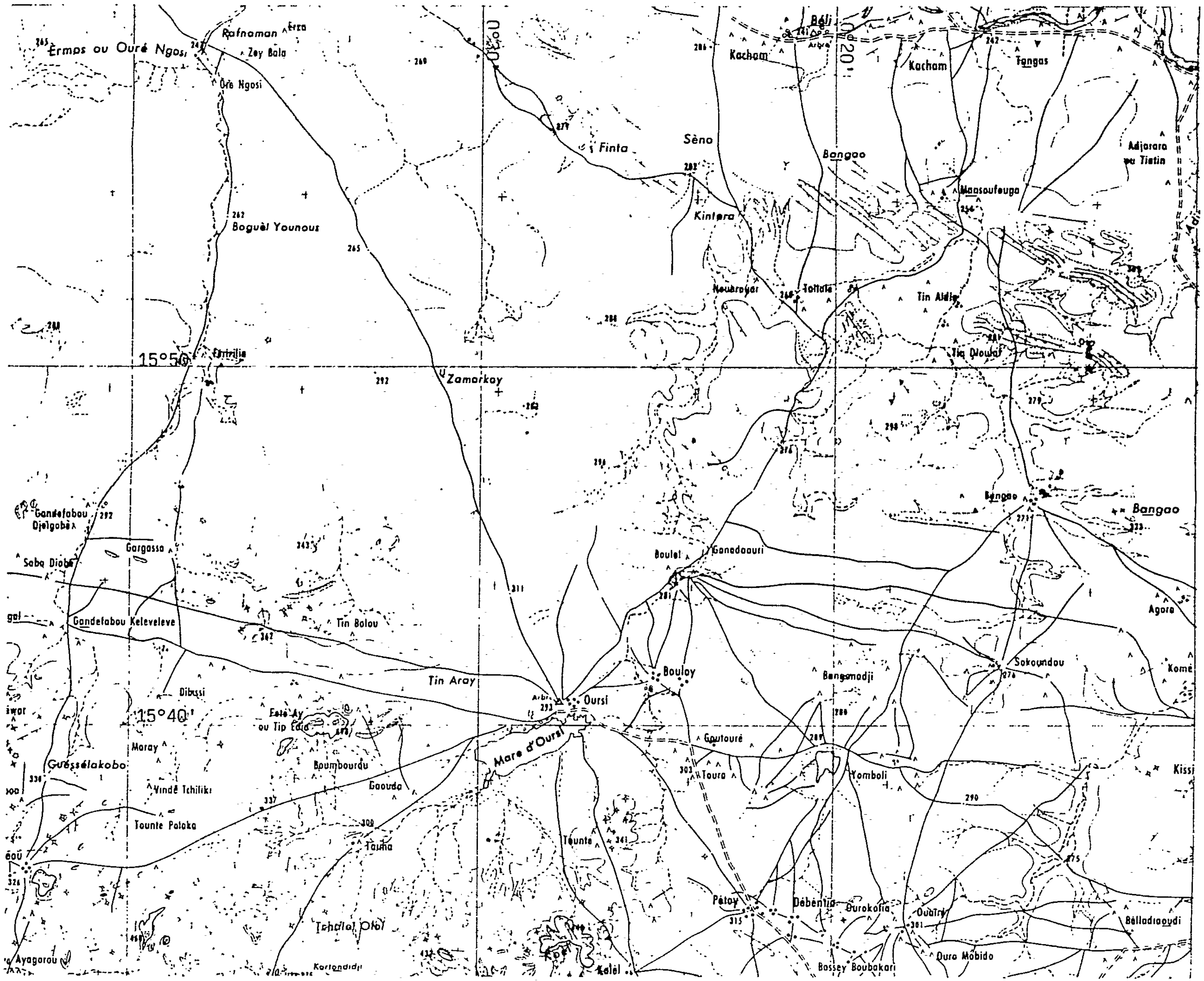

Figure A : topographic map of Oursi land at 1/200 000 (from I.G.N. map) whose camps are grouped around subperennial ponds. After the series of great droughts that began in 1973, nomadic populations tend to settle down, and thus contribute to increase the cultivated surfaces and the grazing areas near the pond of Oursi [BARRAL77].

The problem is to obtain a diagnosis of the Sahelian environment and follow up its evolution, by means of the quantification of the areas covered with ligneous vegetation and of their variations in shape. We are only concerned with the ligneous vegetation, since the herbaceous cover varies from year to year, according to the amount of rains and their distribution, and therefore cannot be considered as a good indicator in the mean term of the environment dynamics.

The evolution of the ligneous cover in the Sahel may be characterized, among other things, by the contraction of wooded and brush groups. This contraction results in the unequal resistance of certain species to drought emphasized by an increasing human pressure, it acts differently depending on the topoedaphic conditions of the environments under study [COUREL 84].

The Oursi landscape groups a great variety of the different forms of ligneous cover that may be encountered in the rest of the Sahel : the alternation of two environments, dune bars and interdune plains, with different topographic, pedological and hydrographic characteristics, results in several modes of vegetation contraction :

- on dune bars, ligneous vegetation is concentrated in *groves* in interdune depressions,
- in interdune plains, ligneous vegetation is either arranged in slightly sinuous large *strips* whose orientation is parallel or perpendicular with respect to the bars,

or in "*tiger bush*" (regular alternation of wooded strips and bare strips with the aspect of a tiger skin seen from above).

In order to distinguish between ligneous vegetation and herbaceous vegetation, we have selected an image of dry season (12/17/86), period during which the dry herbaceous vegetation has not the same spectral characteristics as the ligneous vegetation which is still chlorophyllian.

On each of the images corresponding to the three spectral bands, the different vegetable organizations described in the preceding, appear under the form of subcircular spots and dark strips of varying size and spacing (cf. figure B).

2. DELIMITATION OF LIGNEOUS AREAS

In order to delimit ligneous areas, the image is partitioned by classifying the pixels according to a previously established taxonomy of the main components of the landscape, based on our knowledge of the field and on the examination of aerial photographs and of the color composite (cf. figure B). The taxonomy consists of four elements :

- ligneous vegetation
- dark soils
- clear soils
- water

The descriptors used for the classification are the three spectral bands of SPOT on the one hand, and the green vegetation index computed from the red and near infrared spectral bands by means of the following formula :

$$IVGV = XS3 - XS2/XS3 + XS2$$

The first component resulting from an analysis into the main components of the three spectral bands is added to these descriptors.

The classification is performed through a supervised approach : from the

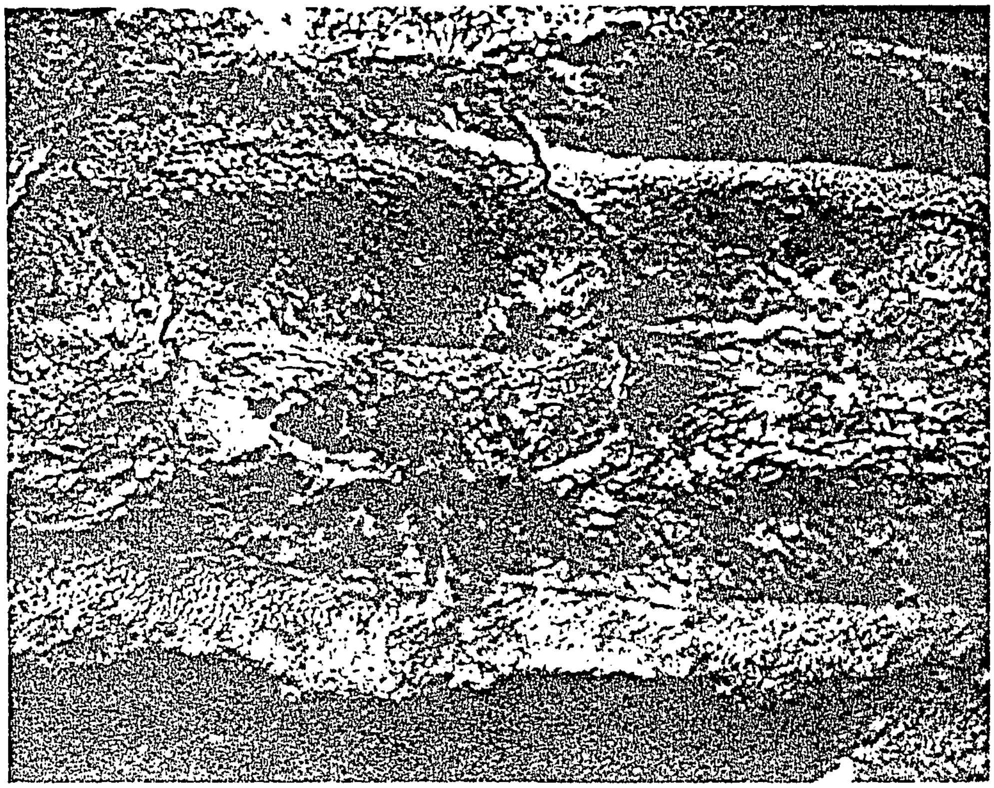

Figure B : Color composite from SPOT image of 12/17/86.

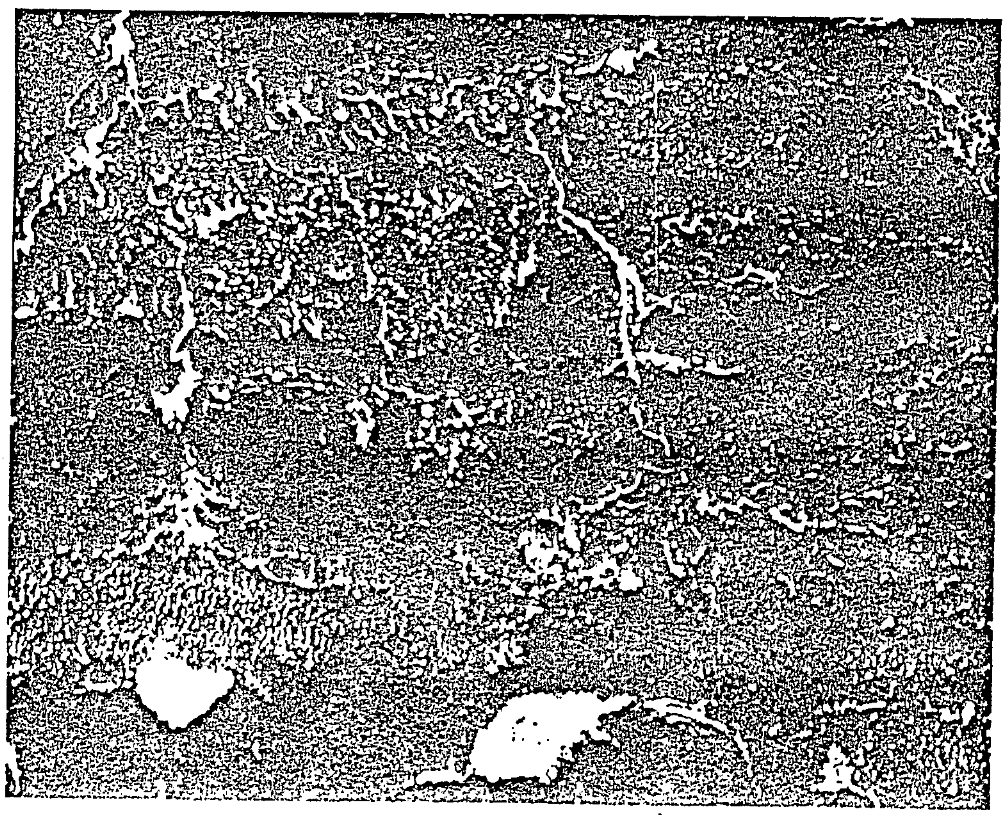

Figure D : The "vegetation" class

learning areas representative of the different classes, we try to determine the signature proper to each class, by emphasizing characteristic *segments* (4) of the classes.

To do so, we use a *non parametric discrimination method* [CELEUX 82] which performs the segmentation of the quantitative variables that best discriminates the a priori determined classes.

2.1. Principles of the discrimination method :

The method is probabilistic. It allows to partition the whole set of the pixels of the scene by assigning them to one of the a priori determined classes. We assume that the a priori classes are disjoined and that they constitute a partition of the scene.

The method is based on a two-class discrimination of a quantitative variable. It is easily generalized to a multi-class and multivariate method.

X designates the descriptive variable that is considered in our model as a random variable describing the total population as two separate classes W1 and W2.

F1 and F2 designate the distribution functions corresponding to W1 and W2.

The operator works on a sample $(x_1,...x_N)$, which corresponds to a sample of the test areas. This sample is considered in the model as a realization of the variable X.

The method consists in determining the discrimination threshold "C" between W1 and W2 by minimizing the *Bayes risk*, i.e. by minimizing the risk of a wrong classification of a new pixel x_{N+1}.

It is proved that minimizing the Bayes risk is equivalent to maximizing the *Kolmogorov-Smirnov* distance D(c) between the two distributions.

$D(c) = \sup_z |f_1(z)-f_2(z)| = f_1(c)-f_2(c)$

where f_1 and f_2 are the empiric distribution functions of W1 and W2.

The basic procedure is generalized to the case of several variables by performing the first split on the variable which provides the greatest Kolmogorov-Smirnov distance.

When several variables are used to discriminate the two classes, one iteration is generally not sufficient to obtain the two required classes, since it works on one variable only.

If one of the two segments satisfies the stop test, it becomes a *terminal segment.*

An extension of the procedure to problems with K classes consists in considering them as a sequence of two-class problems for which we want to obtain a unique decision tree.

Let A be the set of two-class partitions of the set W.
In this case, the chosen class A is the union of the a priori classes that maximizes D(C).

If we deal with several variables, we look for the class A for each variable, and then we choose the split c_j* by the procedure described in the preceding section.

The stop test is determined as follows : the cardinal of each class within the segments has to be high enough to allow a reasonable evaluation of the density ratio which is estimated by the ratio of the number of elements contained in each class within the segment. Thus, the partition process is stopped each time that the next partition does not insure to provide samples of minimal size for each class within each segment. *The operator must then determine the minimal number of items contained in the majority class and in the minority class as well as the minimal size of any segment in order to carry on the partition.*

2.2 Results of the discrimination

nS	S	C	PS(%)	PC(%)
1	XS1 < 48	water	100	100
2	XS1 > 48 ACP1 < 101	clear soils vegetation	99.24 2.92	97.39 2.61
3	XS1 > 48 ACP1 > 101 IVGV > 132	vegetation dark soils	92.50 0.96	98.23 1.33
4	XS1 > 48 101 < ACPI <115	dark soils vegetation	14.10 4.17	80.00 18.18
5	XS1 > 48 ACP1 > 115 IVGV > 132	dark soils vegetation	84.94 0.42	99.62 0.38

Figure C : Recapitulative table of terminal segments
(nS : segment number, S : segment definition, C : class,
PS : percentage of the pixels of the class that belong to the segment,
PC : percentage of the pixels of the segment that belong to the class)

2.3. Classification and validation

The image pixels are classified by being applied the terminal segments resulting from the preceding analysis. Each pixel is assigned to the majority class of the corresponding segment. The classification thus performed is validated by *control parcels* (5) : on each parcel, we count the number of pixels that have been correctly classified. This criterion has been retained to determine the best classification resulting from several segmentation attempts. This is how the segmentation proposed in the preceding section has been selected.

The delimitation of ligneous areas is obtained by selecting the pixels classified as vegetation. The result is expressed under the form of a binary image (cf. figure D).

3. SURFACE MEASUREMENT AND SPATIAL ORGANIZATION FORMS OF LIGNEOUS AREAS

In order to perform measurements from the image, we use the methods of the Mathematical Morphology which are based on transformations of euclidean sets (the set corresponds to a shape against a background) [SERRA 82].

The form resulting from the previous binarization and corresponding to the "vegetation" class is here assimilated to a unique set, denoted X hereafter.

Surface measurements are globally performed on the whole portion of the analyzed image.

Texture measurements are performed on squares of 85 x 85 pixels, extracted from the image (6). Each square illustrates a typical form of contracted vegetation :

- dune groves (cf. figure E1),
- tiger bush in interdune spaces (cf. figure F1)
- large strips in interdune spaces (cf. figure G1)

3.1. Area measurements :

The total surface of the ligneous areas is estimated from the calculation of the area of set X, which is obtained by computing the number of points that constitute the set X.

This computation is effectuated from a framework of 900 lines by 1371 columns. Both the area and the occupation ratio of X are measured.

Area (X) = number of pixels (X) = 11737
Occupation ratio of X = approximately 10%
Knowing the spatial resolution of SPOT, it is then possible to estimate that the ligneous area of the studied region is 4693 ha.

3.2. Size distribution of ligneous aggregates:

The ligneous aggregates are here considered as the connected components of the set X.

In order to assess the size distribution of the connected components of X, we use the method of *granulometry by opening*. It consists in transforming the set X by an *opening* (7) with the hexagonal structuring element B. The connected components of a size smaller than that of the structuring element are eliminated. By increasing the size n of the structuring element, the elements of size n-1 are successively eliminated as though they were sieved. The computation of the area and of the number of the elements suppressed by each opening allows us to evaluate the size distribution of the elements of X.

G(n) the size distribution in measure and F(n) the size distribution in terms of number are computed by using the following formulas:

$$G(n) = (A(X) - A(X_{B(n)})) / A(X) \qquad n>=0$$

$$F(n) = (N(X) - N(X_{B(n)})) / N(X) \qquad n>=0$$

where,

A(X) is the area of X
N(X) is the number of connected elements of X
$X_{B(n)}$ is the set X opened by the hexagonal structuring element B of size n

These distributions allow to evaluate the total area and the number of the parts (8) of the set X eliminated by openings of radius inferior to n.

These distributions, computed for each of the squares E1, F1, G1 are represented graphically in the 3 figures E2, F2, G2. The abscissa gives the size n of the structuring element B, the ordinate indicates the corresponding values of G(n) and F(n).

The two curves F(n) and G(n) merge in the case where the number of connected elements varies in the same way as the surface occupation : if X is mainly composed with convex connected elements of large size, the curve G will be situated under the curve F for a long time. If X is composed of convex connected elements whose shape is very close to that of the structuring element and whose size is equally distributed, the two curves

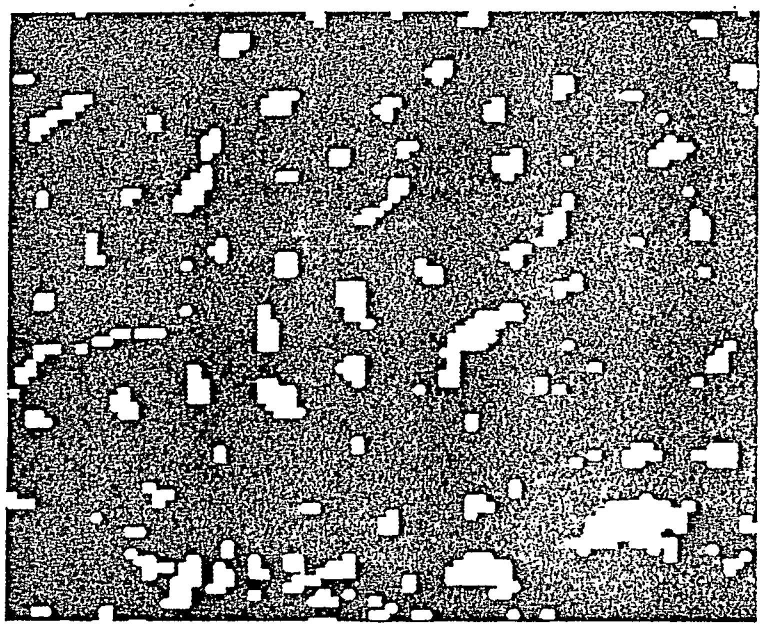

figure E1 : Dune groves

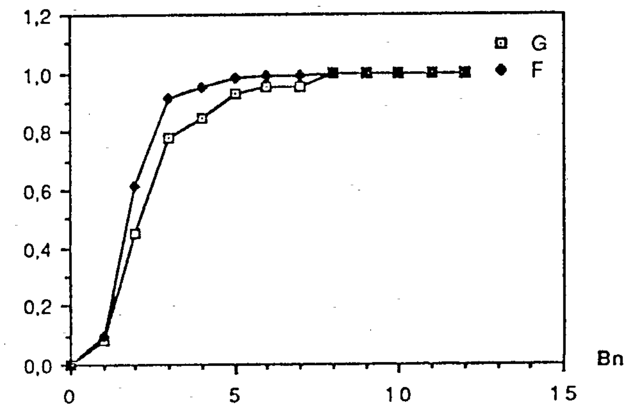

figure E2 : Size distribution in measure (G) and in number (F)

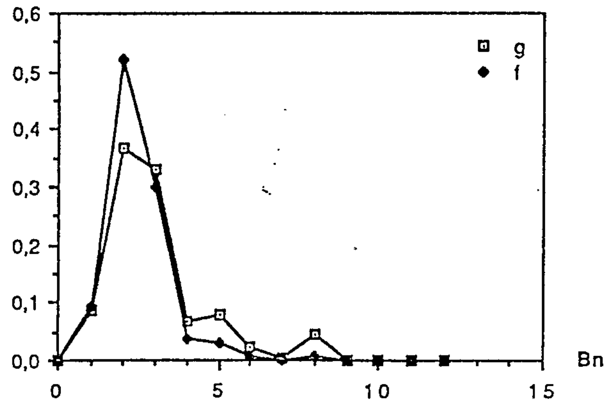

figure E3 : Granulometric density in measure (g) and in number (f)

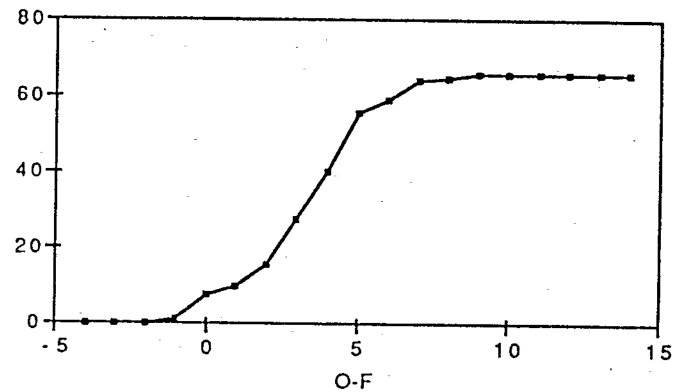

figure E4 : Texture index

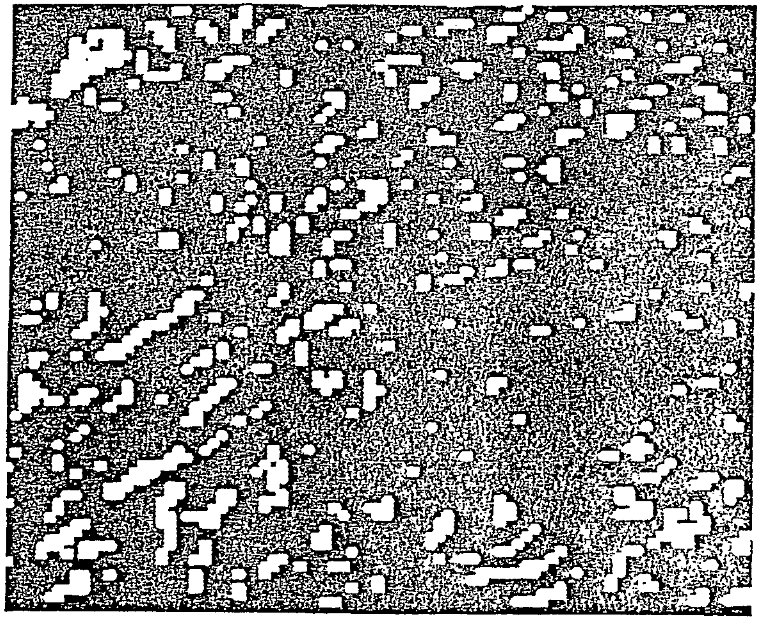

figure F1 : Tiger bush in interdune spaces

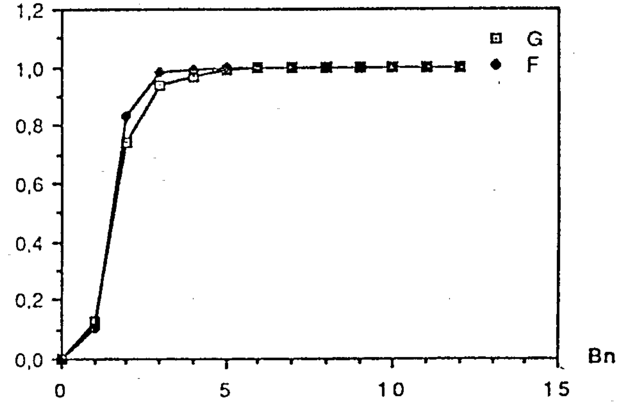

figure F2: Size distribution in measure (G) and in number (F)

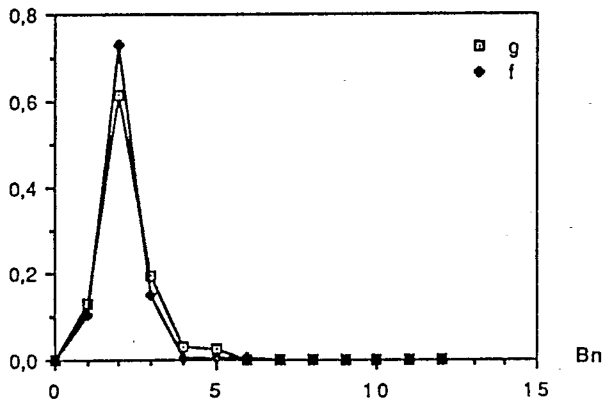

figure F3 : Granulometric density in measure (g) and in number (f)

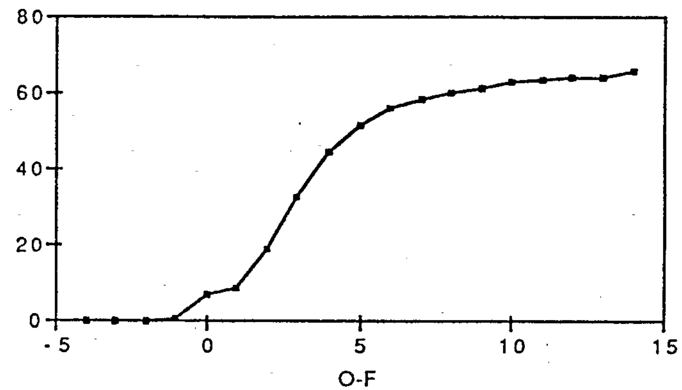

figure F4 : Texture index

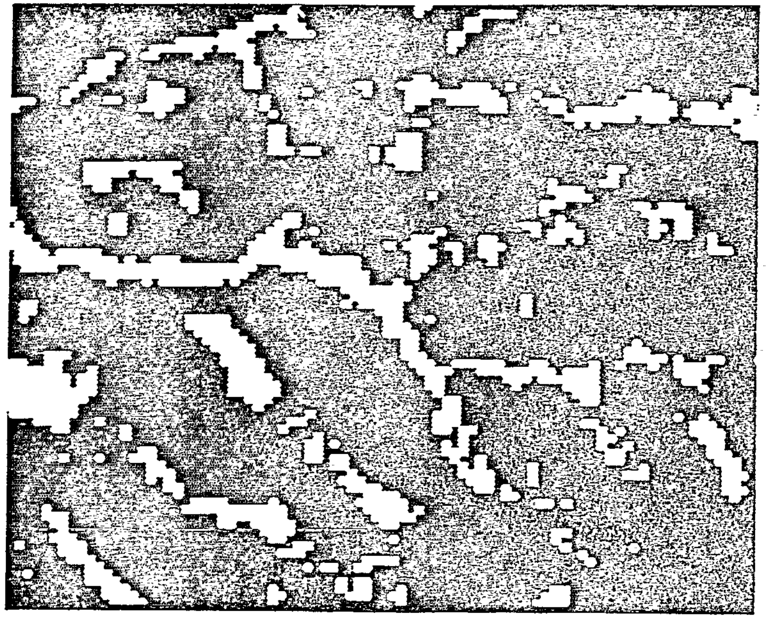

figure G1 : Large strips in interdune spaces

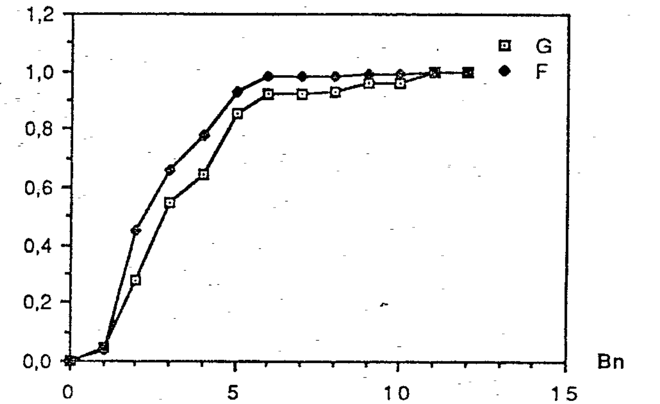

figure G2 : Size distribution in measure (G)and in number (F)

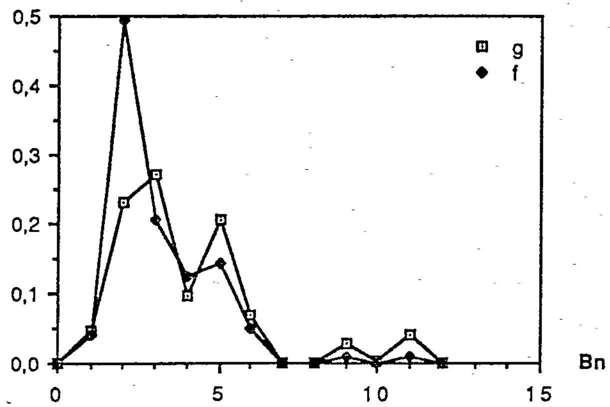

figure G3 : Granulometric density in measure (g) and in number (f)

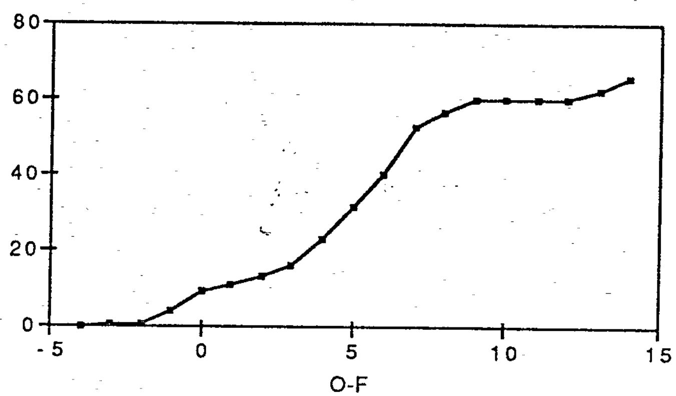

figure G4 : Texture index

merge and have the same convex outlook. In case of non convex parts, F(n) does not increase regularly.

The diagram F2 emphasizes the pointillist texture of the *tiger bush* : it is constituted of grains almost all of which are of a size smaller than 1.

The curves of the diagram G2, of lower gradient with respect to other samples, show the existence of several sizes of grains the number of which decreases progressively as the size increases. The area of the grains increases in a steady manner. A threshold is detected, that tends to distinguish between two classes of grain size.

The diagram E2 shows that the size of dune groves varies continuously. The curves display an almost continuous plotting between abscissas 1 and 4.

Similarly, it is possible to evaluate the *granulometric density* in measure g(n) and in number f(n) by means of the following formulas :

$$g(n) = (A(X_{B(n)}) - A(X_{B(n+1)})) / A(X)$$

$$f(n) = (N(X_{B(n)}) - N(X_{B(n+1)})) / N(X)$$

Computing the granulometric density enables to evaluate the proportion in measure and in number of the parts of X suppressed between two successive openings of respective radius n and n+1.

These densities, calculated for each of the squares E1, F1, G1 are represented graphically in the 3 figures E3, F3, G3. The abscissa gives the size n of the structuring element B, and the ordinate indicates the corresponding values of g(n) and f(n).

Density curves allow to visualize the relative proportion in measure and in number of the parts of X of size n.

According to figure F3, one can see that the *tiger bush* is almost completely constituted with elements of size 1.

According to figure G3, the curves indicate the presence of four sizes of grains. There is a high proportion in measure and in number of elements of size 1 and 2.

In figure E3, the two curves f and g indicate there are three sizes of grains whose great majority is of small size.

3.3 Texture of the ligneous cover

In order to assess the relative arrangement of the parts of X in the studied window, openings of decreasing size are successively performed on the image, the maximum size of the openings corresponding to the disappearance of the set X, and then *closings* of increasing size until the window is inhibited at 1.

These texture indices, computed for each square E1, F1, G1, are represented graphically in figures E4, F4, G4. The abscissa gives the size n of the structuring element B, the ordinate gives the number of residual pixels after each transformation; the opening radii are indicated by an increasing series of negative numbers, from -5 to 0, whereas the closing radii are indicated by positive numbers from 1 to 15.

The regularity of the curve expresses the regularity of the layout of the shapes on the background.

This index characterizes a type of texture by means of only one parameter in a window of fixed size. Therefore, it may be used as a quantitative describer for texture based analysis and classification of landscape units.

3.4. Measurement of the spatial dispersion of ligneous aggregates :

Here, the spatial dispersion of the connected components of X is evaluated by computing the *covariance* function of the set X. The covariance function C(X,h) for a bounded stationary set is defined as follows :

$$C(X,h) = A((E^h(X)) \cap (E^h(Z))) / A(E^h(Z))$$

where
Z is the measuring mask
A(X) the area of X
$E^h(X)$ the erosion of X by a couple of points separated by a length h.

The procedure consists in performing successive erosions of the set X and of the measuring mask Z (10) by a couple of points of increasing spacing h, and of orientation α (11) and from which is deduced the covariogram $C(X,h,\alpha)$ of the set X.

The covariogram emphasizes the dispersion state of the elements within the measuring mask, in a given direction. As a general rule, the properties of the covariogram allow to deduce some characteristics of the dispersion state of the studied set [COSTER 85] :

- The directional aspect of the covariance gives information as to the *anisotropy* of the set X. In particular, the slope at the origin is equal to the reverse of the connectivity number $N_{L\alpha}$ in the α direction : for equal surfaces, the more accentuated the slope, the finer the structure.

- The oscillations of the covariance render the presence of *periodicities* of the set X. The undulations are all the more accentuated as the periodicity is noticeable. In case of a perfectly periodic structure, where the components are roughly of the same size, the distance between consecutive minimum and maximum depends on the mean thickness of the components in the studied direction, whereas the distance between two consecutive maxima depends on the mean distance between two consecutive components in the studied direction.

The covariogram corresponding to the horizontal direction (α=0) is computed for each square E1, F1, G1.

The covariograms are shown in figures E5, F5, G5 : the abscissa represents the length h of the couple of points; the ordinate represents the result of the covariance calculation.

The covariograms of the three squares all stresses a certain periodicity in the structure of the vegetable cover. However the amplitude and the height of the undulations vary noticeably from one square to another.

The covariogram of the square E, which corresponds to the *dune groves*, shows oscillations of varying amplitude. The distance between a minimum and a maximum varies from 1 to 7 and the distance between two maxima varies from 2 to 7.

The covariogram of the square G, corresponding to the *large strips* is characterized by the superposition of two periodicities : an undulation of great amplitude composed of undulations of lesser amplitude. This phenomeno expresses the existence of two interwoven structures. By analysing the elementary undulations, one notices that the distance between a minimum and a maximum varies from 1 to 10 and the distance between two maxima varies from 5 to 12.

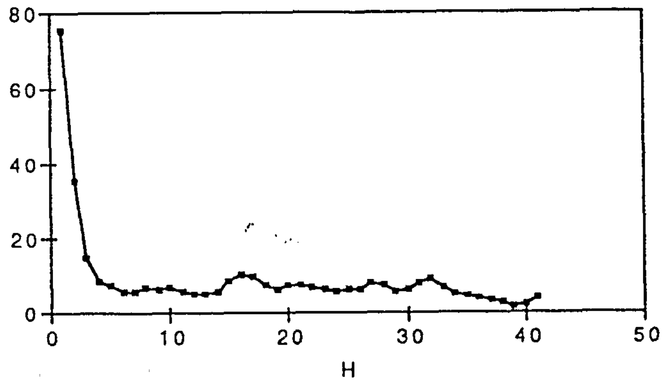

Figure E5 : Covariogram of dune groves

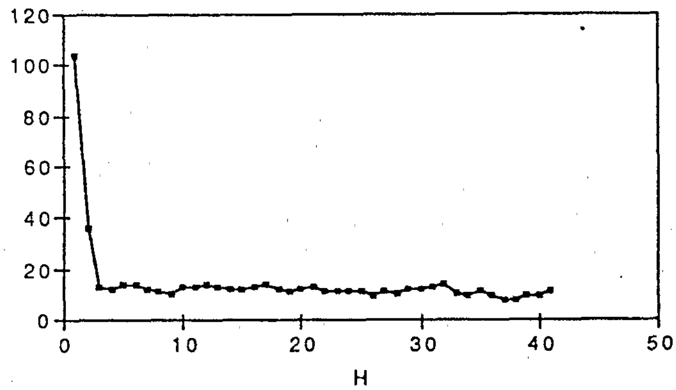

Figure F5 : Covariogram of tiger bush

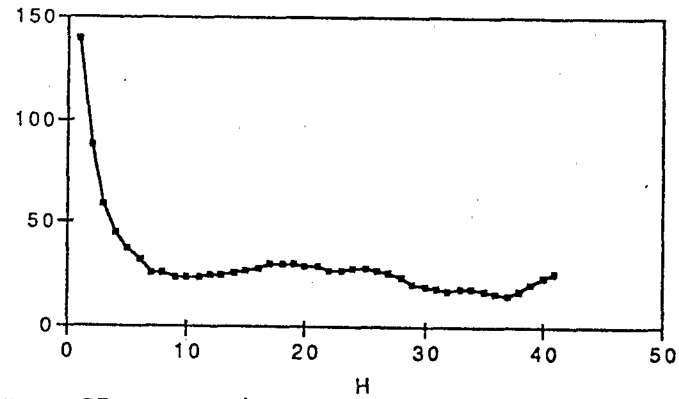

Figure G5 : Covariogram of large strips

A systematic use of the covariograms on the whole satellite image, by means of jointed measuring masks should enable a taxonomy of the Sahelian landscape units according to the dispersion state of the vegetable cover.

CONCLUSION

The methods of quantitative analysis of image processing in order to evaluate the areas covered with ligneous vegetation and to characterize their texture provide reproducible results that may be directly used for the inventory and follow-up of the ligneous resources of the Sahelian environment.

This method is quite satisfactory when the ligneous cover is dense enough locally to be differentiated from dark bare soils on satellite images. The obtained descriptors may also serve as a basis to the taxonomic analysis of the landscape units with the discontinuous cover of the semi-arid environments.

NOTES :

(1) The studied area is situated between the longitudes 14°40'-14°50'N and the latitudes 0°60'-0°40'W.

(2) The rain fall is approximately 350 mm per year, distributed all along the rain season, lasting from june to september.

(3) Endoreism : Organization of regions whose drainage network is not connected to the general basic level of the sea and ocean, but either to an stewage plain, or an interior lake or sea (P. George, Dictionnaire de la géographie).

(4) The segments correspond to the union of the jointed intervals computed from the variable segmentation. Each segment family corresponds to a partition of the set of the pixels contained in the scene. The term segments is used as well to designate the sub-sets of pixels resulting from segmentation.

(5) We mean the image fragments delimited from the field-reality and from aerial photographs, which serve to control the results of the classifications performed on the image a posteriori.

(6) Inside the squares, we have chosen a factor 3 magnification. This choice is that which enables the best discrimination of the studied textures. We consider, in the future, the systematic study of the results obtained through the discrimination of the different types of cover according to the used factor.

(7) and (9) Erosion and dilation are the two basic morphological transformations, whose definition is the following :

Let X be a set belonging to $P(R^2)$ and B a structuring element equipped with a centre x and denoted Bx. The *set X eroded by B*, denoted $E^B(X)$ is the locus of all the centres x of Bx such that Bx is included in X.

The *set X dilated by B* and denoted $D^B(X)$ is the locus of all the centres x of Bx such that Bx hits X. It is proved that to dilate a set X is equivalent to erode its complementary set Xc and conversely. We say that erosion and dilation are dual operations under complementation.

Opening and closing may be defined from the erosion and the dilation, as follows :

The opening of a set X is performed by a structuring element B, by eroding X by B^v which is the symmetrical element of B and then by dilating the result by B. X_B denotes the opening of X by B.

In the same way as the dilation may be defined as the dual operation of the erosion, the closing is defined as the dual transformation of the opening : the closing of X by the structuring element B is performed by opening the complementary set of X by B^v and by taking the complementary set of the resulting set. X^B denotes the closing of X by B.

(8) The parts of X are the connected components of X.

(10) The measuring mask is the square window which delimits the set X

that is measured. Here, it is a square of 256 × 256 points.

(11) A couple of points corresponds here to a pair of points distant of length h. It is a non connected set contrary to the right-hand segment.

REFERENCES :

[BARRAL 77] H. Barral: Les populations nomades de l'Oudalan et leur espace pastoral. Travaux et Documents de l'ORSTOM n°77, 1977, 111p.

[CELEUX 82]G. Celeux, Y. Lechevallier : Méthodes de segmentation non paramétriques. Revue de statistique appliqué, vol. XXX, n°4, 1982.

[COSTER 85]M. M. Coster et J.L. Chermant : Précis d'Analyse d'images. Edition du CNRS, Paris, 1985, 521p.

[COUREL 84] M.F. Courel : Etude de l'évolution récente des milieux Sahéliens à partir des mesures fournies par les satellites. Thèse de doctorat d'Etat, Paris In 1984, 407p.

[MERING 87a] C. Mering, Y. Poncet, C. Jacqueminet, M. Rakoto Ravalontsalama : Quantitative description of denudation forms in the Western African Sahel. Advanced Space Research, 7(3), Pergamon Press, London, 1987, pp. 31-39.

[MERING 87b] C.Mering, C.Jacqueminet: An approach of quantitative description of sand-hills shapes in the West African Sahel form Remote Sensing Imagery. Acta Stereologica, Ljubljana, 1987, pp. 951-956.

[SERRA 82] J. Serra : Image analysis and mathematical morphology. Academic Press, London, 1982.