QUANTITATIVE DESCRIPTION OF BARE SOILS PATTERNS IN THE WEST AFRICAN SAHEL*

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Abstract

In western african Sahel, the everlasting denudation of the soils is a danger for their potential productivity, as bare light sandy soils have often been over exploited by cultivation and grazing. Hence, these areas are threatened by sequences leading to unproductivity, increased by climatic variations: the well-known droughts from 1972 to 1974 and 1984 had heavy impacts and more especially the enhancement of the frequency of strong winds. From remote sensing datas of Landsat MSS, we study a set of desertification indicators. We experiment reproductible procedures that may allow the identification and measurement of parameters connected to these indicators.

We process two kinds of application:

- first, description of sand-hill patterns by modelizing their shapes and by quantifiying their principal and secondary orientations;

- then, description of bare areas around villages: typology of bare areas based on their shapes; modelization of the "bare soils set" from which can be calculated different parameters.

The employed algorithms run morphological transformations and measurements of predefined objects on the image. Their degree of generalization let us give quantified elements to built typologies of some peculiar geographic and geomorphologic features having typical shapes. In the same manner, it let us use them on images coming from different periods, allowing chronological studies.

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The study of natural environment and the study of the impact of human activities are not resolved, in this semi-arid environment, by the only spectral signature of objects. Problems of interpretation are related to the environment characteristics: its dynamics, related to meteorological and climatic changes, are very rapid; the spectral signature of each element setting up the landscape features are not yet wellknown; the spectral channels are highly correlated and the landscape units are often distinguished only by low radiometric gradients; moreover these weak contrasts are still reduced, here in the Sahel, by frequent sandy and dusty haze. So, in order to analyse thematic in addition to spectral answer, we use the concept of the shape of the objects, as seen from the azimuthal point of view, the spectrum beeing an interface between the objects and their shapes.

Environmental determinisms (as climate, slopes, surface of soils...) and human impacts (as types of land-use, factors of production, and the different elements of the relationship between man and his environment) build the features of the landscape; the landscape units are interwined one with the anothers, outlining more or less regular shapes; in some systematic examples, shape may become the indicator of the visible landscape unit: limits of fields, dendritic hydrographic nets, irrigation features for instance... In the sahelian environment, some of these shapes are connected to landscape units threatened by desertification. We describe hereafter two examples chosen for the following reasons:

- they are significant of actual processes that can be observed and measured in many countries in the Sahel and the semi-arid area in the world: shapes are significant of processes related to aridity; hence measurements are highly useful;

- the apparently simple shapes, resulting from complex geographical processes, allow an easy and specific modelization.

The relationship between the objects on the field and their shape from an azimuthal point of view is identified, hence modelized, by the thematician. Then the shape is extracted and measured. In the two following examples, we assume different types of measurements such as orientation, perimeters, diameters, surfaces... In both cases, we use the quantitative methods: filtering by convolution, texture analysis and especially Mathematical Morphology. Objects are extracted by specific algorithms. Measurement parameters are defined by mathematical formulas, reproductible.

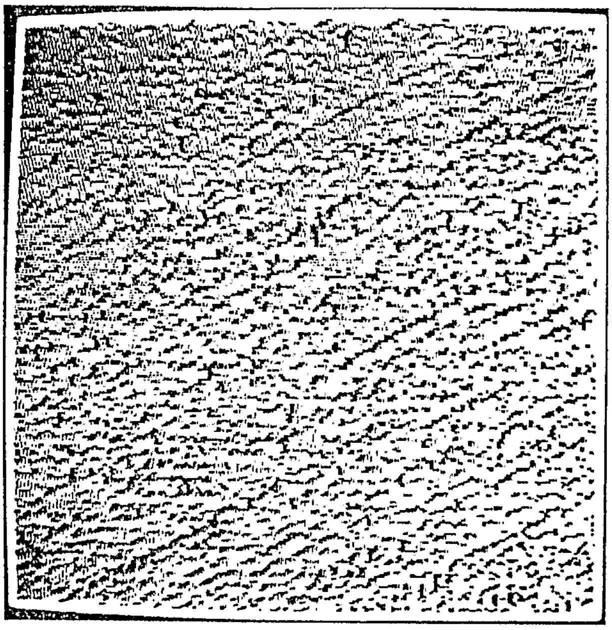
MEASURES OF ORIENTATION: SAND-HILL BARS IN THE NORTH OF LAKE FAGUIBINE (MALI)

In the northern part of the region, sand-hills seem to be organized as long regular bars, approximately oriented North East - South West, with a coverage of grass and scare shrubs in the dune valleys, and the marks of an ancient hydric erosion. In the South West, sand-hills become irregular, oriented North - South, with more visible gullies, which draw the very structure. Our objective is to quantify the modifications of the shape of sand-hills in order to find a relation between the differences in their structure and hypothesis on their genesis.

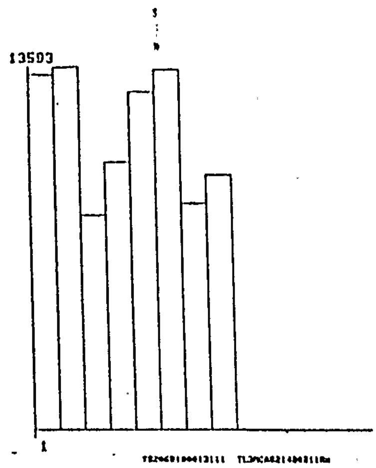
The basic image is a MSS Landsat, 212-048, May 10 1982.

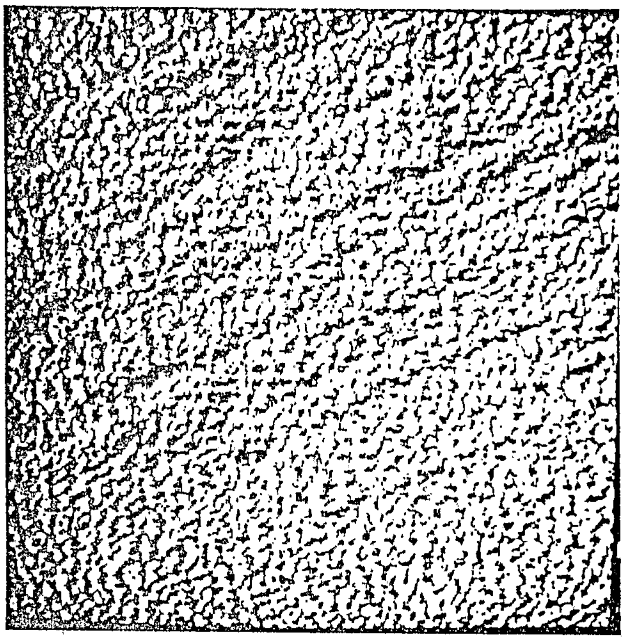
To study the transformation of the sand-hill structure, we have selected seven samples having the same size (300 pixels x 300 pixels) regularly set along a NE-SW axis, submitted to the same numerical treatments.

The initial processed image is in any case the image of eight directions

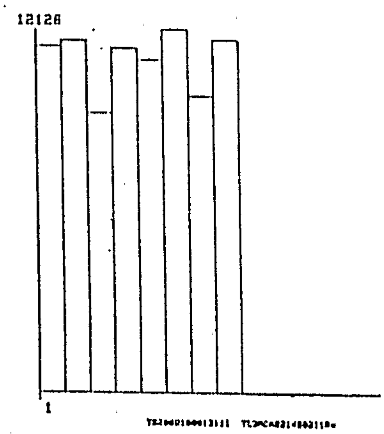


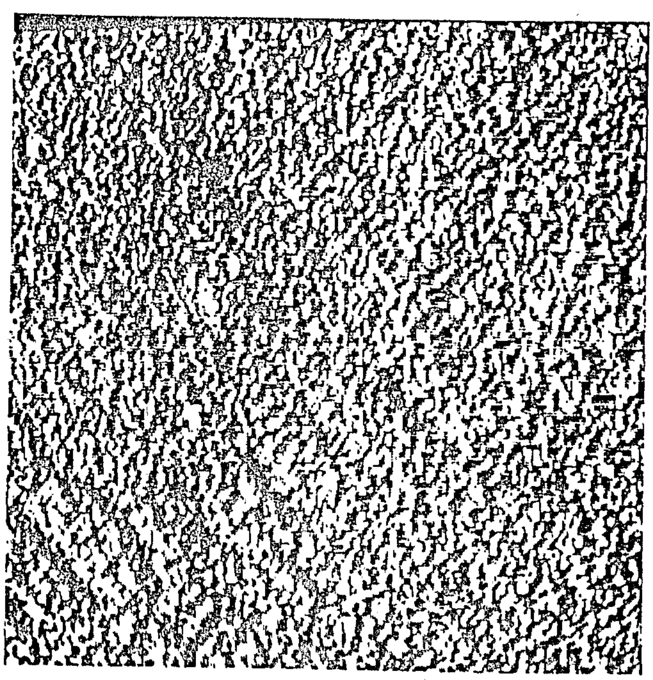
A



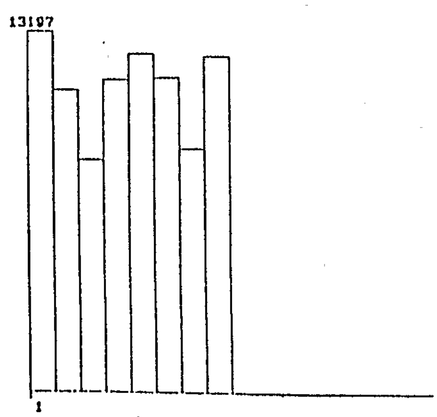


B





H



Gabarit directions images

achieved by a Gabarit filtering on the first principal component given by the four MSS bands: this image has eight different shades of grey, each shade representing the code (from 1 to 8) of the highest local gradient direction, calculated inside a 3 x 3 window by the Gabarit method (Robinson, 1977).

Two types of treatment have been processed:

- statistical study on the eight directions of each sample;

- treatments using Mathematical Morphology methods.

The aim of these two different sets of treatments is to quantify principal and secondary directions for comparison of the samples, called A,B,C,D,E,H,I. The figures hereafter show the samples A,B and I.

1. Statistical study:

The first basic treatment consists in working out the distributions of the eight directions in each sample. This analysis is completed by two processes quantifying the regularity of the directions inside each sample. They consist in comparing statistics on two successive windows.

a) We process calculation of the Khi 2 distance between two successive windows called here Fn and Fn+1, described by the variable "Direction" obtained by the Gabarit filtering:

$$\text{Khi } 2(Fn, Fn+1) = \sum_{j=1}^{8} \frac{1}{f_{.j}} \left[\frac{f_{nj}}{f_{n.}} - \frac{f_{n+1j}}{f_{n+1}} \right]^2$$

$$f_{j} = \sum_{n=1}^{NF} f_{nj} \qquad f_{n} = \sum_{n=1}^{8} f_{nj}$$

NF is the total number of windows
fnj is the relative frequency of pixels having the direction j in the window Fn

b) We process calculation of the number of permutations of the order of the frequencies of the directions between Fn and Fn+1.

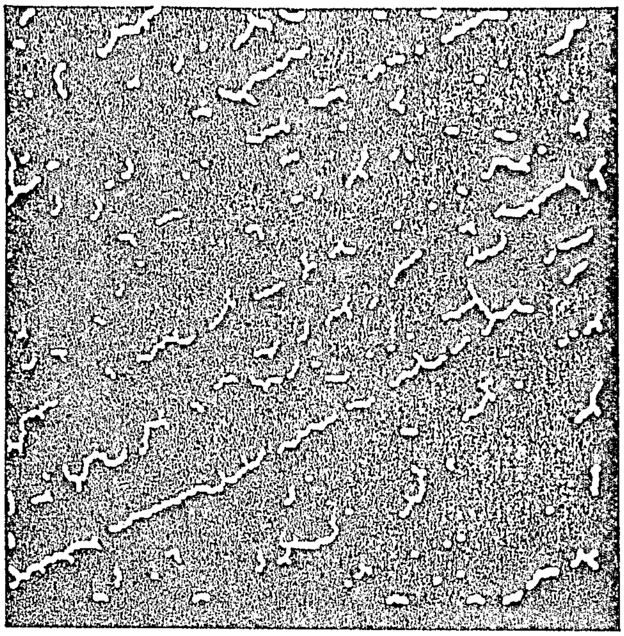
The parameters describing these samples are given by summing up the 150 values of "Khi 2" and "Permutations" relative to the 150 concentric windows. The results relative to the seven samples are shown on the following table.

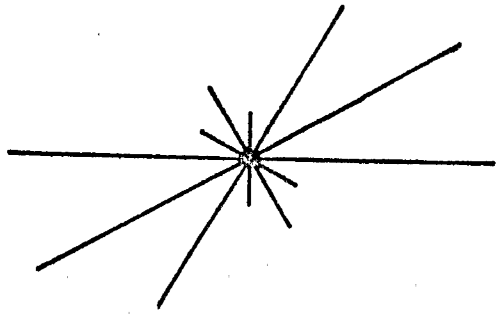
Samples	Khi 2	Number of permutations
A	0.0001324	133
B	0.0001055	241
C	0.0001245	170
D	0.0003169	102
E	0.0002144	120
H	0.0001858	127
I	0.0004412	167

The two variables Khi 2 and Permutation are not correlated. The results on

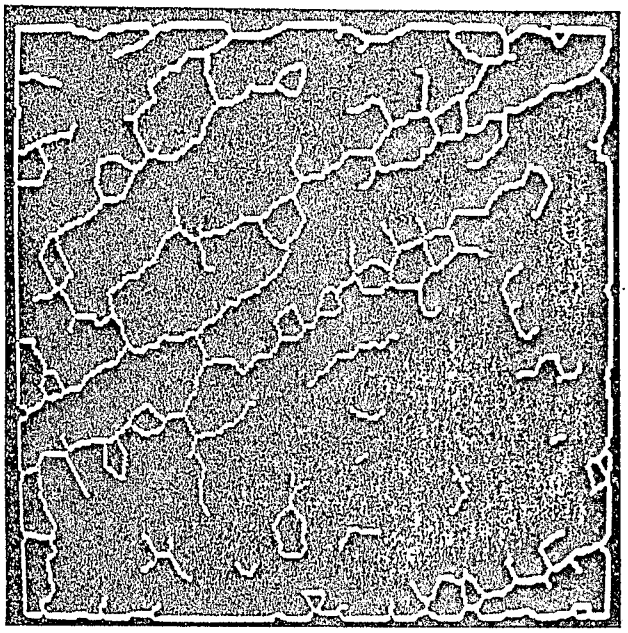
Skeletons, sand-hill bars

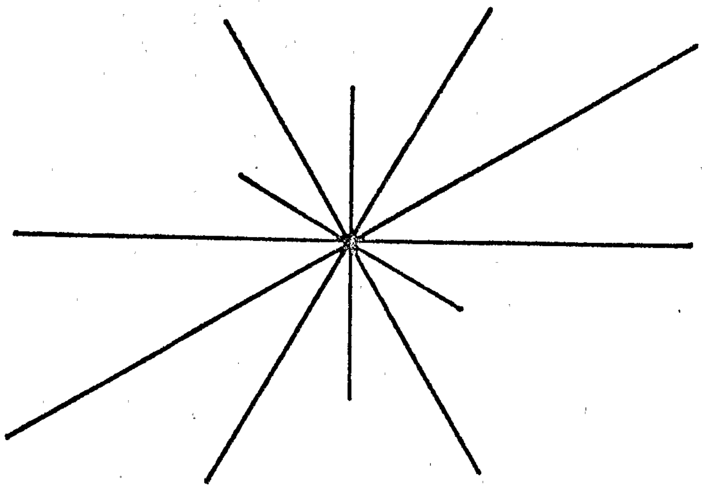
Roses of directions, sand-hill bars



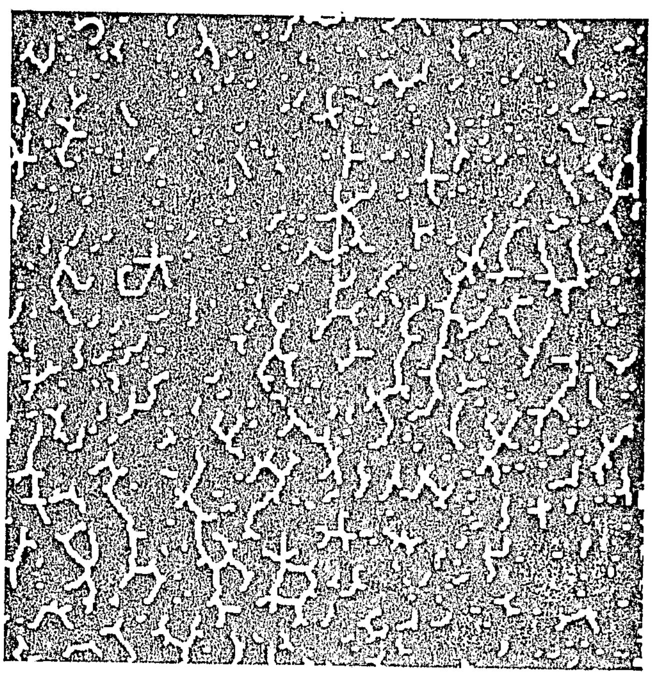


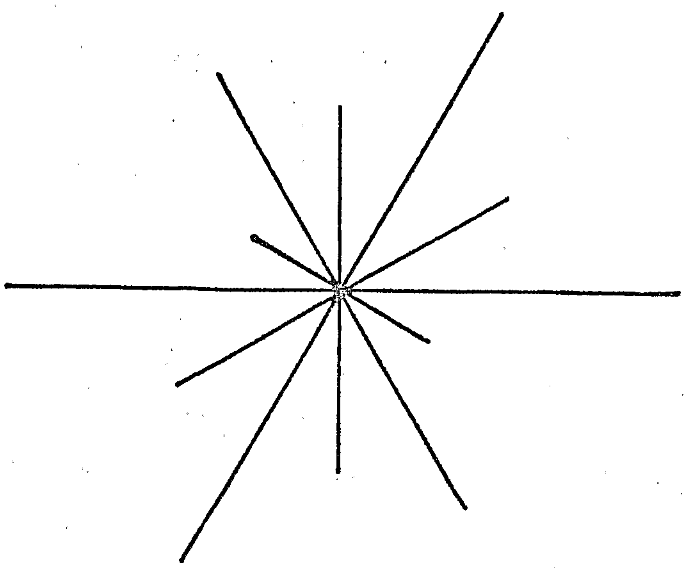
A





B





H

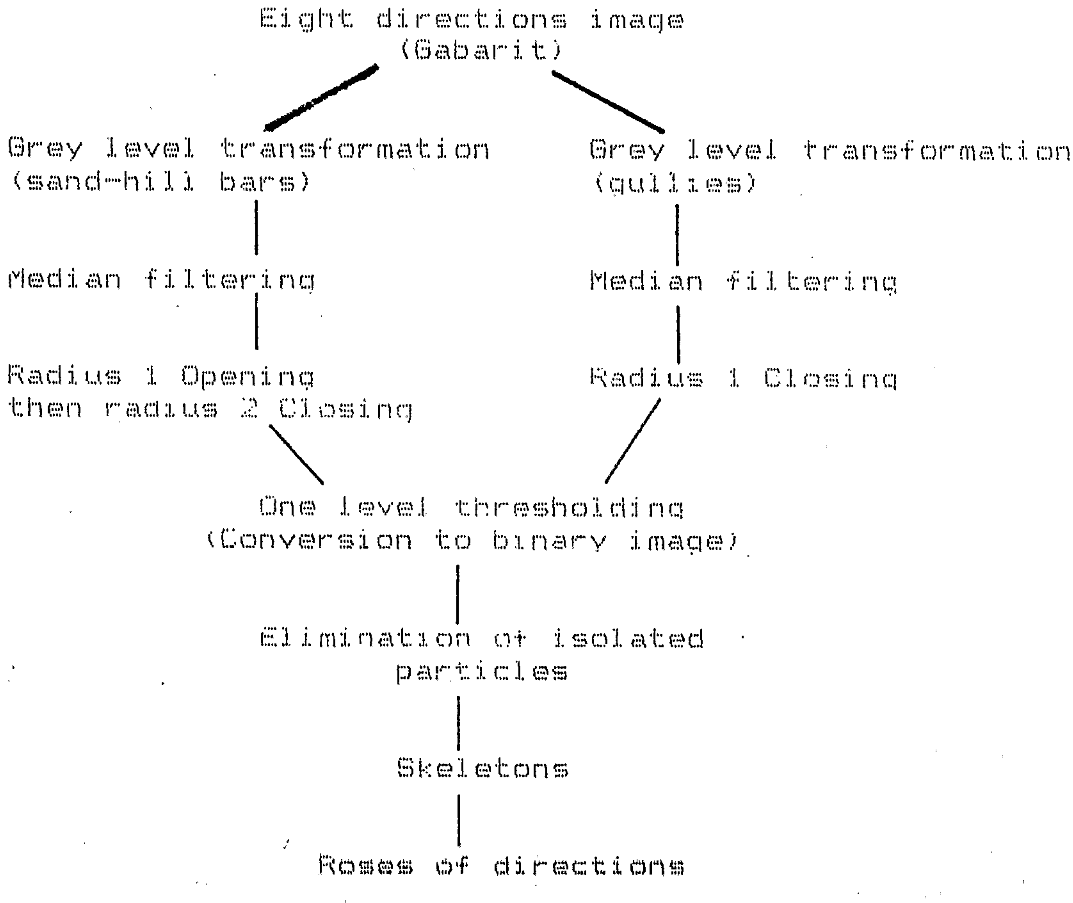
the sample B are typical with the lowest Khi 2 and the highest number of permutations. It can be explained both by the high number of changes in the local gradient direction in the southern part of the sample and by the regularity of the frequency of the changes in the same area. The values of the two variables Khi 2 and Permutation indicate both the high number of permutations in the order of frequencies of directions between two successive windows and the low level of variations between the two distributions of these windows.

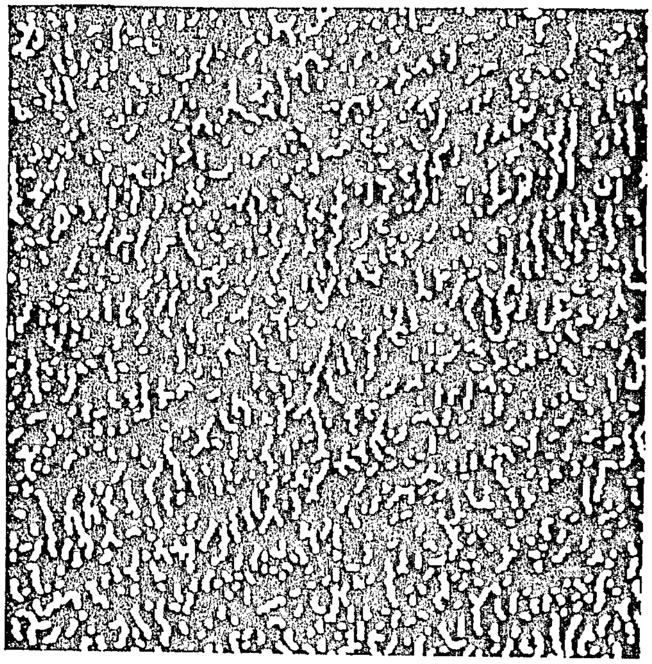
The sample I has the highest Khi 2 and a low number of permutations: a new pattern appears in the South-West of the sample, the distance between bars is higher than in other samples and bars themselves have less linear shapes than in samples A and B.

The analysis of the directional gradients repartition in the windows gives us scalar parameters; however, it does not allow the perturbations of directions to be located inside the image: this is the subject of present development; moreover, the structural direction is reached here through a local orientation inside the texture. For this reason, we make measurements starting with the extraction of the shapes (sand-hill bars, gullies) achieved by morphological transformations.

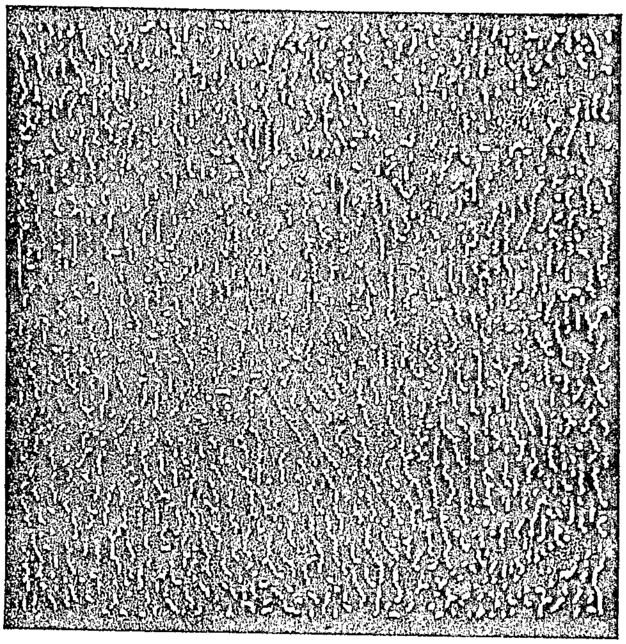
2. Morphological transformations:

Algorithms are applied to the same image of eight directions as above. We make separate filterings for the main structure (the bars) and for the gullies, in order to estimate the importance of each direction and to compare samples to each others: the use of two different algorithms, one for extraction and measurement of bars, one for extraction and measurement of gullies, is here justified by the difference of significant grey level of each theme.

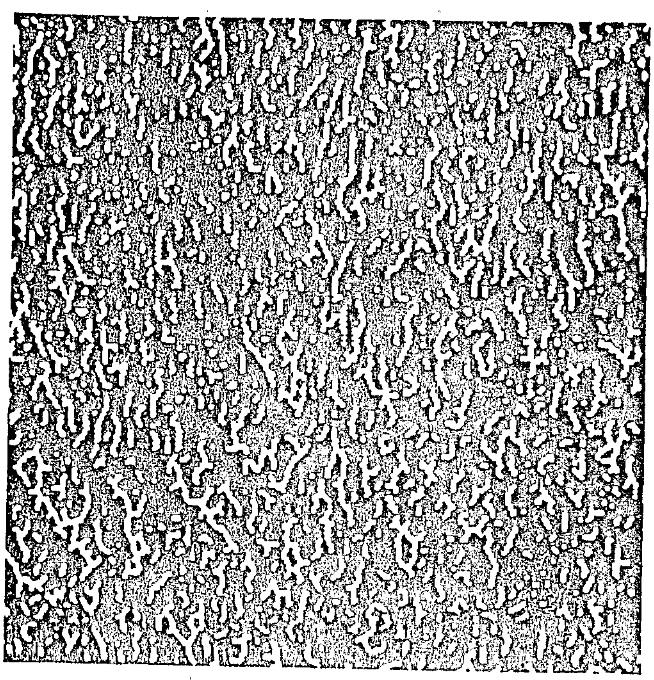




A



B



H

Skeleton, gullies

As the estimation of the order of directions is precisely the object of our research, we choose an isotropic structuring element to prevent any "a priori" about the anisotropy of the image. With the rose of directions method (Coster et Chermant,1985) we can parameter twelve directions in place of eight.

With the gabarit filtering and the Mathematic Morphology in grey level technic, we can obtain a shape represented by a set of consequent grey level and we can study separately each directionnal structure: in every sample the principal structure (bars) and the secondary structure (gullies).

The roses of principal direction (ENE-WSW) are well noted in samples A and B; in B we notice the growth of the direction NNW-SSE (contact between sand dunes and clay "valleys"). In H (not shown here), the previous principal direction is replaced by the new NNE-SSW; the phenomena is more visible in sample I, where the direction NNE-SSW is clearly the highest: we notice the important decreasing of the previous ENE-WSW.

In opposition with the bars structure, the directions of gullies are almost the same in the samples. The skeletons are similar and there is no rotation of the directions (as seen in the bars).

Hence, we have given rise to a 12 levels variable, which allows a quantitative characterization of the structure anisotropy: we consider this characterization as a signature of the extracted structure.

MEASUREMENTS OF LAID BARE CULTIVATED AREAS, GONDO PLAIN, MALI

In the Gondo plain, permanent settlements are organized as concentric circles or rings:

- in the middle, the village: high trees, shadow of the walls, flat clay roofs; low level of radiance;
- a thin circle of permanent stamping by men and cattle with quite bare sandy soil: very high radiance;
- the dense aureole of close fields, every year under cultivation and laid bare during the eight months dry season, with scarce trees (Acacia albida) and shrubs: radiance is high;
- an area more or less structured, more or less cultivated with fallow fields, where grassy and woody coverage is high: the spectral values are numerous and various, generally lower than in the previous ring;
- and the external area of woody bush used for firewood and grazing.

The sketch (see following pages) gives an idea of the morphological organisation of these areas, the set of which makes up the "terroir" of each settlement.

The circle of permanently cultivated close fields is highly threatened by degradation because of the fanning of light organic elements during all the dry season; it is equally important to watch over the fallow area, as its internal border will probably get degraded.

On the scene presented as an example (Landsat MSS, 211-050, March 31, 1976) and on the other scenes we read, the theme "fields permanently under cultivation" is easily seen (high level of radiance, circular shape) but an obvious single thresholding cannot be achieved as it can be for the neighbouring themes. Estimation of its surface needs a specific analysis of spatial organization of pixel values to be done. Such an analysis is based on the tools of Mathematical Morphology. The following algorithm shows the sequence of procedures that leads to a classification and to a quantitative description of the rings.

First principal component
on the four bands
(Karhunen Loewe Analysis)

Identification of the common
center of the rings

Dilation by isotropic and
increasing structuring elements

Reckoning of the mean value
inside each dilation ring

Graphs of the resulting values
according to the radius of dilation

Measures
on the graphs

Descriptive parameters
of the rings

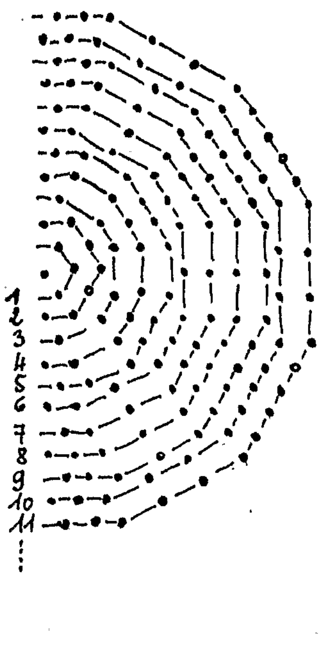
Classification
on types of the circles
described by the graphs

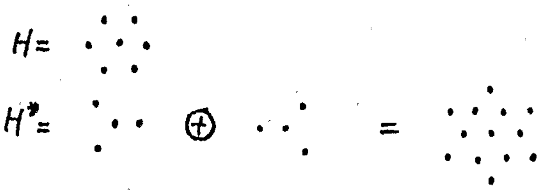
The steps of the procedure are the followings.

1. Identification of the center of the circles: on interactive terminal, the coordonates of a center are identified with a cursor and memorized in a binary image.
2. Successive dilations of this mask with isotropic structuring elements: the basic lattice is hexagonal; hence, the structuring elements are hexagons. When the radius is increasing, the hexagon looks less and less like a very circle, so we have replaced it by a dodecagon. Dilation by the dodecagon is processed as follows:

The ordinary dodecagon has the following form:

$Di = nH + n*H*T$



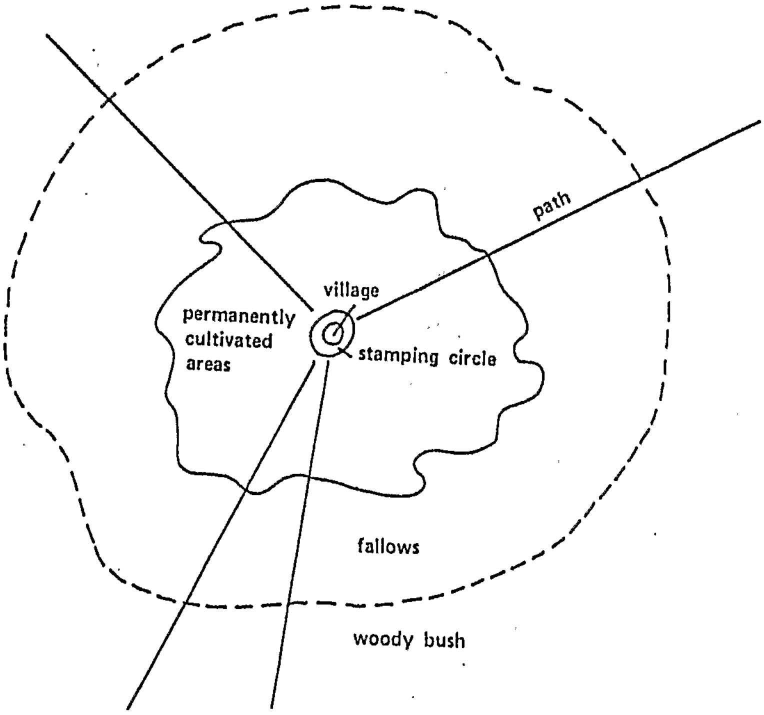


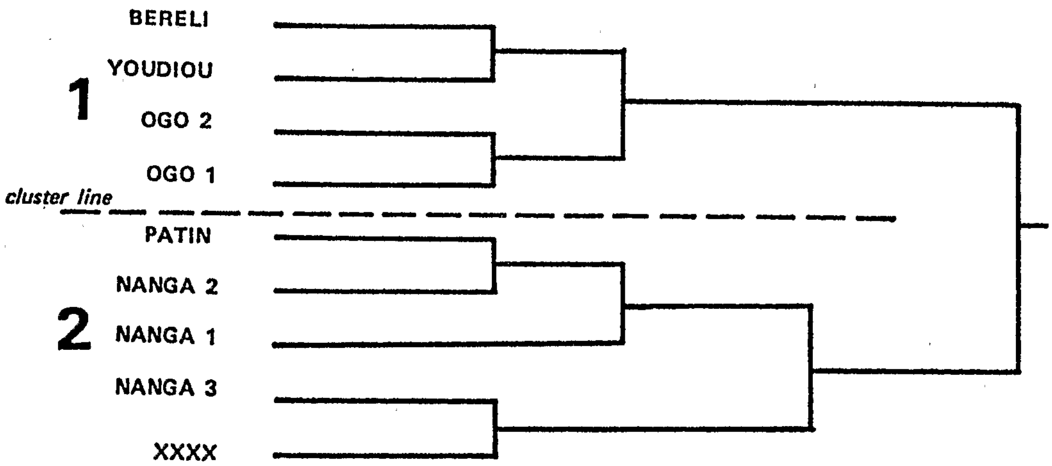
To obtain the following one, calculate $\alpha = \dfrac{(n+1)\ (n-1)}{3n^*\ (n^*+1)}$

If $\alpha \leqslant 1$, then $D_{i+1} = (n+1)\ H \oplus n^* H^*$
if not, $D_{i+1} = (n-1)\ H \oplus (n^*+1)\ H^*$

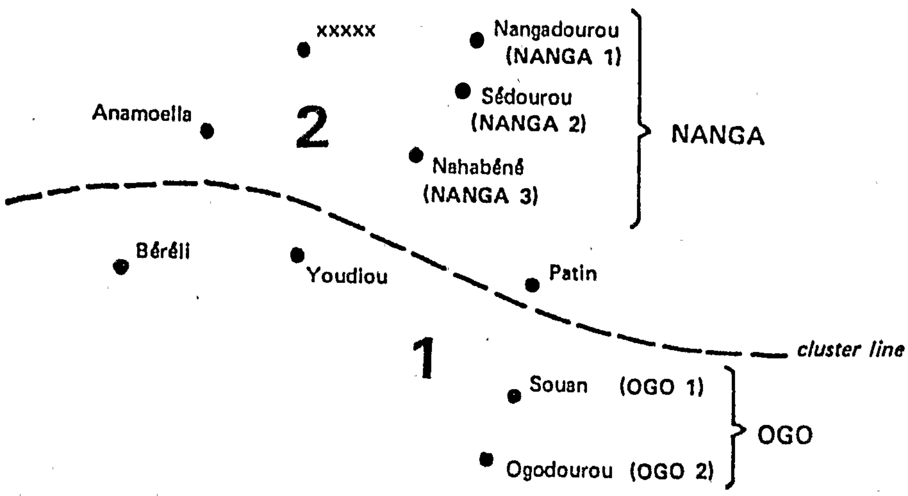
i	1	2	3	4	5	6	7	8	9	10
n	1	2	1	2	3	2	3	4	5	4
n*	0	0	1	1	1	1	2	2	2	2.5
S	7	19	31	55	85	109	151	199	253	295

This sequence cannot be used for a granulometry. For instance: D6 is not open by D5. One has to take one decagon out of two from i=4.



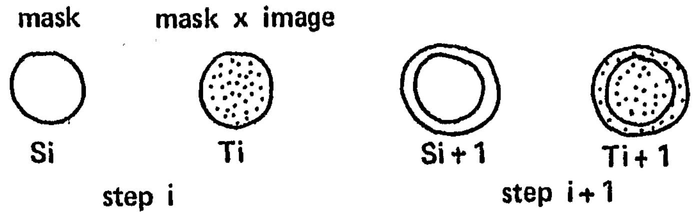


The tree from correlation of the profiles



from the 1/200 000 map

3. Computation of each dilation ring:



$$M(i+1) = \frac{Ti+1 - Ti}{Si+1 - Si}$$

S = surface
T = sum of numeric values

For each village, we process to a graph of 40 points.

4.Hierarchical classification tree: the correlation between all these graphs is computed. After descending hierarchical classification, one can notice a discrimination: the circles of the northern villages are thinner and more reflectant than the southern ones.
5.Direct measures on the graphs: abscissa and ordinate of the maximum, width of the lobe at a given height, slope from a given distance.

This whole procedure is founded on the estimation of a distance from a center: it is specific of the description of a simple concentric circular system. We have experimented an other procedure, that can be used for geometrically more complex systems. This second procedure is founded on the compacity of the shapes outlined by close grey levels; for each grey level a compacity index of the corresponding binary image is estimated by calculating the quotient of the surface of the Opening by the surface of the Closing: the graph A represents the stability of the surface:

$$\frac{S(O+C)}{S}$$

S = Surface, O = Opening, C = Closing.

The graph B represents the stability of the number of particles:

$$\frac{P(O+C)}{P}$$

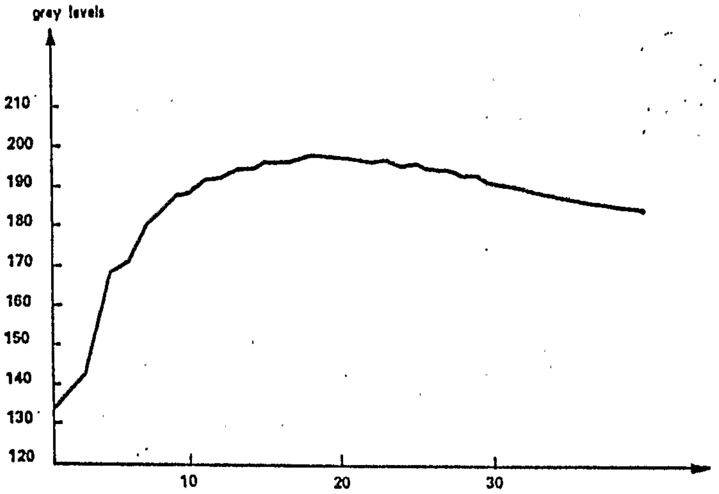
P = number of particles.

Both gives us three thresholds. The original image (principal component) is restituted from these three thresholds, giving a four classes image:

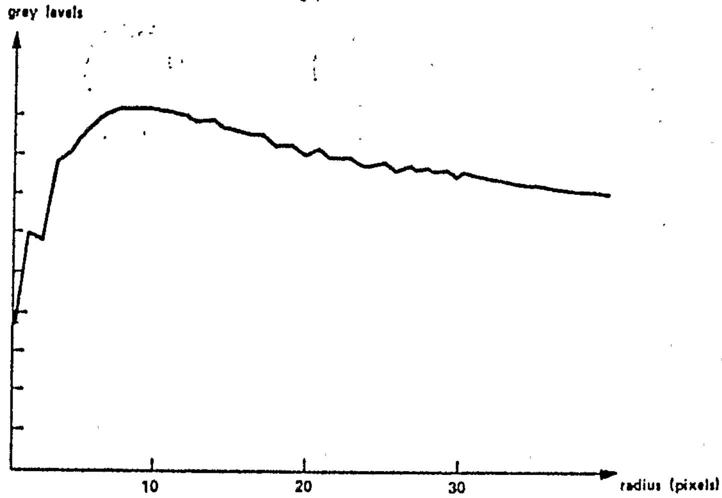
- permanently cultivated area.
- woody bush

and between them, two classes which are supposed to be two different types of fallow fields: a verification on the ground is to be done.

The application of these procedures to the whole Gondo plain may allow quantitative studies upon differencies between "terroirs", differencies which are to be explained by physical or human factors (pedology, land-use, history...). The application to chronological sequences of MSS images may allow a quantification of the evolution in each "terroir", particularly the quantification of the amount of the permanently cultivated areas. It should give useful informations for further control of the potential of production at the local and regional levels.

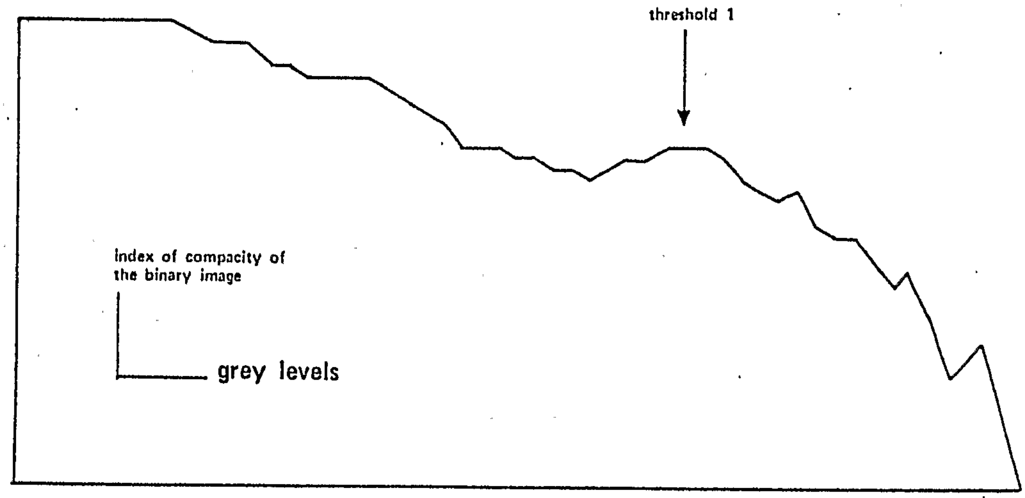


YOUDIOU

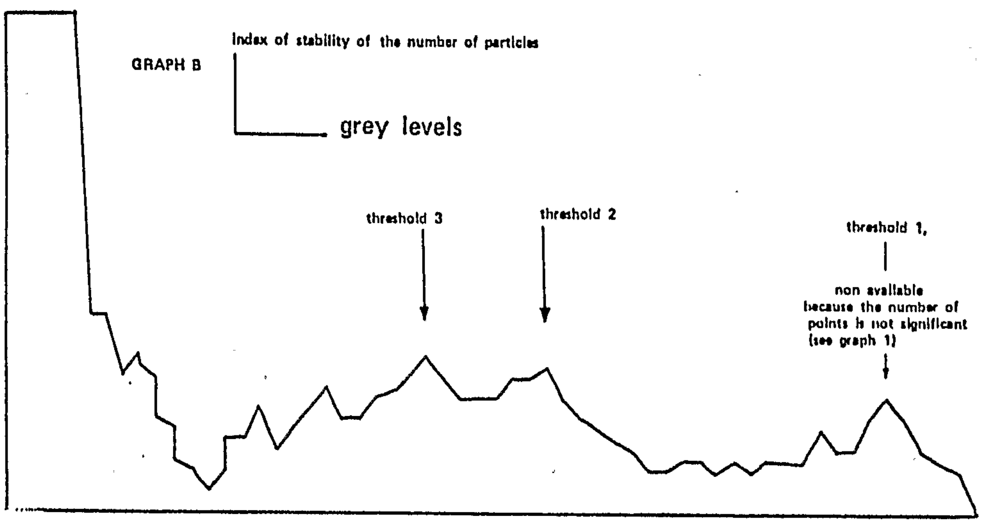


XXXXX
(village without a name on the map)

GRAPH A



GRAPH B



CONCLUSION

With above processings, precise measurements on landscape shapes and structures are made possible: then very precise and detailed comparisons become equally possible, allowing to find a relationship between elements of the very same structure or to estimate little changes in a given structure. Moreover, the parameters we obtain, processed from Landsat MSS numerical datas, can be related to other analytic measurements about the same objects, the same phenomena.

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