Methods to Characterize Landfacets Using Remote Sensing Data and GIS in Burkina Faso

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ABSTRACT

The aim of this research is to improve statistical information about land use and more precisely, about agricultural activities.
The method suggested in this paper is based on a stratification of the landscape, at different levels, in order to characterize agricultural domains. This method uses GIS capabilities with: satellite imagery, D.E.M., agro-hydrologics models, ground measures and field enquiries.

After a description of the methodology, some of the main results already obtained are presented. It concerns definition of agro-ecologic zones, the discrimination of cultivated domain, the characterisation of topographic facets using D.T.M. and the mapping of run-off potentiality. These criteria form the basis for satellite image stratification.

First results show that the method exceeds the improvement of the agricultural statistics to concern also agriculture and resource management in general.

INTRODUCTION

This study is made in the context of a project entitled: "Methods to characterize agricultural domains using GIS and Remote Sensing in Sudano-Sahelian countries".

The aim of this research is to improve statistical information about land use and more precisely, about agricultural activities.

This research project is based on close collaboration between different partners:
- Laboratory of Remote Sensing and Regional Analyses of the "Université Catholique de Louvain-la-Neuve";
- DA VINCI consulting S.A. (Belgium);
- Laboratory of Agricultural Hydraulics of the Faculté des Sciences Agronomiques de Gembloux (Belgium);
- Geographic Department of the University of Ouagadougou (Burkina Faso);
- The Geographic Institute of Burkina Faso (I.G.B.);
- AGRHYMET center of the CILSS (International Committee against drought in Sahel) in Niger;
- The Common Research Center of the EEC in ITALY which has provided all the data (satellite images, digital elevation model and aerial photography).

The main specifications of the project are:

1. A precise technological objective consisting in developing tools designed to integrate, process and present information directly accessible prior to any decision making in a operational perspective.

Two phases can be distinguished (fig. 1):
- a phase of pre-processing data to establish layers constituting a first level of information workable within a GIS. Different kinds of information are already available:
    - information on land use and land cover derived from satellite imagery;
    - information on relief derived from a Data Elevation Model (D.E.M.) (slopes, orientation, hydrographical network, topographic units,...);
    - information on agro-hydrological conditions: run-off and water storage conditions.

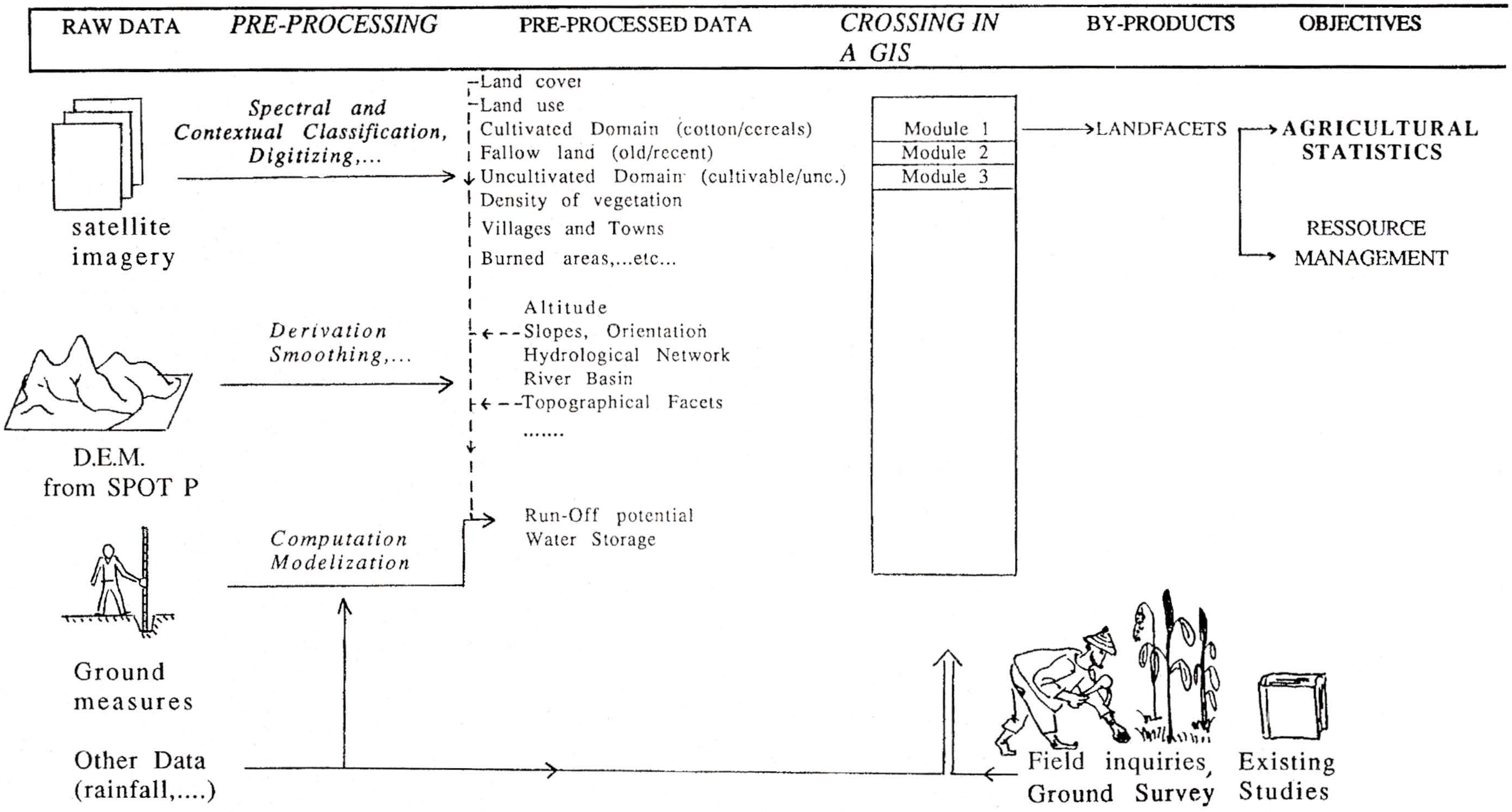


Fig. 1 - Integration, processing and production of information using GIS, remote sensing and ground data.

- a phase of crossing these different layers according to different scenarios constituting numerous channels leading to computerized modules and directly usable documents.

2. A multidisciplinary approach which integrates socio-economical, agro-hydrological and geomorphological aspects. Ethnic factors and agricultural strategies, for instance, are studied on the basis of field enquiries made in collaboration with the department of geography of the University of Ouagadougou.

In the context of the first phase of the present project, the approach developed right down to the level of the user involves improving agricultural statistics. This first operational scenario facilitates the selecting of samples and their exploitation. This paper sums up the development of this first phase.

The pilot zone for testing this method is located to the south-west of Burkina Faso and corresponds to a SPOT scene in the lower right hand corner of which are visible the outskirts of the town of Bobo-Dioulasso (fig. 2).

1. PROBLEM OF IMPROVING AGRICULTURAL STATISTICS

Agricultural surveys currently being conducted in West African countries are based on sampling conceived according to socio-demographic criteria (PADEM 1985, Min.Agr. Burkina, mentioned by Bartholome, 1988): size of villages, number and types of farm holdings per village. This kind of sampling is relatively difficult to implement and does not take into account local constraints. The plots chosen are assessed in a relatively rudimentary manner. In this way, the decennial agricultural survey in Mali covered

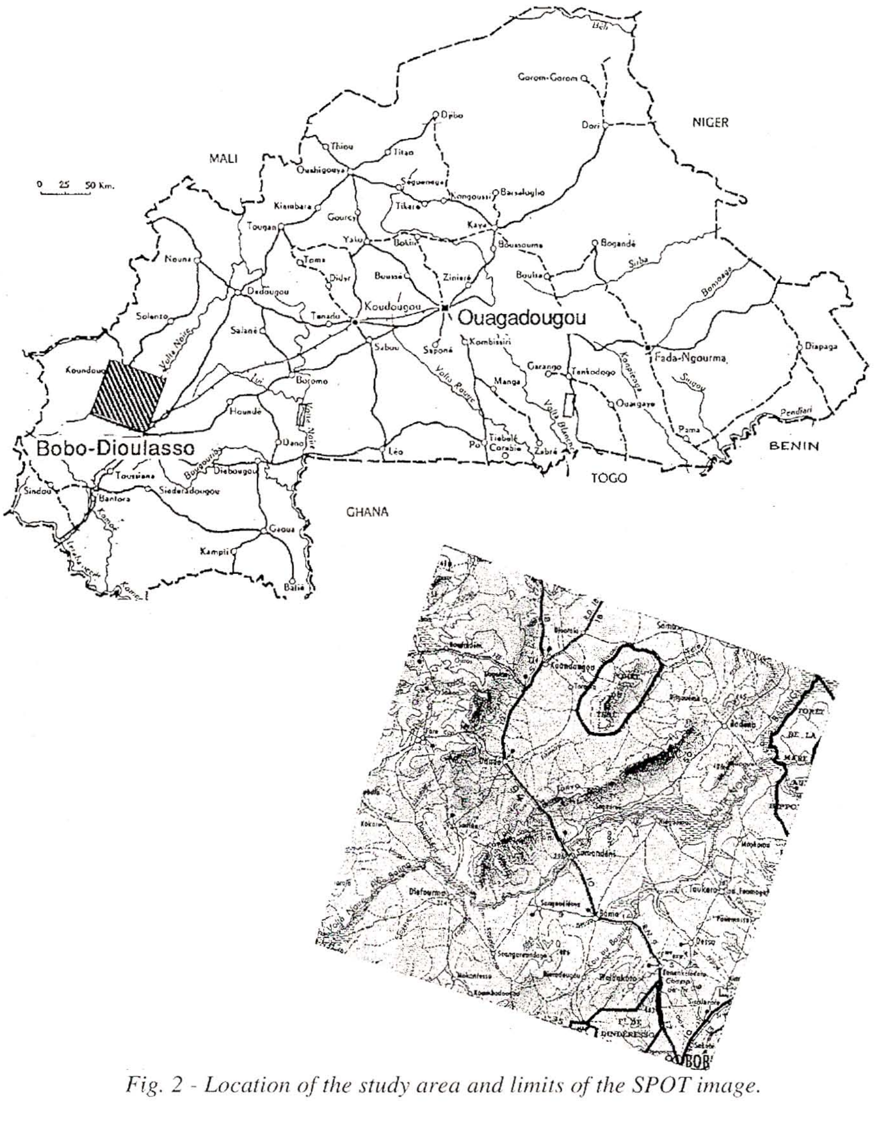


Fig. 2 - Location of the study area and limits of the SPOT image.

approximately 0,45% of farming units (PADEM 1984, quoted by Bartholome, 1988).

It is obvious therefore that agricultural surveys can be greatly improved.

This improvement should focus essentially on the following points (Bartholome, 1988):
- the nature and number of samples;
- the homogenisation of sampling by taking into account environmental factors, in order to reduce observation variabilities;
- lightening the work load of ground surveyors so as to limit the source of errors.

Among the different methods for enhancing agricultural statistics, remote sensing appears an ideal means on account of its synoptic, repetitive and digital character. However, different experiments conducted up till now in the Sahel have not yet provided satisfying results. This situation can be ascribed to two principal categories of problems:

- Certain features intrinsic to African agriculture limit the possibilities of discriminating crops:

- small fields;
- crops in association;
- trees in the fields;
- species with poor cover, low density sowing,...

Radiance values recorded by the captor emcompass several objects (soils, trees, straw, plants,...) which explains the difficulty of discriminating crops.

- Spectral derivation

The spectral signature of land use varies both in time and space. Different hypotheses are regularly put forward to account for this spectral derivation in Western Africa (Bartholome, 1987; Defourny, 1990;...):
- the horizontal heterogeneity of the atmosphere (cloud cover, mist, fog,...);
- edaphic conditions of the environment (soils types, hydromorphy,...);
- the phenological stage of vegetation;

...

The same objects will thus have different spectral signatures according to their localisation in the image. The first operation before classification is thus to establish a zoning of the image in order to have "equal reasoning zones".

As we will see later the methodology suggested here offers new possibilities to establish an automatic zoning.

2. SUGGESTED METHODOLOGY

This method has been presented by Bartholome (1987). The reasoning is based mainly on a stratification of the landscape at several levels: agricultural regions, landfacets, samples or plots to be visited (fig. 3). This helps define the nature and importance of the sample whether on images or in the field. The type of stratification advocated differs from those generally carried out statistically to appraise agricultural production. Indeed, attention is focused on environmental criterias even if socio-demographic criteria are taken into account.

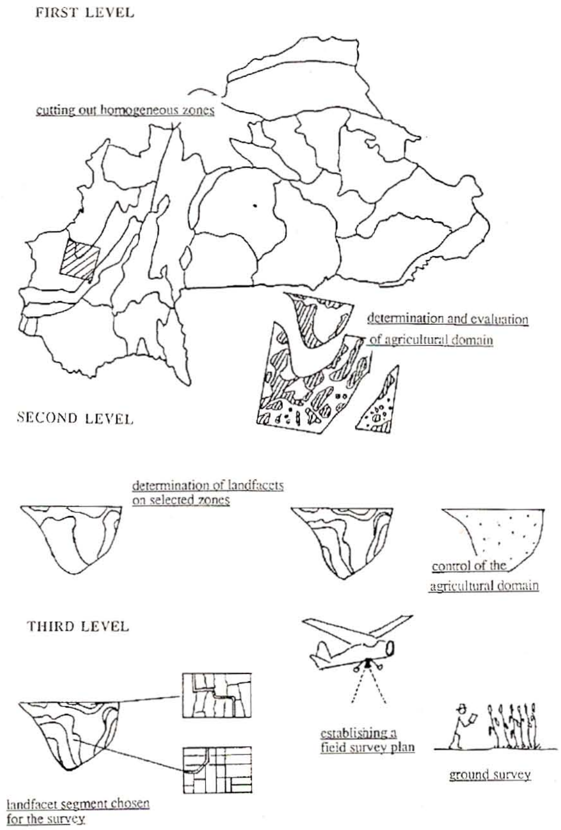


Fig. 3 - Spatial aspect of stratification (from Bartholome 1987, modified).

2.1 Agricultural regions

This first level can be considered as a part of land within which reign the same environmental and development conditions. This infers a more or less homogeneous agricultural structure in the whole stratum.
Such stratum corresponds to the "equal reasoning zone".

Manual methods of area subdivision using satellite imagery are well known (Gilg and al., 1990, Meyer Roux, 1990). They rely generally upon visual interpretation of colored composite of satellite data. The use of numerical methods is less frequent (Gallego, 1990, Hay and Al., 1982, Strahler, 1981). The notion of landfacets offers new possibilities to establish an automatic zoning.

2.2 Landfacets

This notion occupies an important position in the methodology.

The landfacet is defined as a limited portion of land associating specific morphopedological and management conditions.

In our methodology these facets are derived from the crossing of morphopedological, agro-hydrological and management conditions (fig.4). Topographic units are derived from a D.E.M. (Digital Elevation Model) (point 3.3.). Run-off potential and water storage are derived from agro-hydrological models based on ground measures and satellite imagery treatments. Management conditions are, in a first analysis, produced by a classification in "land use domains": year-crops, fallows and un-farmed land (see point 3.2). Field enquiries are also made to complete management information and to appraise the main evolution factors of agriculture in this region.

At each step other information can be added for a better characterization of the "landfacets".
They will serve as a basis for sampling agricultural space for crop survey and they can be used for other purposes such as resource management.

As far as the spectral derivation is concerned, landfacets (nature and importance) will also serve as a basis for an automatic zoning of the image. Conceptually, this procedure is fully justified: the landfacets integrate factors which influence the spectral signature of objects (soils types, hydromorphy, phenologic state,...).

2.3 Plots of land

The different segments are chosen in landfacets which are cultivated.

The delimitation of plot layout is made on the basis of aerial photograph enlargements and crop surveys are made within the segment.

The department of geography of the University of Ouagadougou has executed a crop survey for the last campaign (1991).

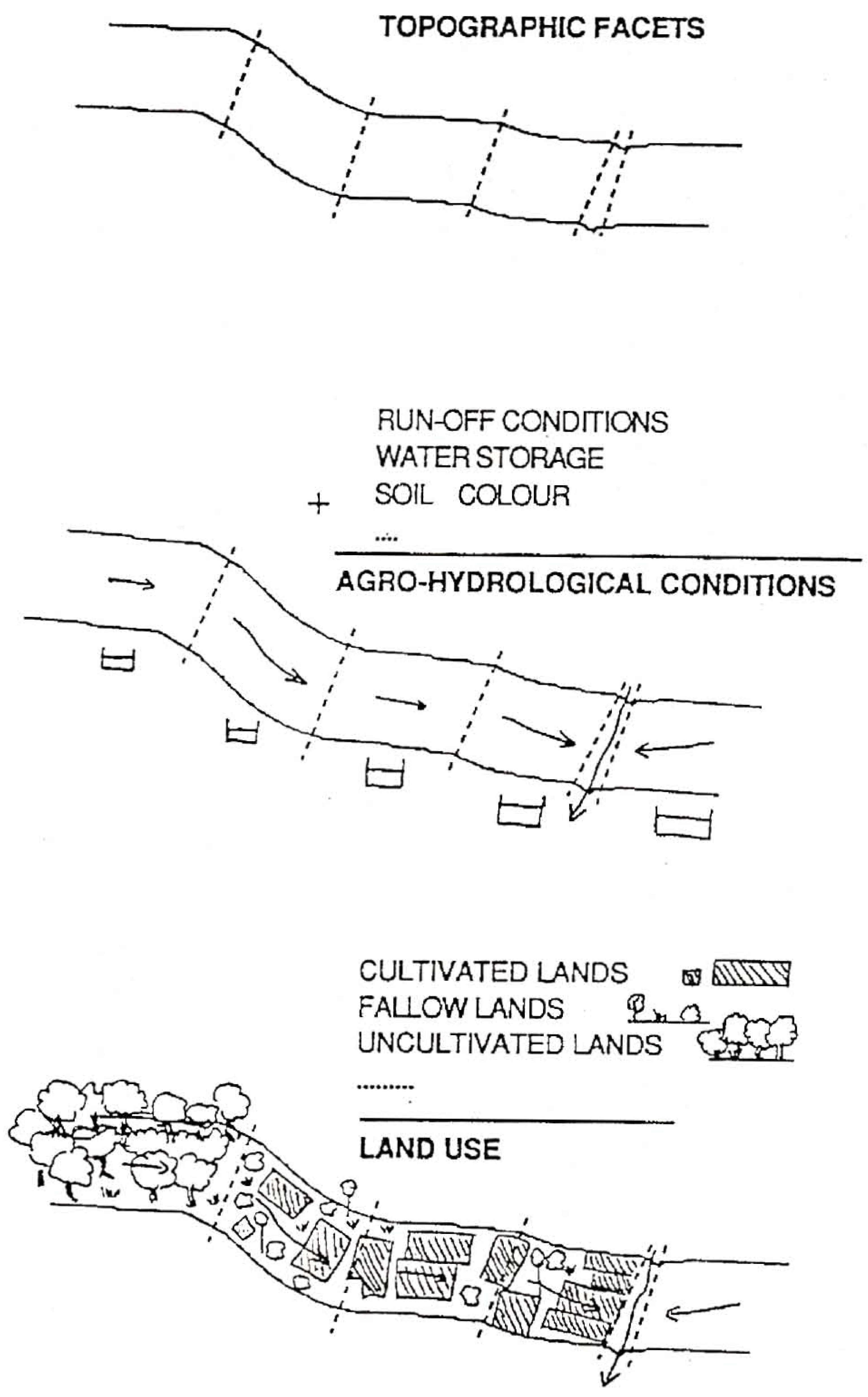


Fig. 4 - Diagram of the building of land facets.

3. PRELIMINARY RESULTS

3.1 The agricultural regions

Analysis is made on a false colour composite of a SPOT image which has been taken at the end of the dry season (09/06/91). This period seems to be the best for discriminating different kind of agronomic conditions. An image of November 91 leads to the same delimitations but shows some limitations due to burned areas and cloud cover.

Three zones can be distinguished. A recent mission (June 1992) has shown that these zones correspond to different realities:

- A first zone characterised by a favourable morphopedological environment (low glacis, sandy-clayed soils) with a very high human density caused by recent emigration of Mossi coming from the north regions (Totté M., Henquin B., report mission June 1992). The farm plot layout is not visible on the image and it corresponds in the field to a continuous agricultural domain where fallow lands are rare. The main crops are sorghum and cotton.

- A zone of rubefied soils (red soils). Those soils present some agricultural constraints (high drainage, poor chemical characteristics). The farm plot layout is far more visible than elsewhere: crops are grouped into large distinguishable blocks surrounded by fallow. This indicates a particular organisation: each lineage or big family is cultivating a block of parcels. The main crop is millet with some gardening in plains.
- A zone less occupied and markedly more forested than the others with a few scattered fields. The principal crop is sorghum with some gardening in villages near Bobo-Dioulasso.

The criteria used to perform this analogic zoning are essentially, in a first analysis:

- the colour, linked to the importance of vegetation cover, the nature and hydric state of soils and to the presence of duricrust;
- the organisation of farm plots (size and distribution of fields).

This delimitation, in three zones, corresponds to a very general zoning which can be found to a certain extent, in physiographical, geological and socio-demographic maps of the region.
Observation of the geological map reveals a certain parallelism between the limit "sandstone with inclusion of quartz-dolomitic schistous sandstone" and the limit of the south-eastern zone. The limit of the south-western region can be found, although less clearly, on map of physiographic units of Burkina-Faso (Guillobez 1985).

Of course, other conditions also influence land use:
- proximity of a big town like Bobo-Dioulasso;
- presence of irrigated and organized agriculture like the rice growing areas of BAMA an BANZON;
- existence of a main road,...

LAMBIN (1988) reported that natural factors can not account for the totality of variance of spectral signature of an image. The ethnic factor (more precisely the agrarian organisation: size and distribution of fields) appears on a contrary predominant. Such criteria will be taken into account by a contextual analysis after classification of the cultivated domain in order to define the "keys" of an automatic zoning.

The general delimitation into three zones seems to be relevant for discriminating general agricultural conditions. These zones will be treated separately.

3.2 Classification in cultivated domain, fallow lands, non-cultivated domain

The method chosen to discriminate the different domains (cultivated domain, fallows and un-farmed land) is an unsupervised classification in a large number of classes (50 clusters) followed by an interactive thematic pooling. This kind of classification has successfully been used to stratify natural vegetation (Strahler, 1981).
This classification in a large number of clusters is very useful to analyse the distribution of the classes in the space of the infra-red and red bands (fig. 5) or in the space of neo-bands (fig. 6: Normalized Difference Vegetation Index (NDVI) and Brightness Index (IB)) in order to see the separability of the different domains.
Cultivated domain is defined as year crops. Fallow lands are associated with higher vegetation coverage. Difference between fallow lands and a non-agricultural domain is rather theoretical. Some part of the non-agricultural domain has been cultivated long time ago and thus includes also old fallows. The discrimination (thematic pooling) has been performed analogically using topographic criteria combined with spectral ones: high lands covered with dense vegetation are considered as non-agricultural domain.

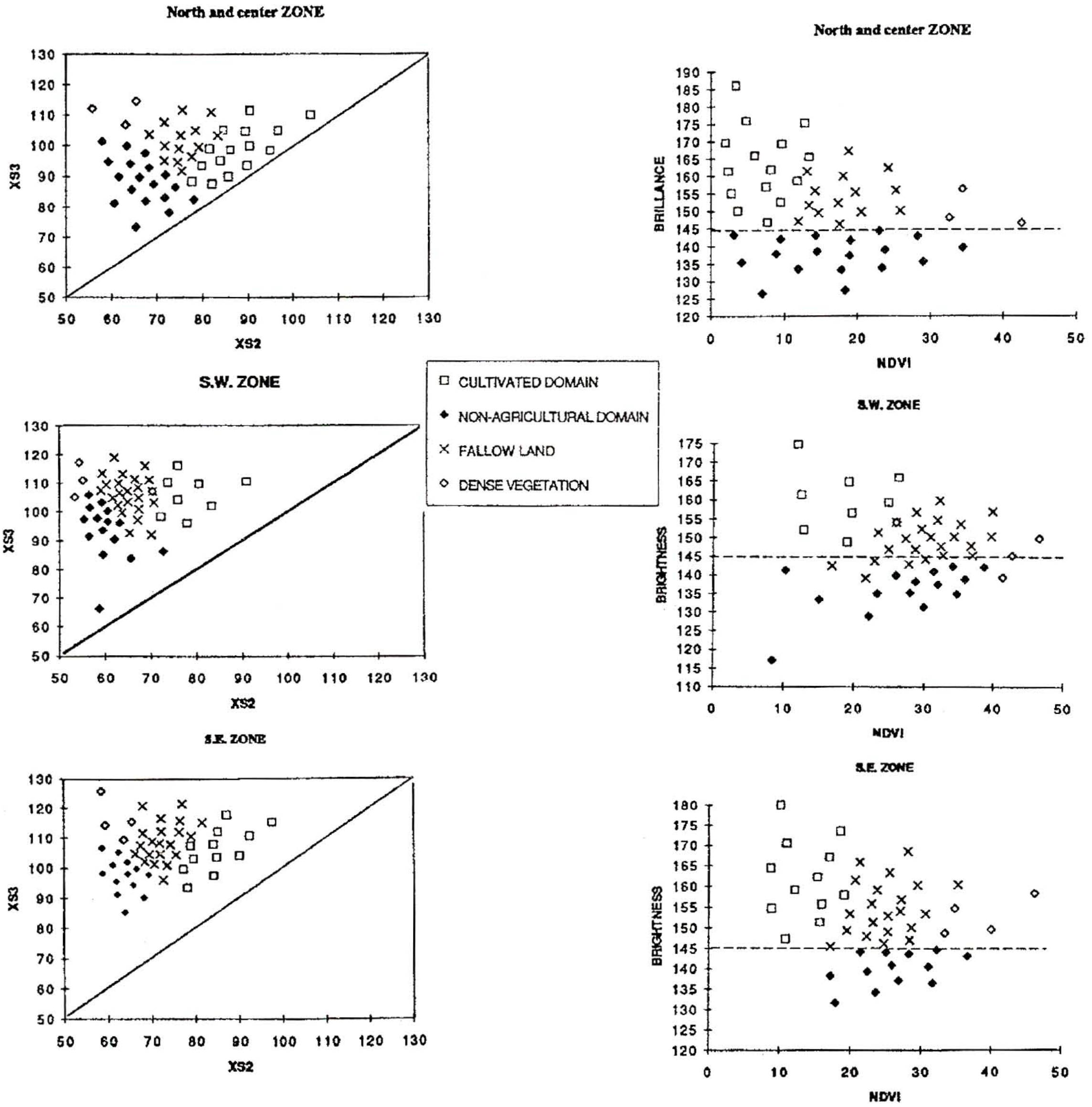


Fig. 5 - Distribution of the 50 classes in the Red/Infra-Red space.

Fig. 6 - Distribution of the 50 classes in the IB/NDVI space

*(NDVI = ((XS3-XS2)/(XS3+XS2)+1)*128 ; IB =* $\sqrt{XS_1^2 + XS_2^2 + XS_3^2}$ *).*

Figure 6 illustrates, for instance, how a simple threshold of the brightness index (IB) proves to be relevant, and relatively constant according to the zone, to distinguish non-agricultural domain from the rest.

The distinction between cultivated and fallow lands is, as can be expected, far harder to perceive. Examination of spectral signatures points out the difficulty of distinguishing these areas solely on a spectral basis. The confusion occurs principally between recent fallow and un-tilled fields. An image taken a little later in the field preparation season should prevent certain confusions. Such a period is however relatively restricted and fluctuates from one year to the next depending on the onset of the rainy season.

Table 1 indicates the percentages of the different domains for the three zones.

Table 1: Result of the classification of principal land uses according to the 3 zones of the SPOT image.

%	*S.E. Zone*	*S.W. Zone*
Cultivated Domain	24.37	14.33
Fallow Lands	42.86	48.31
Non-agricultural Domain	32.77	37.36

These percentages will be validated according to the crop survey. A first comparison with aerial photographs shows a good accuracy (96 %). Figure 7 presents the results of part of the S-E region.

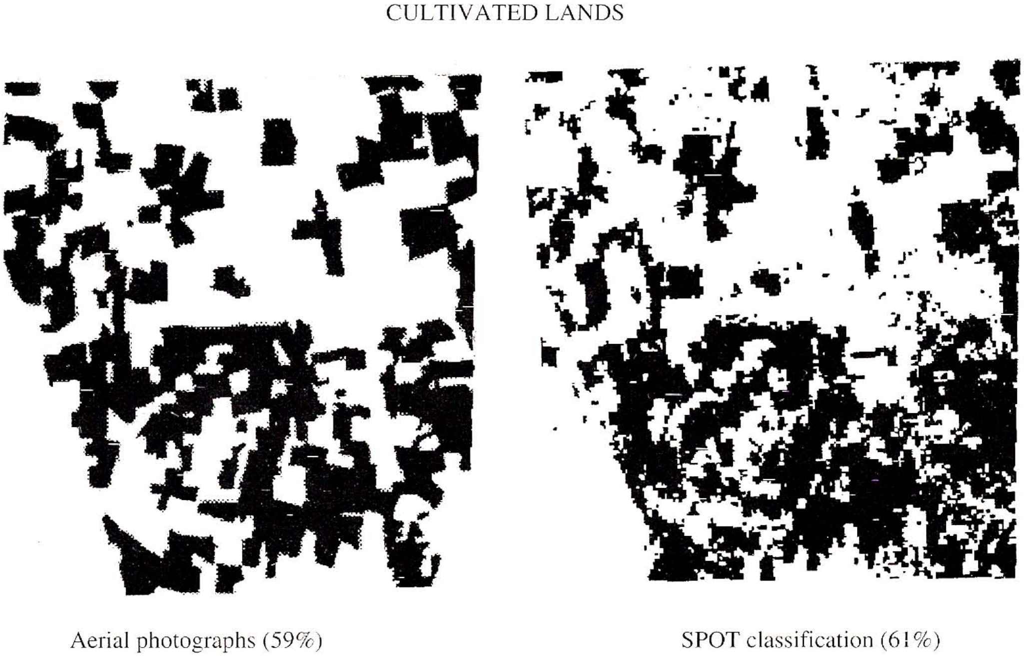


Fig. 7 - Comparison between aerial photograph interpretation and classification result for a part of the South-East region.

The first 3 classes will serve as a basis for further classification. Each class is used as a mask and applied to other images (relative to other periods of the same scene) to improve classification and to obtain other information (e.g. discriminating cotton from cereals).

3.3 Topographic facets

As mentioned previously (fig.4), topographic facets are the basis of the characterization of landfacets and are deduced from a DEM analysis.

This DEM proceeded from 2-SPOT Panchromatic imagery treatment using a stereopair of images recorded on 22 and 23 october 1990. Elevation values are given in 0.1 m units.

Treatment of the DEM has been made on MORPHOTERRA™ software and IDRISI. Its major limitation is a relief in steps (fig. 8). Indeed, the majority of these steps do not represent ground truth.

Figure 8 shows the topographical profile after several smoothing filters of varying sizes and shapes. The filter

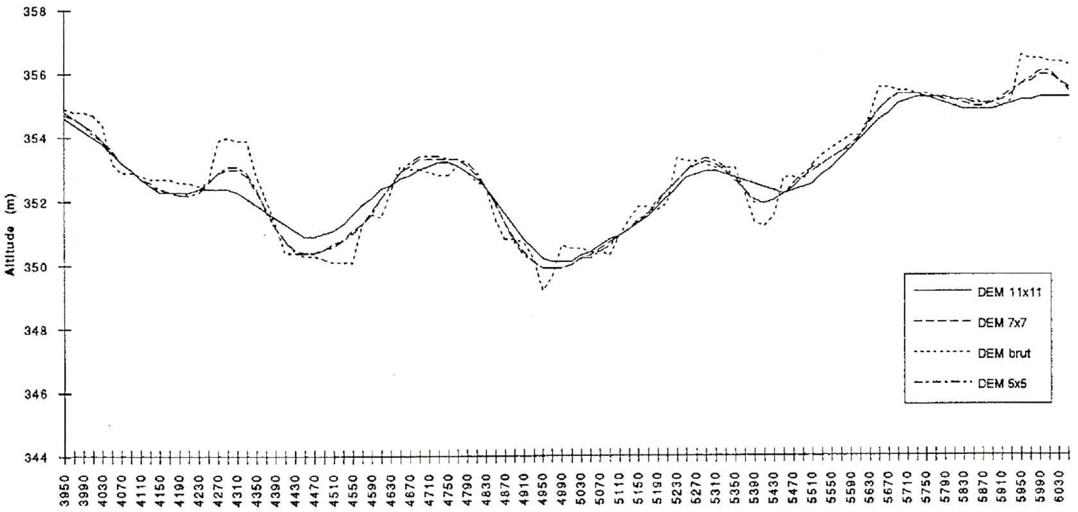
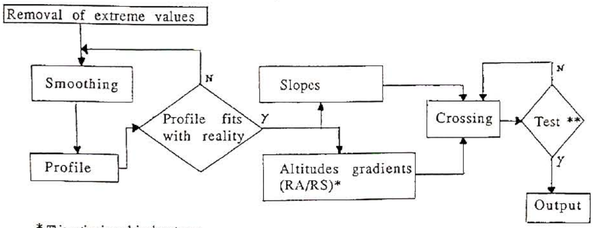


Fig. 8 - Profile in the DEM with different smoothing filters.

11x11 has been chosen after confrontation with profiles obtained from topographic maps and analysis of aerial photographs: Figure 9 sums up the method.

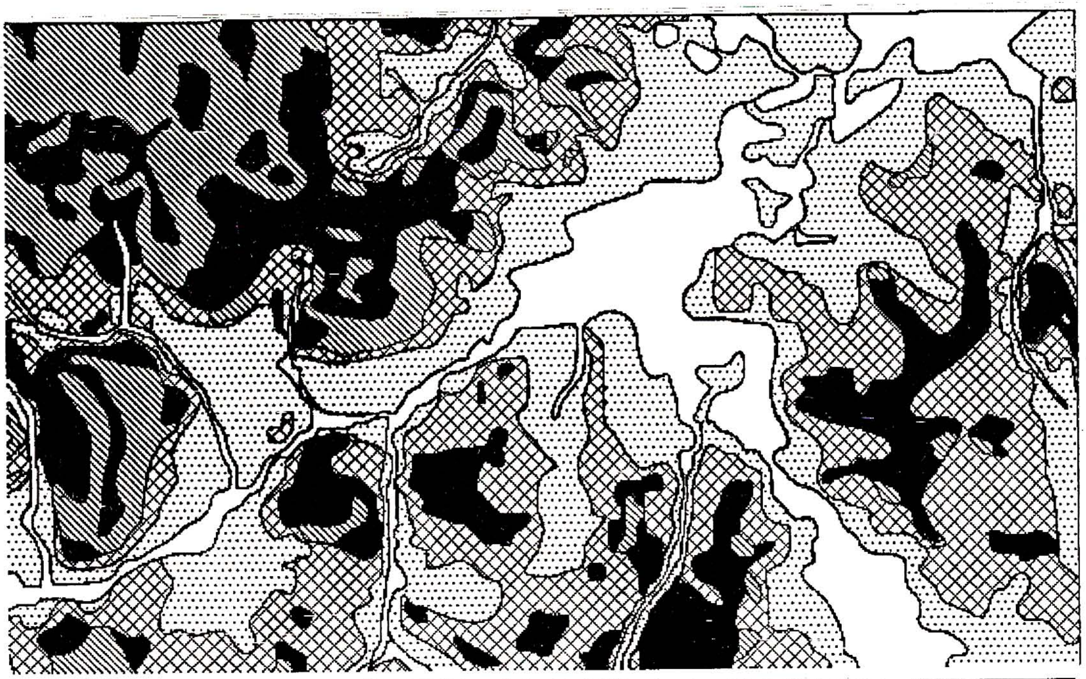
The RA/RS calculation is the result of a division between the altitudinal relation (RA) and the spatial relation (RS) from a point to its outlet. More simply, it represents a mean slope from a point to the river. The advantage of this procedure is that RA/RS ratio is independent of the DEM resolution. The result is crossed with a slope map to obtain morphologic units.

First results are presented in the following figures.
Scale = 1:400.000



* This notion is explained next page
** correspondance with geomorphological facets (ground control, existing maps)

Fig. 9 - Method used to treat the D.E.M.



UNIT	RA/RS °/oo	SLOPES %	GEOMORPHOLOGICAL CORRESPONDANCE
1	3 - >50	6 - >15	HILLSLOPES
2	16 - >50	0 - 5	PLATEAUS and DURICRUST
3	10 - 15	0 - 5	PIEDMONT - GLACIS
4	3 - 9	0 - 2	LOW- GLACIS
5	0 - 2	0 - 2	ALLUVIAL PLAIN

Fig. 10a - Detail of the topographical map resulting from the crossing of slopes and RA/RS.

Echelle = 1:400.000

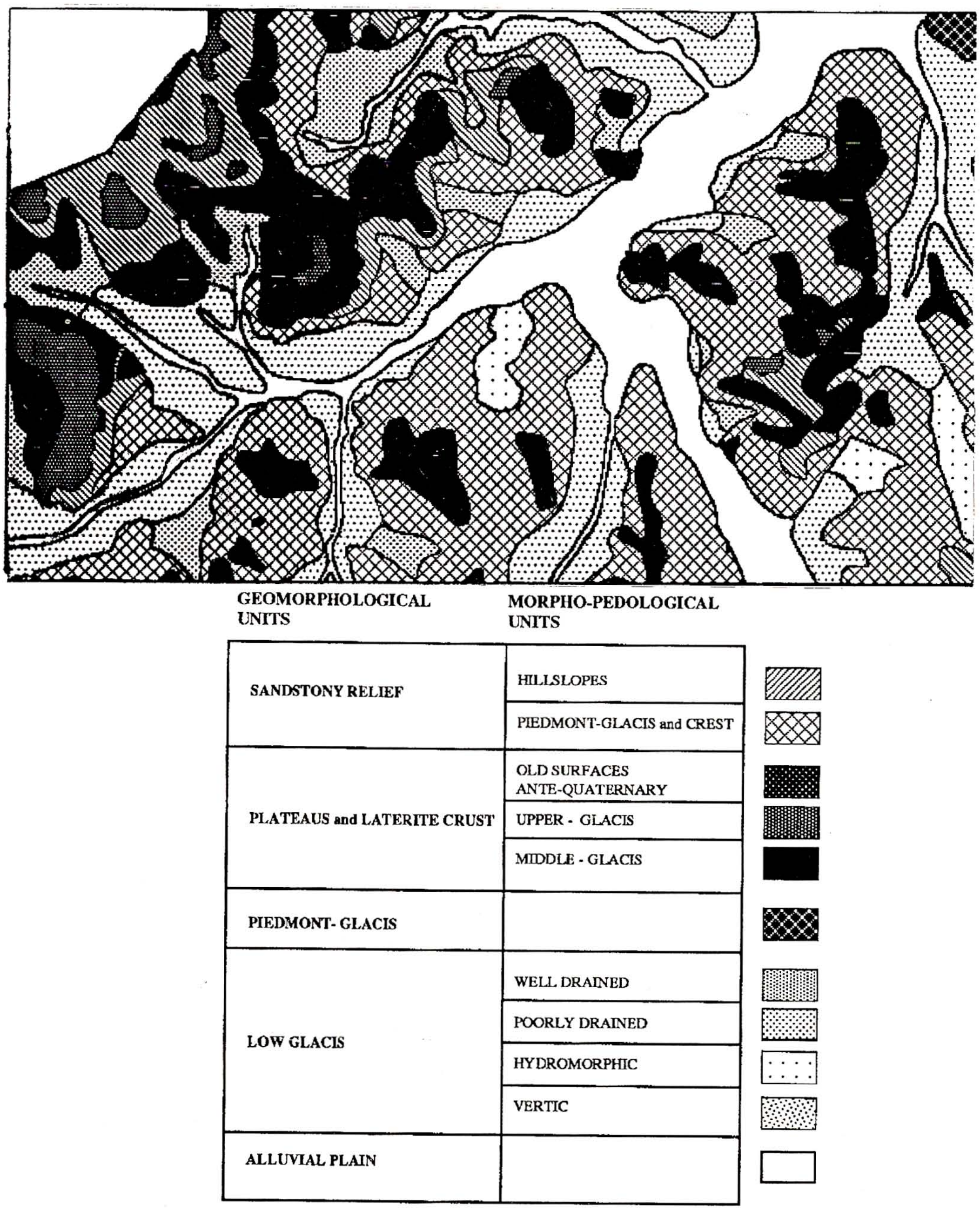


Fig. 10b - Detail of the morphopedologic map of Guillobez (1979).

Comparison between the two maps shows a good resemblance. Research based on break of slope and geological maps is in progress to improve limits of those morphologic units.

However, with this preliminary result one can imagine the potentiality of this kind of map for operational purposes like resource management, land management, control erosion,...

3.4 Agro-hydrological conditions

At this stage of the work we will only present the procedure and the results of treatment concerning the determination of the soil **run-off potential**.

The set up method evaluates the advantage of high resolution satellite information, used simultaneously with other cartographic data within a Geographical Information System, to determine explanation factors used in one of the most widespread methods for run-off potential estimation: the SCS method (US Soil Conservation Service, SCS, 1972).

This American method determines amongst other things the direct flow of waterway spate, by establishing a simple relationship between height of fallen water and flow of sheet of water, designated empirically in the following manner:

$$R = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)}$$

R = Run-off
P = total height of rain considered
S = retention parameter, estimated in function of the hydrological complex soil-plant coverage soil humidity of the considered watershed

Evaluating run-off potential (which is in fact a spate flow potential) leads to considering three parameters: average soil occupation, slopes and types of soils. All of these criteria, usual components of conceptual hydrological models, generally present a spatial variability at the watershed scale. This information is usually obtained from a laborious and expensive compilation of cartographical documents and field data. Remote sensing techniques and the use of geographical information methods allow the representation, management and manipulation of them in a convenient manner.

Land use is determined by supervised treatment algorithms. The map is redefined by estimating the level of plant coverage with the calculation of a normalized vegetation index.
The slopes are derived from the Digital Elevation Model with the method described in point 3.3.
Pedological characteristics are defined by the numerisation of existing soil maps, completed by a pedological prospection carried out in December 1992. Each pedological unit can be translated into the corresponding hydrological soil group following soil classes proposed in the SCS method.

At this stage it is possible to link this data through an indexation macro-matrix (or geographical information system) for a context analysis of essentially spatial information. Then, following a method set up by laboratory of Gembloux, an ordely array of computer functions (RM-Fortran languages on ERDAS) enables the integration and calculate for each pixel the value of CN (Curve Number for the runoff potential) in a watershed knowing the characteristics required in the SCS method (Nonguierma, Dautrebande, 1992).

The result of this approach is a spatial cartography of the soils aptitude to run-off in the studied region (Figure 11). One will notice that zones with a high run-off potential are those with slopy reliefs and those with low plant coverage, such as agricultural land in dry season.

One thus possesses a base document useful to predict exceptional spates following the SCS method, also useful (in conjuction with other data on morphopedology, agricultural structures modes,..) to characterize landfacets aspects which should enhance resource management and improve agricultural yield predictions.

3.5 Perspectives

Some developments are carried out to automatize as much as possible the different building procedures of the different information layers.

A recent mission has been made in Burkina Faso to study the agricultural strategies of the population in order to improve our stratification criterias and to appraise the main evolution factors of agriculture in this region. One important factor appeared during this mission: the importance of cash crops like cotton, in certain zones of the SPOT scene. This crops modifies the traditional strategies of the population. The use of chemical fertilizers set the population free from certain environmental constraints. This information, the importance of cotton, will be taken into account as a new criteria for the landscape stratification. Some research made in Burkina Faso (Lainé and Alii, 1990) shows that it is possible, to a certain extent, to discriminate cotton from cereals in this part of the country.

A further step will be the crossing of these layers into a GIS to build the final frame for the stratification. After that, the result of the crop survey made for campaign 1991 will be used to establish agricultural statistics for the entire scene.

(scale factor : 1: 200.000)

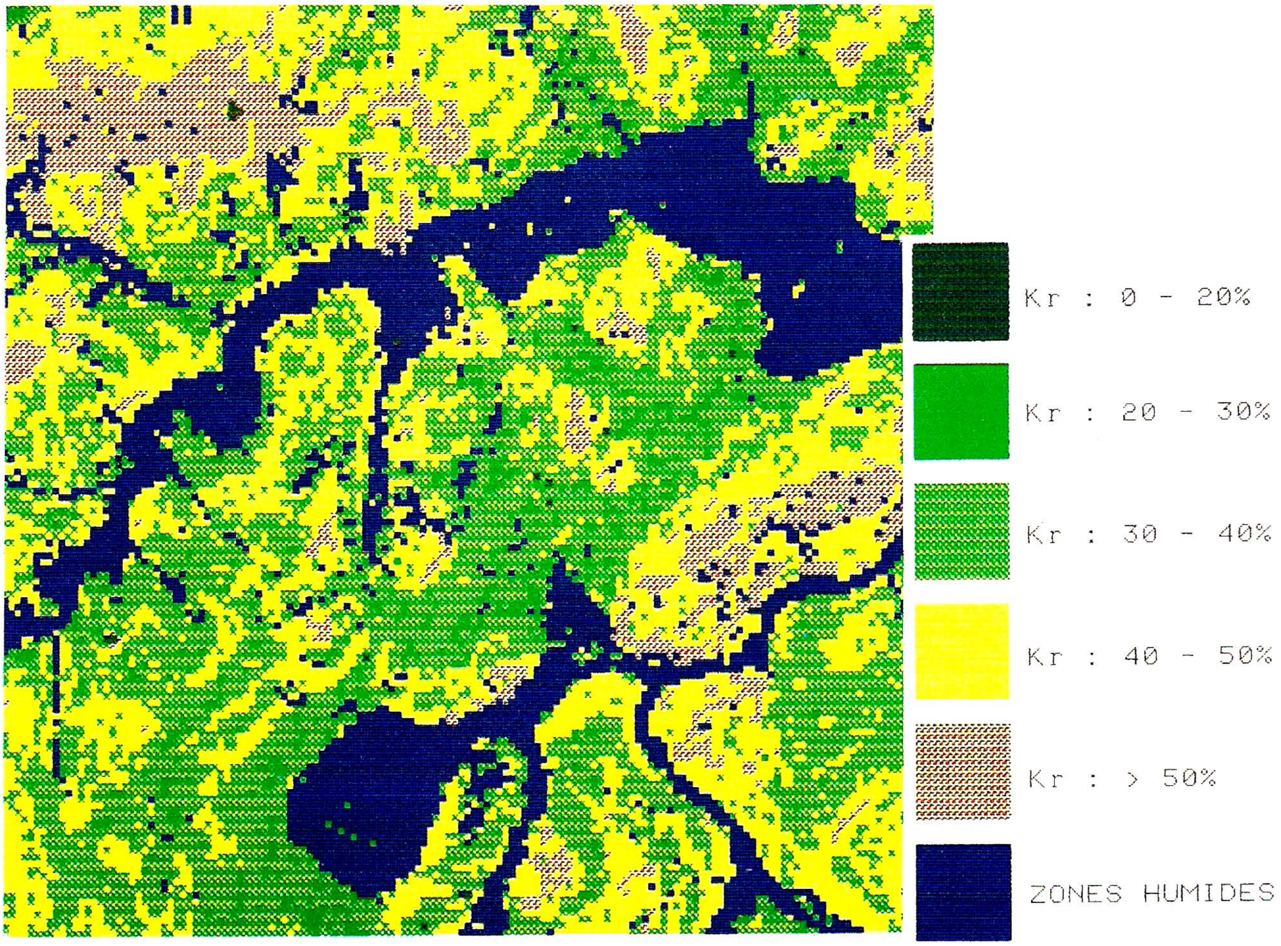


Fig. 11 - Map of run-off potential in a part of the studied zone.

CONCLUSIONS

After a description of the stratification methodology used in this research to improve agricultural statistics, some of the main results are presented.

The main criteria of the landscape stratification already obtained are:

- agro-ecologic zones, at a first level;
- topographic facets, run-off and main management conditions at a second level.

A recent mission in Burkina faso has shown that those criteria correspond in a certain extent to ground truth: Research is in program to improve those results particularly according to the morphologic characterization of the landscape.

A further step will be the crossing and analysis of these information layers incorporated in a GIS.
In the future, a phase of transfer of the methodology is planned after a phase of improving and validation on other SPOT scenes. The nature of information used to build this stratification method, exceeds the purely statistic aspect. Indeed, the different laboratories involved in this research are constantly planing emphasis on developing other uses. Our request is that the data base and the concepts built in this research will be valorized for other purposes in the future.

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