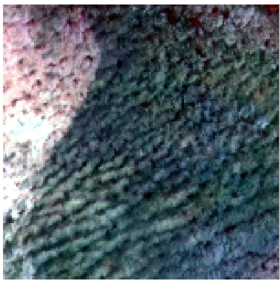
GROUND DATA PROCESSING & PRODUCTION OF THE LEVEL 1 HIGH RESOLUTION MAPS



VALERI 2000

Gourma site
(grassland)

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January 2008

CONTENTS

1. Introduction

Within the framework of the VALERI project, the objective is the production of high resolution, level 1, biophysical variable maps. Level 1 map corresponds to the map derived from the determination of a transfer function between reflectance values of the satellite image acquired during or around the ground campaign, and biophysical variable measurements (LAI-2000 or hemispherical images). The spatial sampling of ground measurements consists in setting the minimum number of Elementary Sampling Units (ESU) at the optimal location to provide robust relationships between LAI and high resolution spatial images. An elementary sampling unit is made of 10 to 15 individual measurements. For information, the sampling protocol is available on the VALERI website: http://www.avignon.inra.fr/valeri/fic_htm/methodology/main.php

As the protocol sampling was in the course of development in 2000 and the Gourma site was homogeneous, the campaign in 2000 (annex or http://www.avignon.inra.fr/valeri) provided an "accurate estimation of 3 parameters characterising the vegetation layer, namely the herbaceous cover fraction (fCover), the herbage mass and the Leaf Area Index (LAI) at the scale of 1 x 1 km cells". The methodology is described in the campaign report (annex or http://www.avignon.inra.fr/valeri). Note that the herbage mass variable is not taken in account in the VALERI project. The biophysical variables estimations derived from LAI-2000 instrument are:

● Leaf Area Index (LAI): LAI corresponds to effective LAI derived from the description of the gap fraction as a function of the view zenith angle;

● cover fraction (fCover): it is the percentage of soil covered by vegetation between 0° and 7° view zenith angle.

The Gourma site is located within the "sahelian zone, in the Malian Gourma. The landscape is characterised by "gently undulating dunes with a sand content of about 90%". The site coordinates are described in Table 1:

	UTM 30, North, WGS-84 (units = meters)		Geographic Lat/Lon WGS-84 (units = degrees)	
	Easting	Northing	Lat.	Lon.
Upper left corner	653654.3890	1696268.3260	15.33844936	-1.56860860
Lower right corner	656674.3890	1693248.3260	15.31097236	-1.54067118
Center	655164.3890	1694758.3260	15.32471123	-1.55463898

Table 1. Description of the site coordinates: they correspond to SPOT image coordinates.

2. Available data

2.1. SPOT Image

The SPOT image was acquired on September 23rd 2000 by HRVIR1 on SPOT4 while the ground measurements were carried out from 27th August to 3rd September 2000. The projection is UTM 30 North, WGS-84. The image was geo-located by SPOT image (SPOT Scene, level 1B). No atmospheric correction was applied to the image. However, as the SPOT image is used to compute empirical relationships between reflectance and biophysical variable, we can assume that the effect of the atmosphere is the same over the whole 3 x 3 km site. Therefore, it will be taken into account everywhere in the same way.

Figure 1 shows the relationship between Red and near infrared (NIR) SPOT channels: the soil line is marked and no saturated point is observed. Note that the SPOT image was unfortunately "acquired three weeks after the measurement campaign that is at the beginning of the dry season when the herbage cover was already senescent".

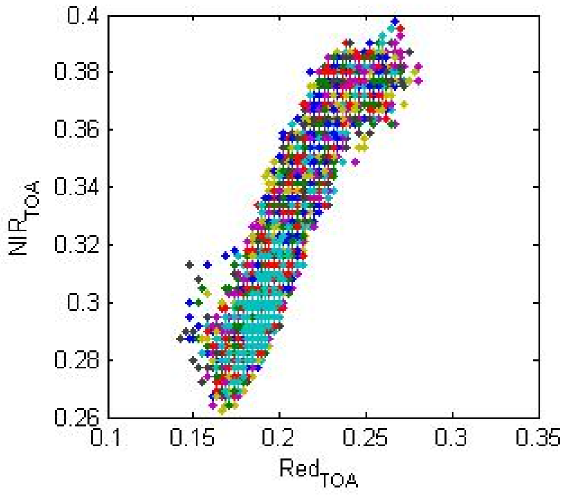

Figure 1. Red/NIR relationship on the SPOT image for Gourma, 2000.

Figure 2 shows that the Gourma site is homogeneous, even if a "burnt area crossing the cells #7 and #8 can be easily identified" (annex or http://www.avignon.inra.fr/valeri).

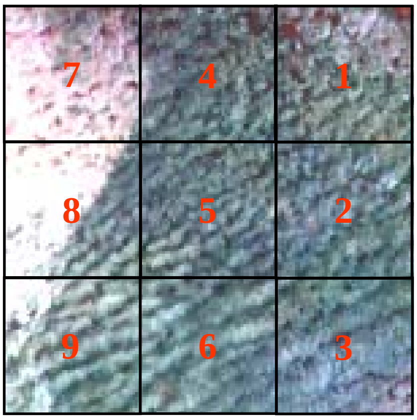

Figure 2. SPOT colour composite image acquired the 23rd September 2000 over the Gourma site (3 x 3 km grid)

Note that NDVI values are also homogeneous over the whole Gourma site:

	min	max	mean	std
NDVI	0.147	0.357	0.220	0.014

2.2. LAI-2000 measurements

For each 1 x 1 km cell, the biophysical variable value was estimated (details in annex or on the VALERI website: http://www.avignon.inra.fr/valeri):

- LAI from herbage mass and Specific Leaf Area (SLA) measurements;
- fCover from LAI-2000 instrument and visual estimation.

As the biophysical variables are generally estimated from LAI-2000 instrument or the hemispherical images within the framework of the VALERI project, the values estimated from LAI-2000 instrument were used. However, note, that LAI and fCover values seems slightly overestimated as compared with values estimated from others methods (annex or http://www.avignon.inra.fr/valeri).

The LAI and fCover data are described in Table 2:

Cell (see figure 2)	Easting (m) UTM 30 North, WGS-84	Northing (m) UTM 30 North, WGS-84	LAI LAI-2000 (m^2/m^2)	fCover LAI-2000 (%)
1	656011	1695593	0.84	27.7
2	656019	1694486	0.84	27.2
3	656025	1693579	0.81	26.2
4	655002	1695586	0.84	27.8
5	655009	1694590	0.68	22.7
6	655015	1693572	0.58	20.1
7	654022	1695579	0.41	14.3
8	654021	1694583	0.68	23.0
9	654028	1693566	0.73	23.8
		mean	*0.71*	*23.6*
		std	*0.14*	*4.1*

Table 2. Mean and standard deviation (std) values of the vegetation parameters for the 9 considered 1 x 1 km² cells.

LAI varies from 0.41 to 0.84 and fCover from 14.3% (0.143) to 27.8% (0.278). As the site is homogeneous in terms of LAI and NDVI, the average value of the biophysical variables seems representative. Therefore, even if the production of high resolution, level 1, biophysical variable maps is not possible because of the sampling protocol, the average of biophysical variable values at the scale of the Gourma site is proposed.

Following, the results over the whole Gourma site:

	LAI	fCover
Gourma site, 2000	0.71	0.236

Table 3. Average LAI and fCover values applied to the whole site for the two biophysical variables

3. Conclusion

The protocol sampling applied in 2000 was not allowing to produce high resolution, level 1, biophysical variable maps. However, the Gourma site is relatively homogeneous in terms of LAI (§2.2) and NDVI (§2.1). Moreover, the methods used to estimate the biophysical variable values (LAI and fCover) at the scale of 1 x 1 km cells are consistent (annex or http://www.avignon.inra.fr/valeri). Therefore, the average biophysical variable values seem representative over the whole Gourma site. For more information, please read the campaign report which is very detailed. The SPOT image (projection: UTM 30 North, WGS-84) is available on the website: http://www.avignon.inra.fr/valeri

4. Acknowledgements

We thank **Éric Mougin, Lionel Jarlan, Camille Lelong, Georges Marty** (CESBIO), **Pierre Hiernaux** (ILRI) and the **people from Mali** which have participated to this campaign.

ANNEX

VALERI-2000 CAMPAIGN IN GOURMA (MALI)

Participants:

Mougin Eric, Jarlan Lionel, Lelong Camille, Marty Georges (CESBIO)

Hiernaux Pierre (ILRI)

August 27 – September 3, 2000

VALERI-2000 CAMPAIGN IN GOURMA (MALI)

The VALERI-2000 campaign took place in the Gourma region in Mali from August 27 to September 3. This date was chosen to fit with the middle of the rainy season when the herbage cover is supposed to be at its maximum of greenness. Four people from CESBIO, one from the International Livestock Research Institute (Niamey) and three people from Mali have participated to this campaign. The overall objective was to provide an accurate estimation of 3 important parameters characterising the vegetation layer, namely the herbaceous cover fraction, the herbage mass and the Leaf Area Index (*LAI*) at the scale of 1 km x 1 km cells.

Description of the test site

The test site is located within the sahelian zone, in the Malian Gourma (Figure 1, see also Annex 1). The site corresponds to a 3 km x 3 km square whose the central co-ordinates is 15°19'23" N – 1°33'22" W. In this area, the landscape is characterised by gently undulating dunes with a sand content of about 90%.

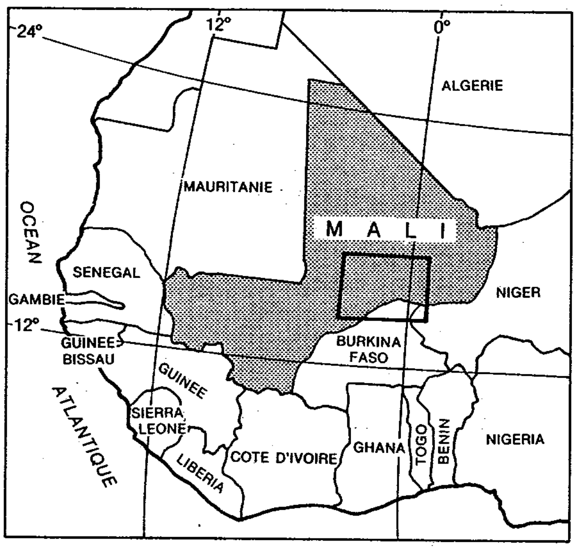

Figure 1: Localisation of the Gourma (Mali)

Within the test-site, the vegetation is usually sparse and principally composed of annual herbaceous species whose growth is mainly determined by the soil moisture regime which depends on the pattern of rainfall and on site geomorphology. Vegetation development starts after the first rains, in June or July, and unless the annual plants wilt before maturity by lack of rain, the senescence follows the fructification which matches with the end of the rainy season in September. The peak of the rainy season occurs in August. During the long dry season, there is no green vegetation apart from a few trees and shrubs.

Over the period 1984-1999, the mean annual rainfall is about 290 mm but is characterised by a strong interannual variation (Figure 2). The 1984 and 1999 years were the driest and the wettest seasons with a total amount of 95 mm and 582 mm, respectively. The 2000 rain season can be considered as an average year with a total amount of 292 mm.

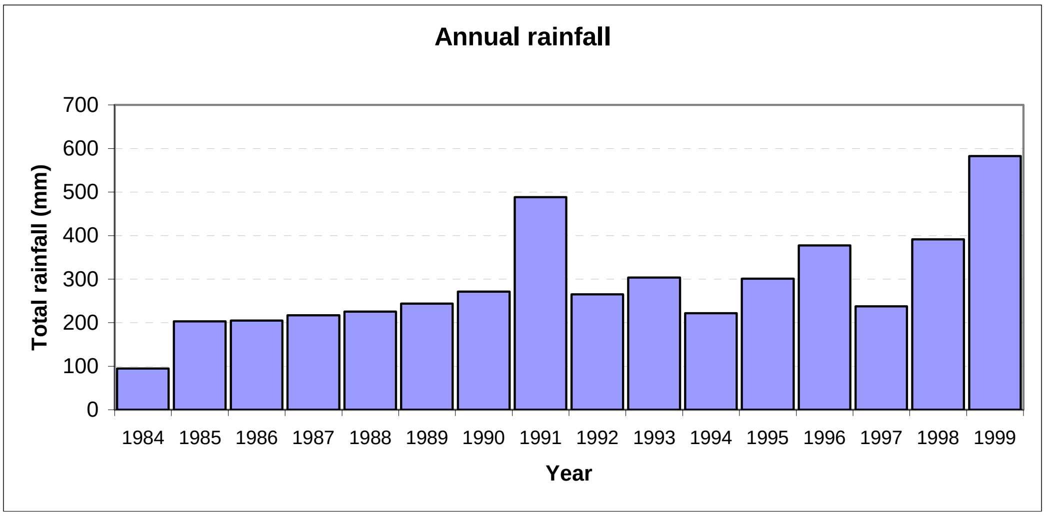

Figure 2: Interannual variation of the annual rainfall for the period 1984-1999. The data were acquired by the meteorological station of Hombori, located at a few kilometres from the VALERI site.

Similarly, changes in vegetation production accompany closely the interannual variation in rainfall. Over the period 1984-1999, the average herbaceous aboveground production, estimated by a measure at the end of the growing season, is about 99.4 kg of dry matter per square meter (g DM m^{-2}) with a coefficient of variation of about 44%. The corresponding maximum herbaceous cover fraction is about 11%. The herb layer is dominated by annual grasses (80% of the herb cover) with species such as *Aristida mutabilis*, *Cenchrus biflorus*, *Dactylotenium aegyptiaca*, *Tragus berteronianus* and *Schoenfeldia gracilis*. Besides, the average cover fraction of the woody plants canopy is smaller than 3%. Main tree species are *Leptadenia pyrotechnica*, *Acacia raddiana* and *Combretum glutinosum*.

Methodology

The land surfaces of the Gourma consists of a mosaic of facets, each one characterised by distinctive combinations of landforms and soil types (*Diallo et al., 1999*). The soil type and the supply of moisture (mostly by rainfall) determine the edaphic conditions which are of crucial importance for plant growth. The selected VALERI test site is representative of vegetation formations on sandy soils which cover more than 50% of the whole Sahel.

The VALERI site is covered by a sparse herbaceous cover whose spatial distribution may greatly vary between two successive years. Accordingly, an *a priori* classification of the area into homogeneous and distinct classes is not feasible before the beginning of the field campaign. Giving these limitations, we have adopted the following strategy:

a) Firstly, we used a SPOT image in combination with a morpho-pedology map of the whole area to delineate the main soil types and landforms. We then selected the 3x3 grid within a homogeneous zone exclusively located on sandy soils (see Annex 2).

b) Secondly, we defined a 3 km x 3 km grid which was georeferenced and superimposed onto the SPOT image in the Geographical Information System 'ArcView'. Each of the 9 cells of 1 km square was then georeferenced and labelled as shown below (Figure 3 and Annex 3).

7	4	1
8	5	2
9	6	3

Figure 3: Geometry of the 3 km x 3 km grid.

c) In each cell, we defined a sampling line of 1 km long and oriented along the North-South direction. In the field, the 9 sampling lines were positioned with the help of a GPS. The corresponding co-ordinates in Lat/Lon are given in Annex 4. Observations and measurements were performed along the 9 sampling lines during the VALERI campaign.

d) Finally, we assumed the sampling line to be representative of the corresponding cell and we attributed the estimated mean and variance values to this cell.

Sampling strategy

Only the characteristics of the herb layer were measured during the 2000 campaign. Along the sampling line, the following parameters were estimated using a two level stratified random technique (*Hiernaux, 1992*):

- Above-ground herbage mass, *Bm* (g DM m^{-2})
- Vegetation cover fraction, f_{cover} (%)
- Leaf Area Index, *LAI* (m^2 m^{-2})

The stratification of the site includes the following steps: a) Major differences in vegetation induced by terrain features were identified as facies sampled individually. b) Within each facies, four strata were systematically distinguished every meter on the basis of the apparent density of the herbaceous layer that is bare soil, and relatively low, medium and high density.

For each considered parameter, measurements were performed within 12 quadrats of 1 m x 1 m that were randomly positioned along the sampling line in order to get 3, 6 and 3 samples in the low, medium and high density stratum, respectively. In each quadrat, the floristic composition is noted, the vegetation cover fraction is visually estimated and the aboveground herbage mass is weighted after total clearance cutting and drying. Prior to the harvest of the herbage layer, measurements were acquired with the LAI2000 instrument (Li-Cor, 1992).

Along a sampling line, the mean value of a given parameter calculated for a given stratum is then weighted by the relative importance of the 4 strata and facies identified along the sampling line to get the estimated mean X :

$$X = \sum_{i}^{n} (p_i \, . \, x_i)$$

Where p_i, x_i and n denotes the relative frequency of the stratum i, the mean value of the parameter measured for the stratum i and the total number of strata ($n = 4$).

The associated variance is calculated as (*Cook and Stubbendieck, 1987*) :

$$Var(X) = \sum_{i}^{n} [\ p_i \,.\, (s_i^2 / n_i)\ ] \ + \ 1/\ [\ \sum_{i}^{n} P_i\ ].[\ \sum_{i}^{n} (p_i \,.\, x_i^2) - x^2\ ]$$

Where s_i^2, n_i and P_i are the variance of the considered parameter, the number of samples in the stratum *i* and the absolute frequency of the stratum *i*, respectively.

Ancillary measurements consist of the determination of the Leaf Angular Distribution (*LAD*) and the Specific Leaf Area (*SLA*) for the dominant herbaceous species.

Results

1) Stratification

Figure 4 illustrates the measurements recorded along the lines #1 and #7. The stratification is performed every meter and reported here every 10 meters. The line 7 crosses the burnt surface which is well identified on the SPOT image acquired on September 23, 2000 (see Annexes 2 and 3). For these two particular contrasted lines, the cover fraction for the bare soil and the low, medium and high density herbaceous layer is about 0.5%, 18%, 68% and 13.5% for the line #1 and about 30%, 42.5%, 25% and 2.5% for the line #7, respectively. The final results of the stratification are given in Figure 5. The largest bare soil covers are found for lines #7 and #8 which cross the burnt area. Unfortunately, the SPOT image was only acquired three weeks after the field campaign that is at the beginning of the dry season when the herbage cover was already senescent. Accordingly, the spatialisation of the stratification measurements at a larger scale than the 1-km sampling line could not be achieved.

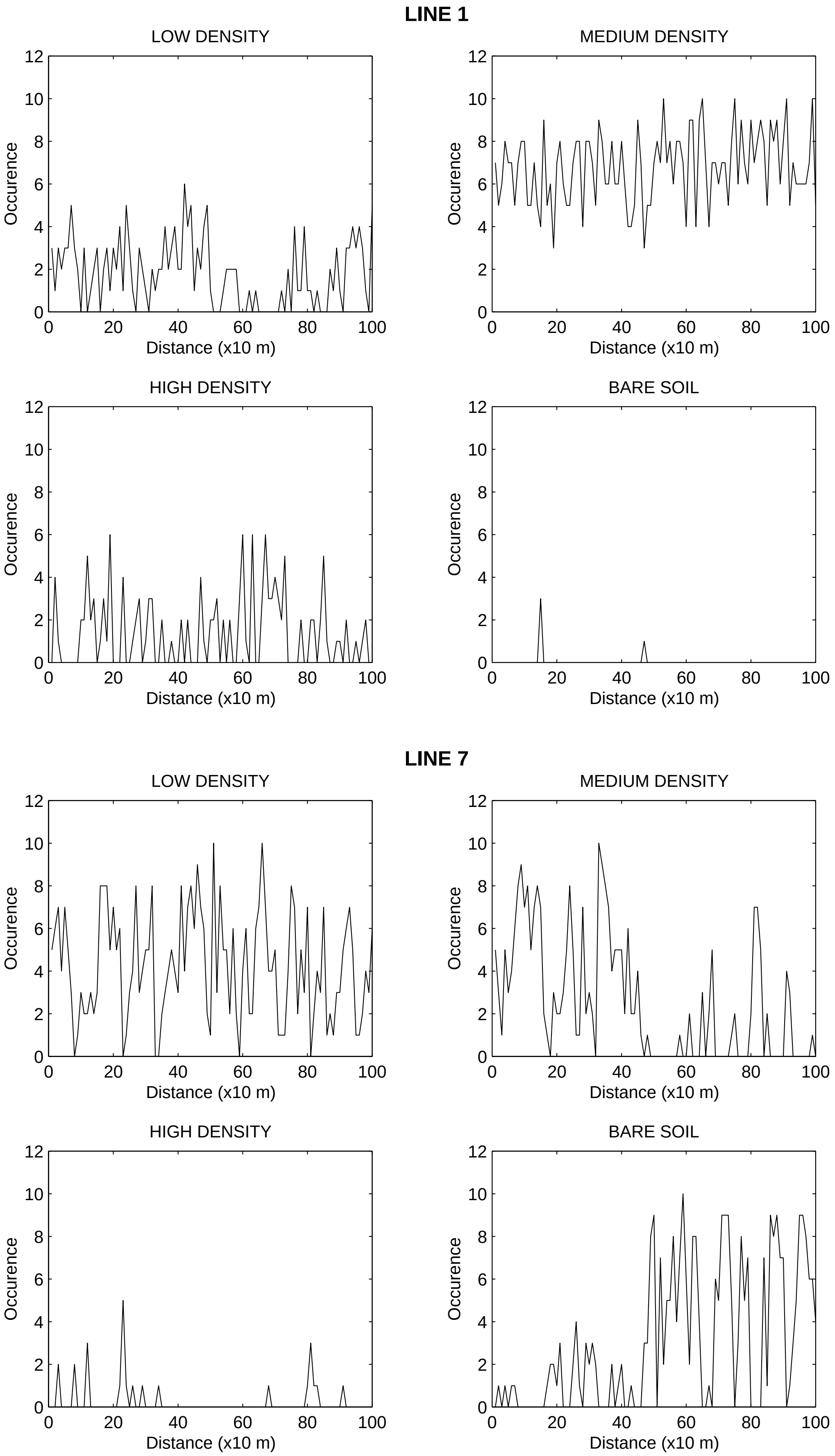

Figure 4: Stratification measurements along the sampling lines #1 and #7.

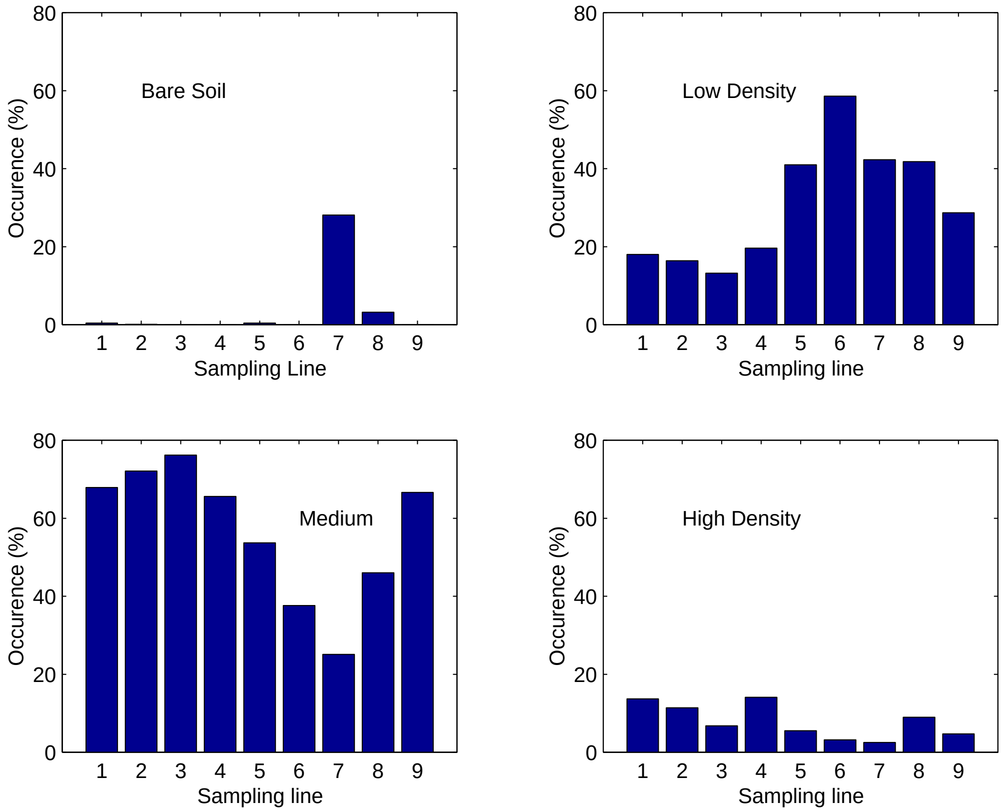

Figure 5: Results of the stratification for the 9 sampling lines.

2) Vegetation Cover Fraction f_{cover}

The LAI2000 instrument measures the fraction of diffuse incident radiation that passes through the herb layer for a given zenith angle (θ_v). The transmittance or gap fraction $T(\theta_v)$ is defined as the ratio between the below-canopy and the above-canopy measurement. Measurements are acquired in five zenith angles, centred at about 7°, 22°, 37°, 53° and 68°.

For a given quadrat, the vegetation cover fraction f_{cover} can be derived from the measurements of the gap fraction $T(7°)$.The vegetation cover fraction f_{cover} can be simply written as:

$$f_{cover} = 1 - T(7°)$$

Figure 6 shows the comparison between the LAI2000-derived f_{cover} values and those obtained through a visual estimation. Overall, there is a large discrepancy between the two estimations at the quadrat scale whereas there is a good correlation between the two data set at the sampling line scale. However, LAI2000-derived f_{cover} values are systematically overestimated (at least by a factor 2).

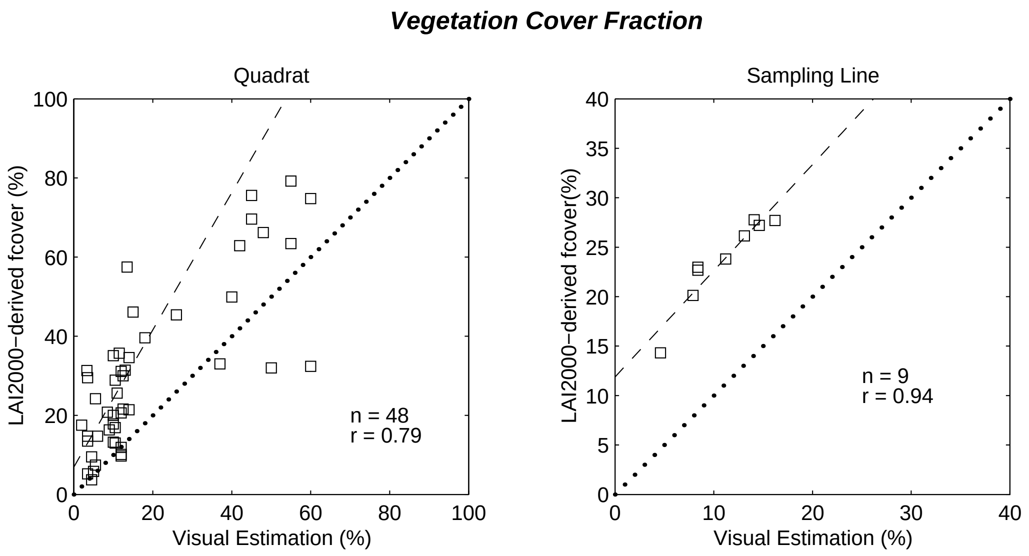

Figure 6: Comparison between the visual and the LAI2000 derived estimation of the vegetation cover fraction at the quadrat and at the sampling line scale, respectively.

3) Leaf Area Index

Two methods were carried out aimed at estimating the *LAI* within each quadrat: a) the *LAI* was estimated from herbage mass and Specific Leaf Area (*SLA*) measurements, b) the *LAI* was estimated using the LAI2000 instrument. The resulting mean values for the 3 strata were then weighted by the respective cover fraction of each stratum to obtain the estimated *LAI* along a given sampling line.

3a) Estimation of the LAI using herbage mass and SLA measurements: LAI-SLA

The *LAI* is simply calculated as :

$$LAI\text{-}SLA\ (m^2\ m^{-2}) = Bm\ (g\ DM\ m^{-2})\ .\ SLA\ (m^2\ g^{-1}\ DM)$$

The Specific Leaf Area, *SLA,* is estimated for the dominant herb and grass species using a digital camera for the determination of the foliar surfaces.

3b) Estimation of LAI with the LAI2000: LAI-2000

We performed LAI2000 measurements along the sampling lines 1, 2, 3 and 4. In each quadrat, five records were made one at the centre and 4 along the diagonals. Two reference records were acquired just prior and after the 5 measurements. The LAI2000 lens was partly screened with the 180° mask. However, due to the high solar elevation, measurements were only feasible before 11:00 a.m. and after 3:00 p.m.

From the transmittance measurements, the LAI2000 instrument provides an estimation of the *LAI* and the Average Leaf Angle (*ALA*). These computed *LAI* and Average Leaf Angle (*ALA*) values were compared to the results obtained by using two other estimation methods that were implemented by Marie Weiss (INRA Bioclimatologie, Avignon). The latter were based on the inversion of the relationship between the monodirectional gap fraction $T(\theta_v)$, the *LAI* and the ellipsoidal leaf inclination angle distribution $\xi(\theta_l, \theta_v)$:

$$T(\theta_v) = exp(-LAI \,.\, \xi(\theta_l, \theta_v))$$

The minimisation of the error between the measured gap fraction and the computed one was performed using either the simplex optimisation method (Nelder and Mead, 1965) or a Look Up Table (LUT) approach. *LAI* and *ALA* values computed by the LAI2000 software were used as a priori values.

Figure 7 gives the comparison between the different calculations. For the Leaf Area Index, the three inversion methods provide similar results although two unexpected high values are found using the simplex algorithm. As well, LAI2000 calculations are in concordance with the two other methods when the Average Leaf Angle is considered. Mean *ALA* values are about 62°, 62° and 65° for the LAI2000, the LUT and the Simplex method, respectively. Furthermore, these values are close to the measured *ALA* in the field (~60°). Accordingly, only the LAI2000 computation was used.

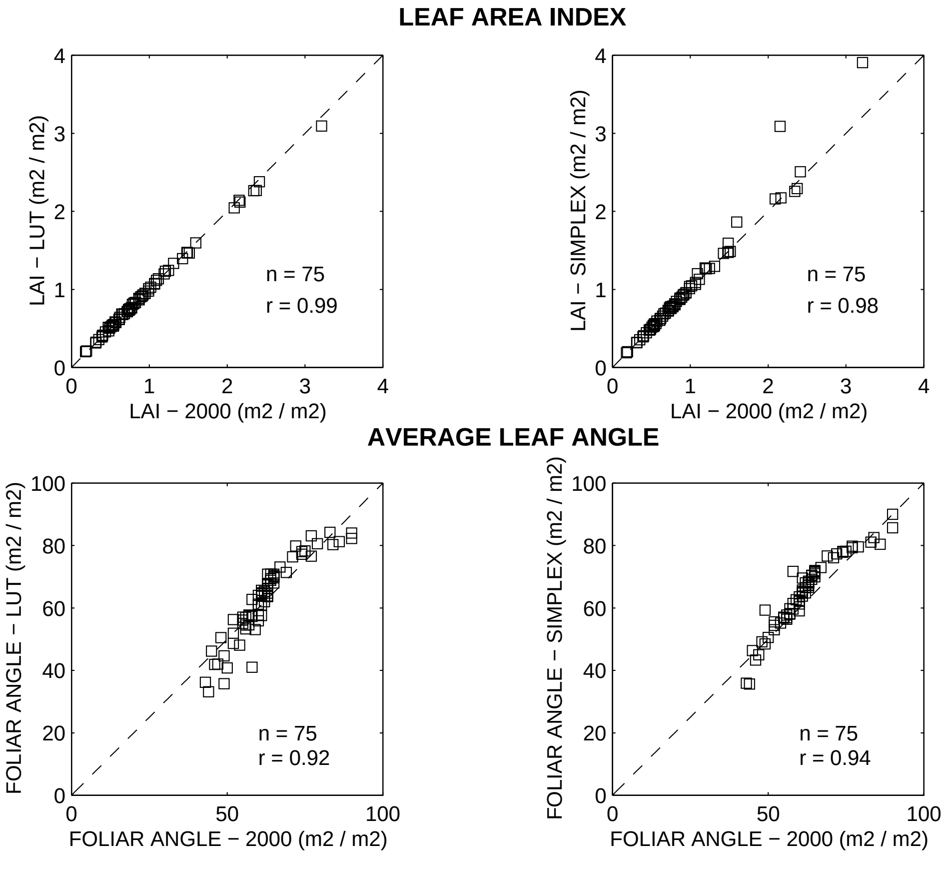

Figure 7: Comparison between the different approaches to derive *LAI* and *ALA* estimations from LAI2000 measurements.

3c) Comparison between LAI-2000 and LAI-SLA measurements.

The *LAI* values derived from herbage mass and *SLA* measurements were taken as reference values and compared to the LAI2000 estimations. This comparison includes measurements made along the sampling lines #1 to #4 (n=48) as well as additional measurements made outside the lines (n = 29).

Results show a good agreement between the two methods (Figure 8) However, the LAI2000 values are generally overestimated when compared to those derived from mass and *SLA* measurements. The overestimation ranges between 30 and 40%. In addition to the uncertainties related to the determination of the Specific Leaf Areas, two main sources of errors can be identified in the use of the LAI2000 data: a) the presence of a tree layer, b) the presence of senescent leaves within the herbage layer. These two possible sources of contamination have the same effect leading to an overestimation of the calculated *LAI*. Despite its low cover fraction, the tree layer certainly affects the measurements made with the LAI2000 instrument. For instance, values above 2.0 were systematically recorded in the vicinity of a tree (Figure 9). However, the removal of the highest values only slightly reduces the overestimation at the scale of a sampling line. Accordingly, no correction was applied and the *LAI-2000* values must therefore be considered as the sum of the herbage and the tree layers (by neglecting the effect of the senescent leaves). Other possible sources of errors may originate either from mis-manipulations by the operator (for instance, when the leaves are too close from the sensor) or from bad sky conditions (high solar elevation).

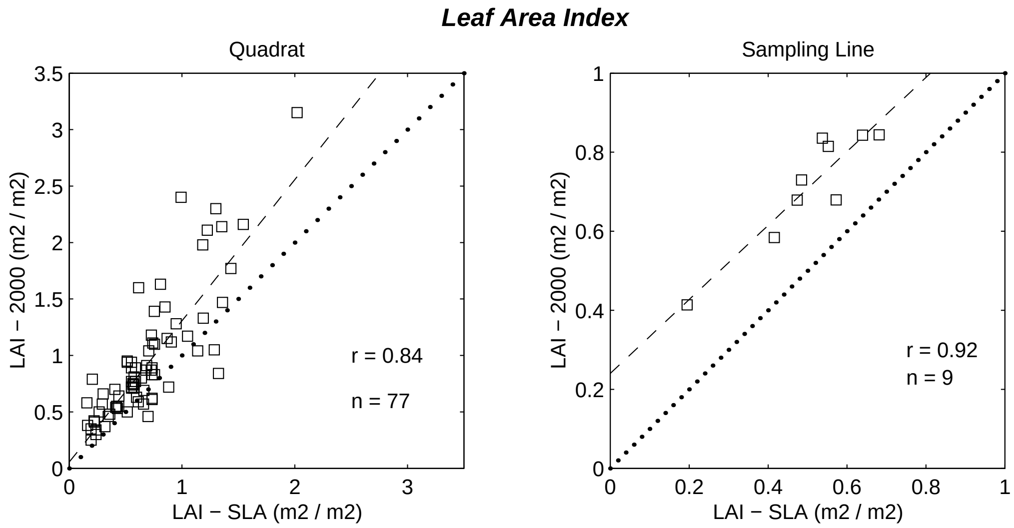

Figure 8: Comparison between *LAI –2000* and *LAI-SLA* estimations at the quadrat and at the sampling line scale, respectively.

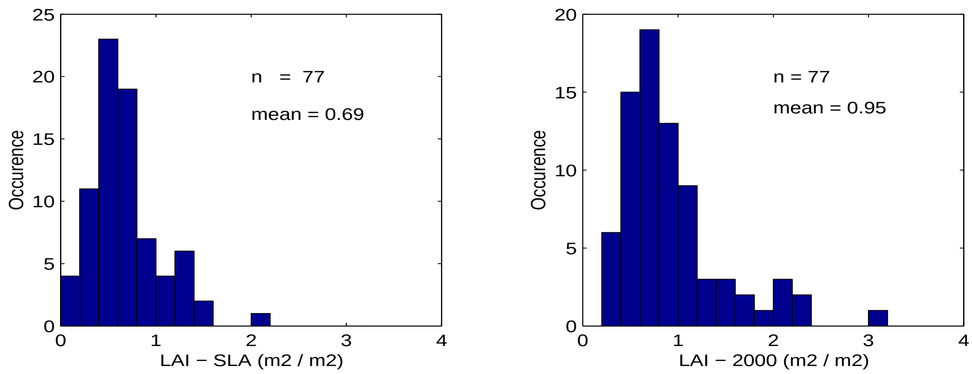

Figure 9: Distribution of *LAI* values estimated with the LAI2000 and the *SLA* measurements.

Synthesis

Table I gives a synthesis of the 3 main vegetation parameters that were estimated at the scale of a 1-km long sampling line (and therefore at the scale of a 1km x 1 km cell).

Cell #	Herbage Mass (g DM / m^2)	f_{cover} -visual (%)	f_{cover} - 2000 (%)	LAI-SLA (m² / m²)	LAI-2000 (m² / m²)
1	92.7 (3.8)	16.2 (1.1)	27.7	0.68 (0.07)	0.84 (0.22)
2	79.4 (4.0)	14.6 (1.0)	27.2	0.54 (0.06)	0.84 (0.24)
3	76.9 (4.7)	13.1 (0.8)	26.2	0.55 (0.07)	0.81 (0.16)
4	94.1 (4.6)	14.1 (1.3)	27.8	0.64 (0.07)	0.84 (0.13)
5	83.7 (4.0)	8.4 (0.5)	22.7	0.57 (0.06)	0.68
6	61.7 (2.7)	7.9 (0.6)	20.1	0.42 (0.05)	0.58
7	28.9 (1.5)	4.6 (0.4)	14.3	0.20 (0.02)	0.41
8	68.9 (3.6)	8.4 (0.5)	23.0	0.47 (0.05)	0.68
9	71.9 (3.5)	11.2 (0.6)	23.8	0.48 (0.05)	0.73
Mean	**72.8**	**10.7**	**23.6**	**0.50**	**0.71**

Table I: Estimated mean and standard deviation values of the vegetation parameters for the 9 considered 1x1 km² cells.

Conclusion

The VALERI-2000 campaign aimed to test a methodology for the determination of 3 important herbaceous parameters at the scale of 1 x 1 km^2 scale. For a sparse vegetation like in the Sahel, results have shown that an accurate estimation of the different parameters could be achieved using a two level stratified random technique. It was also shown that the *LAI* values derived from the LAI2000 instrument were consistent with the estimations based on mass and *SLA* measurements. However, LAI2000-derived *LAI* and f_{cover} were found to be overestimated. On this specific test site, this cannot be only attributed to the presence of the sparse tree layer even if its contribution cannot be obviously neglected. The presence of senescent leaves as well as mis-manipulations are possible sources of errors. These points should be checked during the VALERI-2001 campaign.

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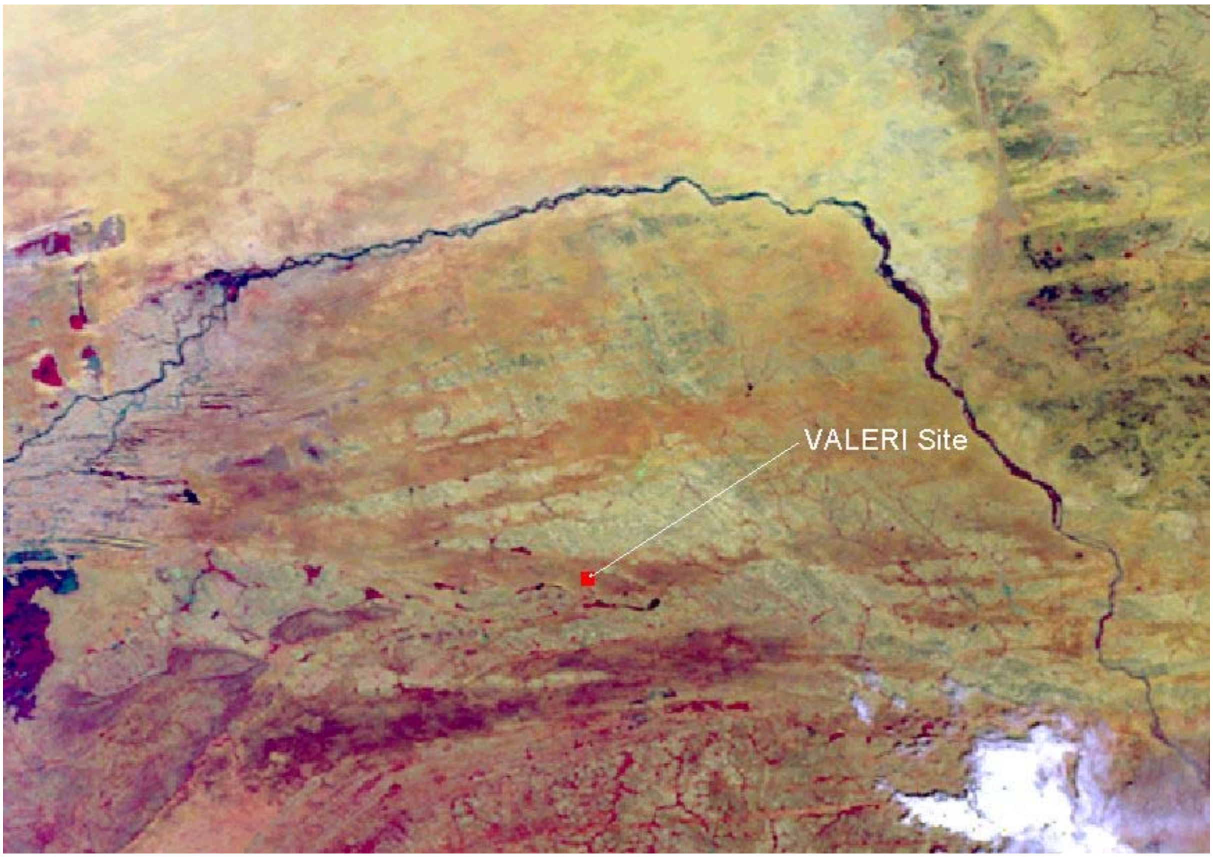
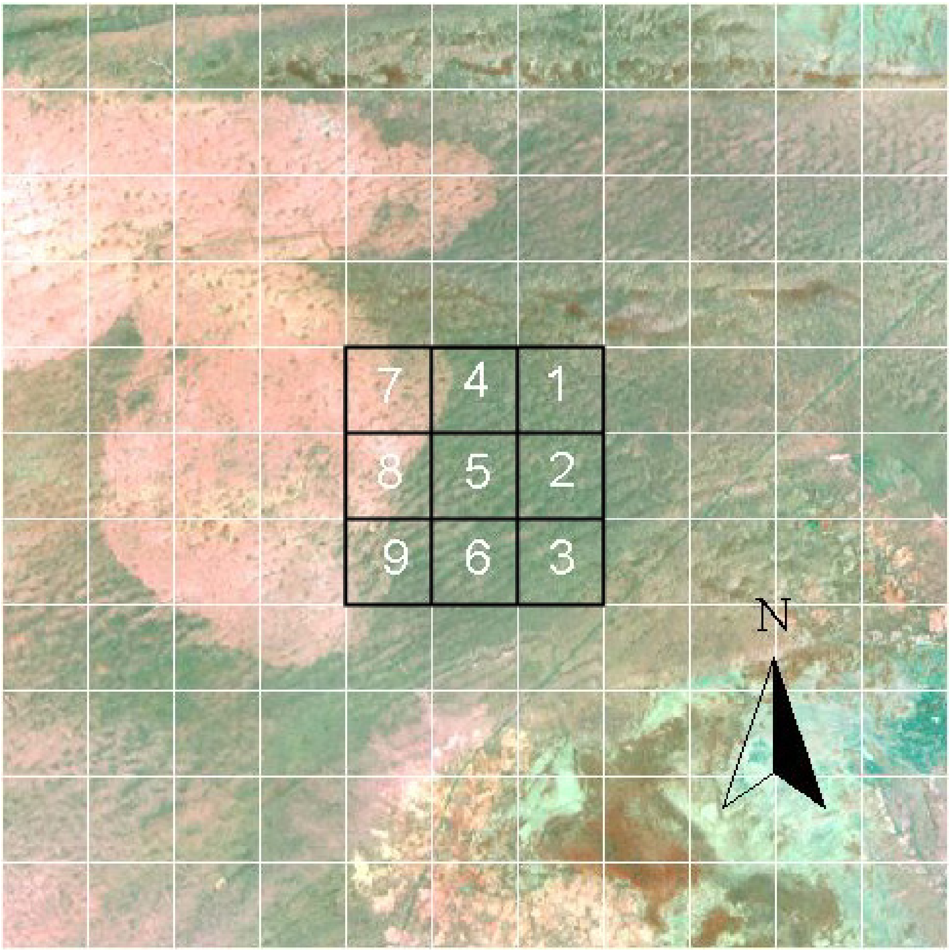
Annex 1 :

VEGETATION Colour Composite Image of the Gourma region (Mali) showing the location of the VALERI test site. The Gourma region is delimited to the West, North and East by the *Niger* river. Image acquired on October 11, 1999. The size of the image is approximatively 450 km x 380 km.



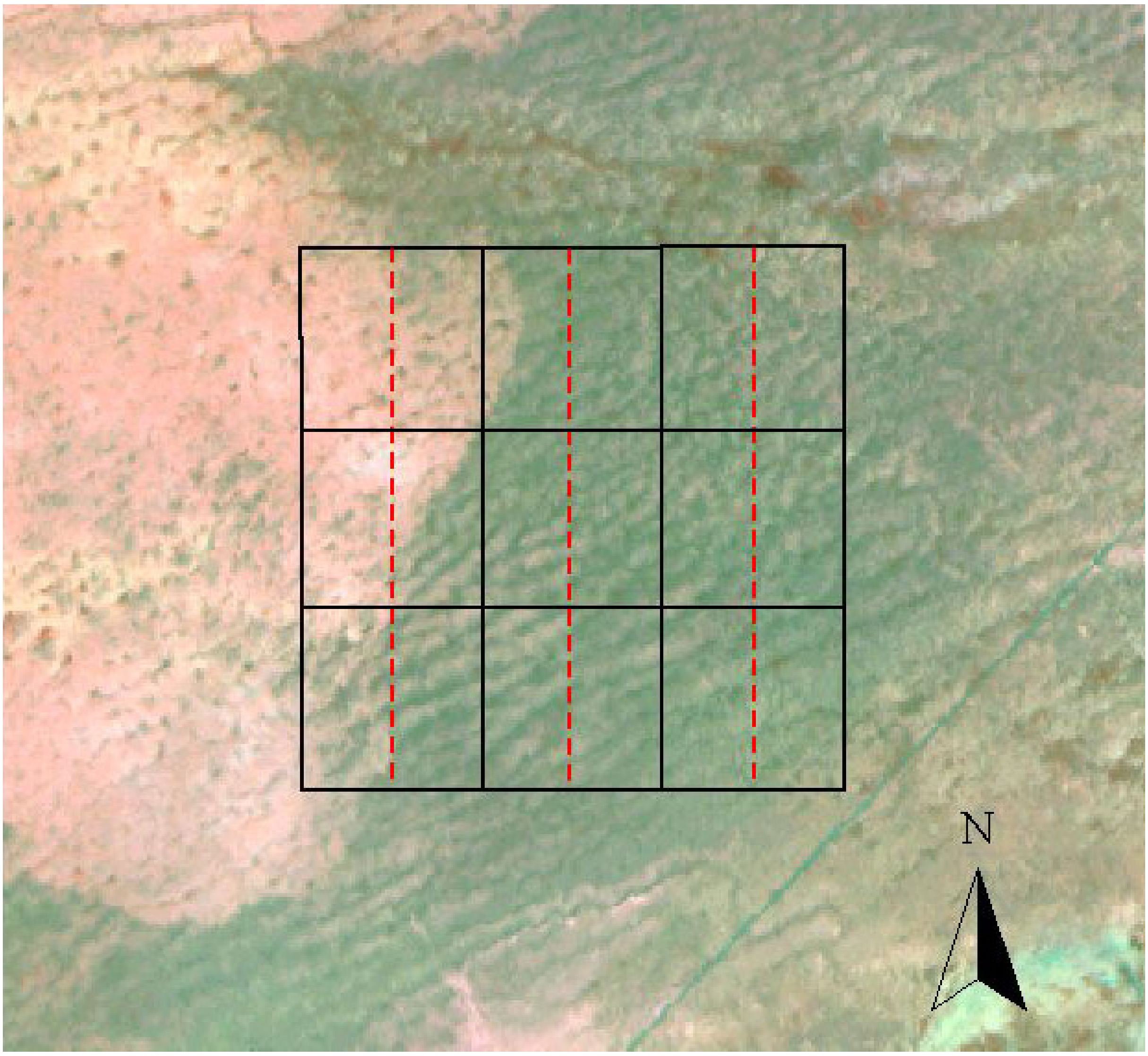
Annex 2:

SPOT Colour Composite Image acquired on September 23, 2000 over the Gourma site (Mali). The VALERI 3 km x 3 km grid is also indicated. A burnt area crossing the cells #7 and #8 can be easily identified.



Annex 3:

SPOT Colour Composite Image acquired on September 23, 2000 over the VALERI test site showing the 9 sampling lines (---).



Annex 4

Co-ordinates of the sampling lines.

Line Number	Latitude (N)	Longitude (W)
1	15°20'12" - 15°19'40"	1°32'48"
2	15°19'40" - 15°19'07"	1°32'48"
3	15°19'07" - 15°18'34"	1°32'48"
4	15°20'12" - 15°19'40"	1°33'22"
5	15°19'40" - 15°19'07"	1°33'22"
6	15°19'07" - 15°18'34"	1°33'22"
7	15°20'12" - 15°19'40"	1°33'55"
8	15°19'40" - 15°19'07"	1°33'55"
9	15°19'07" - 15°18'34"	1°33'55"