Département amélioration
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UGANDA
Coffee Wilt Disease and Remote Sensing Project

FIELD ENQUIRY AND AIRBORNE DATA ACQUISITION CAMPAIGN REPORT

15 january – 8 february 2002

Camille LELONG
Mars 2002
CIRAD-AMIS N° 20
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Summary

Four weeks of field work have been performed, allowing to collect a data base in support of the remote sensing mapping of the coffee wilt disease in three sites in Uganda. These sites are coffee growing areas of about 15 x 10 km in dimensions, located respectively near Mukono, Kiganda (Mubende district), and Kyenjojo. This set of data includes ground truth information records on crops and landscape, and on coffee trees architecture and sanitary status, leaf area index and crops spectral properties measurements. The work was focused on the Mukono site, selected as the training site for remote sensing tools development. For this area, a large amount of records in a large range of variability have been managed, a little less for the two others. At the same time, Borstad and Associates attempted several flybys over the sites in order to acquire CASI hyperspectral images. Due to bad weather conditions, only Kiganda and Mukono sites have been shot at the end.

Contents

I. Introduction : main objectives and participants

This campaign aimed at collecting a set of data, as a basis material for remote sensing images analysis of three coffee growing sites in Uganda. These sites had been selected in a former mission and already described in former report (cf. CIRAD document : CP SIC – 1453, January 2002): Mukono, Kiganda, and Kyenjojo. Each field work area of these sites corresponds the high spatial resolution satellite (IKONOS) and high spatial and spectral resolution airborne multispectral images (CASI) that had been ordered as the working material for this study. The corresponding geographic coordinates are given in Table 1.

Table 1 : Geographical coordinates of expected images to be worked on, for the three selected test sites of Mukono, Kiganda, and Kyenjojo.

	MUKONO	KIGANDA (Mubende)	KYENJOJO
CASI scene	32°42'35" – 32°50'15" E 00°26'50" – 00°31'30" N	31°37'00" – 31°45'15" E 00°27'50" – 00°30'30" N	30°34'00" – 30°42'15" E 00°37'00" – 00°39'50" N
IKONOS scene	32°42'30" - 32°50'30" E 00°26'40" – 00°32'40" N	31°37'40" – 31°43'50" E 00°27'00" – 00°32'10" N	None

These field data are expected to be used to establish correlation between ground truth and radiometric data, in order to interpret the remote sensed signal of the vegetation in this context. For instance, they should provide enough information to discriminate between different kinds of crops, at different levels of heterogeneity and at different phenologic and sanitary status. Therefore, an enquiry form was prepared previously to the mission, allowing to resume the relevant characteristics of a given plot as accurately as possible while very quickly. The model of this form is given in Annex 1.

The participants of this campaign were split in two teams :

Team 1:

- Pauline Aluka, plant breeder, CORI, Kituza, Uganda
- Africano Kangire, plant pathologist, CORI, Kituza, Uganda
- Fabrice Pinard, plant pathologist, CIRAD/CABI, Nairobi, Kenya

Team 2:

- Georgina Hakiza, plant pathologist, CORI, Kituza, Uganda
- Camille Lelong, remote sensing specialist, CIRAD, Montpellier, France

Both teams had the mission to take records of the largest number of plots than possible, so that the largest variability of contexts could be sampled. In addition, Team 1 was also dedicated to collect some wilted coffee barks for pathology analyses, while Team 2 had to perform some spectro-radiometric measurements. At last, an "evening team", composed of Camille Lelong and Fabrice Pinard, had the objective of acquiring a set of Leaf Area Index (LAI) measurements at dusk.

During the work in Mukono district, the Coffee Officer of the District Agriculture Office guided the team 2 through the villages, introducing our work, and finding the small path to get in remote places.

II. Ground truth information

An enquiry form (see Annex 1) was prepared previous to the campaign in order to record ground truth information on characteristics that could give support to the remote sensing data analysis. These variables include:

- the location, shape and size of the parcels,
- the type of crops found in them,
- their mixing association, proportion, and level of heterogeneity with other crops,
- coffee trees architecture and cover
- observations on canopy structure and other details like localisation of shading trees
- disease status in the field
- soil colour
- landscape topography and parcel slope

This set of data will be the basis of the understanding of the image organisation, and of its analysis. It will help selecting characteristic spectral signatures of the different crops to allow a good discrimination between parcels containing coffee trees and the others. This will lead to the construction of a mask dedicated to the study of the coffee crops only. Inside these relevant parcels, the ground truth will support the analysis of the image texture and structure combined to the spectral signatures analysis, in order to characterise the different organisations of coffee crops at different levels of heterogeneity and different canopy architectures. The variety of crops on which observations were done is listed in Table 2.

Table 2 : Variety list of crops that were found in the field and for which a form has been filled.

Site Name	Crop sampling	Site Name	Crop sampling	Site Name	Crop sampling
MUKONO	Coffee	KIGANDA	Coffee	KYENJOJO	Coffee
	Banana		Banana		Banana
	Cassava		Cassava		Cassava
	Sweet potato		Sweet potato		Sweet potato
	Tomato		Maize		Tea
	Tea		Yam		Maize
	Mango		Eucalyptus		Yams
	Maize		Weeds		Papyrus
	Sugar cane		Elephant grass		Weeds
	Papyrus		Star grass		Elephant grass
	Eucalyptus		Short grass		Pasture land
	Mulch		Swamp / grass		
	Weeds		Bush		
	Elephant grass		Forest/jungle		
	Short grass		Bare soil		
	Pasture land				
	Bush				
	Jungle				
	Bare soil				

At the end, 225 parcels were visited, with the filling of a form, in Mukono site, 86 parcels in Kiganda site, and 59 parcels in Kyenjojo site. Their location in the respective covered areas are shown as red diamonds (◆) in the figures of Annex 2. For about half of the visited parcels, numerical photographs were taken as a visual support of ground truth data. Especially, this will help remembering what exactly meant some qualitative descriptions. Some examples of parcels providing coffee with different levels of heterogeneity are shown on Figure 1, Figure 2, and Figure 3.

In addition, bark samples of coffee trees showing coffee wilt disease symptoms were collected and documented (location and parcel characteristics records). Their respective location is shown as a blue cross (+) in the figures of the Annex 2. The whole set was split in two in order to lead their analysis separately in CIRAD-Montpellier and in CORI-Kituza.

Figure 1 : Examples of pure coffee crops in Mukono (left) and Kiganda (right) sites.

Figure 2 : Examples of intercropped coffee and banana in Mukono (left) and Kiganda (right) sites.

Figure 3 : Examples heterogeneous mixture of coffee & other crops in Mukono (left) and Kyenjojo (right) sites.

III. Spectro-radiometric measurements

A spectro-radiometer was brought from CIRAD to perform reflectance measurements. It was a UNISPEC-Reflectometer device from PP-Systems, measuring light fluxes in the range 305-1135 nm. The principle, explained on Figure 4, is to measure consecutively the intensity reflected by the surface of interest and then by a white calibrated standard reference sample, and then to derive the surface reflectance as the ratio of these variables multiplied by the reference reflectance. The Figure 5 shows Dr Georgina Hakiza recording spectral measurements in the field with this instrument.

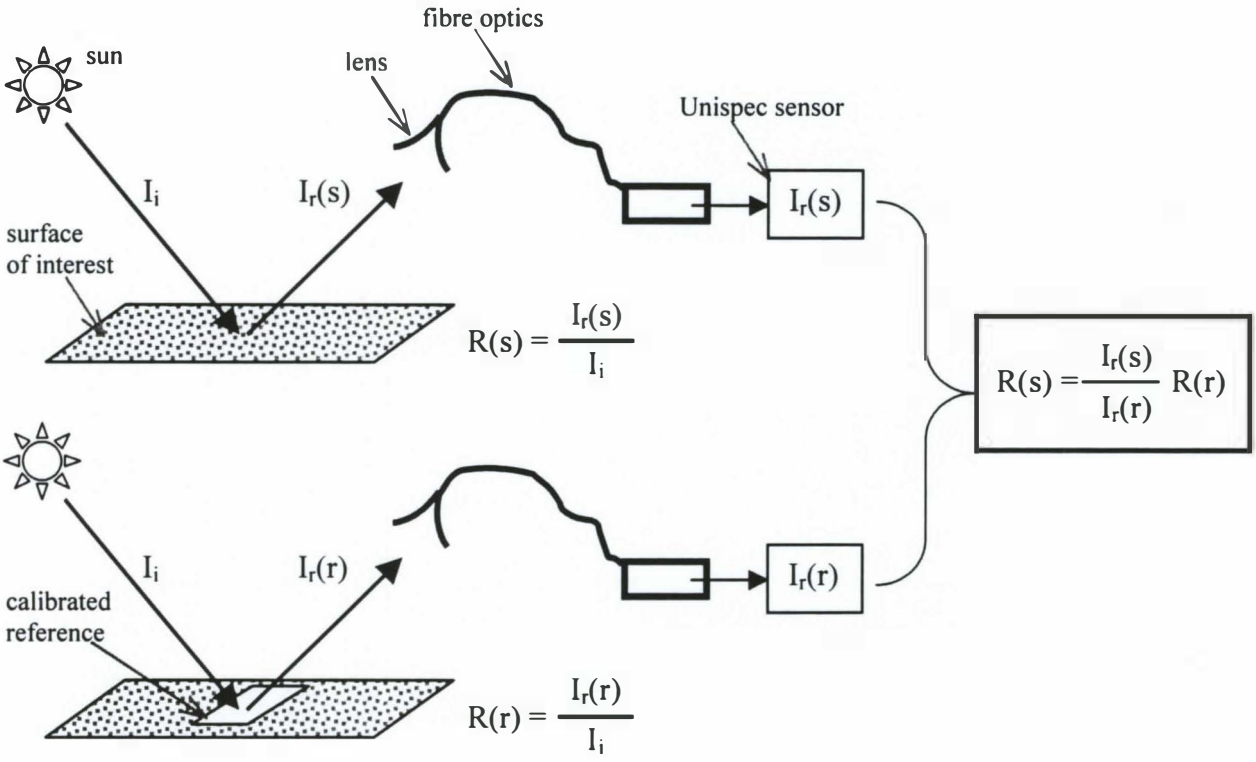


Figure 4 : Principle of reflectance measurement with the Unispec device. *(I_i is the light intensity incident on the surface, $I_r(s)$ and $I_r(r)$ are respectively is the light intensity reflected by the surface of interest and the reference standard, R(s) and R(r) are respectively the reflectance of the surface of interest and of the reference standard)*

III.1. Pseudo-invariant targets for calibration

Raw (or pre-processed with basic corrections, as they are provided by the reseller) satellite and airborne multispectral images only give the value of radiance of the observed surface. In order to transform these data into reflectance, which is the physical measurements that is fully intelligible for interpretation, they have to be calibrated. One calibration method consists in fitting a linear regression between the radiance and the reflectance values of known surfaces used as a reference. This can be done measuring at the ground level, with a spectro-radiometer for instance, the reflectance of some target-areas according to some specifications:

- these targets have to be homogeneous at least at the scale of the image resolution to avoid any mixture effect, and even twice larger to be sure to measure a "pure pixel". This place has to be very precisely located with a GPS to find the corresponding pixel in the image;
- these targets have to be flat to avoid any directional effects;

- they are preferably constituted by soil or any material having a more or less "flat" reflectance spectrum, which means the less absorption features than possible.

These associated characteristics describe what is called "spectrometric pseudo-invariant targets".

A total of sixteen of those targets have been acquired at Mukono site, twelve at Kiganda, and height at Kyenjojo. Their location in the different sites are shwon as green dots (●) in the figures of Annex 2. The corresponding surfaces have been chosen to be at least 8 m in large, without bordering trees or houses shading. They have been selected to provide a good sampling of very dark and very bright colours, in order to cover the larger variability of spectral intensities and thus get the more accurate regression at the extreme behaviours. The reflectance was measured using a fiber-optics and a small lens providing 12° of field of view. At each acquisition the lens was exactly looking at the target and the white reference with same angles, both measurements taken consecutively. The *Table 3* gives their exact location and description an their respective reflectance spectrum measured in the field is plot in Annex 3. The 440-940 nm spectral range only is shown, corresponding to the domain covered by multispectral images.

III.2. Crops leaves

Spectral libraries published as a reference in the literature, or available on the internet, do not provide much information about tropical crops. As we had the opportunity to use a spectro-radiometer in the field during this campaign, we acquired several spectra on different crops, to create a spectral signature data base for use in this project. Many crops have been sampled at different vitality states, using a special leaf clip allowing to measure accurately the optical properties of the leaf itself. This clip allows to use an internal light source though the fibre optics, discarding any contamination by other light sources, and fixing the fibre optics in a single position relative to any measured surface.

The complete set of data is described at *Table 4*. The corresponding most representative spectra are plot in Annex 4, for each category of crop at different states, and for a same kind of state for different crops. The 440-940 nm spectral range only is shown, corresponding to the domain covered by multispectral images.

IV. Leaf Area Index measurements

A LAImeter was brought from CIRAD, lent by the Cemagref based at the Maison de la Télédétection, for use in the fields. It is a LAI2000 from LICOR, which operates in the PAR (Photosynthetically Active Radiation) domain. This device allows to calculate the canopy transmission coefficients out of the measurement of the incident scattered light intensity (measured above the canopy) and of the light intensity transmitted through the canopy (measured below the canopy). Then, coupled with a trivial model of canopy, it leads to simple derivations of the effective Leaf Area Index (LAI), the Average Leaf Angle (ALA) and the Gap Fraction of the canopy. The Figure 6 shows Dr. Camille Lelong using this instrument in the field, acquiring the measurement of flux below the canopy.

These measurements have to be performed when no direct sun lights the canopy leaves, mostly to avoid underestimation of LAI due to specular reflections and reflection in the sensor direction. That means that the optimal conditions for that purpose are:

- dawn, without clouds passing towards the sun
- dusk, without clouds passing towards the sun
- overcast sky, very homogeneously grey, with no broken clouds

In any case, the weather has to be very stable, as light conditions must be comparable at times of below and above canopy flux measures acquisitions.

These conditions are very difficult to meet under the tropics and especially near the Equator like in Uganda, because dawn and dusk are very short. Thus, only a short time window per day is available. During this campaign, we chose four clear and stable evenings, each providing about 1.5 to 2 hours of measurements, in the site of Mukono. As a result, fourteen plots were sampled, which GPS coordinates and crops description are given in *Table 5* , and which locations are given as blue empty diamonds (✧) in the figure on Annex 2. The acquisition below the canopy was done in the middle of the parcel, and repeated 4 times around this point at 2m away from it, as described in the Figure 7. This leads to a mean estimation of LAI in a square area of 4m, corresponding to the size of a pixel.

Figure 5 (left): Utilisation of the UNISPEC-reflectometer in the field by G. Hakiza

Figure 6 (above): utilisation of the LAI200-canopy analyser in the field by C. Lelong

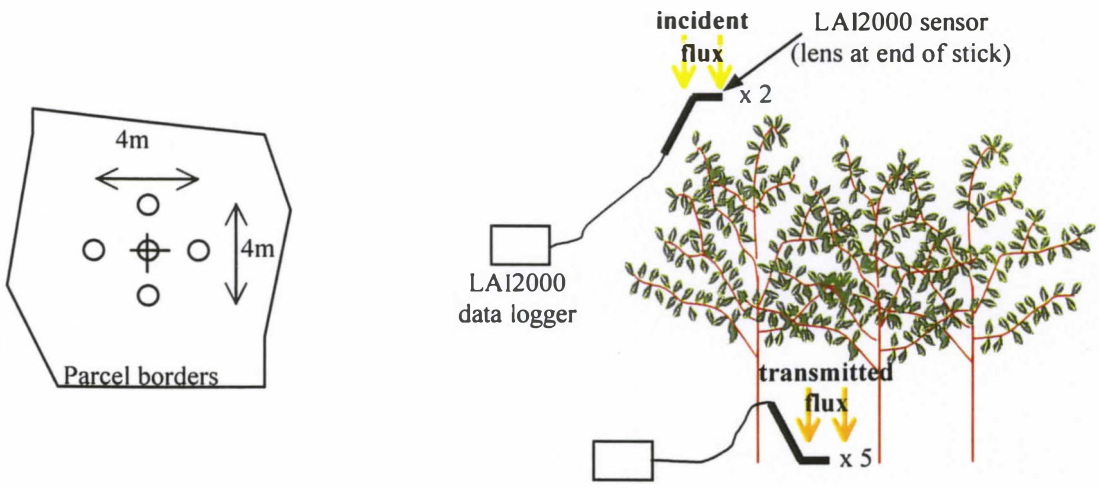


Figure 7 : Schematic view of the LAI2000 measurements in a given parcel. The cross (+) corresponds to the GPS acquisition, at the centre of the parcel. Circles indicate the LAI2000 acquisitions below the canopy: one at the centre, and then one at 2m from the centre in each four directions. One record is performed above the canopy before the five records below the canopy, and another one after them.

Table 3 Location and description of spectral pseudo-invariant targets measured during the campaign

Site	Target name	Latitude (N)	Longitude (E)	Description
MUKONO	I1	0°30.71462	32°45.76459	Dark red soil (yard)
	I2	0°30.50702	32°46.70540	Red soil (yard)
	I3	0°29.85492	32°47.09936	Brighter soil (yard)
	I4	0°28.85263	32°51.61996	Ploughed field
	I5	0°28.90864	32°51.47576	Ploughed field
	I6	0°28.91314	32°51.46868	Mulch
	I7	0°29.55365	32°51.86908	Red soil (yard)
	I8	0°29.93152	32°51.21924	Small ploughed field
	I9	0°29.94086	32°51.06539	Grass
	I10	0°29.79924	32°50.57132	Bright soil (large yard)
	I11	0°31.38732	32°44.89974	Bright soil (large yard)
	I12	0°29.73036	32°45.53832	Red soil (yard)
	I13	0°29.56814	32°45.89462	Red soil (very large yard)
	I14	0°30.69982	32°45.62909	Bright sand at tarmac road border
	I15	0°30.70207	32°45.62651	Sandy tarmac on tarmac road
	I16	0°30.70142	32°45.60688	Dark tarmac in middle of the road
KIGANDA	IKIG1	0°28.46221	31°38.15168	star grass
	IKIG10	0°29.76480	31°42.10322	soil (yard)
	IKIG11	0°29.01550	31°44.17506	Grass
	IKIG12	0°28.2600	31°44.700	soil (yard)
	IKIG2	0°28.48056	31°38.16552	white soil (yard)
	IKIG3	0°28.57679	31°38.25178	white soil (yard)
	IKIG4	0°28.96078	31°38.41271	Football field
	IKIG5	0°29.48799	31°38.82438	soil (yard)
	IKIG6	0°30.95795	31°37.02226	Ploughed field
	IKIG7	0°28.04636	31°41.85860	grey soil (yard)
	IKIG8	0°29.21763	31°41.69799	Ploughed field
	IKIG9	0°29.78411	31°42.09775	soil (yard)
KYENJOJO	IKYE1	0°37.93985	30°38.88183	big stones
	IKYE2	0°38.07600	30°39.98100	red soil lmixed with sand
	IKYE3	0°38.05540	30°40.07467	brown soil
	IKYE4	0°37.68783	30°40.06565	short grass
	IKYE5	0°38.01002	30°38.99384	light soil area
	IKYE6	0°37.87483	30°38.78914	Football field
	IKYE7	0°37.84973	30°38.77176	grass, rather yellow
	IKYE8a	0°38.52114	30°35.75524	dark ploughed field
	IKYE8b	0°38.52114	30°35.75524	Tea

Table 4 : Spectral signatures data base acquired on tropical crops during this campaign

CROP	Description of measured leaf	CROP	Description of measured leaf
Coffee leaves	Green	Banana leaves	Green
	Yellow		Green/yellow young leaf
	Brown		Old dark green
	Green but stressed		Yellow
	Green		Dry
	Glossy green		Very dry
	Dark green		Green
	Baby leaf		Green (yellowish)
	Bright orange/yellow	Yam leaves	Green
	Copper coloured		Green
	Very brown		Yellow
	Yellow (nitrogen stress)		Copper coloured
	Yellow (nitrogen stress)		Very dark green
	Glossy green on stressed tree		dry
	Mat green	Cassava leaves	Green
	Yellow		Dark brown baby leaf
	yellow		Yellow green
Sweet potato leaves	Old purple		Dark yellow
	Young purple		Green
	Purple		Dark green
	Green	Jack fruit tree leaves	Copper coloured
	Green		Very dark green
Papaw leaves	Green		Dry
	Dark green		Baby leaf
	Yellow		Dark green
	Yellow		Glossy green
	Old green		

Table 5 : Location and description of plots where LAI have been measured

Plot	Latitude (N)	Longitude (E)	Description	LAI
L1	0°29.81501	32°50.57261	coffee	1.38
L2	0°29.81758	32°50.59192	coffee +very few banana (negligible)	0.96
L3	0°29.86490	32°50.86969	Banana	3.19
L4	0°30.35928	32°50.60544	Banana (very dense)	3.37
L5	0°30.35542	32°50.61542	Cassava	1.33
L6	0°30.34995	32°50.58194	Coffee (very scattered)	0.63
L7	0°30.87845	32°49.90410	Coffee (Nanga farm)	1.16
L8	0°30.89776	32°49.89605	Coffee (Nanga farm)	0.77
L9	0°30.84401	32°49.60219	Coffee (Nanga farm)	1.13
L10	0°30.86139	32°49.60251	Coffee (Nanga farm)	2.27
L11	0°30.30006	32°49.41229	Banana (very dense) +very few coffee	2.83
L12	0°29.77478	32°49.11006	Cassava heterogeneous	1.24
L13	0°29.87455	32°48.35045	Banana (very dense)	2.99
L14	0°28.55298	32°45.29531	Cassava	1.13
L15	0°28.64535	32°45.35164	Banana jungle	2.64
L16	0°28.70136	32°45.72178	Coffee (very scattered)	0.67
L17	0°28.66338	32°46.03431	Banana	2.03
L18	0°29.07086	32°46.78104	Coffee (scattered)	1.16
L19	0°29.08502	32°46.80196	Coffee (scattered) with shading	1.32
L20	0°29.16388	32°47.08037	Coffee	2.90
L21	0°29.14907	32°47.07490	Coffee	2.45
L22	0°29.64024	32°47.77689	banana (very dense)	3.96
L23	0°29.70042	32°47.90306	coffee + banana	1.88
L24	« «	« «	Idem	1.24
L25	0°29.71974	32°47.93396	Banana	3.03
L26	0°29.79248	32°48.00477	sugar cane	3.75
L27	0°29.89580	32°48.24520	banana (scattered)	0.95
L28	0°29.73261	32°45.53446	coffee + banana + cassava (heterogeneous)	1.54
L29	0°29.71974	32°45.53832	coffee + banana + avocado	1.75
L30	0°29.72521	32°45.57501	coffee + banana + cassava (heterogeneous)	1.53
L31	0°29.70751	32°45.57308	Banana	1.50
L32	0°29.70300	32°45.68445	banana + very few cassava	1.40
L33	0°29.68143	32°45.72886	Coffee	1.88
L34	0°29.73004	32°45.87209	coffee + banana	1.36
L35	0°29.80632	32°45.99118	coffee (scattered)	1.18
L36	0°29.86651	32°46.11156	cassava (dense)	2.45
L37	0°30.16391	32°46.20812	coffee (scattered)	1.45
L38	« «	« «	Idem	2.41
L39	0°30.39758	32°46.19653	Coffee under shade	4.42
L40	0°30.40531	32°46.19525	Same plot, no shade	2.97

V. Airborne CASI spectral images acquisition

Borstad and Associates (Gary Borstad; Mar Martinez) and the Desert Locust control Organisation for East Africa (Captain Arraleh, pilot; S. Majura, engineer) installed the CASI instrument on board a Beaver from De Havilland from the 12th to the 16th of January. They attempted in vain to flyby the three sites during a period from the 17th to the 24th of January, while the weather conditions were the worst that could happen during the season, supposed to be a dry and clear season: a lot of dust and thick haze were present in the sky, and even some thunderstorms and showers occurred on the 18t, 19th, and 20th of January. A short window opened on mornings of the 19th and the 21th of january, as C. Lelong replaced M. Martinez as the co-pilot and GPS navigator on board the aircraft. For both mornings, a very small area was out of clouds, corresponding almost exactly to the sites of interest in Mukono (on the 19th) and Kiganda (on the 21th). Moreover, the time window was also very short between two long periods of overcast weather and the two attempts were lucky to succeed... The airborne data acquisition campaign will be reported in its whole by Borstad and Associates in a separate document.

VI. Timetable

Table 6 : Effective timetable during this mission, with list of activities and their location. List of initials cited in this table: YG=Yves Gillet, FP=Fabrice Pinard, CL=Camille Lelong, GB=Gary Borstad, MM=Mar Martinez, GH=Georgina Hakiza, PA=Pauline Aluka, AK=Africano Kangire, A=Captain Arraleh, SM=S. Marjura, DK=Denis Kyetere

Date	Activities	Location
16.1	Meeting at the European Delegation in Kampala: YG, FP, CL	Kampala
	Final definition of the CASI campaign and time schedule: GB, MM, FP, CL	Entebbe
17.1	Field work learning session and training by CL: GH, PA, AK, FP	Kiganda site
18-21.1	Field work at Kyenjojo site: ground truth information records, spectral measurements (GH, PA, AK, FP,CL)	Kyenjojo site
22-24.1	Field work at Kiganda site ground truth information records, spectral measurements (GH, PA, AK, FP,CL)	Kiganda site
25.1	First debriefing to CORI director Denis Kyetere, and workshop on the need for CASI campaign prolongation due to total failure of the mission: DK, GH, PA, AK, GB, A, SM, FP, CL.	Entebbe
26.1	Airborne CASI data acquisition on Mukono site (GB, A, SM, CL).	Entebbe/Mukono
	Weather Forecast Center visit for Meteosat images analysis (GB, CL).	Entebbe Airport
27.1	Field data sorting and airborne experiment report.	Entebbe
	Weather Forecast Center visit for Meteosat images analysis (GB, CL).	Entebbe Airport
28.1	Airborne CASI data acquisition on Kiganda site (GB, A, SM, CL)	Entebbe/Kiganda
	Field data sorting and airborne experiment report.	Entebbe
29.1	Field data sorting. Visit of CORI Center in Kituza, and final CASI debriefing: GB, DK, GH, AK, FP,CL.	Kituza
30.1-1.2, 4-6.2	Field work at Mukono site: ground truth information records, spectral measurements (GH, PA, AK, FP,CL), LAI2000 acquisitions (FP,CL).	Mukono site
7.2	Final debriefing and workshop on perspectives of the project: DK, GH, PA, AK, FP, CL.	Kituza
	Data backups and duplications, exchange of information and data between CORI and CIRAD: GH, PA, AK, FP, CL.	Kituza
8.2	Final data sorting, files exchange, and conclusive meeting: FP, CL	Kampala

ANNEX 1

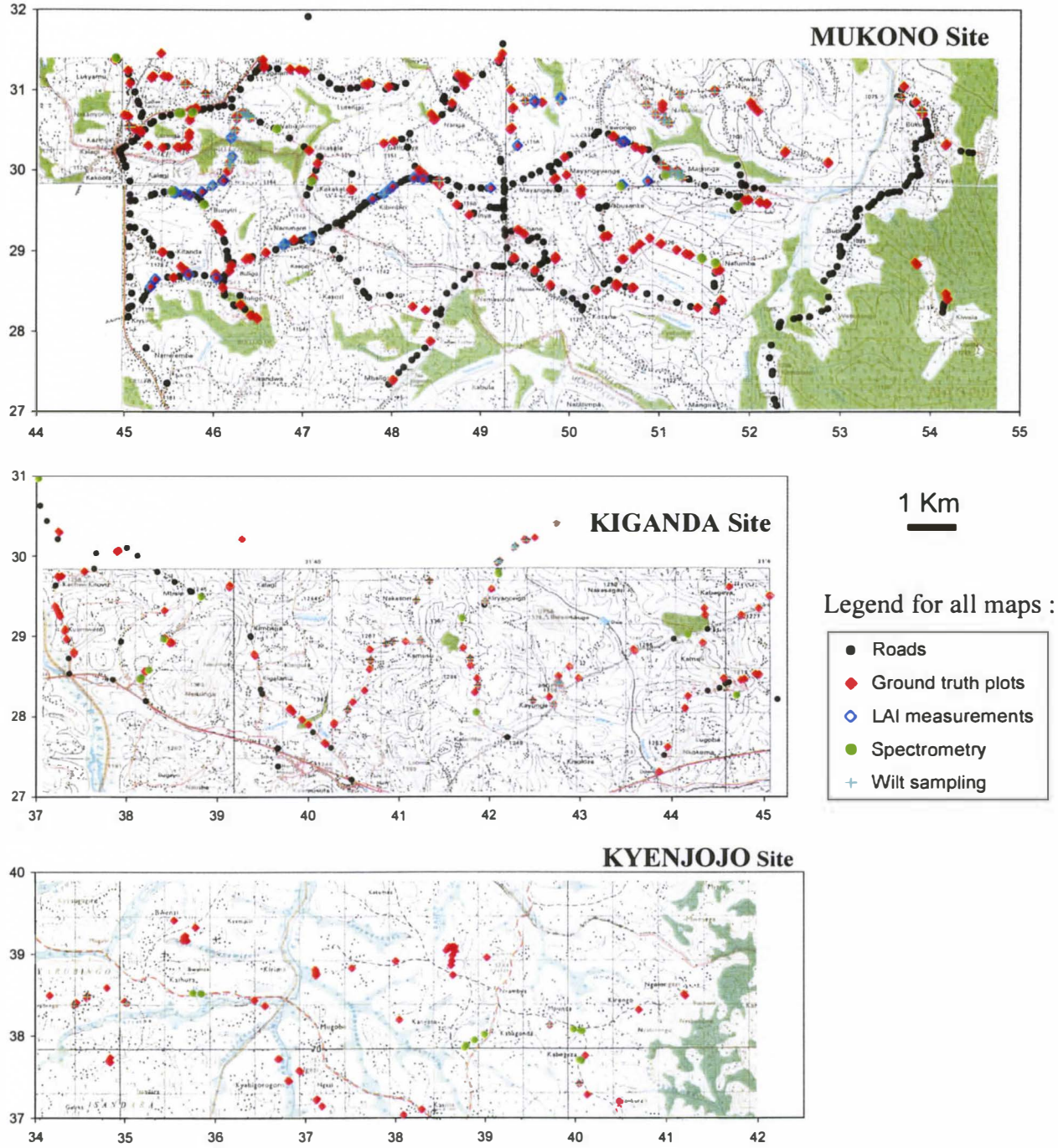
UGANDA COFFEE WILT DISEASE REMOTE SENSING PROJECT 2002 *Prepared by Dr. C. LELONG -CIRAD- jan.2002*

FIELD GROUND TRUTH ENQUIRY FORM

Site name : (strike out wrong statements)	MUKONO KIGANDA KYENJOJO	Date = Time =
Name of enquirers =		
Parcel center GPS coordinates =	- -	Name of GPS file record =
Parcel corners coordinates/ parcel dimensions and orientation =	- - - - - -	
Any indication regarding the parcel location or surrounding characteristics that could be valuable =		
Type of surrounding landscape	☐ Flat ☐ Hilly ☐ Very hilly	
Parcel global topography	☐ < 20% ☐ > 20% and < 40% ☐ > 40%	
Rough estimate of soil color	☐ Red ☐ yellowish ☐ brown ☐ black ☐ other =	
List of cultivated crops in the parcel and relative density (%) =		
If several kind of crops, precise	☐ Intercrop ☐ Heterogeneously mixed	
Management of parcel	☐ Clean ☐ Dense but managed ☐ Almost unmaintained	
Undercover	☐ dense ☐ rare ☐ none ☐ green ☐ yellow ☐ dry (mulch)	
Details for parcels containing coffee	☐ Pure coffee (or almost pure) ☐ Regularly intercropped with bananas ☐ Heterogeneously mixed with bananas	☐ Heterogeneously mixed with several other types of vegetation (at the canopy level)
Estimated density of coffee in the parcel (eg : number of ranks /bananas, distance between two coffee trunks...) =		
Coffee trees architecture	☐ tall and slim ☐ medium ☐ short and thick ☐ tall and thick	Estimated diameter of coffee tree projection = / Estimated height =
Wilt disease status	☐ Few isolated infected trees ☐ Several infected trees ☐ Large spread disease	
Accurate indications on the location of a recorded diseased tree or area (precise extent), and level of affection =		

ANY OTHER COMMENTS ON THAT PARCEL:

ANNEX 2 :
LOCATION OF MEASUREMENT PLOTS IN THE DIFFERENT SITES

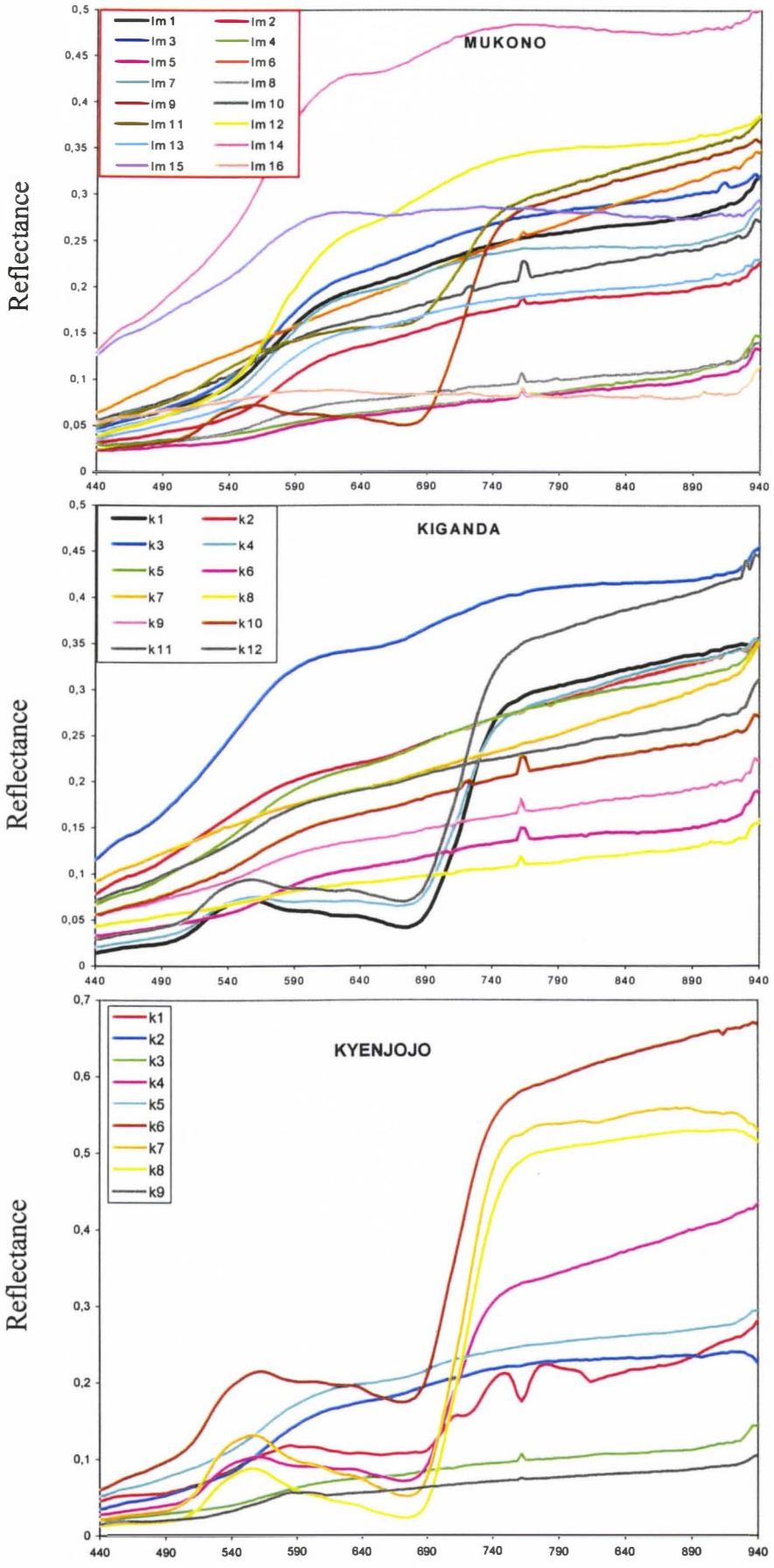


Maps of the areas of study for the three test sites (Mukono, Kiganda, and Kyenjojo), and location of : ground truth plots where an enquiry form has been filled (red diamonds), canopy LAI measurements (dark blue empty diamonds), invariant targets spectral measurements (green dots), and sampling of bark on wilted coffee trees (light blue cross). Black dots indicate points located on roads where a GPS recording was performed, data useful for image georefencing.

The vertical axis represents the latitude and the horizontal axis the longitude. Figures appearing on the vertical axis corresponds to the minutes of 0°N. Figures appearing on the horizontal axis corresponds to minutes of 32°E for Mukono site, of 31°E for Kiganda site, and of 30°E for Kyenjojo site. This means for instance that a point located at coordinates (48,30) on the Mukono graph corresponds to the geographical point of latitude 0°30'N and longitude 32°48'E.

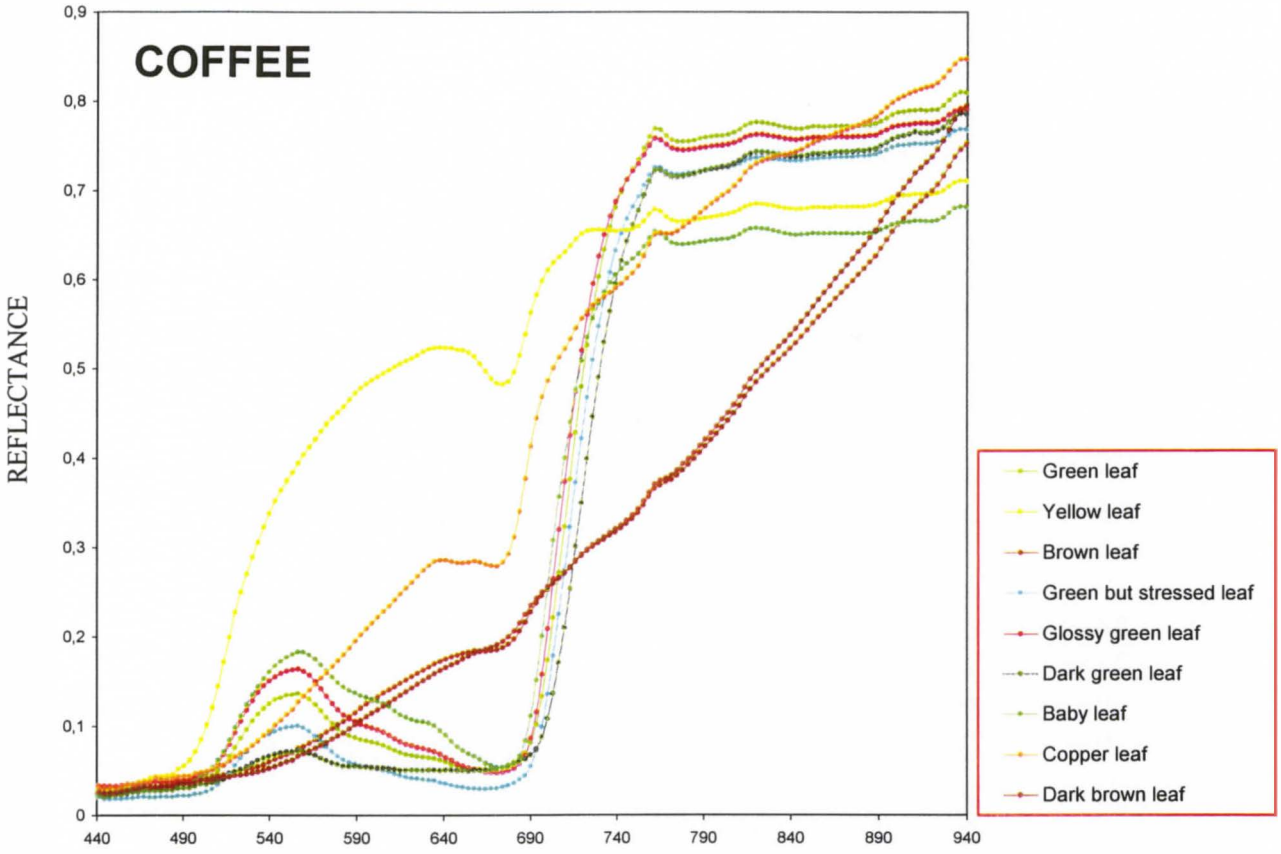
ANNEX 3 :

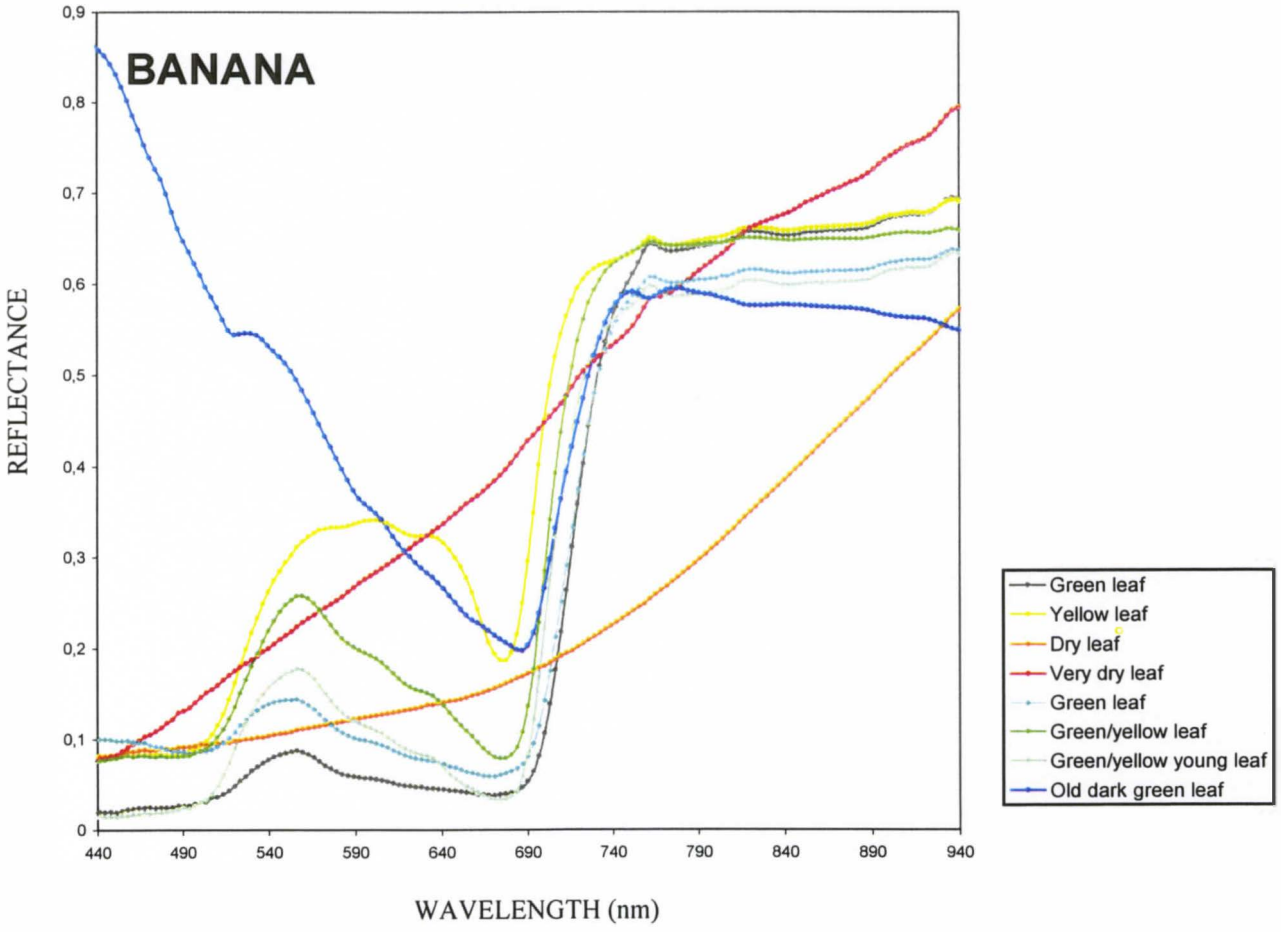
PSEUDO INVARIANT TARGETS REFLECTANCE SPECTRA



ANNEX 4

TROPICAL CROPS REFLECTANCE SPECTRA MEASURED IN THE FIELD





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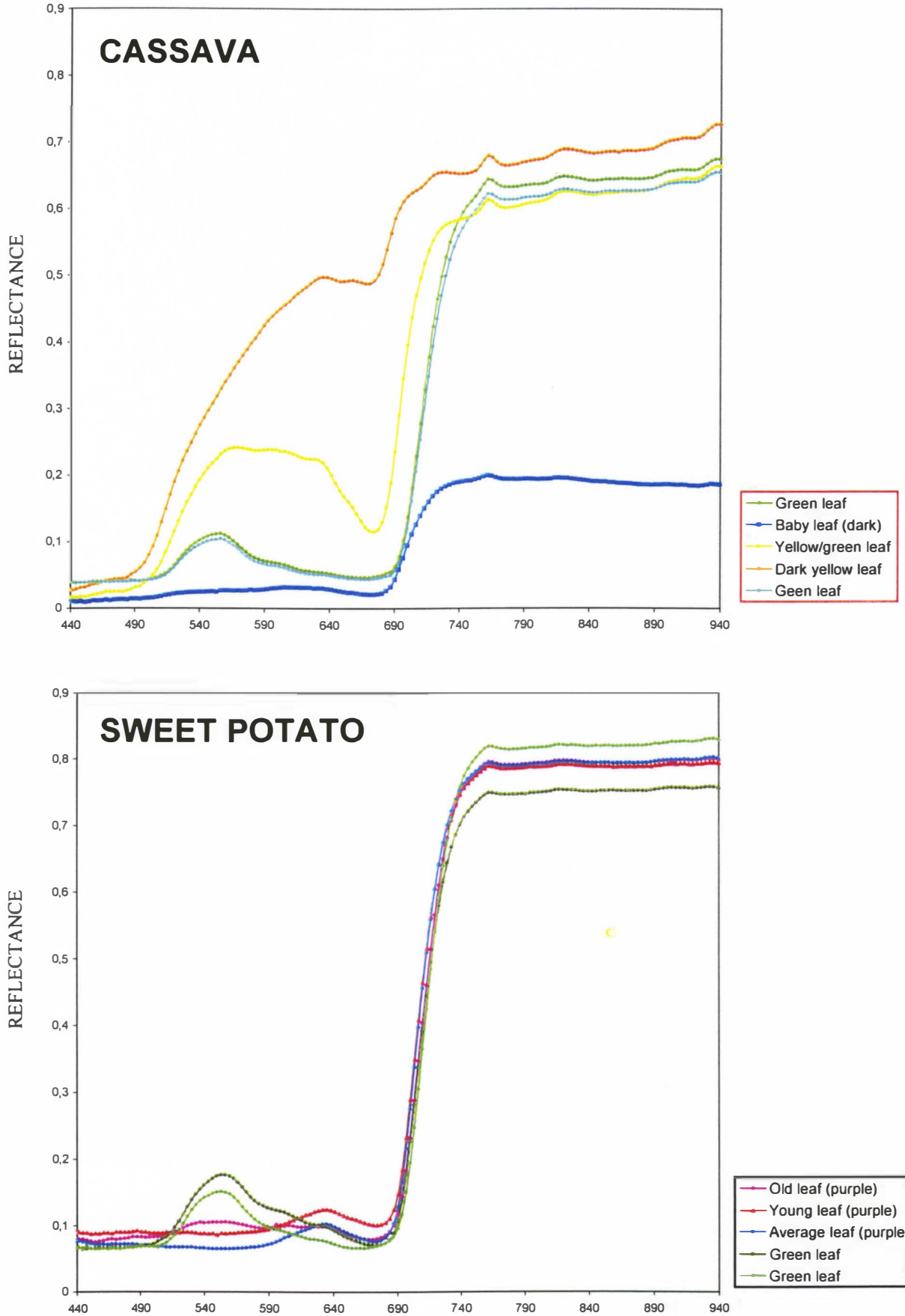
TROPICAL CROPS REFLECTANCE SPECTRA MEASURED IN THE FIELD



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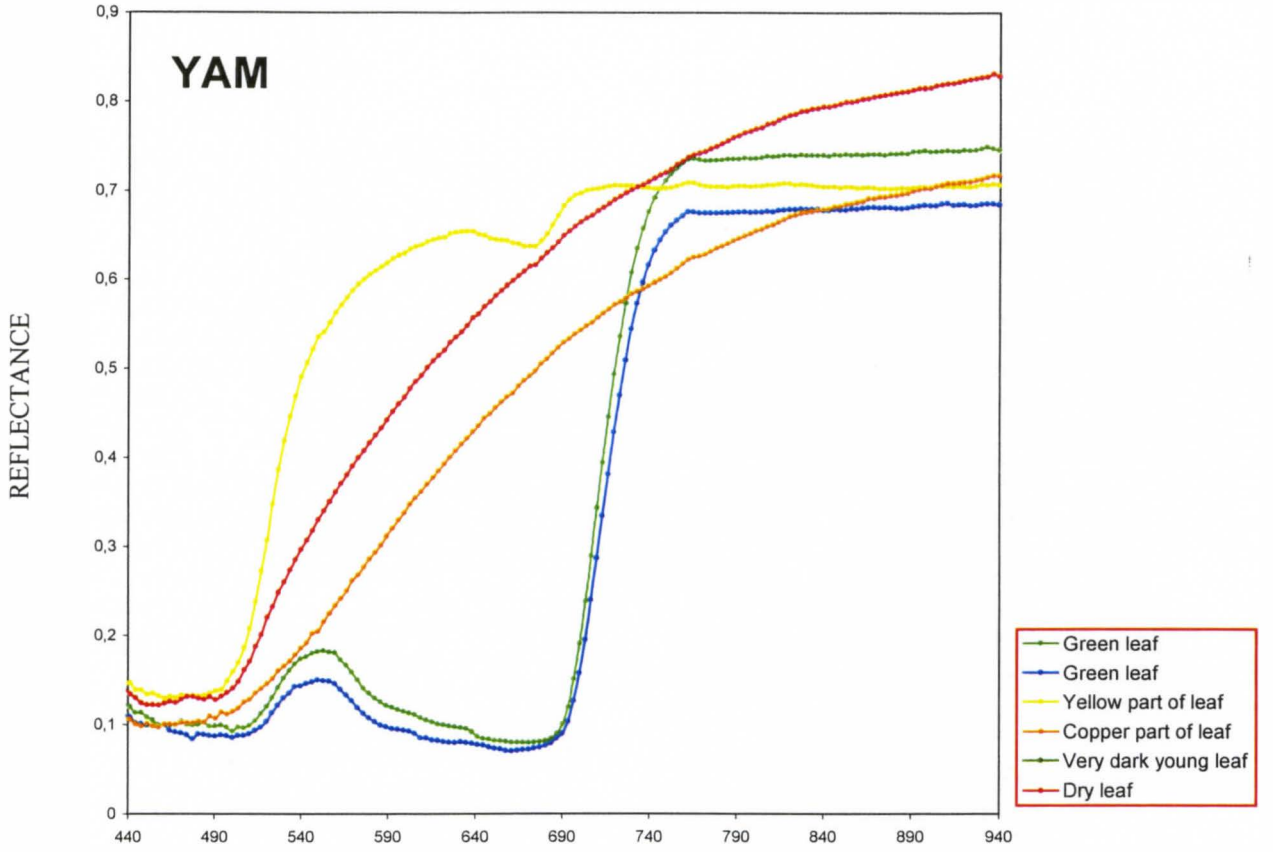
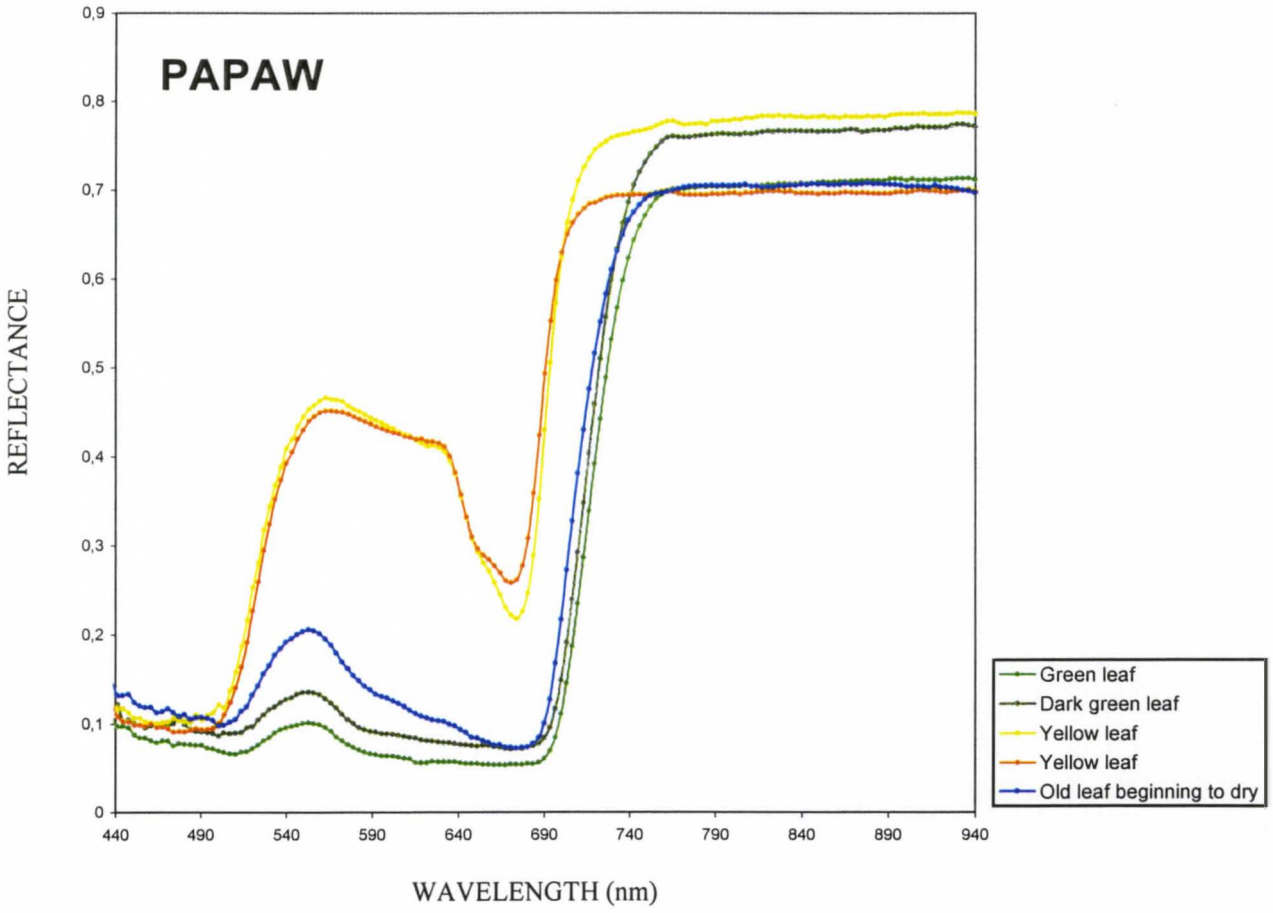
TROPICAL CROPS REFLECTANCE SPECTRA MEASURED IN THE FIELD





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TROPICAL CROPS REFLECTANCE SPECTRA MEASURED IN THE FIELD