Département Amélioration des Méthodes pour l'Innovation Scientifique
Cirad-amis

Unité Mixte de Recherche en Télédétection, Environnement, Territoires et Information Spatiale
UMR TETIS

Centre de Coopération Internationale en Recherche Agronomique pour le Développement

UMR TETIS Télédétection, Environnement, Territoires et Information Spatiale

VERY HIGH RESOLUTION SATELLITE-IMAGERY-BASED AGROSYSTEMS MAPPING

to help defining geographic indications for the Arabica Coffee in the Kintamani County of BALI

Camille LELONG
CIRAD-AMIS
March 2005

VERY HIGH RESOLUTION
SATELLITE-IMAGERY-BASED
AGROSYSTEMS MAPPING

to help defining geographic indications for the Arabica Coffee in the Kintamani County of BALI

Camille LELONG
CIRAD-AMIS
March 2005

Résumé

Ce projet consiste en l'analyse couplée de données issues de **l'imagerie satellitaire à très haute résolution spatiale (0,65m)**, d'une enquête de terrain concernant les systèmes de cultures et d'autres informations géoréférencées, ayant pour objectif d'apporter une dimension cartographique à la définition d'indicateurs géographiques visant à délimiter un **Terroir Arabica** dans la région de **Kintamani à Bali**.

Il en résulte la production de plusieurs cartes incluant:

a) une **carte des principaux agrosystèmes** rencontrés dans cette région: cultures vivrières, systèmes de culture associés aux grands arbres d'ombrage (Erythrina, Leucaena et Albizia), systèmes fondés sur des cultures pérennes (giroflier, cacao, agrumes, associations agrumes + caféier Arabica, caféier Arabica cultivé sans ombrage),

b) une **carte des grandes agro-régions** distinguables dans cette zone (agriculture dominée par les vivriers, par l'ombrage sous grand arbres, par les agrumes et leurs associations et par le giroflier)

c) le **modèle numérique de terrain** (MNT) de la région.

Ces différents produits permettent une **analyse spatiale** de la distribution des agrosystèmes à base de caféier Arabica et une estimation des **variables quantitatives** concernant les surfaces plantées en caféier Arabica dans la région. Ces produits constituent la base d'un **Système d'Information Géographique** (SIG) permettant la superposition de données ancillaires variées comme les résultats d'analyses sensorielles, la localisation des centres de procédés sur le café Arabica ou encore les niveaux topographiques, pour mener à bien une analyse spatiale des relations entre ces différents facteurs.

Cette approche montre que certaines caractéristiques sont clairement liées à la production de bons cafés Arabica. Ces bons cafés sont localisés au sein de l'agro-région dominée par les systèmes à base d'agrumes (en monoculture ou en association) et plus précisément à l'ouest d'une ligne Ulian/Dausa, et sont cultivés uniquement au dessus de l'altitude 1100m. Le système de culture pratiqué pour la culture du café Arabica (par ex. ombrage de grands arbres ou d'agrumes) semble en revanche ne pas avoir d'effet sur sa qualité. Il semble toutefois qu'on ne puisse extraire aucune limite évidente et restrictive du Terroir Arabica de Kintamani à partir de cette première étude.

On propose alors de récolter des informations supplémentaires et de les corréler à ces premiers résultats pour avancer vers une délimitation possible de ce terroir. En particulier, il ressort un fort besoin d'une carte des Subak Abian (structures socio-religieuses traditionnelles à Bali qui seront l'unité de base pour toute délimitation), une carte de la composition du sol, des cartes de caractéristiques des pratiques agricoles (par ex. utilisation des terrasses et des haies, nature de la couverture au sol, densités de plantation, densité et hétérogénéité de l'ombrage...) qui peuvent êtres obtenues par une photo-interprétation plus poussée de l'image satellitaire, et des données de qualité sensorielle de la tasse basée sur un nouvel échantillonnage de cafés.

L'intégration de toutes ces données dans le SIG et leur analyse spatiale devraient largement faire progresser la compréhension des composantes géographiques d'un bon café Arabica dans la région de Kintamani à Bali.

Abstract

Very high resolution (0.65m) satellite imagery, field enquiry about cropping systems and other georeferenced information are analysed in order to provide with maps of interest for the definition of geographical indicators to help delimiting a **"Terroir" Arabica** in the region of **Kintamani in Bali**.

It results in the production of several maps including:

a) **map of the main agrosystems** practiced in this region: food crops, systems associated with dense shading by large trees (Erythrina, Leucaena and Albizia), systems based on perennial crops (Clove, Cocoa, Citrus, associations of Citrus and Arabica coffee, Arabica coffee cropped without shade),

b) **map of the main agro-regions** distinguishable in this area (agriculture dominated by food crops, by large trees shading, by Citrus and associations with Citrus, and by Clove),

c) **Digital Elevation Model** (DEM) of the region.

These different products allow to implement **spatial analysis** of the Arabica coffee-based agrosystems distribution in the region of Kintamani in Bali and to derive **quantitative data** about the areas planted with Arabica in this region. These products constitute the basis of a **Geographical Information System** (GIS), enabling the superimposition of various ancillary data like sensorial quality characteristics, location of Arabica coffee processing places or topographic levels, to lead a spatial analysis of the relationships between these independent factors.

This approach shows that some characteristics are clearly linked with the production of good Arabica coffees. They are located inside the central agro-region dominated by Citrus associations (and more precisely at West of the line Ulian / Dausa), and cropped only above the altitude limit of 1100m. The agrosystem used for Arabica coffee growing (e.g. shading by large trees or by Citrus) seems to have no effect on its quality. Nevertheless, it seems that no trivial and restrictive limits can be extracted for the "Terroir" of Kintamani Arabica Coffee out of this first study.

Propositions are made for additional information to be collected and correlated with these first results to help leading to a conclusion about the potential limits of the "terroir". Especially there is a strong need for a map of the Subak Abian (traditional Balinese social and religious structures) that will be the area unit for any delimitation, a map of the soil composition, maps of crops management characteristics (e.g. use of terraces and fences, undercover nature, planting density, shading density and heterogeneity...) that could be extracted out of further photointerpretation of the satellite image, and additional coffee berry sampling and cup quality analysis.

The integration of all these data inside the GIS and their spatial analysis should largely improve the understanding of components of good coffee growing and their relationships with geographical indicators.

Contents

List of Figures

List of Tables

Introduction

The first objective of this work was to provide, on the basis of the satellite imagery, with a map of the Arabica Coffee growing plots in the region of Kintamani in Bali, where a Geographical Indication is under definition. After the first field enquiries achieved at the beginning of the enlarged project by other colleagues of CIRAD, it appears obvious that most of the coffee in this area was grown under shade of different densities, as could be predictable. But satellite sensors are only taking a view from above and not penetrating the vegetation covers: it can only show the first layer of eventual agroforestry systems. The initial objective was then shifted to the production of a map of the different agrosystems in relation with the presence of coffee and essentially with arabica.

This mapping was based on

- the acquisition of a Quickbird Image providing spatial resolution up to 0.65m and a spectral information in four bands (visible and near infrared),
- a field campaign providing with ground-truth information and constituting the training data base for the image analysis,
- computer-assisted photointerpretation of each cropped plot and anthropized areas.

This report presents the characteristics of the purchased image and the pre-processing needed to extract any information out of this image, including the production of a digital elevation model based on a simple paper printed topographic map.

Then the field campaign will be reported, and the data and keys extracted out of them will be presented to explain how the photointerpretation worked. The different agrosystems characteristics and opportunities to be discriminated will be discussed.

Finally, the resulting map will be described and coupled to ancillary data such as altitude and sensorial analysis results in order to help defining some areas of specific interest for the definition of the Geographic Indication for the Arabica Coffee of Kintamani in Bali.

Most of the digital work on the images (satellite image, map scans, DEM...) was done using ENVI 4.1, the "Environment for Visualizing Images", software distributed by Research Systems, Inc. (http://www.ResearchSystems.com/envi). Some specific actions like the DEM interpolation was done with ArcView GIS 3.3 (http://www.esri.com).

1. Localisation of the area of study

Bali is located Indonesia, and is a still active volcanic small island just in the step of Java (see Figure 1 for a general map of Bali). The major city is Denpasar, located at the southern coast, since the construction of the close International Airport, while it former used to be Singaraja, located at the northern coast.

The area of study is almost the most central region of Bali, more or less on the south-western slopes of the volcanic crater made by the erection of the Mount Batur, volcano still active that last erupted in 1999. The main local town is Kintamani, just on the rim of the crater, which gave more or less its name to the surrounding area. This is a very mountainous region, very cold, windy and misty at night that can become very hot during the day time. The landscapes are mostly ruled by steep slopes and lots of hills and ravines, crops often managed in terraces and forest following the rivers and ravines. The Space Shuttle acquired a very nice view of Bali with an imaging-altimeter (SRTM), that shows the very complex relief and the variety of lands that can be found in Bali (see Figure 2).

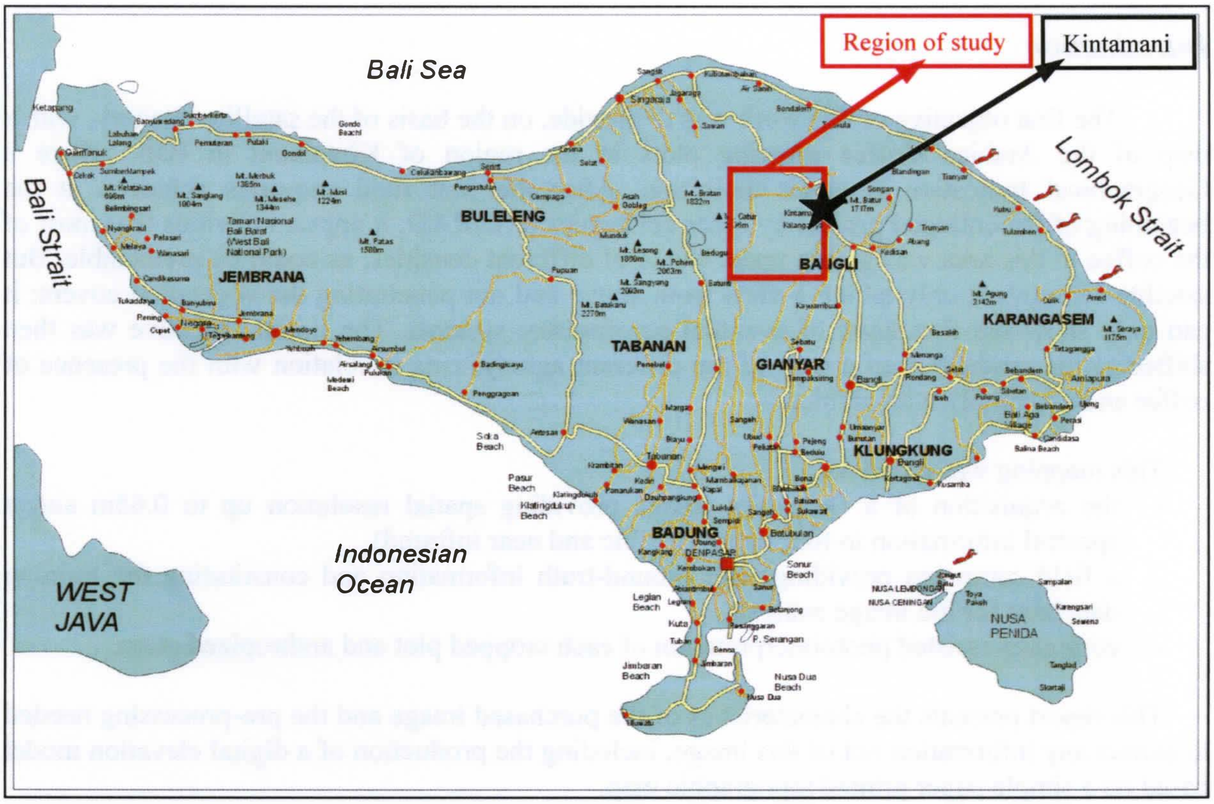


Figure 1: General map of Bali, Island of Indonesia,
and location of the area of interest for this study: the region of Kintamani.

Colleagues working formerly on the overall project aiming at defining a Geographical Indication for the Arabica Coffee of Kintamani region gave some first limits of the area of interest on the basis of their field observation of coffee agricultural practices, processing, taste of coffee cup and sociological facts. On this basis we tried to extract an area large enough to encompass the villages where coffee berry sampling were achieved for further sensorial analysis (sources Jean-Jacques Perriot, CIRAD) as well as noticeable villages of Pengiyakan, Satra, Siakin, Belandigan, Pinggan, Kintamani, Batur, Suter, Sekaan, Sekarmurti, Catur… proposed for sociological point of views (sources Valérie Keller, INAO).

At the end, the actual area of study will be delimitated by the availability of satellite images in this region and the image frame resulting of the satellite sensor field of view.

2. Digital Elevation Model Production

The Kintamani County of Bali is set on the slopes of the Gunung Batur volcano, where the geomorphology is extremely complex. The relief is quite mountainous and dominated by steep slopes, hills, ravines, plateaus, peaks, etc… It is of prime interest to have a good knowledge of this topography any time geographic data are analysed in this region, first to understand the complexity of the spatial distribution of dwellings and cropping systems, but moreover while considering Coffee crops which quality is quite dependant of the altitude where it is grown. This topographic information was thus needed to be compiled in a numerical format usable as a convenient tool in this study. The digital Elevation Model (DEM) is the normal kind of product used in geographic applications and provides the topo-sequence as height values organised in a matrix of pixels (a raster) like an image. It is also completely integrateable in a Geographic Information System (GIS).

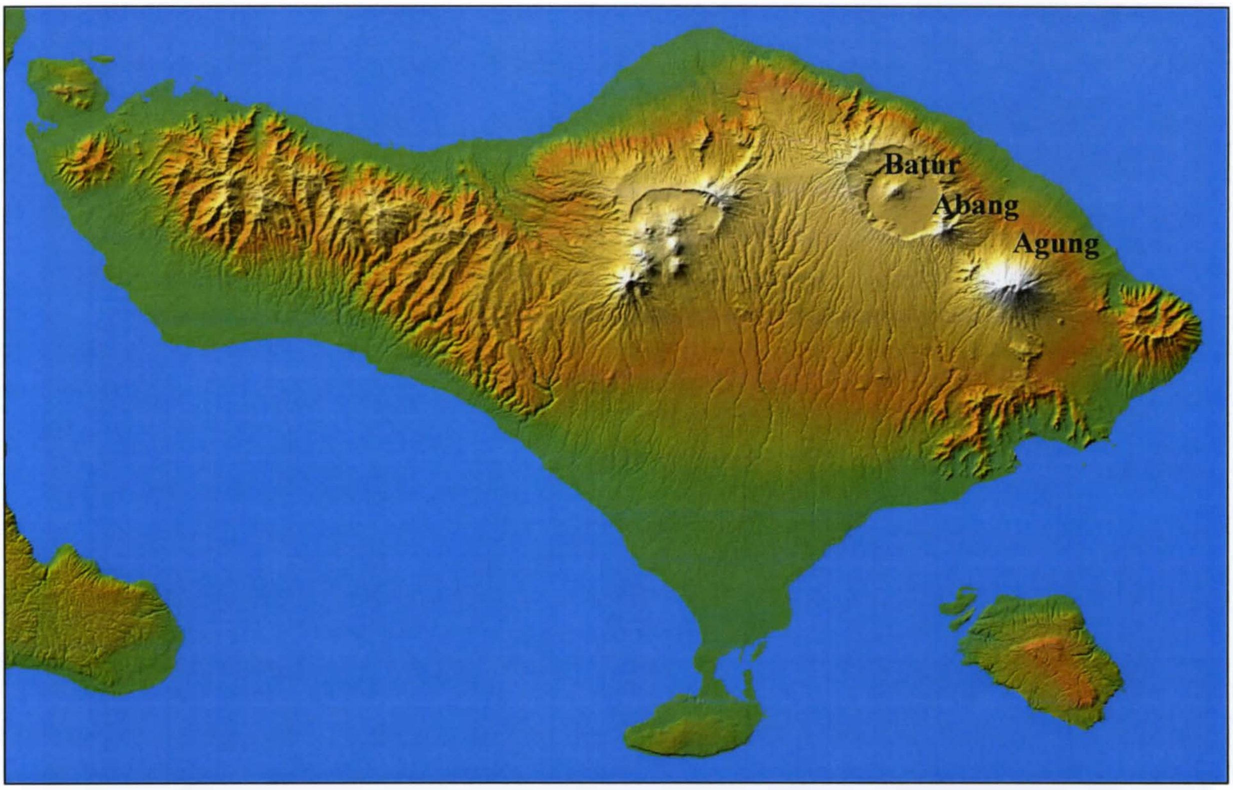


Figure 2: Altimetric data acquired by SRTM on board the Space Shuttle over Bali, showing the three highest volcanoes of Bali:
Agung, Abang and Batur and the crater of Batur near the centre of the island.

The Digital Elevation Model (DEM) of the area of Kintamani was not available yet from any data provider. Later in this project was released the digital data acquired by SRTM and corresponding to the image of the Figure 2 , but the spatial cells of these data are of 90m which is far out of accuracy compared to the satellite image which pixels are 0.65 to 2.4 m large only. The DEM was then to be created on the basis of the topographic maps edited by the Badan Koordinasi Survey dan Pemetaan Nasional (Bakosurtanal) of Indonesia in 2000.

These paper-printed topographic maps provide quadrants of about 14 km x 14 km at the 1:25000 scale, projected in the Universal Transverse Mercator (UTM) grid on the World Global System (WGS 84) Datum and Spheroid, with a vertical precision of 12.5 meters. A sample of these maps is shown on Figure 3 for the surroundings of the village of Mabi (Desa Belantih sub-county). The four respective quadrants were needed to cover the area of interest in the County of Kintamani:

- Kintamani (lembar 1707-641),
- Batur (lembar 1007-623),
- Gitgit (lembar 1707-632),
- Baturiti (lembar 1707-614).

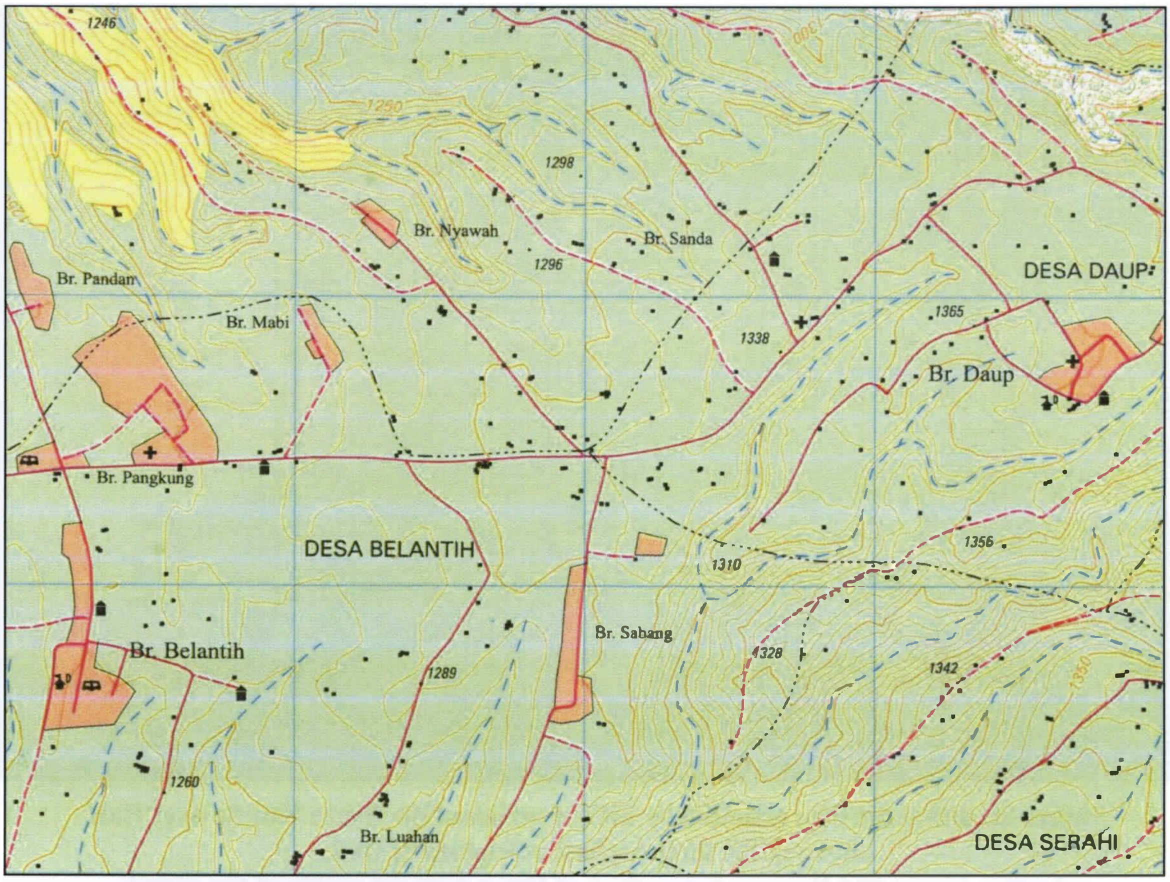


Figure 3: Sample of the 1:25000 topographic map around Mabi village and Desa Belantih sub-county edited by Bakosurtanal and used as a basis for the DEM production.

These four maps were scanned and mosaiked, then georeferenced precisely using the quotes. Each of the main topographic lines (one each 50 meters in altitude: 1500m,1550m, 1600m, 1650m...) were then contoured by hand very precisely, and given the attribute of the corresponding height. This leads to an horizontal scale varying between 5 meters to 1 kilometre depending on the slope and topography in the area. In the flattest regions (for instance in Desa Belantih sub-county), topographic lines giving the 25m-intermediate levels (1225m, 1275m, 1325m, 1375m...) were also recorded to improve the horizontal precision to at least 50 meters everywhere in the area.

A shapefile containing the elevation polylines was then generated under ENVI, then imported to Arcview and converted to a TIN (Triangular Irregular Network) by interpolation of the polylines information. Finally this TIN was converted to a GRID having cells of 10m (grid of height information having the same structure than an image of 10m resolution, or raster) and exported as an ASCII generic image to provide the DEM in a transportable format.
DEM production steps and final DEM result covering the satellite image area are illustrated on Figure 4 and Figure 5.

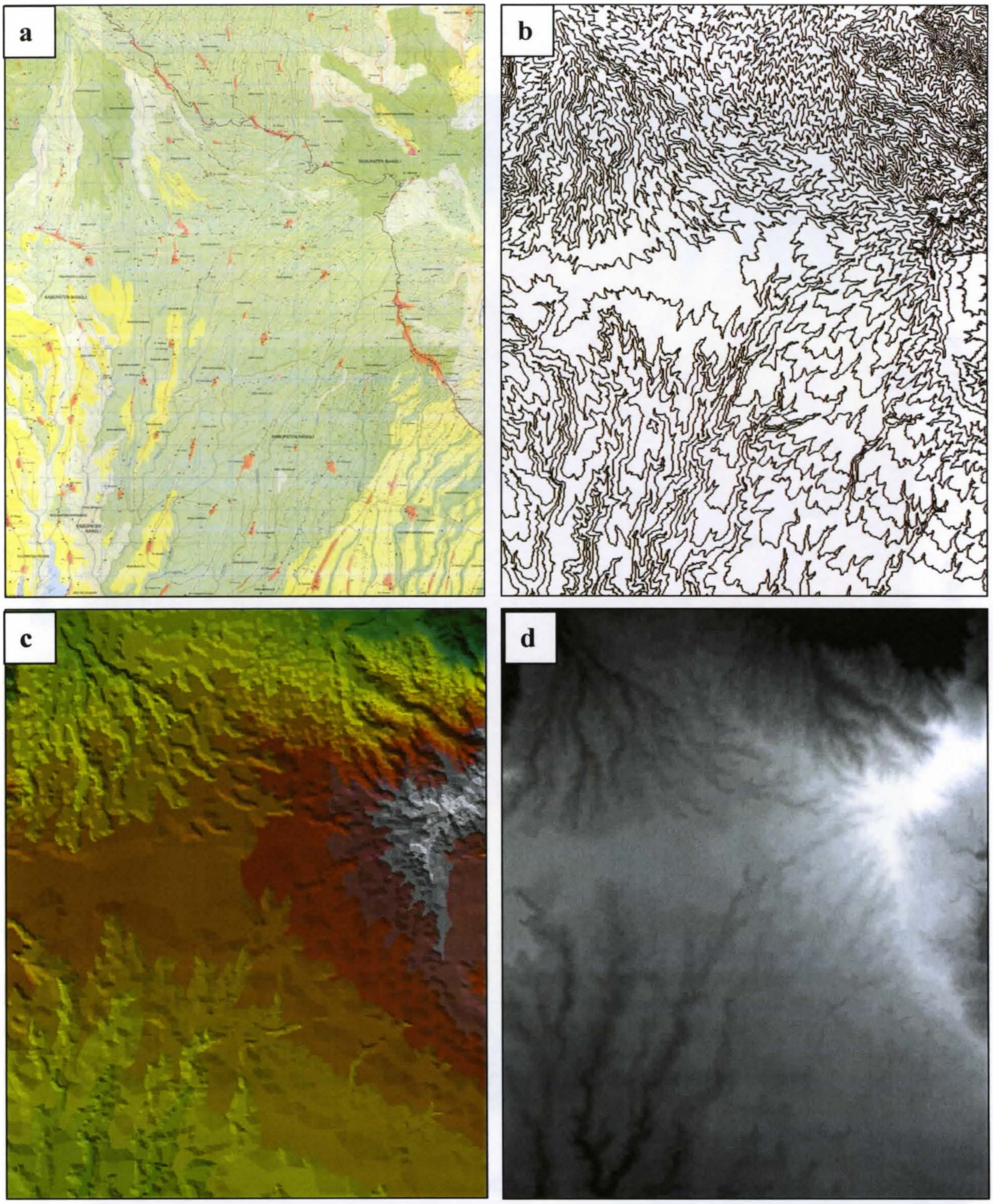


Figure 4: Steps of DEM production over the whole area covered by the Quickbird image, from left to right and from top to bottom:

a) scan of topographic map,
b) hand digitalisation of levels into polylines and constitution of a Shapefile,
c) TIN interpolation of polylines, showing illuminated facets,
d) GRID showing final DEM

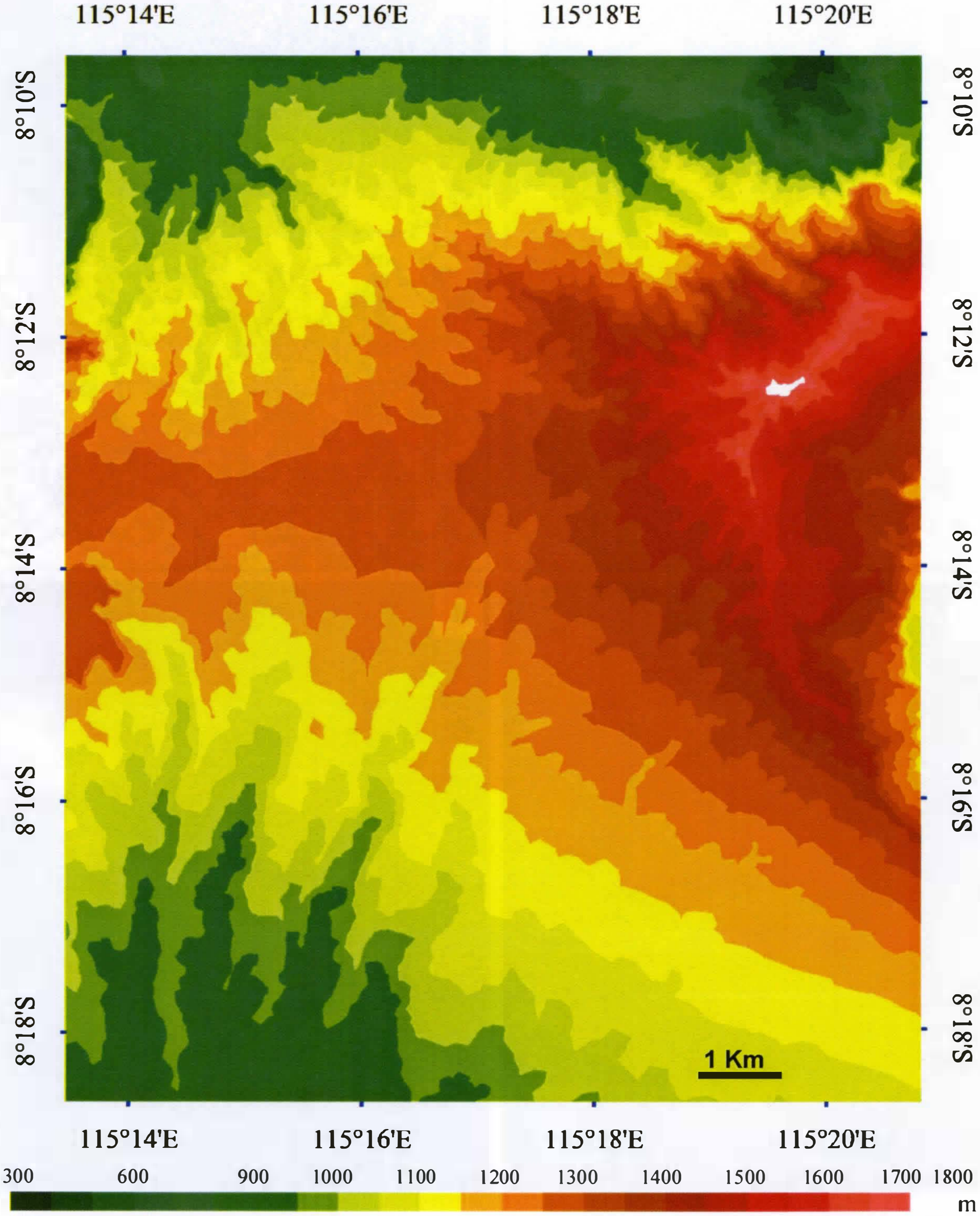


Figure 5: Digital Model Elevation of the Kintamani area of interest for geographical indication on Arabica Coffee in Bali.

3. Quickbird satellite image acquisition

Based on preliminary surveys and coffee sampling in the region of interest during the years 2002 and 2003, a first frame was defined for the possible limits of the so-called "terroir" of Kintamani Coffee. These supposed limits were then proposed to be the villages (Banjar) of: Bayunggede at South-East, Lembean at South, Belok at West, Tegal at North (Desa Tajun sub-county).

A research was then conducted inside the archives of satellite images providing very high spatial resolution (metric or sub-metric precision: Ikonos and Quickbird) in order to find whether any scene was already acquired over the site. Indeed, the climatic conditions in this humid and mountainous tropical region provide very few opportunities to get clear skies at time of satellite swath. Programming a new acquisition was such a challenge that could not be afforded taking into account the project timing. Fortunately, quite good images were acquired by Quickbird satellite in September 2003 with very few clouds. Even if the West/East extension of the covered region was limited and the wished area was split into two different frames, it fitted quite well the delimited scene of interest.

At the end, the two archive frames were purchased to Eurimage, Quickbird official reseller in Europe, at the processing level named "Ortho-Ready Standard LV2A", which means that basic geometric corrections due to view angles and satellite attitude were applied but no surface model was used to provide georeferencing: orthorectification is allowed on this level. Both panchromatic (Visible and Near-Infrared monospectral band giving a black and white image) and multispectral (four discrete bands in the visible and Near-Infrared domains, see Table 1, allowing colour compositions) data were purchased: these two spectral modes were acquired simultaneously at two different spatial resolutions, and both are needed to reach details such as individual trees and dwellings, in one hand, and to get the spectral (colour) information helping compositional characterisation of the surface in the other hand. This means that four files were generated and delivered by Eurimage. Main properties of these products are listed in Table 1. Data were delivered projected in the Universal Tranverse Mercator (UTM) grid on the World Global System (WGS 84) Datum and Spheroid, the UTM zone for Bali being 50 South.

Name of product	Spectral Bands (nm)	Spatial resolution	Size (pixels)	Extreme latitudes	Extreme longitudes	Off-nadir view angle
146022P1 Panchromatic	445-900	0.60 m	22524 x 11620	-8°9'34" -8°13'23"	115°13'30' 115°20'50"	12.4°
146022M1 Multispectral	450-520 520-600 630-690 760-900	2.4 m	5631 x 2905			
146022P2 Panchromatic	445-900	0.60 m	22524 x 20604	-8°11'54" -8°18'38"	115°13'30" 115°20'49"	11.6
146022M2 Multispectral	450-520 520-600 630-690 760-900	2.4 m	5631 x 5151			

***Table 1:** Main properties of purchased Quickbird images to cover the Kintamani area of interest in Bali.*

4. Satellite image pre-processing

- ***4.1 Radiometric calibration***

In order to work with actual radiometric values inside the pixels and not only with digital numbers due to computing of data files, the data radiometric calibration was applied on each of the four files based on the instrumental calibration coefficients given by the sensor constructor. In this study where absolute radiometry will not be used, it may seem of small interest to practice this calibration. But this fast and easy computing also sets each spectral channel to the same relative level and allow an actual comparison of different band files for vegetation index analysis for instance, or even for colour composition interpretation. Indeed, contrast enhancements are then made in realistic proportions for each colour, avoiding misinterpretations of the cover nature and composition.

- ***4.2 Mosaiking***

Then, for the two spectral modes separately, the two split frames of the desired scene were mosaiked without any contrast balancing, in order to provide a single scene for the entire area of interest. Only two files remain: one panchromatic and one multispectral image. Example of the same region in both images is shown at Figure 8.

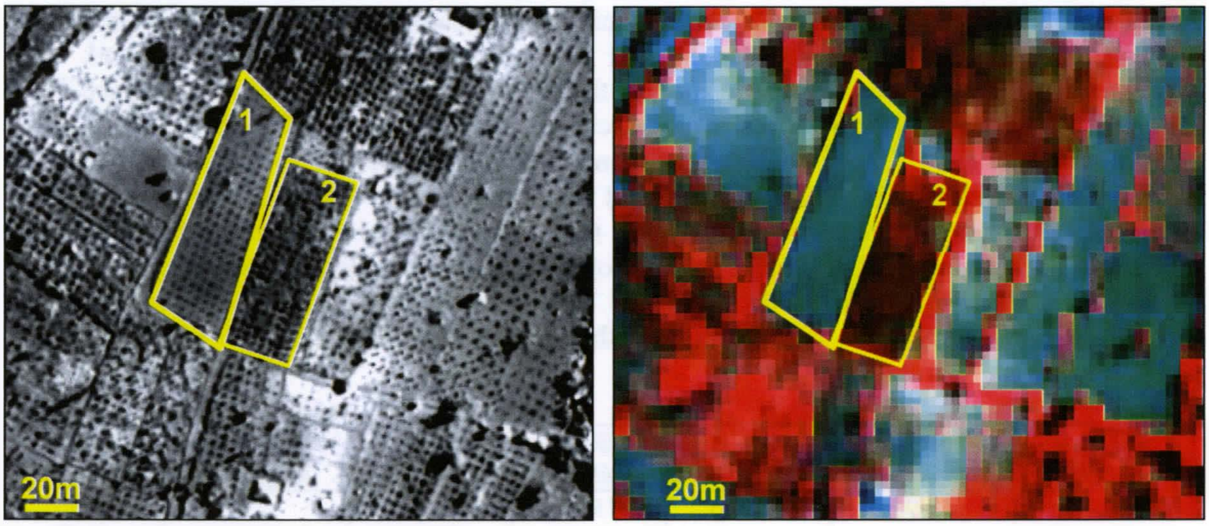


Figure 6: Comparison of information perception provided by the panchromatic (left) and the multispectral (right, in NIR false colour composition) images respectively, over the same plots of tangerine trees. This example shows how strong confusion is made on the interpretation of the multispectral image only, where some tree crops can look like bare soil (1) or like homogeneously covering vegetation (2) but do not provide the information of tree presence.

- ***4.3 Spatial sharpening enhancement***

The panchromatic image shows very high level of details, such as roads, dwellings, but even individual trees as small as tangerines or trucks in the roads. This helps a good recognition of objects based on their shape, size, and also their shadow characteristics. On the other hand, the multispectral image provide information on the composition of the surface and allow the discrimination of covers like forests, grass crops, soil, tarmac, water, etc... but with high level of confusion of heterogeneous covers like tree crops. Indeed, the size of a pixel is not small enough to have pure pixels of trees and orchards look like a bare soil areas when undercover is poor or like grass crops when it is dense. Moreover, associated crops are undistinguishable with such spatial precision. This is illustrated at the Figure 6 where the same tangerine plot is displayed in the two available modes.

Figure 7: Final Quickbird satellite image mosaic used in this study,
displayed in true colours composition (blue, green and red bands of the multispectral image:
this display looks exactly as if seen by human eyes).

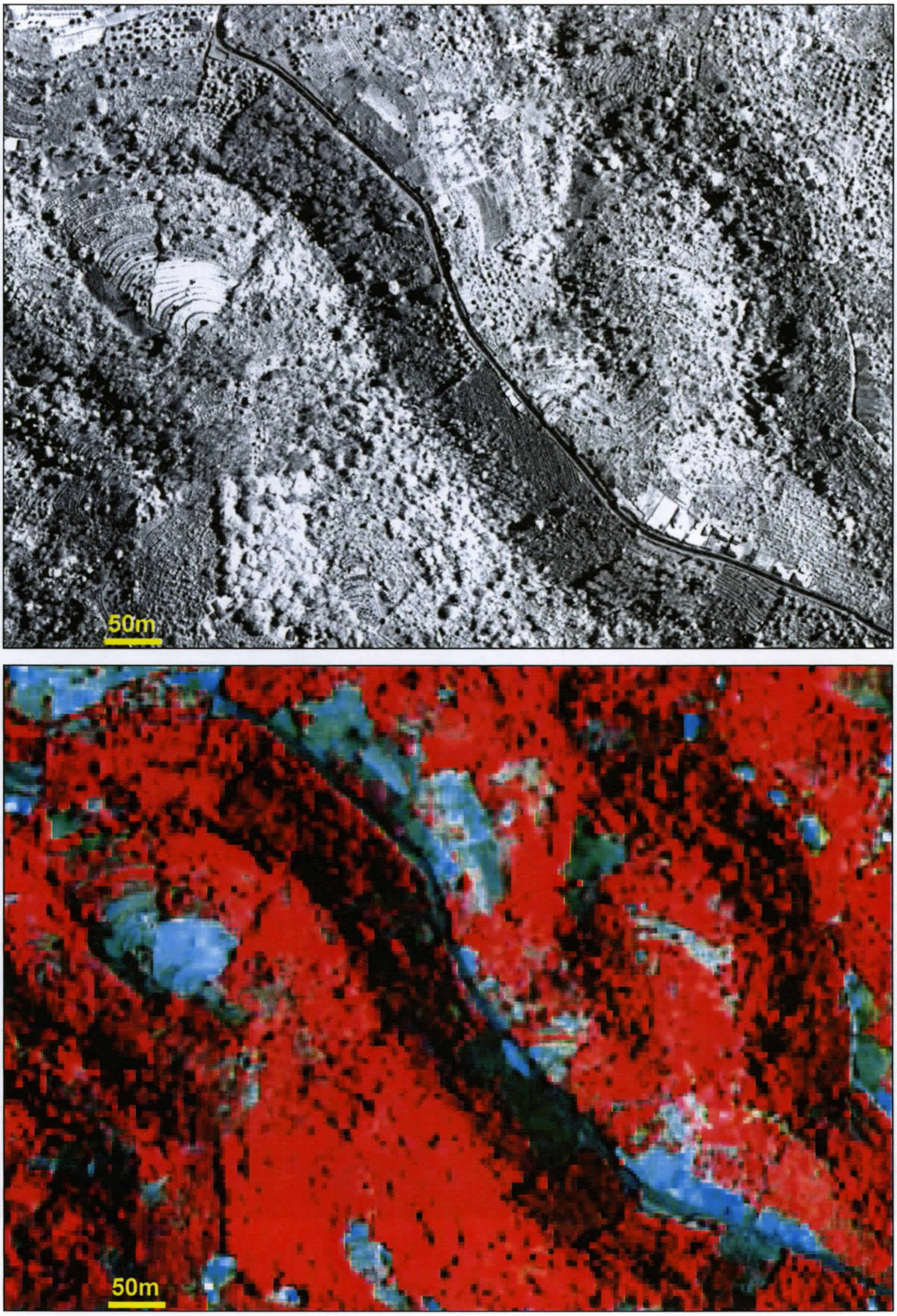


Figure 8: Same region of the image presented in the two Quickbird satellite image modes: panchromatic (up) and multispectral (bottom).
The colour composition, called as "NIR false colour", is obtained with the green, red and near infrared spectral bands and shows vegetation in red and bare soil in blue.

In order to combine the two types of information in a single image, a spatial sharpening or enhancement operation was achieved, recombining the spectral information inside the panchromatic image. A basic "HSV" model was applied because of the very high level of contrasts in the image and the huge heterogeneity of surfaces (tests were done applying a Brovey transform but results were very bad due to the complexity of the model to be used to fit any region of the image). This model transforms the image spectral bands three per three in the Hue/Saturation/Value space, substitutes the panchromatic image to the Hue channel, and transforms back the three channels in the multispectral space. Final result provides a very high spatial resolution colour image, as shown Figure 10. Unless another mode is clearly specified, this final HSV-enhanced image will be the one referred to as "the image" in the following.

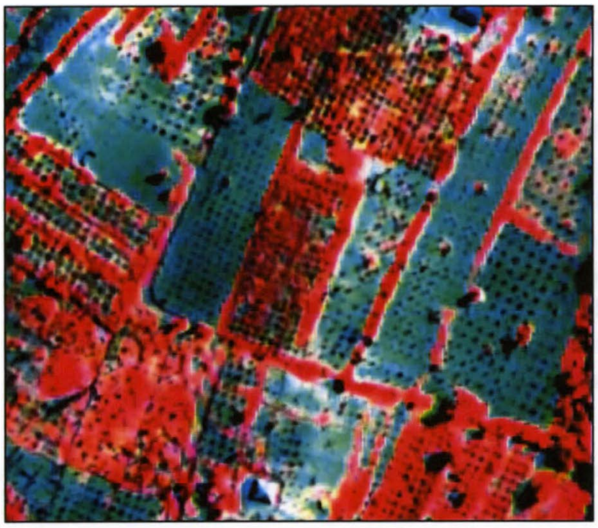


Figure 9: Result of the HSV-enhancement on the same area than presented at Figure 6, showing clearly that both spatial and spectral information are needed to discriminate between different tree crops and other complex vegetation covers.

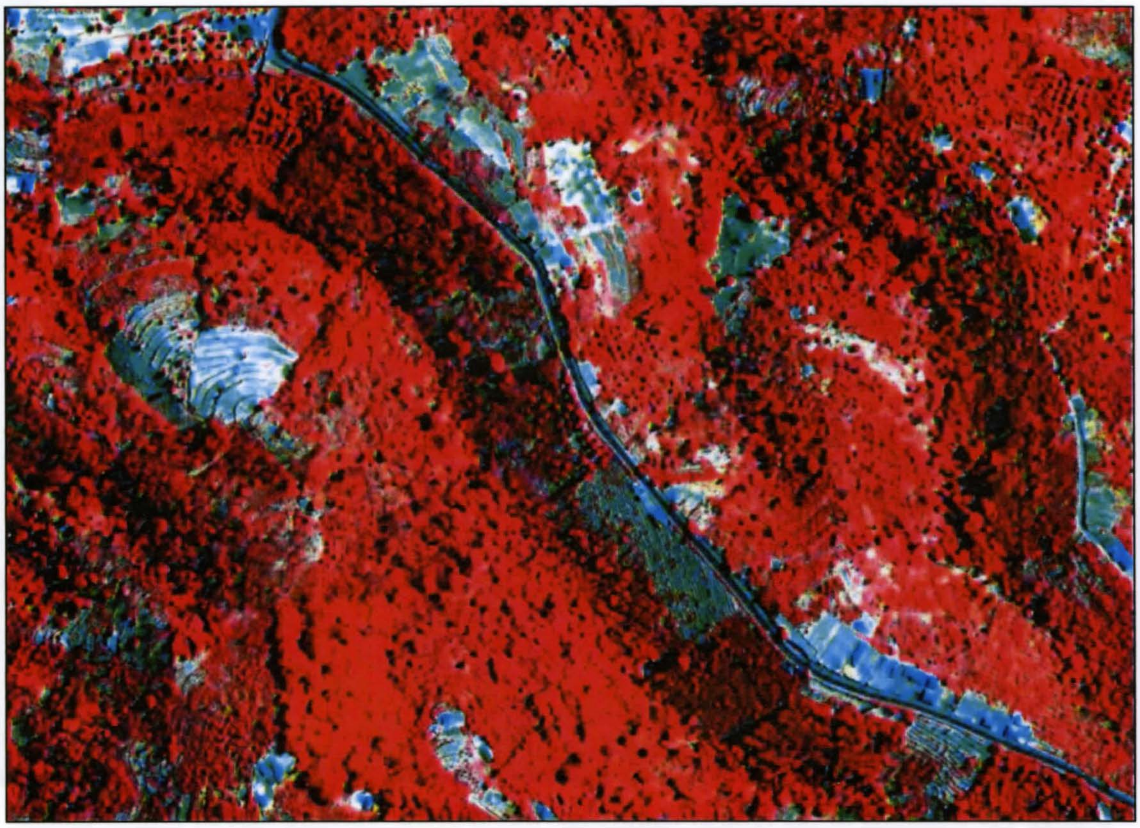


Figure 10: Result of the HSV-enhancement on the same area than presented at Figure 8.

- ***4.4 Image orthorectification and relief draping***

Quickbird satellite attitude parameters data was used combined to the Digital Elevation Model of the area to orthorectify the satellite image, so that segments and areas are correctly projected taking into account local slopes and satellite observing configuration (view angle for instance) at time of image acquisition. Objects in the image are then like reshaped, allowing to give the image an actual metrics close to the reality, useful for area measurements and statistics. It gives also the opportunity to later compare this image and resulting maps on an absolute basis with any georeferenced information coming from other sources (for instance data from Geographical Information System, sub-county boundaries, hydrography or road network, GPS measurements of interesting targets, etc...) or other orthorectified satellite images from any other sensor at any date.

The DEM itself could also be used as an information layer concerning altitude, that can be perfectly superimposed to the image or thematic maps during the vegetation cover map analysis for the "terroir" characterisation.

In addition, a 3D-visualisation tool can be used, draping the image over the DEM, to explore the image with the perspective of the relief. The possibility to "fly" or "navigate" over this scene like in a small airplane. It is illustrated by views of the image looking in two different directions on Figure 12. This helps understanding the very high complexity of the landscape in the area, ruled by hills, depths, steep slopes, ravines... and could also be a tool in itself for the "terroir" geographic indication definition. Indeed, it can be of special interest to help understanding why a given type of cropping system is concentrated in a given area or spread over the region, the spatial organisation of villages and scattered dwellings, the location of specific crops...

Figure 11: Example of the typical landscapes found in the surroundings of Banjar Kuum: hills with steep slopes, crops often organised in terraces...

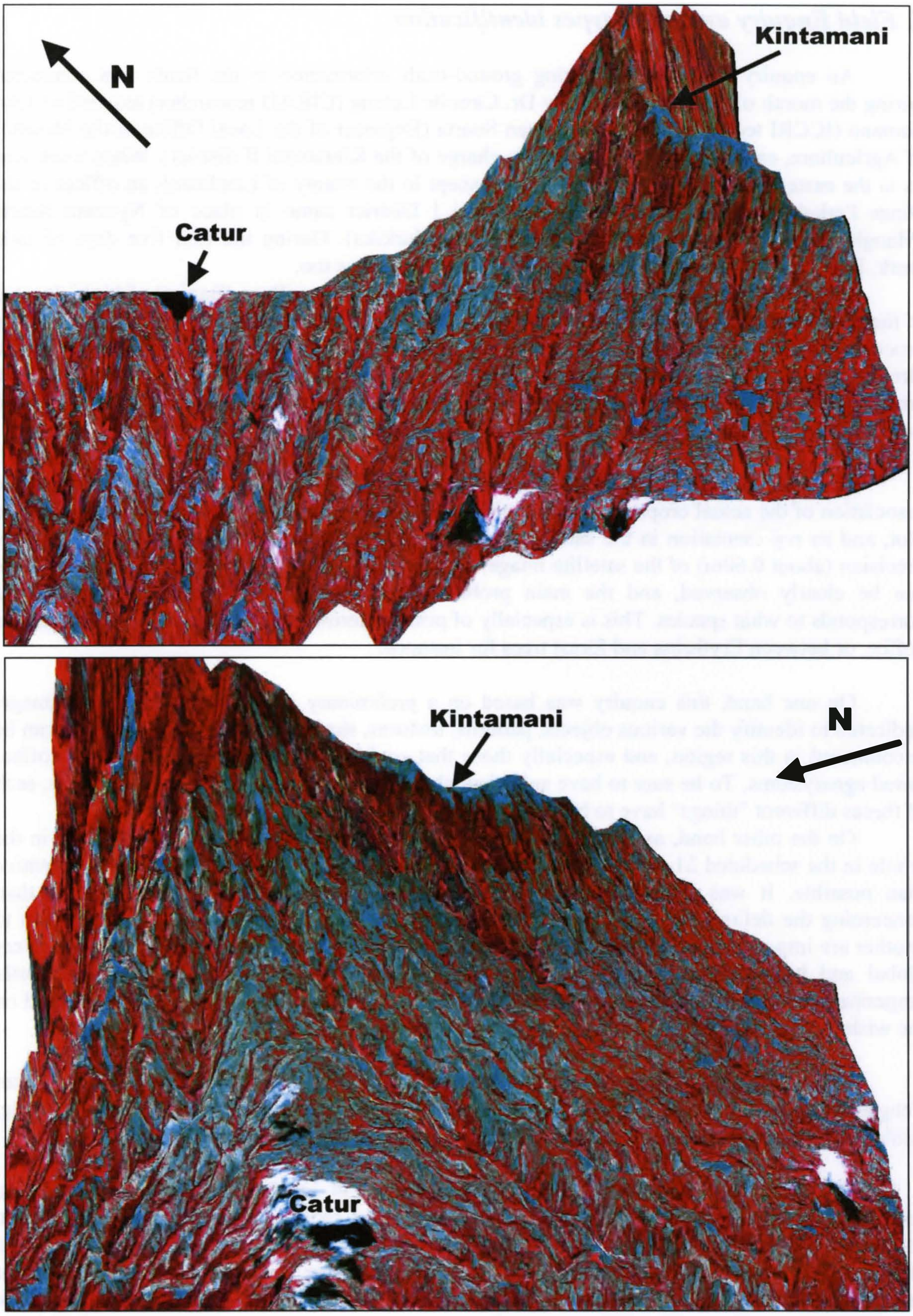


Figure 12: Two examples of 3D-views of the Quickbird image (NIR false colour composition) draped over the DEM: looking North-East (upper map) and looking East (lower map). Vertical exaggeration is factor 20: highest point is at level 1790m and lowest point at 300m.

5. Field Enquiry and cover types identification

An enquiry aiming at collecting ground-truth information in the fields was conducted during the month of September 2004 by Dr. Camille Lelong (CIRAD researcher) assisted of Joko Sumano (ICCRI technician) and I. Nyoman Suarta (Engineer of the Local Office of the Ministry of Agriculture, called Dinas Perkebunan, in charge of the Kintamani II district). When work lead us to the eastern part of the area of interest (except in the county of Lembean), an officer of the Dinas Perkebunan in charge of the Kintamani I District came in place of Nyoman Suarta (Mangku Wijaya (Directeur), Ngaka Oka, Dewa Murkika). During the first five days of field work, Dr. Surip Mawardi (ICCRI researcher) accompanied us too.

The team was based in the cooperative Muli Sarih, in the village (Banjar) of Mabi, located in the sub county (Desa) of Belantih, which lodges coffee producers and also a complete coffee processing organisation (drying, depulping, torrefaction...) where a long work of information had already been achieved about this project. This allowed both to be located near the centre of the area of study and thus a central point to go everywhere, and to experience the all-day life of the coffee producers in Bali.

This collected information is the key of the image interpretation. Indeed, it deals with the association of the actual crops present in a given plot and the type of cropping system lead in this plot, and its representation in the satellite image at very high spatial resolution. At this level of precision (about 0.60m) of the satellite image, different sizes an crown shapes of individual trees can be clearly observed, and the main problem to be solved is to understand which one corresponds to what species. This is especially of prime interest to distinguish between citrus and coffee, or between Erythrina and forest trees for instance.

On one hand, this enquiry was based on a preliminary analysis of the satellite image, dedicated to identify the various objects, patterns, textures, shapes and types of covers that can be encountered in this region, and especially those that could correspond to coffee trees or coffee-based agrosystems. To be sure to have sufficient clues to establish an interpretation scheme, each of theses different "things" have to be observed and informed in the field.

On the other hand, as the area covered by the image was impossible to be visited in the whole in the scheduled 21 days, places had to be selected carefully to be the more representative than possible. It was done following two criterions. First was dealing with the fact that, concerning the delimitation of a "terroir", the transition zones from one kind of agrosystem to another are important targets. This lead to the separation of the image in big parts following very global and basic knowledge of the Dinas Perkebunan and ICCRI agents: cloves at north, tangerine at south, big shading trees spread almost everywhere... Second criterion was based on the wish to locate the limits of arabica and robusta growth transitions.

Finally 21 sub-counties (Desa,) of the county of Kintamani were visited: Abuan, Batur Tengah, Bayunggede, Belantih, Belok, Belok Sidan, Bonyoh, Bununtin, Catur, Daup, Katung, Kintamani, Lembean, Maniklyu, Mengani, Satra, Sekaan, Sekardadi, Selulung, Serahi, Tajun.

760 plots, corresponding to about 334 hectares (3.34 square kilometres) were enquired and several kinds of information recorded: all the different crop species present inside the plot, from ground food crops to big trees and other shading trees, distances between rows and between trees in a row when existing row crops (coffee, cocoa, tangerine, banana, shading trees), relative proportions of different associated crops when any, characteristics of shading cover (open or closed canopy, dense or little foliage, regular or heterogeneous...), overall management, etc... Details concerning all the different species of covers and agrosystems encountered during the field campaign and relative proportion of visited plots are given at *Table 2*, excluding forests that were only spotted but not delimitated in the fields. Types of possible associations are listed, and

possibility to discriminate between the different canopies is discussed in this table. The *Table 3* gives some details concerning associations of different crops with big shading trees that were encountered during the field campaign. These proportions can help giving an idea of the proportion of coffee cropped under large shading trees but is probably an overestimation of this proportion. Indeed, the field campaign was actually oriented to find and map coffee crops, and we preferentially stopped in plots containing coffee trees to record information on them. It thus can only give a maximum of the actual proportions of coffee growing under shading trees.

Exact location of visited plots was drawn directly on paper prints of the satellite image, thanks to the facility of recognition of houses, roads, big trees, and shape of parcels to be confident in the localization of the plot. In addition geographical coordinates of each plot were measured by a GPS Garmin 3+.

At the same time, introduction and explanations were given to the farmers, showing them the satellite image paper prints and especially their own house and location of their plots, objectives of the cartography, introduction of the project of geographic indication of the arabica coffee terroir, and so on... Also questions could be asked about former cultivations the previous year (time of image acquisition) when the reality seemed to mismatch the image of the plot, and helped to understand possible differences.

Sampling of soil was achieved by Joko Sumano (see Figure 13) in some plantations of coffee where berry sampling for sensorial analysis were formerly done, in the aim of laboratory analysis of the chemical and physical properties of the different soils.

Most of the work was done by feet, walking through the parcels and taking notes, while the longer distances separating Mabi from the places to visit were covered on a small motorbike.

Figure 13: Soil sampling by Joko Sumano (ICCRI) in a coffee plantation located in Kembangsari

Forests

Mainly two kind of forests are found:

- *Primary rain forest*, mostly constituted in various proportions of: giant bamboo, various ficus trees, legumes, bracken ferns and a rich biodiversity. Some forests only constituted of giant bamboo are largely found too, most of them following rivers.
- *Conifer forest*, found on the east, west and south slopes of the volcanic crater associated with the Mount Batur and on the rim of which are located Kintamani and Batur towns..

Large shading trees agrosystems (about 50% of visited plots)

- 3 main species are found, alone or in association with one or two of the others:
  - *Erythrina* spp.
  - *Leucaena* spp.
  - *Albizia* spp.
- Big trees are sometimes found, isolated and scattered among the main species, like for instance (non exhaustive list):
  - Jack-fruit
  - Avocado
  - Mangosteen
  - Coconut or other palm trees
  - Ficus (fig trees) and banyan trees
- 3 secondary species are sometimes found as smaller trees associated with the main species (never as a main cover):
  - Calliandra
  - Melia
  - Gliricidea

These trees can be used for cattle food (e.g. Leucanea) or for wood carving (e.g. Albizia). They are mostly used to provide shade for arabica, robusta, cocoa, tangerine, or even for banana and other food crops or for associations of some of those crops. Plots can be as complex as unorganised canopy of mixed erythrinas, albizias and leucanenas providing shade to a mixture of arabica, robusta, tangerine and food crop. Although, these large trees are traditionally associated to the coffee culture and this is more or less confirmed by field observations even if the enquiry was biased by the research of arabica coffee plots. *Table 3* gives the details of relative areas planted by the different shaded crops under this class of cover among the visited plots.

- These trees can be pruned at different levels and densities, and planted at different spacing, providing a large variability of canopies and thus of responses in the satellite image.
- Discrimination between Erythrina, Leucaena and Albizia on the image is often possible but not in most of the cases.
- Discrimination of these covers with rain forest is sometimes difficult, especially when found at the border of this latter, and information like tree shadow (related to the size of trees) or overall density can be useful to distinguish the limits.
- Detection of underlying crops is impossible and the associated amount of coffee/non coffee planted areas can only be estimated through probabilities given by the field enquiry, keeping in mind that these probabilities are biased by the research of coffee plots and thus overestimated in the direction of coffee (cf. *Table 3*).

Nb. of possible vegetal layers = 2 to 6 / Nb. of productive layers = 1 to 5

Clove-based agrosystems (about 10% of visited plots) These trees are cropped for the flower, used as spice and smoking material. They can be cropped alone, or can be associated with arabica, robusta and/or cocoa. The proportions of these crops encountered in the fields are given at the *Table 4.* ▪ Discrimination with other large trees is very easy thanks to the typical shape of cloves in the satellite image (big separated circles like bubbles) even though the great variability in size and spacing. ▪ Detection of underlying crops is impossible and presence of arabica can only be estimated through the probabilities given by the field enquiry like for arabica shaded by other large trees. ***Nb. of possible vegetal layers = 1 to 3 / Nb. of productive layers = 1 to 2***
Citrus-based agrosystems (about 26.7% of visited plots) Most of the cropped citrus in this area is Tangerine, but Grapefruit and Lemon are also largely cropped. Discrimination between these three species is almost impossible on the satellite image. They can be cropped alone on bare soil or with weeds, or associated with food crops (*Tangerine alone or with totally pruned Erythrina ~1.2% of visited plots).* They are also often associated with arabica coffee (*Tangerine with arabica ~25.5% of visited plots).* Coffee trees under tangerine can be detected thanks to the discontinuities in the tangerine canopy, especially due to non connecting rows, and to the change in the regular structure of tangerine organisation. Tangerine can also be intercropped with drastically pruned erythrinas that provide no shade but can be confused with arabica on the satellite image. There is a wide range of variability in the tangerine associated or not with other species, that will be further discussed in this report. ***Nb. of possible vegetal layers = 1 to 6 / Nb. of productive layers = 1 to 5***
Arabica in monocrop (about 2.6% of visited plots) Among the whole of the visited plots, only one was found of arabica mono-cropped without any other vegetation species (in Desa Belantih). Some plots were found with very few and pruned Erythrina, and very few citrus, or with holes in the shading canopy, that can be interpreted in the image as pure arabica plots..
Robusta in monocrop (about 0.2% of visited plots) Some plots of robusta were found with very few and pruned Erythrina, that can be considered as monocrop.
Cocoa in monocrop (about 0.3% of visited plots) Some plots of cocoa without any shade were found (in Desa Lembean).
Food crops agrosystems (about 10% of visited plots) Many different species of food crops are found in the area, but are mainly the following: rice, corn, chilli, sweet potato, beans, yam, tomato, banana, tobacco. Discrimination is possible between row crops (e.g. chilli, tomato, some beans), paddy rice, banana and the other kind of crops but is not of any use for this study. Thus all types of food crops are put in a single thematic class in the map.

Table 2: List of agrosystems encountered during the field campaign and proportions of corresponding visited plots.

Figure 14: Surip Mawardi (ICCRI) introducing the remote sensing work and displaying the satellite image of the surroundings to the coffee farmers in Desa Kembangsari

Figure 15: Nyoman Suarta (Dinas Perkebunan Kintamani) and Camille Lelong (CIRAD) riding motorbike during the field work in Desa Bon.

Arabica	46.3 %
Arabica and robusta	5.4 %
Arabica and tangerine	17.5 %
Arabica and robusta and tangerine	2.4 %
Robusta	7.2 %
Tangerine	14.8 %
Food crop or fallow land	6.0 %
Cocoa (possibly with few arabica)	0.5 %
Total of surfaces planted with arabica	***71.5 %***

Table 3: Proportions of crops shaded by large trees (Erythrina, Leucaena, Albizia) in the set of visited plots.

Arabica	27.0 %
Arabica and robusta	3.9 %
Arabica and robusta and cocoa	0.8 %
Robusta	13.8 %
Robusta and cocoa	48.4 %
Fallow land	6.1 %
Total of surfaces planted with arabica	***31.7 %***

Table 4: Proportions of crops shaded by cloves in the set of visited plots.

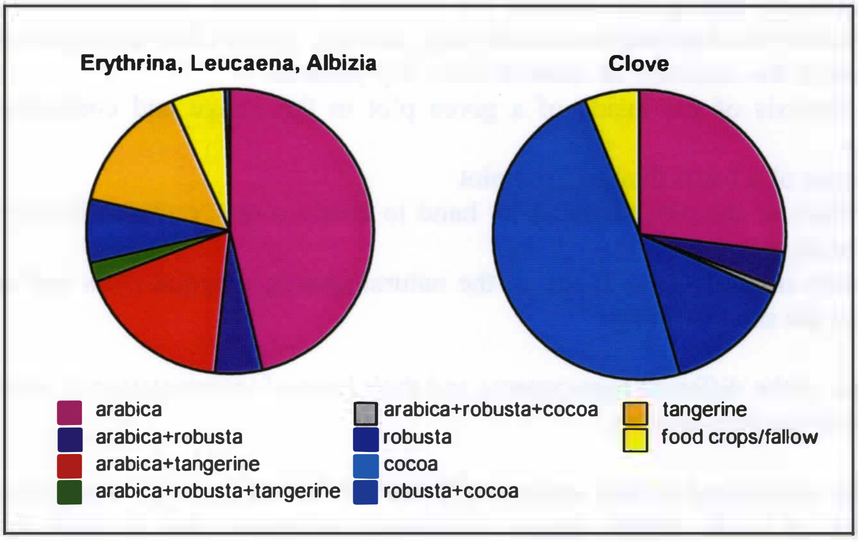


Figure 16: Distribution of the visited crops shaded by large trees and by clove respectively.

6. Computer assisted photointerpretation for agrosystems mapping.

Usually in remote sensing, land cover or land use is mapped thanks to automatic classifications based on radiometric and/or textural profiles statistics. In the present case, such classifications were attempted on the basis of themes corresponding to the main cover types, identified during the field campaign: forests, big shading trees, tangerine in monocrop, tangerine associated with arabica, food crops and dwellings. Unfortunately, these types of covers are very difficult to discriminate in an automatic process even in a very high resolution satellite image. Objects are very detailed and thus very complex and usual methodologies are not adapted yet to such research of information.

Several classical supervised and unsupervised classifications of different kinds, including Maximum Likelihood of radiometric signatures and of textural indices derived from the cooccurrence matrix, were tested, leading to a huge amount of confusion and errors of both thematic assignation and areas delimitation. This might be due to the very accurate criterions that help defining classes such as tangerine in one hand and tangerine associated with coffee in the other hand, or as another example forest trees and large shading trees like Erythrinas or Albizias.

Although, it can seem obvious that any trained observer can interpret the cover types much better than the computer softwares do. This comes from the capabilities of human brain to merge different kind of information like shape of objects, of their shadow, their density, the regularity of objects alignments, the interlaying of different objects very similar but having little differences, the context of connecting plots, and so on... That is probably why the photo-interpretation is still today the more accurate method to classify complex vegetation covers like found in the Kintamani area of Bali.

Computer assisted photointerpretation consists in the following sequence of actions:

a) definition of a list of themes, corresponding to the main agrosystems present in the area, on the basis of the field campaign information analysis,
b) creation of a vector layer for each theme,
c) creation of keys of interpretation associating each theme with corresponding image representations taking into account the eventual variability of characteristics related to a single theme (for instance tree crown size, density, spacing between trees, undercover...): this leads to the selection of identification key patterns
d) visual analysis of the inside of a given plot in the image and comparison to the key patterns
e) assignation of a listed theme to the plot
f) delimitation of the plot contours by hand to create a new polygon in the corresponding vector layer,
g) application of steps d) to f) for all the natural spaces, cropped plots and other anthropic places of the satellite image

The analysis of the different agrosystems and their keys of interpretation in the satellite image are developped in the next section.

For the area considered in this study (~220 km^2 or 22000 ha), this work consisted in more than 700 hours of work, which means a colossal enterprise that is only justified by the impossibility to produce a map by other means.

At the end, the ground truth knowledge is also added to the interpreted vector layers to complete the map, and the whole of those is rasterized as a classification image. The result is shown on Figure 46 for the entire area covered by the satellite image.

7. Vegetation cover types identification

This section aimed at giving an idea of how the work of interpretation of the image was achieved and illustrates remarks concerning the possible keys and limits for this interpretation.

It is obvious that several patterns of objects in the satellite image are associated with a single class of cover, due to the variability in size and shape of a given tree species, leading to various crowns morphologies. On the other side there will be some patterns that look similar but correspond to different types of covers and will lead to a confusion and classification errors. In addition, the image of a given species cover is affected by the spatial organisation of the plot, including tree density, level of vegetation heterogeneity (including possible mixtures of different species) and steepness of slopes. All these parameters have to be taken into account to avoid some confusion and to lead to the more accurate map than possible.

Height kinds of covers, corresponding to seven different agrosystems plus forests, has finally been identified as clearly interpretable in the image and selected as agrosystems themes of the image classification and mapping:

- Clove, in monocrop or associated with any other crop (coffee, cocoa...)
- Dense shading by large trees (Erythrina, Leucaena and Albizia)
- Cocoa without shading
- Citrus, and especially tangerine, in monocrop
- Food crops (rice, corn, vegetable, tobacco, banana...)
- Arabica cultivated under citrus, and especially tangerine
- Arabica without shading
- Forests (Primary rain forest and conifer forest)

Table 5: List of the 8 themes selected for the agrosystems mapping in the region of Kintamani.

- ***7.1 Clove***

Clove trees can be cut in a regular cylindrical shape, or let grown naturally in a conic shape (cf. Figure 17). In the first case the clove crown projection is a smaller disk and it seems more separated from the others than in the second one. Figure 18 to Figure 22 illustrate samples of the Quickbird image showing parcels visited in the fields and taken as reference for the "Clove" class identification.

- ***7.2 Large shading trees***

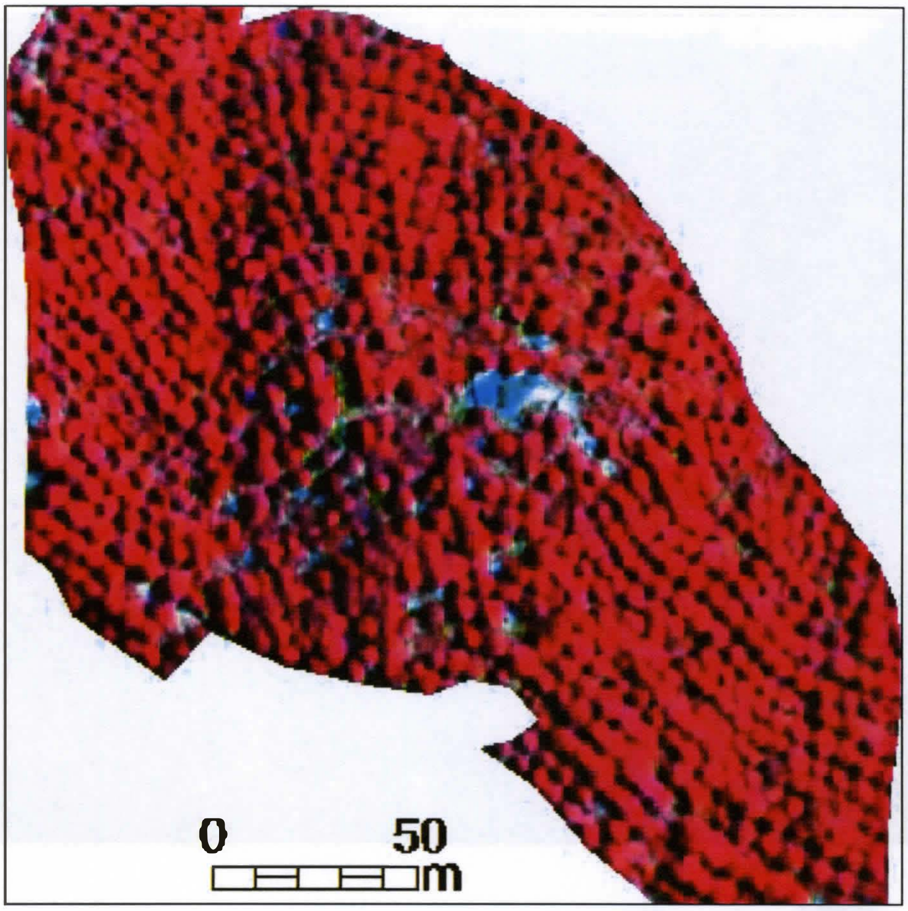
Erythrinas, Albizias and Leucaena are found in many different configurations: they can be planted alone in a plot or in associations, they can be pruned or let grow, and they have different ages so that their crown dimensions vary a lot. These species look very similar from above and at the spatial resolution of the satellite image, except in some cases where the identification is possible. Nevertheless, the need for this level of detail in the cartography is not yet justified and these three species were thus put in a single thematic class called "large shading trees".

Their canopy can be so much dense and thick that light does not penetrate it, and plots look more than a forest than a cultivated area. Nevertheless, some accurate observations can help distinguish this cover from natural forests due to the traces of organisation inside the parcel: trees are more or less still regularly aligned.

Figure 23 to Figure 29 illustrate samples of the Quickbird image showing parcels of Erythrina, Leucaena and/or Albizia visited in the fields and taken as reference for the "Large shading tree" class identification.

Figure 17:
Two different shapes of cloves trees encountered around Banjar Kembangsari:

- cylindrical cut (up),
- conic natural growth (bottom).



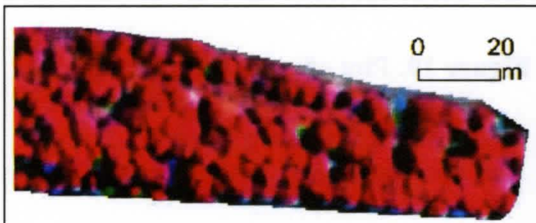


Figure 18: Plots of conical cloves

1. shading arabica coffee planted on steep slopes (up),
2. cropped without undercover on terraces (down and right).

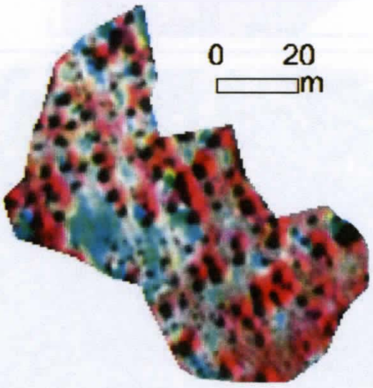


Figure 19: Plot of cylindrical cloves shading arabica coffee crops, planted on steep slope and presenting gaps in the canopy.

Figure 20: Plot of cloves shading robusta coffee plantation.

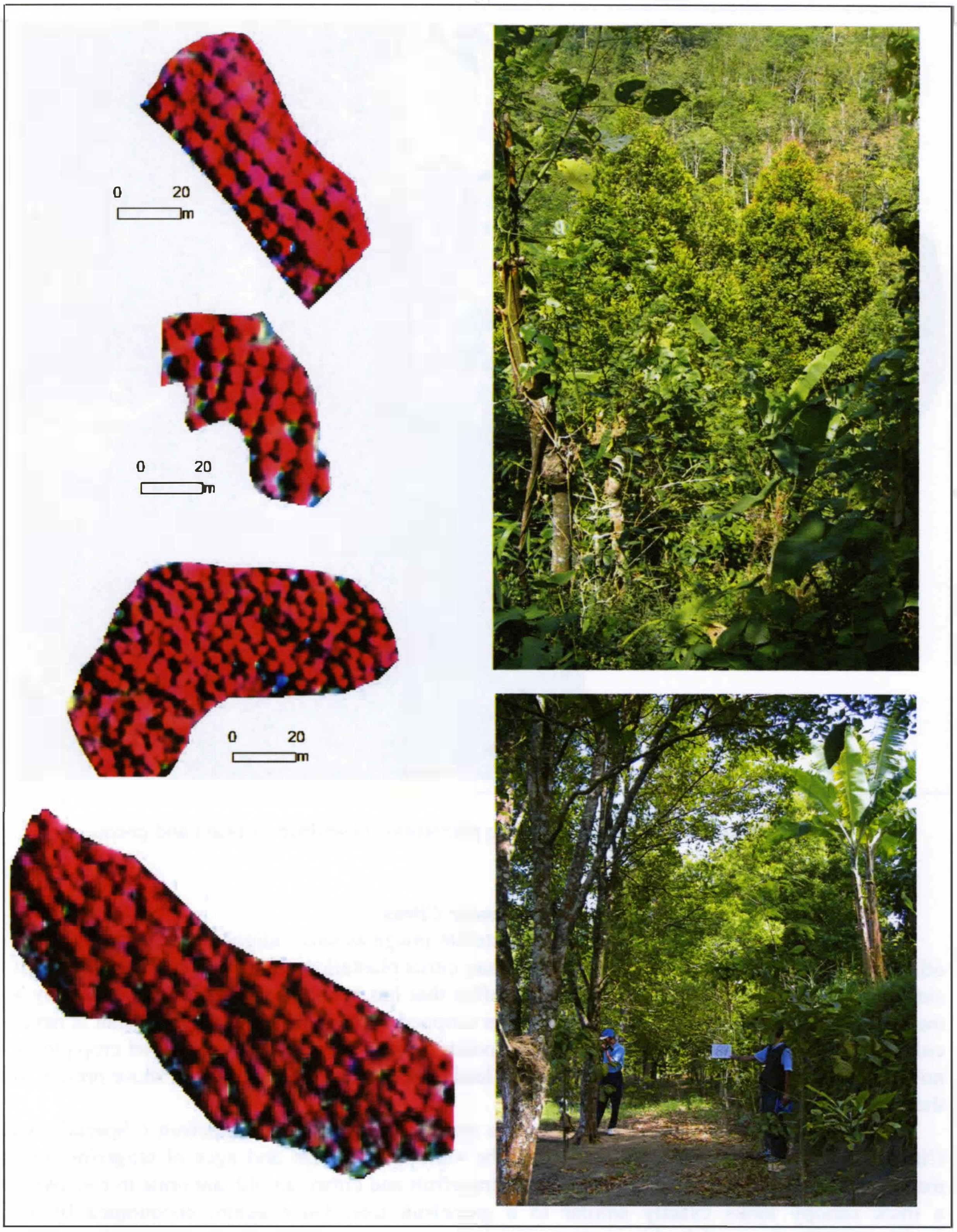


Figure 21: Dense plots of conic cloves shading arabica and robusta coffee crops.

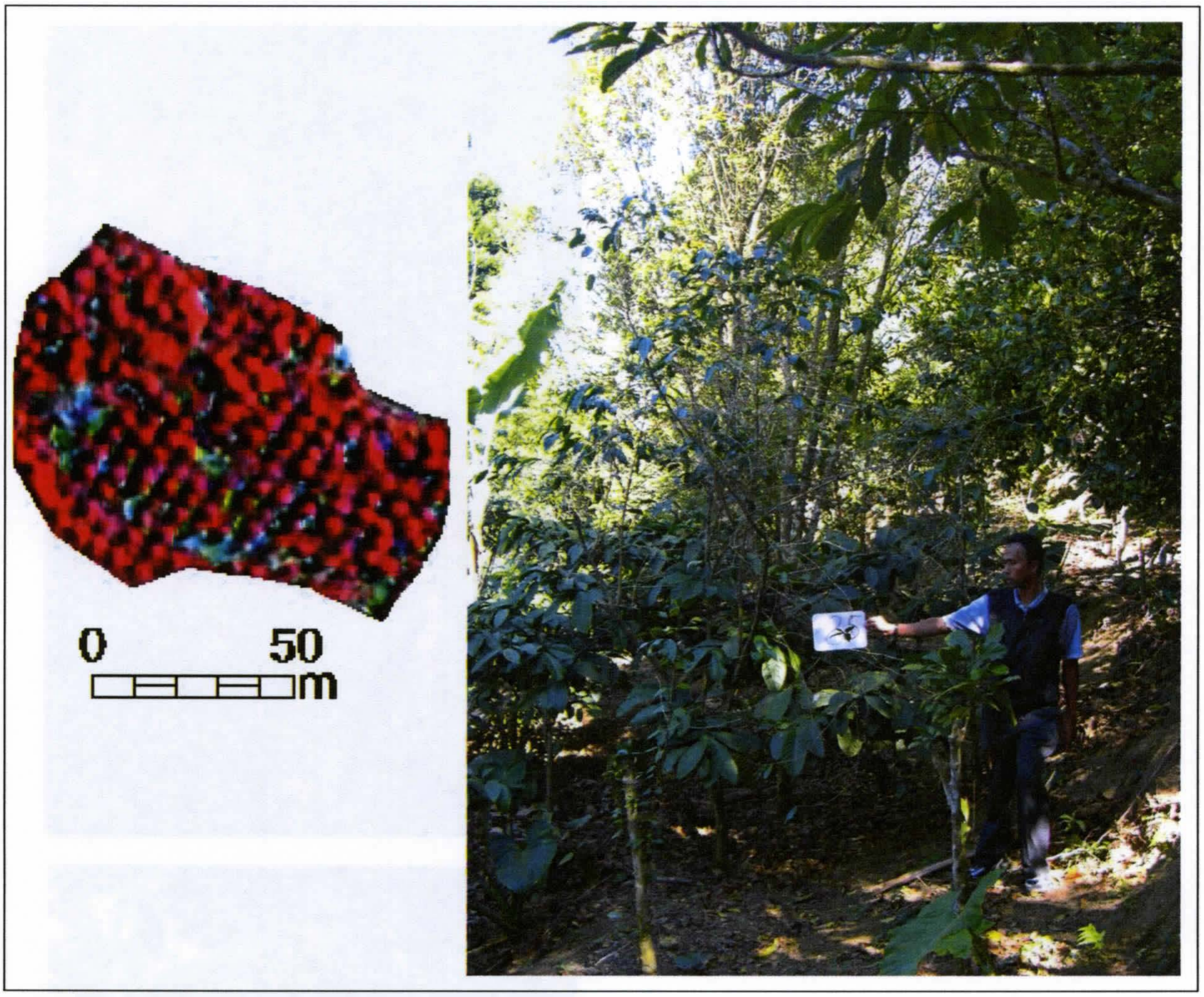


Figure 22: Plot of conic cloves shading plantations of arabica, robusta and cocoa.

- ***7.3 Citrus and Arabica cultivated under Citrus***

Citrus are easily distinguished in the satellite image as small aligned dots. Although, any other orchards might probably look the same than citrus plantations as long as tree crowns are of similar diameter. Hopefully, except arabica coffee that has smaller crown, cocoa that display a more fuzzy alignment pattern and is hardly ever cropped without shade, and banana that is never cultivated as intensive monocrop in this area (mostly planted as scattered tree in food crop plots), no other orchard tree is cropped in this area. It lead to the assumption that any of those present in the image were citrus plantations.

Citrus cropped in the area of study are mainly tangerine, then grapefruit ("Special Bali Citrus") and sometimes big yellow lemon. The variability in size and ages of tangerine trees makes it impossible to distinguish them from grapefruit and citrus: an old tangerine tree showing a thick canopy looks exactly similar to a grapefruit tree. Once again, encouraged by no justification for the need in this study to discriminate between different citrus species, a single class "Tangerine" was selected.

Figure 32 to Figure 35 illustrate samples of the Quickbird image showing parcels of Tangerine visited in the fields and taken as reference for the "Large shading tree" class identification. They illustrate too the big variability of contexts encountered in tangerine crops in terms of age, size, density, spacing, regularity of alignment, undercover, slopes...

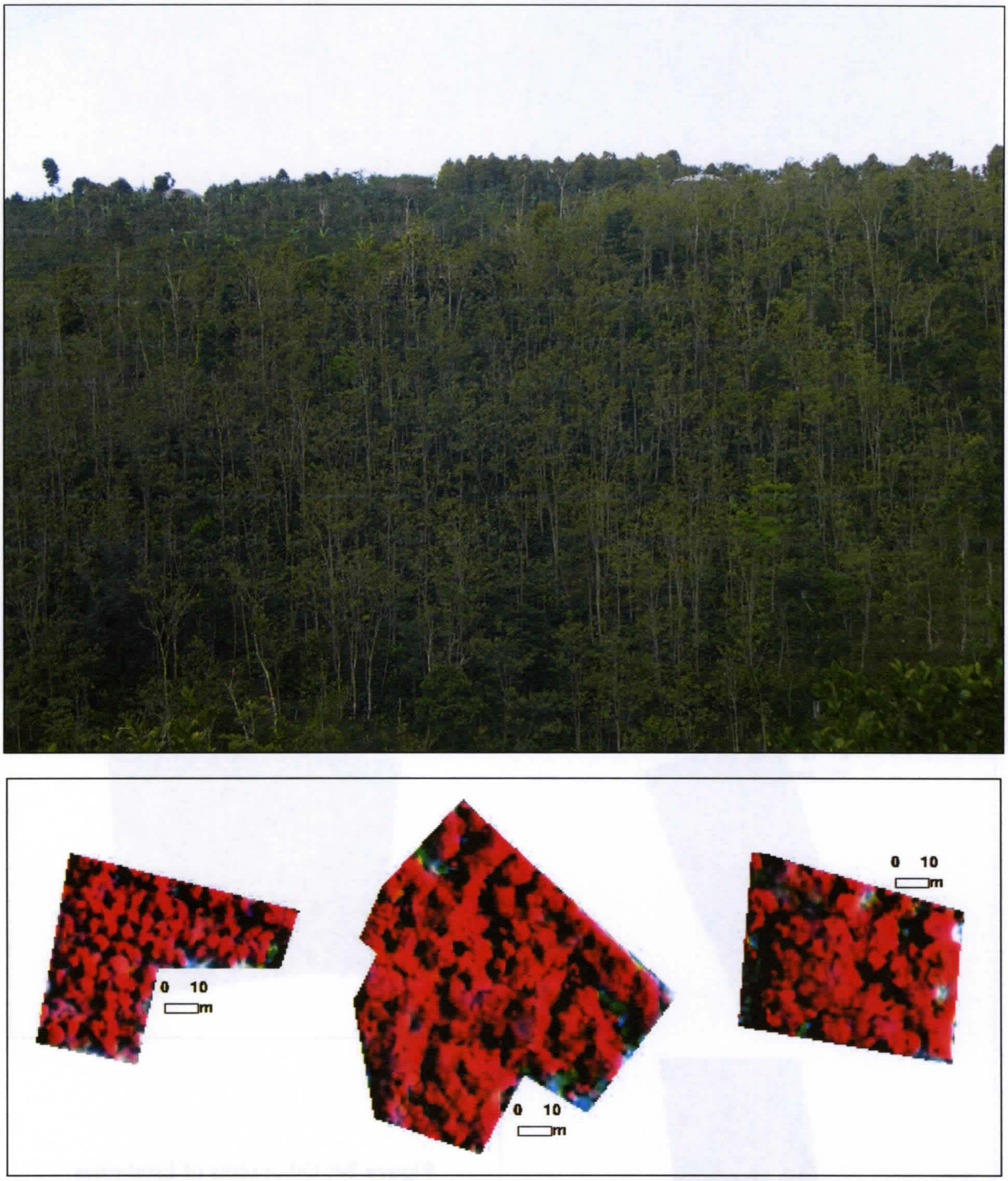


Figure 23: Plots of dense Erythrinas of different crown sizes.

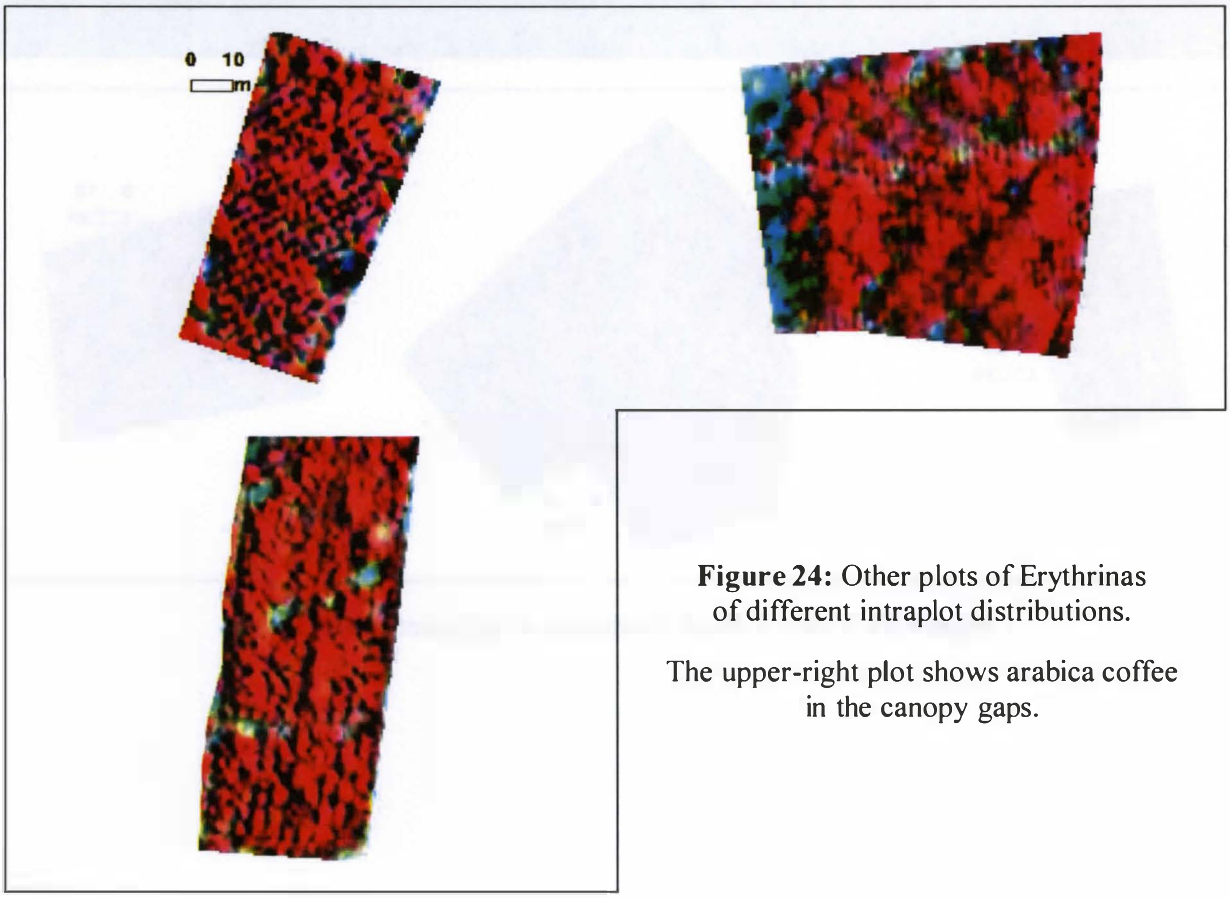


Figure 24: Other plots of Erythrinas of different intraplot distributions.

The upper-right plot shows arabica coffee in the canopy gaps.

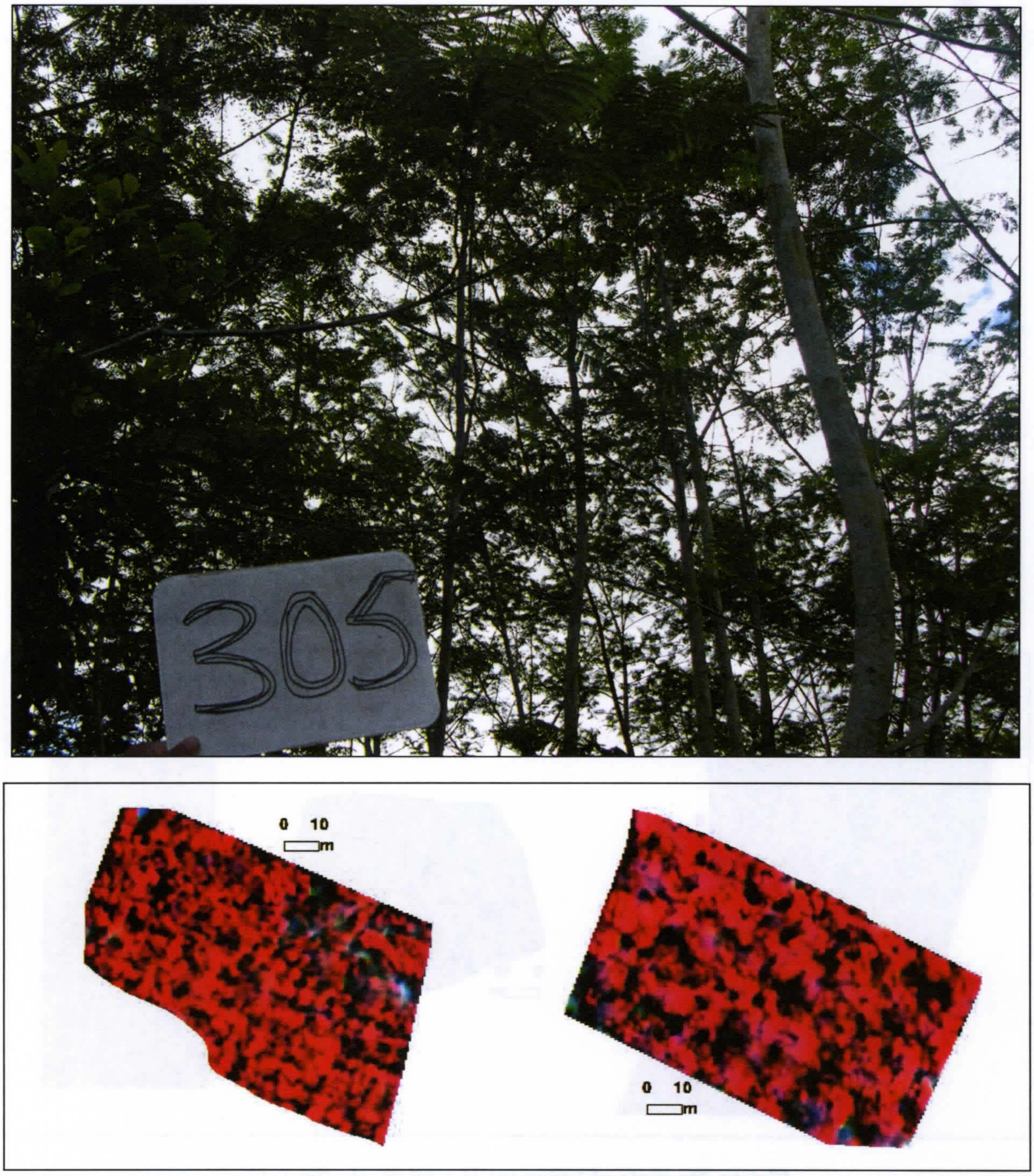


Figure 25: Plots of mixed Albizias and Erythrinas.

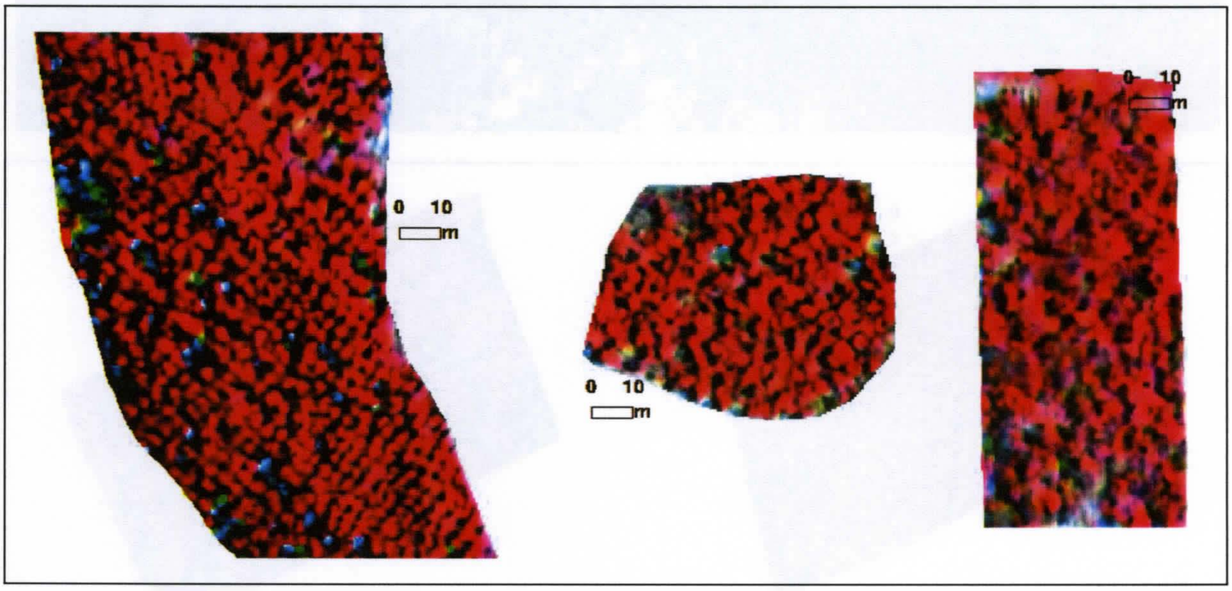


Figure 26: Plots of Leucaena in a relatively flat area.

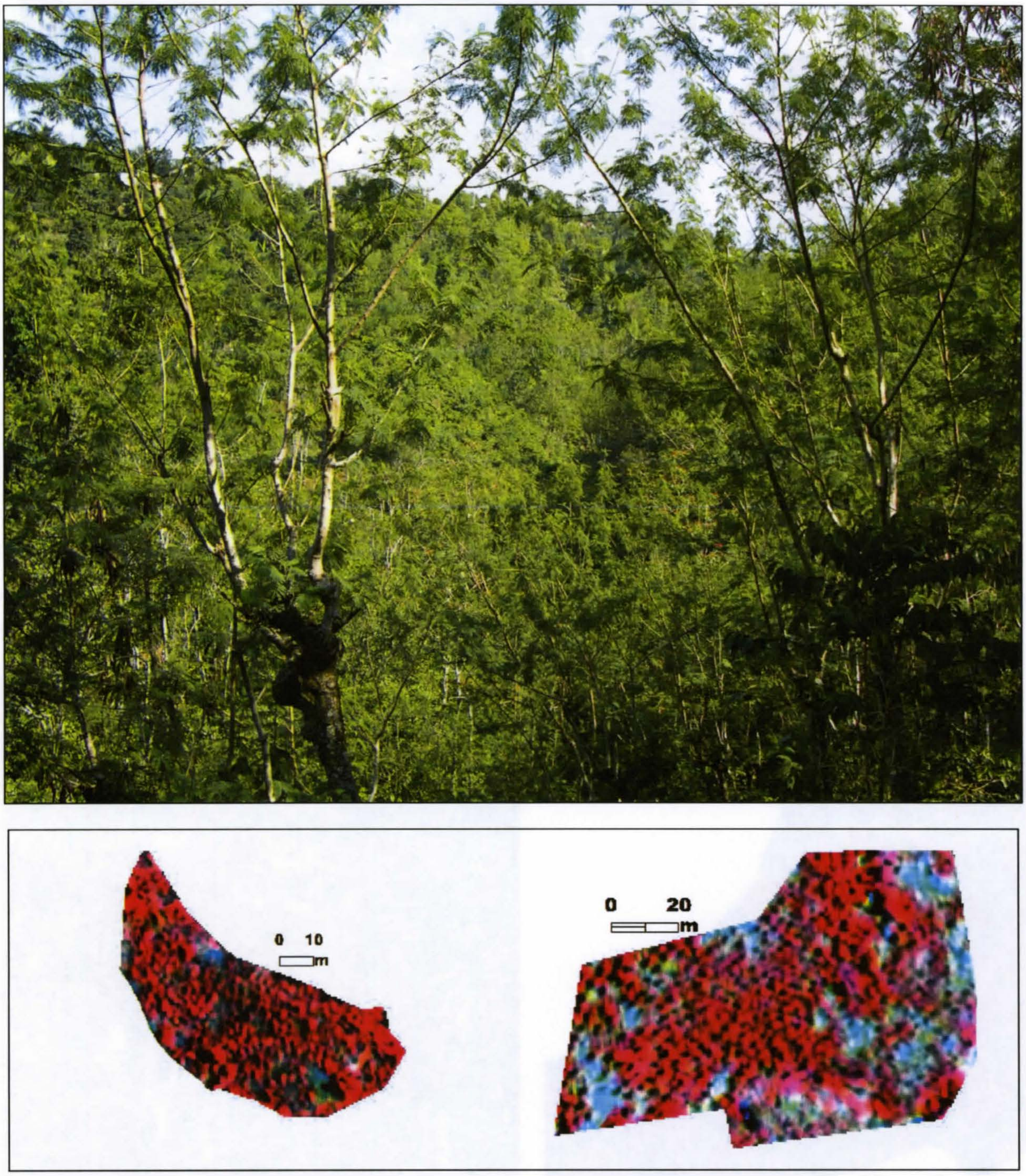


Figure 27: Plots of Leucaena planted on steep slopes.

Figure 28: Plot of Leucaena heterogeneously planted shading a mixture of arabica, robusta, cocoa and other legumes.

Figure 29: Plot of a heterogeneous mixture of pruned Erythrinas, Leucaenas and Gliricideas, shading arabica invaded by weeds.

Figure 30: Large view of tangerine monocrop cultivated on slopes in Desa Daup.

Figure 31: Tangerine harvest in Desa Bon.

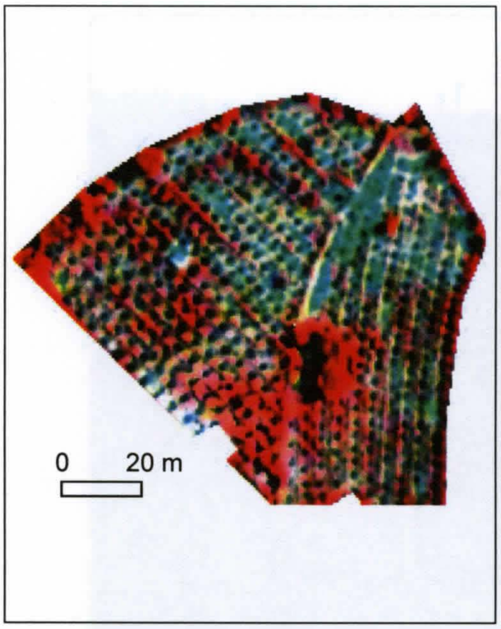



Figure 32: Tangerine monocrop on bare soil.

- Left part of the plot (see upper photo) has no terrace but some young and cut Erythrina.
- Right part of the plot (see bottom photo) is organised in terraces without shading tree.

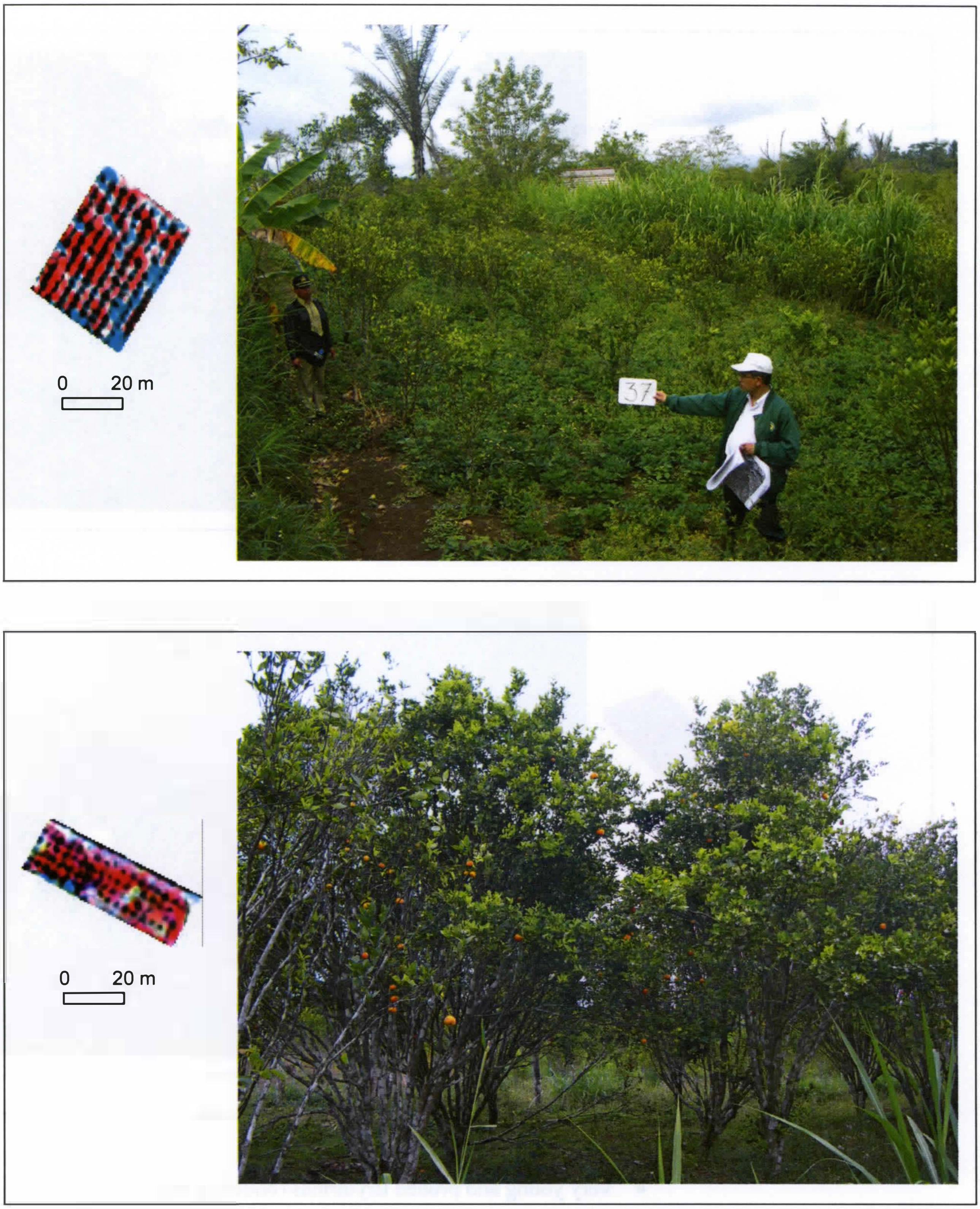


Figure 33: Tangerine monocrop on weeds or on food crops.

- Upper plot is composed of very young tangerine trees.
- Bottom plot has randomly distributed old and younger tangerine trees.

Figure 34: Tangerine trees on bare soil, intercrop with:

- small bushes (upper plot),
- very young and pruned Erythrinas (bottom plot).

Those little trees can be confused with coffee trees on the satellite image.

Figure 35: Tangerine trees having small crowns and large spacing, on weeds, under Leucaena.
This plot may not be clearly identified as tangerine crop in the satellite image.

Figure 36: Tangerine trees with old coffee trees on weeds.
Both canopies are not too dense and do not overlap each other.
Each tree should be seen individually but coffee trees are undistinguishable on the satellite image.

One gaming of this cartography by photointerpretation is to identify the plots where arabica coffee is planted under citrus. Indeed, the density of the tangerine canopy can be too dense and the spacing between each tree to small to see the coffee trees in the gaps. It is very difficult to estimate how many plots containing arabica are missed by the photo-interpreter because a sample test constituted of visited parcel was satisfyingly recognised. Thus the resulting error in the cartography might be very low.

Most of the time, coffee crop is only distinguished by the blurring of the tangerine alignment pattern provoked by the presence of underlying coffee trees. In rare cases coffee trees are clearly seen, showing a different motif of aligned dots.

Presence of much pruned Erythrinas or other bushes intercropped with tangerine, or thick an discontinuous undercover (beans, weeds...) can be confused with the presence of coffee trees, leading to an error in the cartography. Interpreter estimation of this error based on a sample test is of about 10%, which means that 10% of the plots assigned the class "Arabica under tangerine" are only tangerine in monocrop.

Once again, the variability of contexts encountered in the field is huge, as illustrated by the Figure 36 to Figure 40, showing the visited plots taken as reference for the photo-interpretation of the Quickbird image.

- ***7.4 Arabica without shade***

Only one single plot of Arabica coffee monocrop without shade was encountered during the field campaign (near the village of Belantih) and is presented at Figure 41. It is probable that such other crop exists in the perimeter of interest and was missed but it seems that it is rarely practiced.

The pattern of pure coffee plantation is very typical and can be easily distinguished from the citrus one: smaller and closer dots which seem more square than circular, great homogeneity of the parcel in planting density and crown size. It is clearly seen for instance in the first plot displayed at Figure 37 where tangerine trees are very thin and almost invisible except the bigger ones. This pattern is identified in some places in the satellite image (near the villages of Belantih, Lembean and Lawak), mostly in big gaps between large shading trees but even over a whole plot. These plots have thus been assigned the class "Arabica".

- ***7.5 Food crops***

Plots of food crops does not show any texture and are thus very recognizable. They can be thick and much covering (e.g. grown corn, rice, vegetables) and will appear as reddish surfaces, or non-covering (e.g. young plants, sweet potato) and will appear as blue. Paddy rice fields are also very easy to distinguish because the presence of water gives a specific dark green or purple colour to the plot. Row-crops like chilli display a texturally flat image too but with slight parallel lines, and are impossible to miss. Figure 42 and Figure 43 give some example of those crops. Further mapping could separate row-crops from isotropic ones if this was of interest for the study.

- ***7.6 Forests***

Forests pattern in the satellite image is characterised by an heterogeneous mixture of big trees without any organisation (cf. Figure 44 and Figure 45). They are very easy to distinguish except from some dense shading trees, where distribution of crowns size, density of shadows and heterogeneity have to be further analysed to help the discrimination.

Primary rain forest and bamboo forests cannot be distinguished from each other on the image. Conifer forest display a different pattern from these others as long as the slope is not too strong. On steep slopes it is very difficult to discriminate between both kind of covers, and this case occurs very often. The interpreter thus chose to assign only one class for all the different kind of forests. Although, this could be improved if the information was needed, especially as a clue for climate changes in the area (related also with the altitude and exposition to winds).

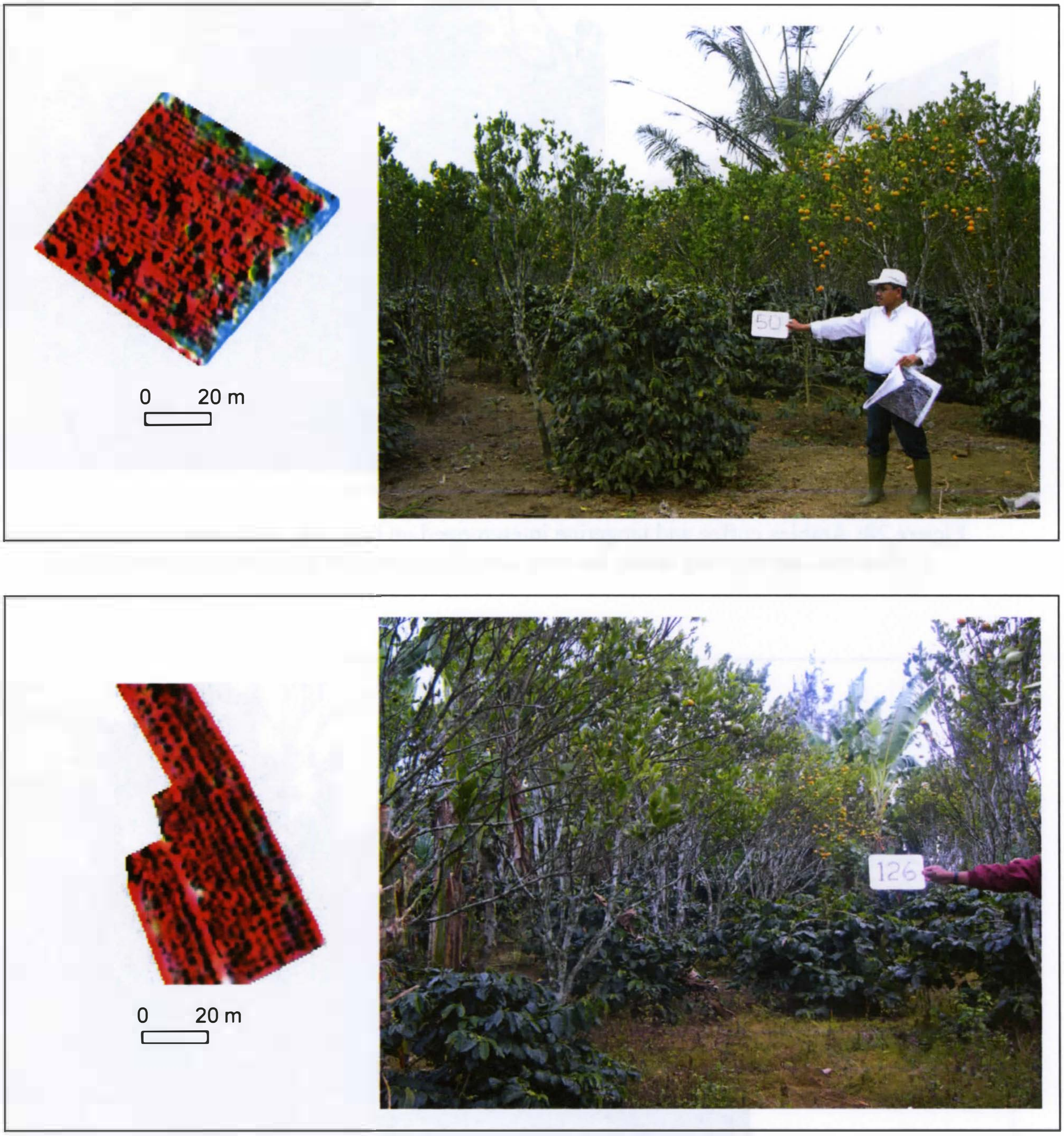


Figure 37: Arabica coffee and tangerine intercropped on bare soil.

- upper plot has thin tangerines and very thick clumped coffee trees. The aligned objects seen in the satellite image are the coffee trees.
- bottom plot shows almost continuous lines of tangerine canopy and coffee trees as spots in between.

Figure 38: Arabica coffee and tangerine intercropped on bare soil, with some scattered banana. Coffee trees are not very dense but very spread and blur the tangerine alignment pattern.

Figure 39: Arabica coffee and tangerine intercropped on sparse weeds. Both canopies are very dense. Coffee canopy is almost continuous like a carpet but clearly blurs the tangerine alignment pattern in the satellite image.

Figure 40: Arabica coffee cultivated under sparse tangerine trees that are not very dense. Coffee canopy is continuous, making a dense carpet of vegetation that disturb the regular pattern of tangerine on the satellite image but which might sometimes be unclear enough to be undistinguishable from food crops.

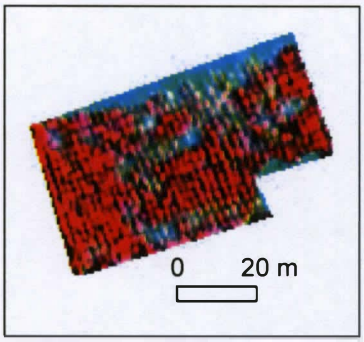


Figure 41:
Arabica coffee trees in monoculture without any shading tree, in a dense and continuous canopy.

Coffee trees are clearly seen in the satellite image.

- *7.7 General remarks*

If this level of information can be of any use in the agrosystem evaluation for the definition of geographic indication on coffee, for instance if such characteristics can be related to coffee quality, further mapping could provide with sub-classes like plots that are cropped continuously vs. those that are separated by fences (clearly identified in the satellite image), crops directly planted on slopes vs. those organised in terraces (distinguishable due to the shadows and also the grass borders), or other component of the landscape and the land cover management.

In the same context, individual plots could be precisely delimited (here connecting plots of a same class are grouped) for statistical analysis of plot dimensions, orientation, clumping by agrosystem, and so on.

Intraplot heterogeneity could even be analysed, such as spacing between trees, regularity of alignments, percentage of shade in the plot ..., providing information about the level of management of the plots.

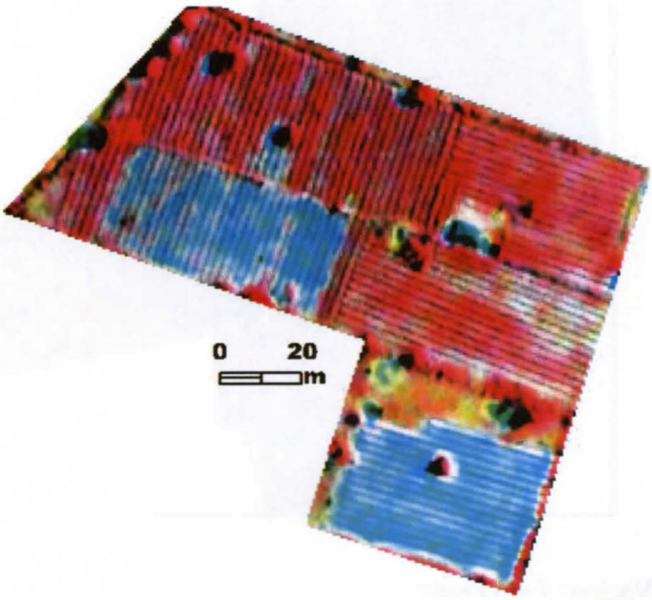


Figure 42:
Chilli plots
in rows of different orientations
and with various undercover.

Bottom charts display a plot with few
tangerine providing shade to chilli.

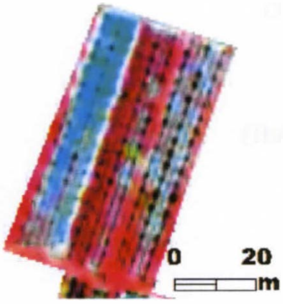


Figure 43: Various food crops:

- Paddy rice (upper left)
- Corn (bottom right)
- Vegetables (bottom left)

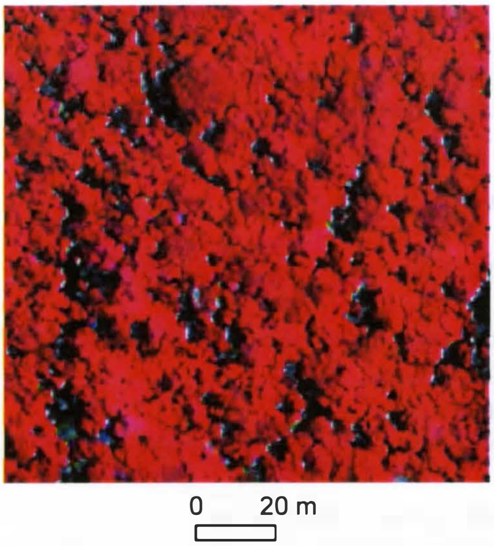


Figure 44: Natural forests.

- Bamboo forest (upper photo)
- primary rain forest (bottom photo)

Figure 45: Conifer forest.

8. Result: Agrosystems map

Figure 46 (see A3-sheet insert) provides with the general map of main agrosystems in the region of Kintamani in Bali, resulting of the very high resolution satellite image photointerpretation.

- ***8.1 Description and discussion of the resulting map.***

The resulting map clearly shows that the Kintamani region can be separated in four agro-regions:

[1] Agriculture dominated by food crops.
This region correspond to all the Southern part of the area, under the topographic limit of 1000m towards the West and 1100 to 1150m towards the East.

[2] Agriculture dominated by crops densely shaded by large trees.
This region geographically "belongs" to the former one and corresponds to the valleys of Mengani and of Lembean.

[3] Agriculture dominated by citrus crops and arabica coffee grown under citrus.
This region covers all the middle of the area, from the altitudes of 1000m to 1100m at South, passing the plateau of Belantih (1250m), and down again on the other slope of the mountain until the altitude of 1150m. It extends to the West until the frame limit of the image but seems to continue until Mount Catur. It extends to the East until the forests bordering the crater rim of the Mount Batur volcano, at 1400-1500m.

[4] Agriculture dominated by clove crops and crops densely shaded by large trees.
This region covers all the Northern slope of the mount from the altitude of 1150m to the frame limit of the image and might continue until the landscape changes for seaside vegetation (coconuts, mango...). This region seems very typical, as clove crops are not found anywhere else while the other crops are almost spread everywhere in the area. It has to be mentioned that it is located on "the other side" of the mountain, on the very steep Northern slope that is influenced by the Sea of Bali climate because of its specific exposition. Humidity, salinity and other characteristics might change abruptly when passing through the rim of the Belantih plateau.

This first result allow to locate precisely the different agrosystems related with coffee, and shows that this distribution is more complicated than only a repartition North/South or altitude delimitations. It rather seems to be a combination of both parameters plus local geographic parameters like rivers, slopes, exposition to wind, lava flows, forests...

This map can help establishing objective criterions for the delimitation of agro-regions based on the agrosystems preferentially adopted. Moreover it can be coupled with other information like crop management, coffee quality data, processing places... It is thus an accurate support as well as an instructive information layer for a Geographic Information System.

Figure 47 (see A3-sheet insert) provides with the general map of the four agro-regions based on Arabica coffee crop in the region of Kintamani in Bali. This map is the result of a "Majority Analysis" of the map presented at Figure 46, which means that each pixel is assigned the class occurring in majority inside a square perimeter of about 130m around this given pixel, followed by a treatment discarding small isolated regions (less than $(130m)^2 \sim 170m^2$). This map gives a global view of the agrosystems organisation in the region but is not to be substituted to the main agrosystems map, which gives the detailed information of cropping systems at the plot scale.

Figure 46:

General map of main agrosystems distribution in the region of Kintamani in BALI, based on very high resolution satellite image photointerpretation.

Dr Camille CD LELONG, CIRAD, March 2005.

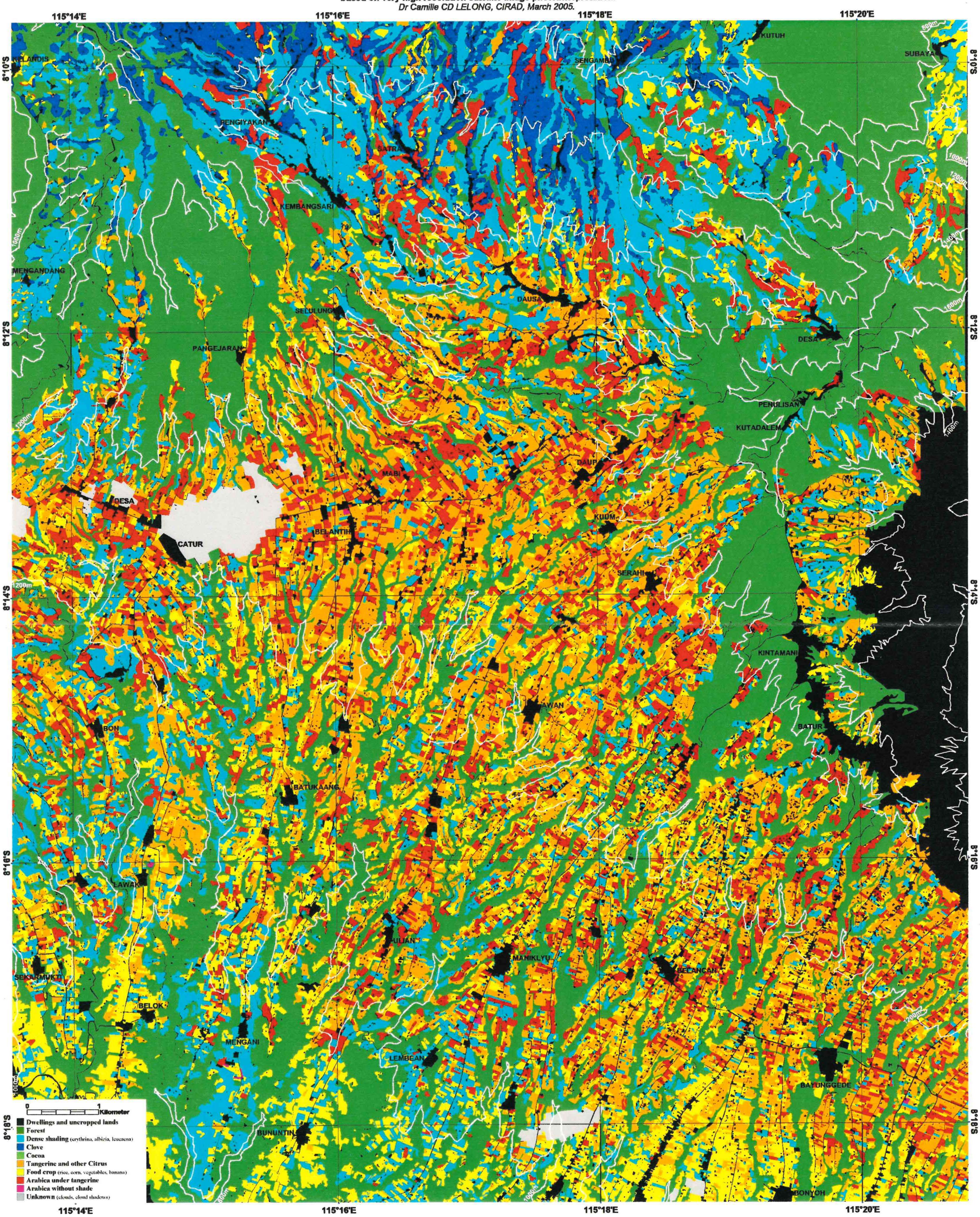


Figure 47:
General map of main agro-regions in the region of Kintamani in BALI, based on very high resolution satellite image photointerpretation.
Dr Camille CD LELONG, CIRAD, March 2005.

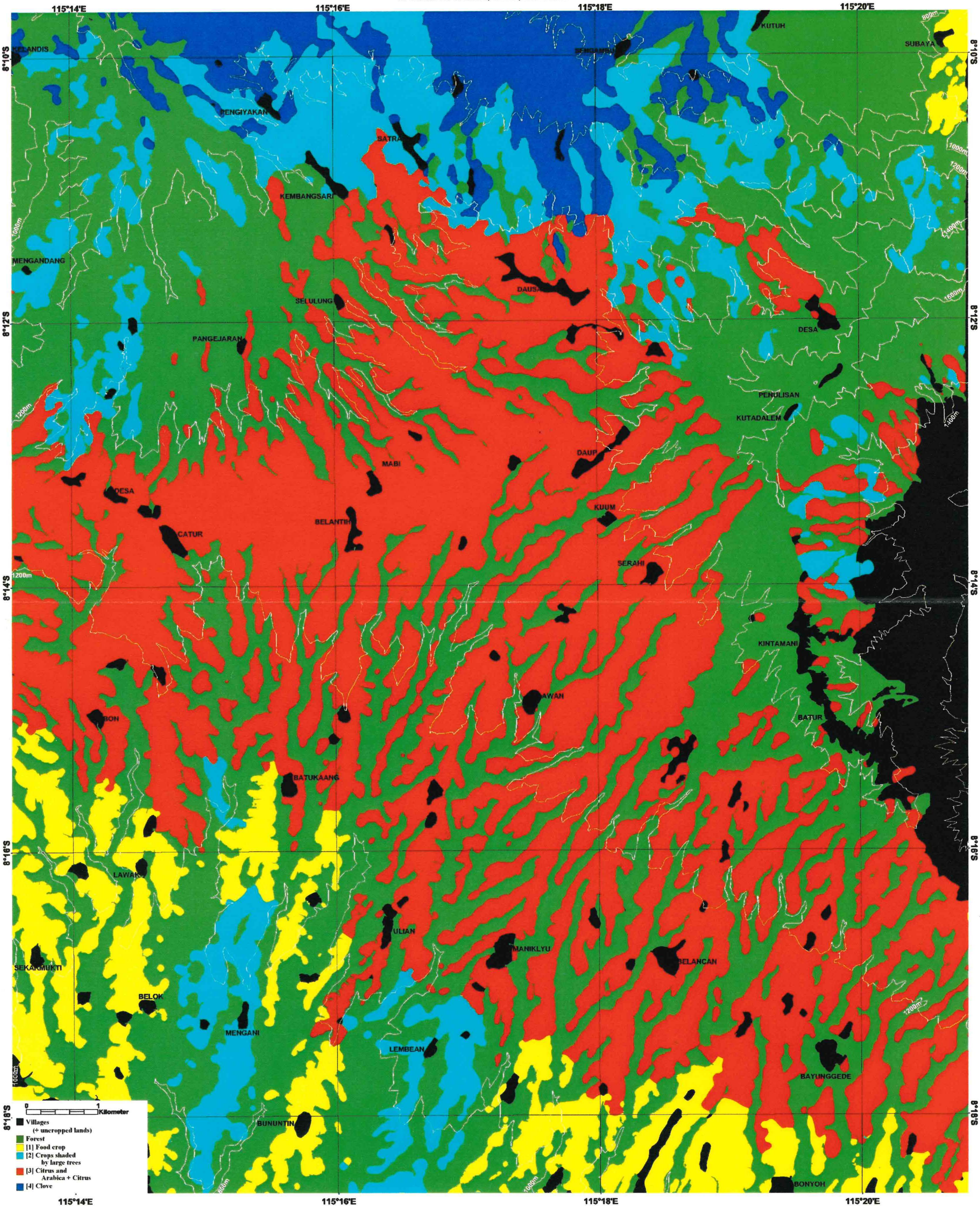


Figure 49 to Figure 57 present six extracts of the general agrosystems map to provide with a closer view of some areas belonging to different agro-regions: Lawak and Bununtin to [1], Lembean to [2], Belantih, Serahi, Kuum and Maniklyu to [3], and Pengiyakan to [4]. These extracts are located inside these overall agro-region of Kintamani at the Figure 48. They give an idea of the spatial accuracy reached for the agrosystems mapping (intraplot scale) thanks to the very high resolution of the satellite image. Any analysis of parcelling out dimensions, relationships with dwellings, rivers vicinity, topography, and links between the different agrosystems can be achieved with this kind of map.

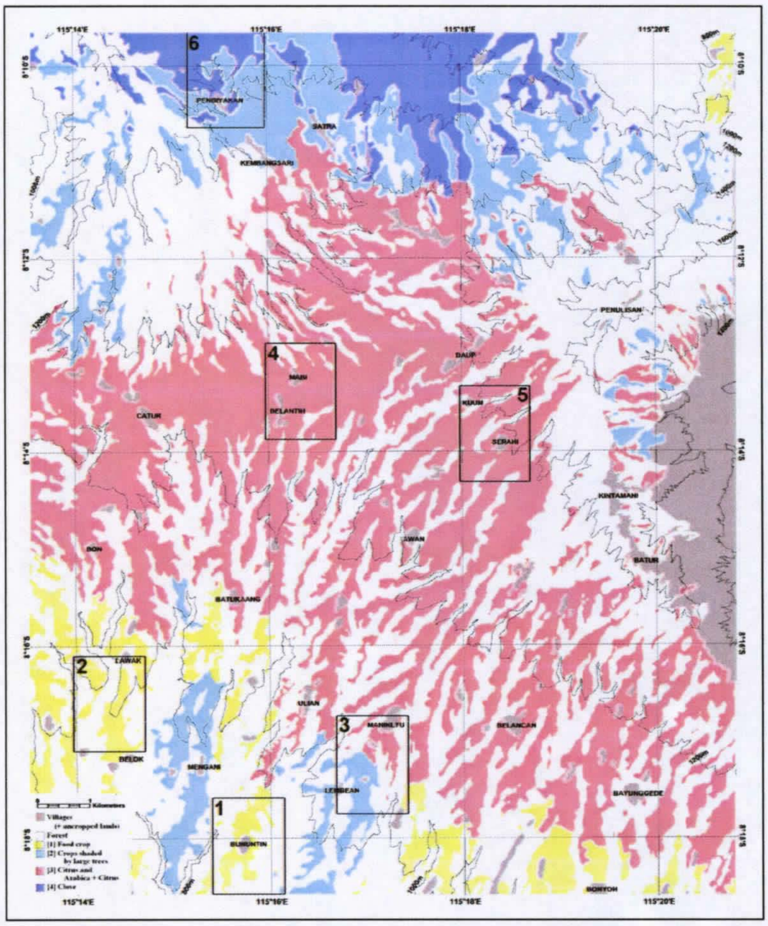


Figure 48: Overall location in the agro-regions of Kintamani of the six extracts of the agrosystems map presented Figure 50 to Figure 57: 1] Bununtin, 2] Lawak, 3] Lembean and Maniklyu, 4] Belantih and Mabi, 5] Kuum and Serahi and 6] Pengiyakan.

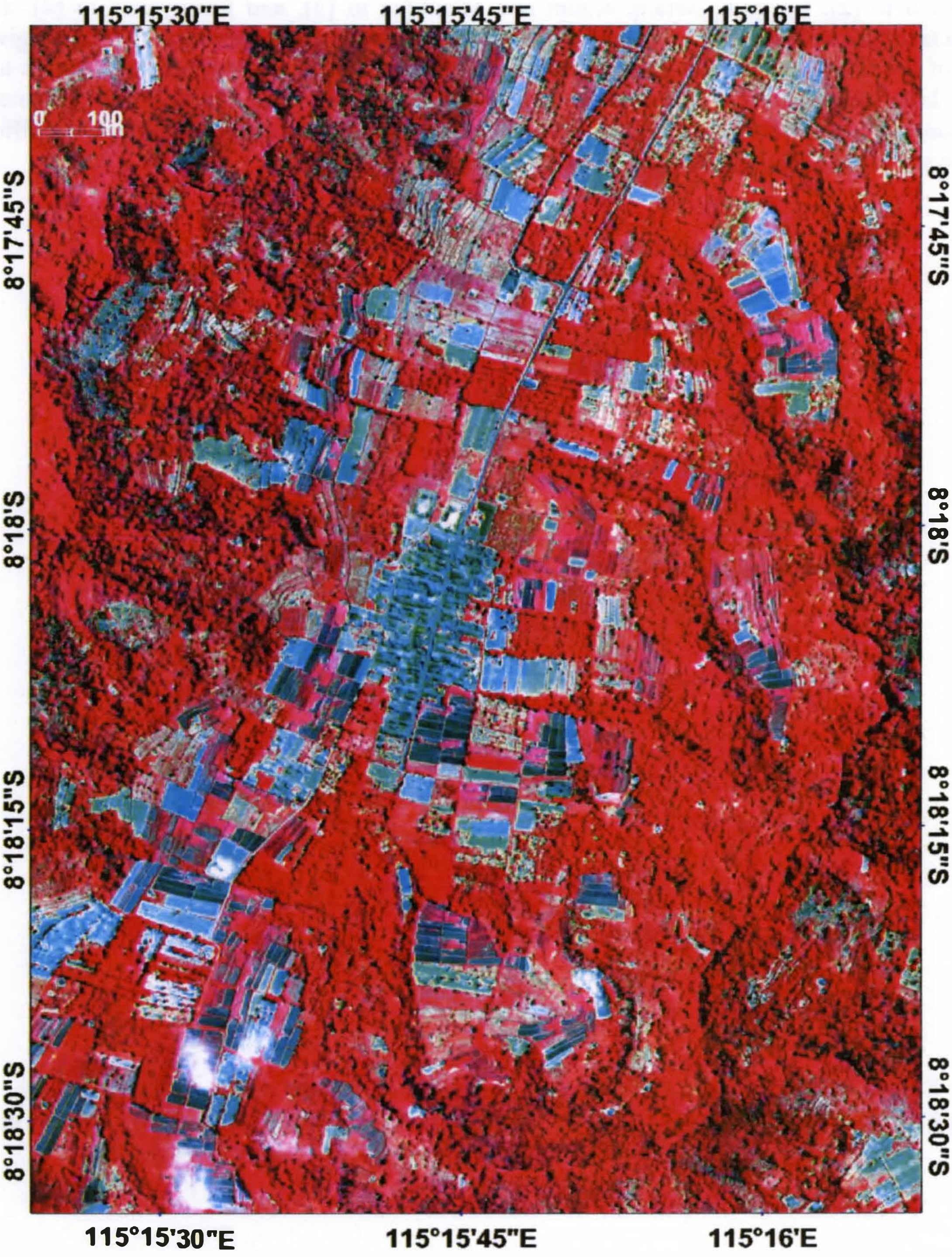


Figure 49: Extract of the Quickbird image displayed in NIR false colour in the surroundings of Banjar Bununtin.

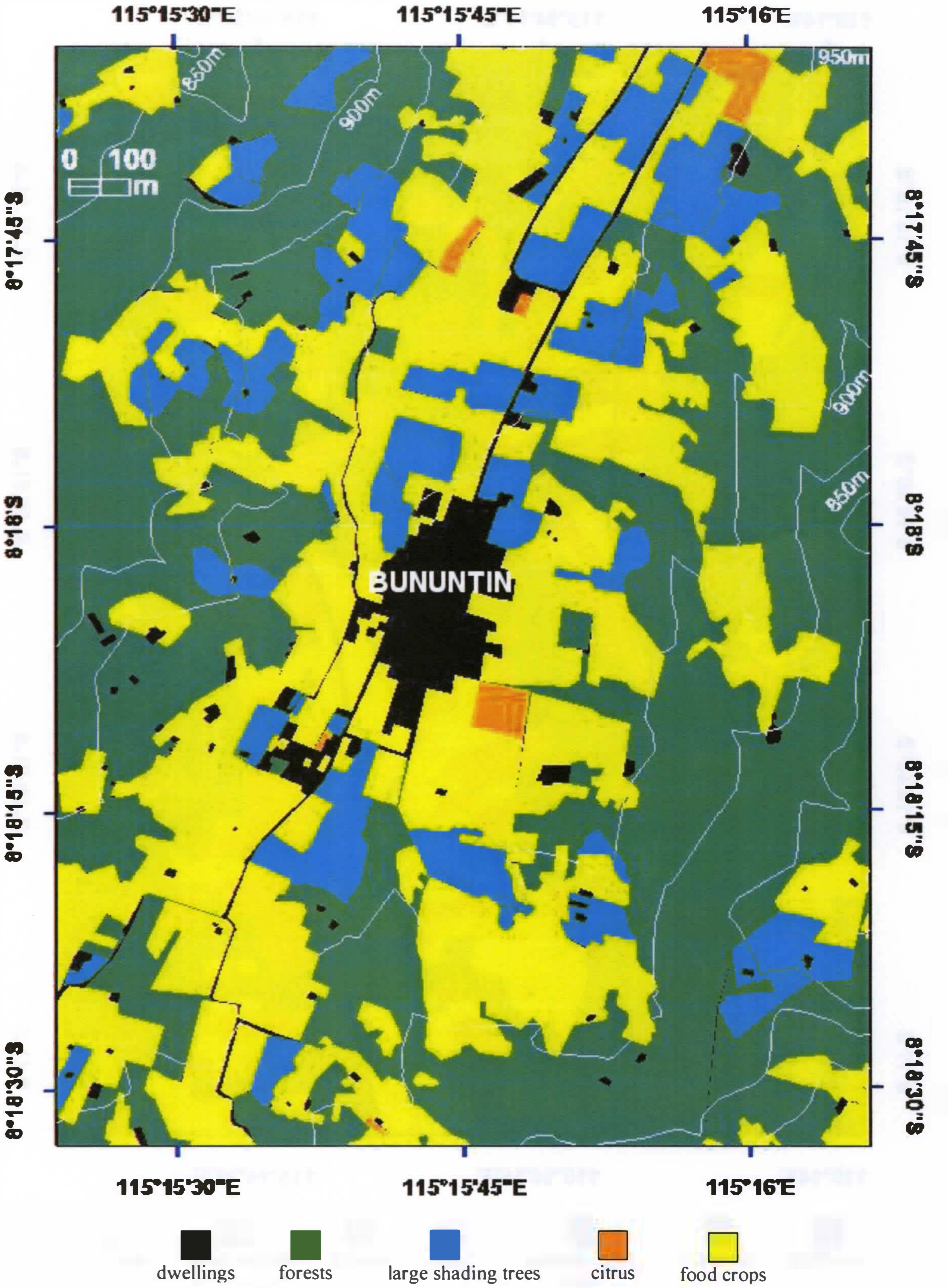


Figure 50: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Bununtin.

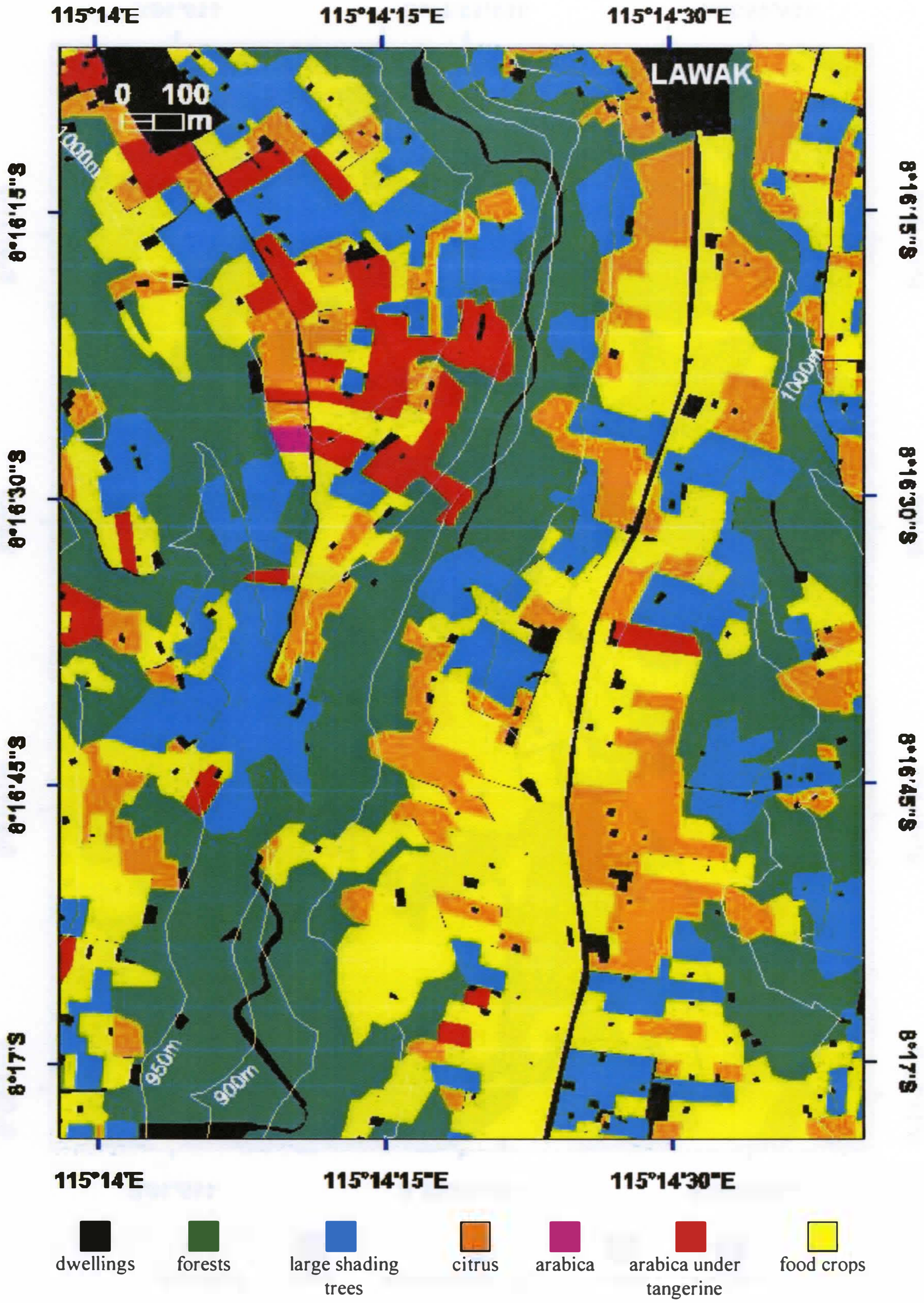


Figure 51: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Lawak (Desa Belok Sidan).

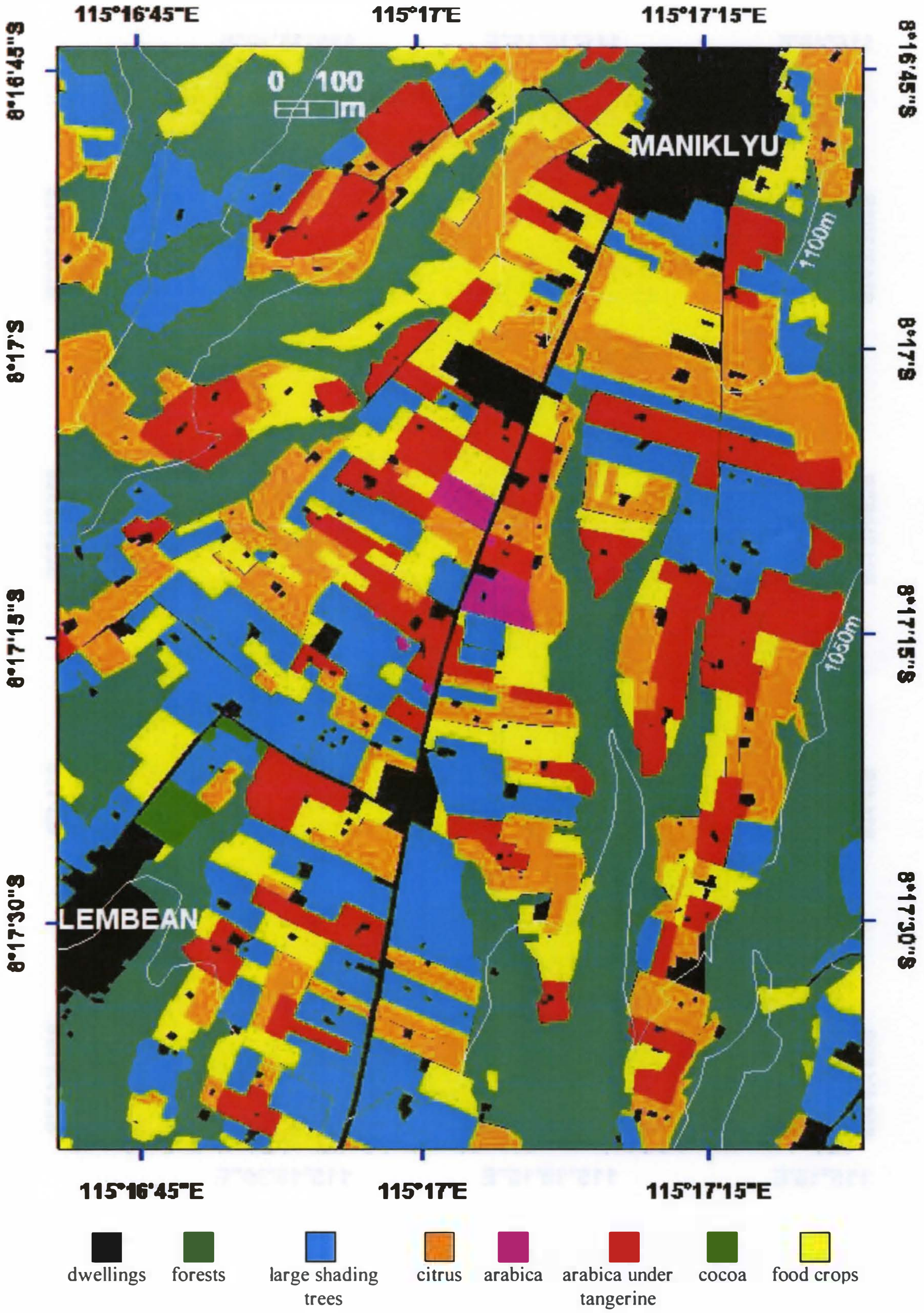


Figure 52: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Lembean and Maniklyu.

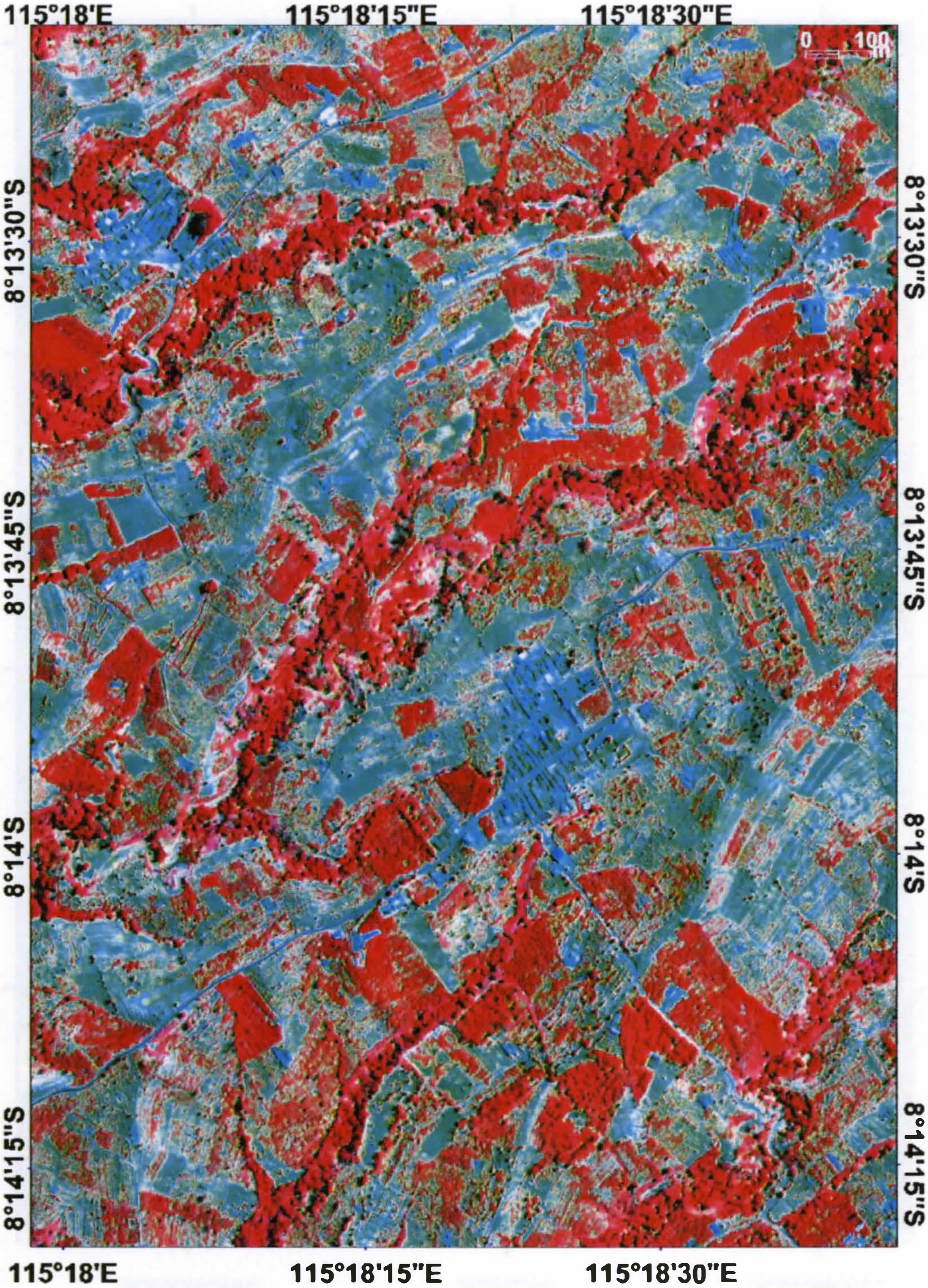


Figure 53: Extract of the Quickbird image displayed in NIR false colour in the surroundings of Banjar Kuum (Desa Sukawana) and Serahi.

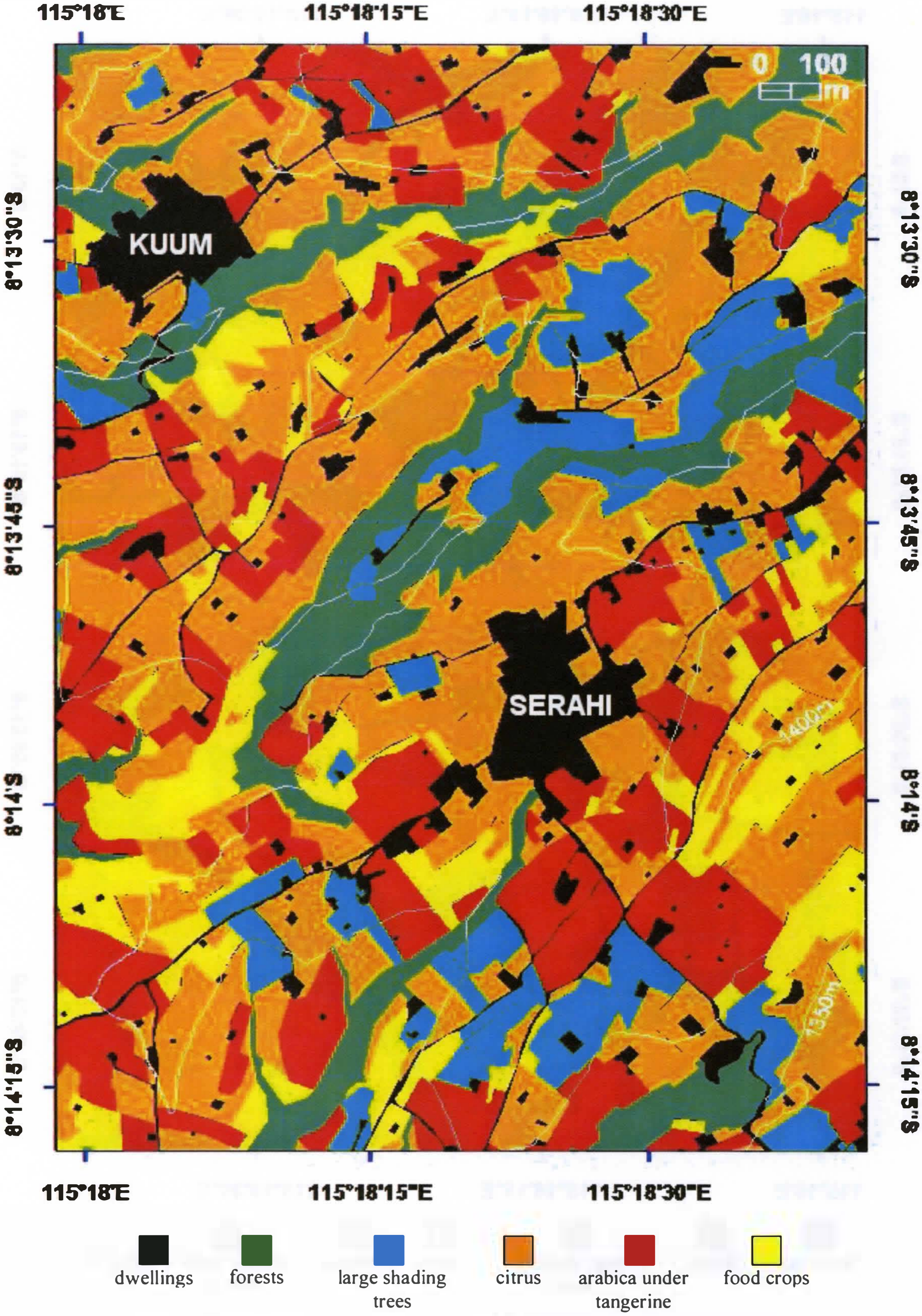


Figure 54: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Kuum (Desa Sukawana) and Serahi.

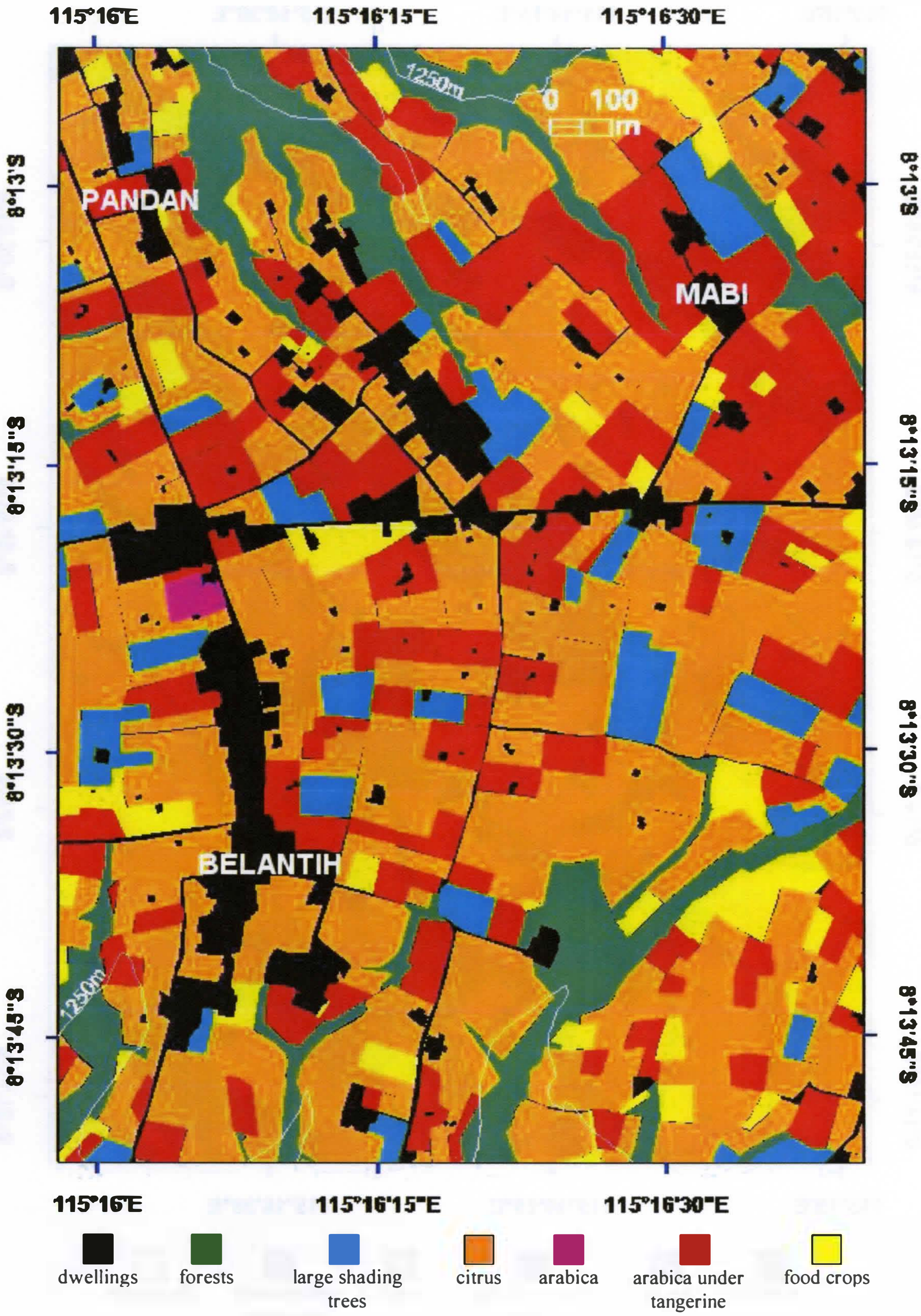


Figure 55: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Belantih and Mabi (Desa Belantih).

- ***8.2 Calculation of surfaces occupied by each agrosystem.***

Even if a given identified agro-region, the proportion of each agrosystem is very variable depending the location one could consider.

Analysing the proportion of each of these agrosystems in relationship with the altitude seemed to be another way to understand the coffee growing organisation inside the region of Kintamani, especially because some quality data seemed to be related with the altitude.

Absolute (in hectares) and relative (in percentage) areas of the different agrosystems are calculated out of the map for each slice of 100m between the altitudes of 1000m to 1500m. The corresponding values are synthesized in Table 6 and Table 8 and represented as diagrams in Figure 58.

Cumulative areas, corresponding to total surfaces found higher than a given altitude, are also given for threshold levels higher than 1000m and a step of 100m in Table 7 and Table 9. They are represented as diagrams in Figure 59.

AREAS in hectares	1000-1100m	1100-1200m	1200-1300m	1300-1400m	1400-1500m	1500-1800m
Dwellings	178.2	240.3	237.9	112.3	130.6	37.6
Forests	1348.5	1536.6	958.2	551.2	546.7	624.7
Large Shading Trees	810.4	645.6	484.6	210.0	137.2	43.5
Clove	129.7	54.9	11.5	1.7	0.0	0.0
Citrus	474.1	1007.4	1306.0	530.0	297.3	65.0
Cocoa	1.3	0.0	0.0	0.0	0.0	0.0
Arabica under tangerine	260.3	494.4	666.0	288.3	109.7	25.0
Arabica without shade	2.1	1.8	2.3	0.2	0.3	0.0
Food crops	638.3	579.2	488.0	142.6	90.6	11.4
Total	3842.9	4560.3	4154.5	1836.3	1312.4	807.1

Table 6: Areas calculated out of the thematic map of the different agrosystems per slices of 100m.

CUMUL. AREAS in ha	H > 1000m	H > 1100m	H > 1200m	H > 1300m	H > 1400m	H > 1500m
Dwellings	936.9	758.8	518.4	280.5	168.2	37.6
Forests	5565.9	4217.4	2680.8	1722.6	1171.4	624.7
Large Shading Trees	2331.2	1520.8	875.2	390.6	180.6	43.5
Clove	197.8	68.1	13.2	1.7	0.0	0.0
Citrus	3679.9	3205.7	2198.3	892.3	362.3	65.0
Cocoa	1.3	0.0	0.0	0.0	0.0	0.0
Arabica under tangerine	1843.7	1583.4	1089.0	423.0	134.8	25.0
Arabica without shade	6.6	4.5	2.8	0.5	0.3	0.0
Food crops	1950.2	1311.9	732.6	244.6	102.0	11.4
Total	16513.6	12670.6	8110.3	3955.8	2119.5	807.1

Table 7: Cumulative areas calculated out of the thematic map of the different agrosystems per slices of 100m.

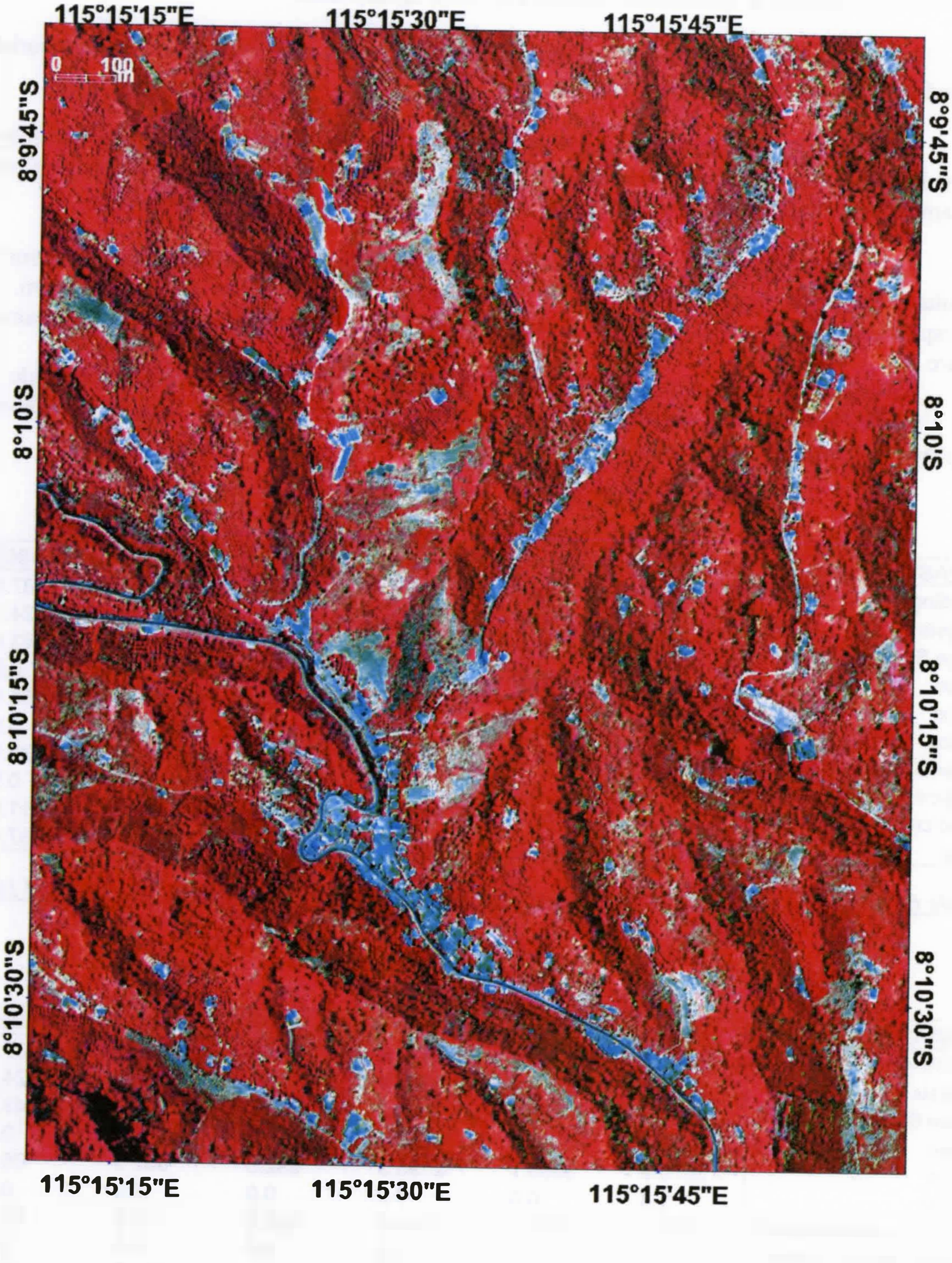


Figure 56: Extract of the Quickbird image displayed in NIR false colour in the surroundings of Banjar Pengiyakan (Desa Satra and Tajun).

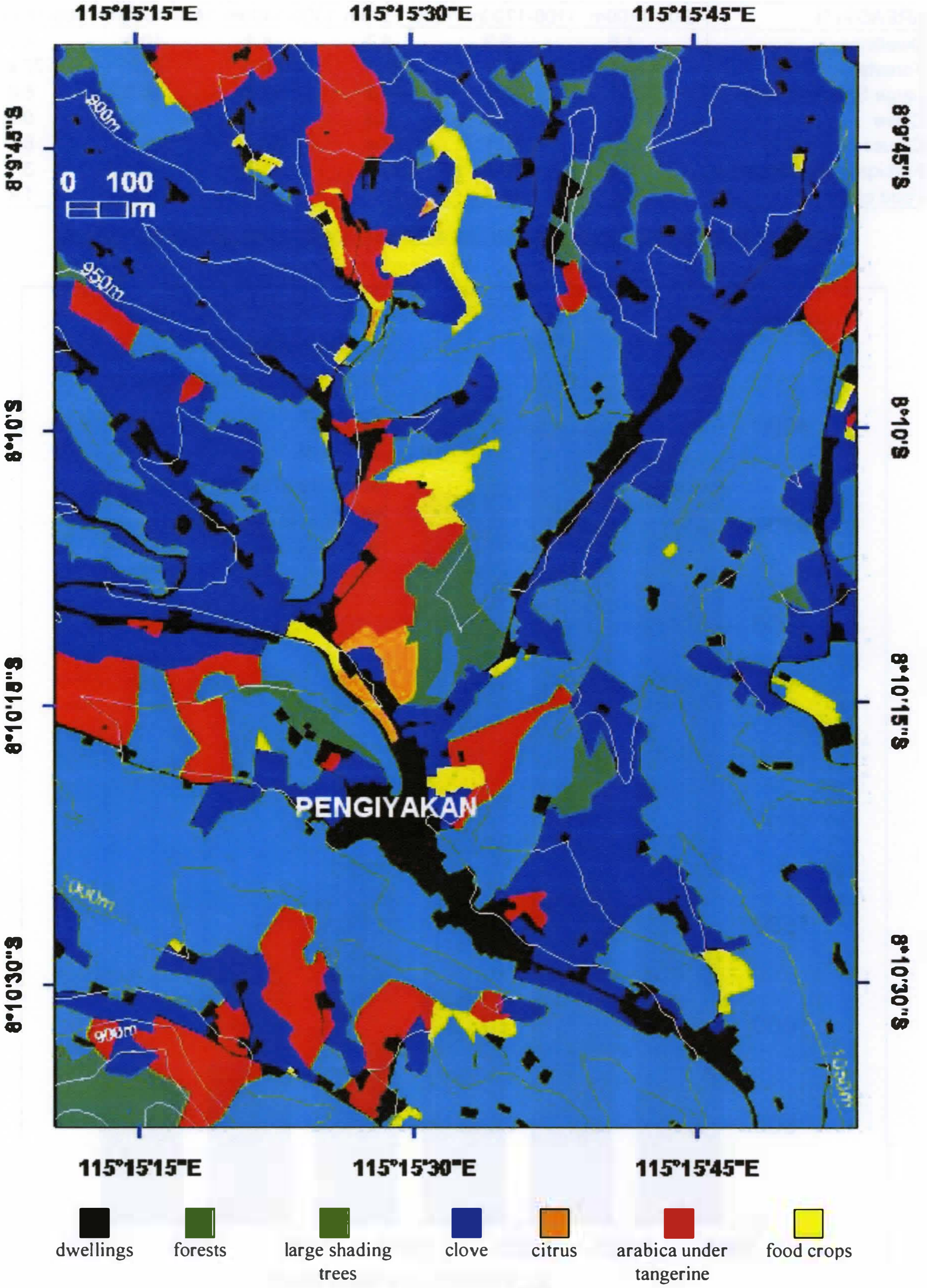


Figure 57: Main agrosystems map (cf. Table 5 p21 for description) in the surroundings of Banjar Pengiyakan (Desa Satra and Tajun).

AREAS in %	1000-1100m	1100-1200m	1200-1300m	1300-1400m	1400-1500m	1500-1800m
Dwellings	4.6	5.3	5.7	6.1	10.0	4.7
Forests	35.1	33.7	23.1	30.0	41.7	77.4
Large Shading Trees	21.1	14.2	11.7	11.4	10.5	5.4
Clove	3.4	1.2	0.3	0.1	0.0	0.0
Citrus	12.3	22.1	31.4	28.9	22.7	8.0
Arabica under tangerine	6.8	10.8	16.0	15.7	8.4	3.1
Food crops	16.6	12.7	11.7	7.8	6.9	1.4

Table 8: Percentage of occupation of the different agrosystems per altitude slices.

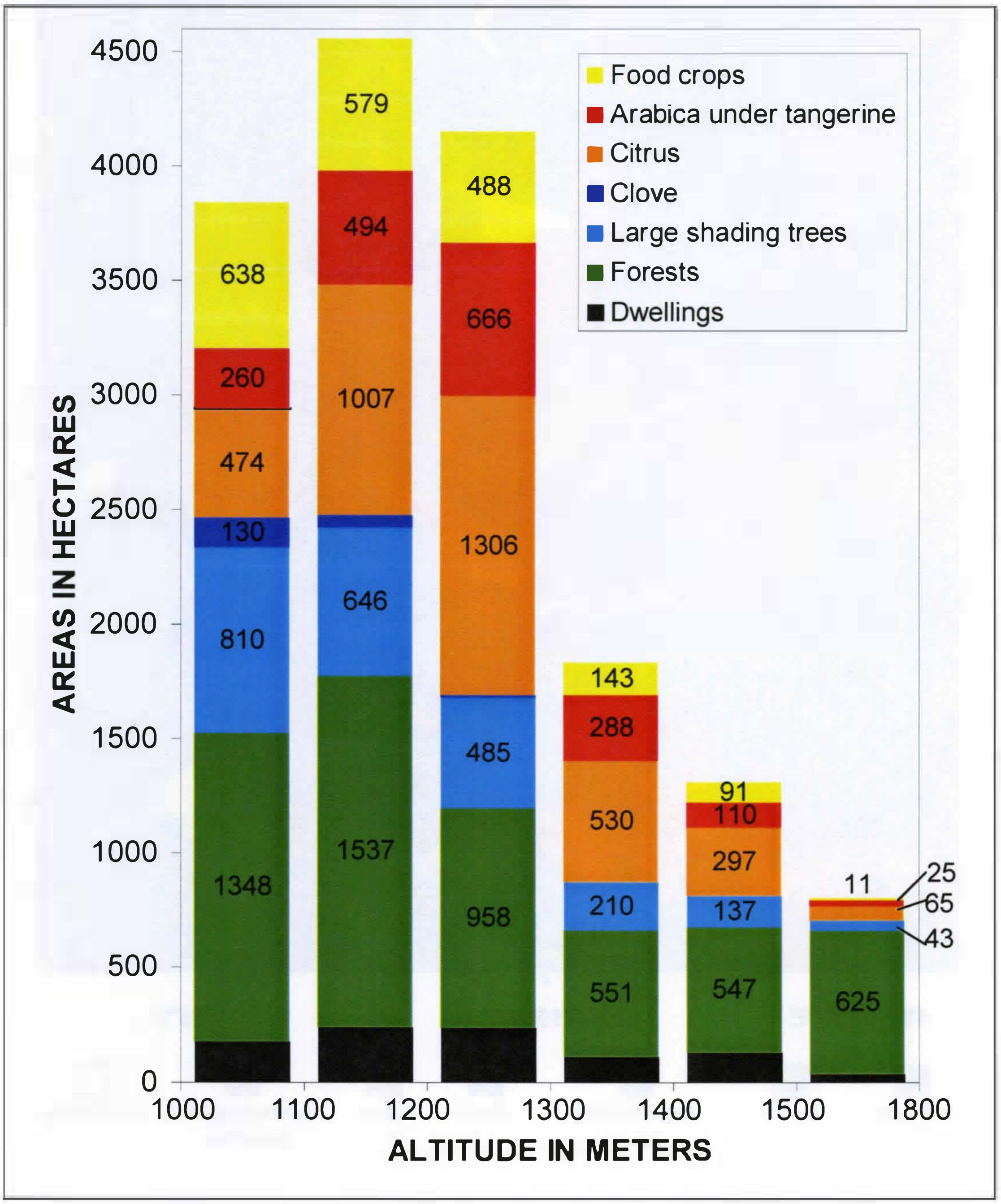


Figure 58: Distribution of the different agrosystems (cf. Table 5 p21) per altitude slices.

CUMUL. AREA in %	H > 1000m	H > 1100m	H > 1200m	H > 1300m	H > 1400m	H > 1500m
Dwellings	5.7	6.0	6.4	7.1	7.9	4.7
Forests	33.7	33.3	33.1	43.5	55.3	77.4
Large Shading Tree	14.1	12.0	10.8	9.9	8.5	5.4
Clove	1.2	0.5	0.2	0.0	0.0	0.0
Citrus	22.3	25.3	27.1	22.6	17.1	8.0
Arabica under tangerine	11.2	12.5	13.4	10.7	6.4	3.1
Food crops	11.8	10.4	9.0	6.2	4.8	1.4

Table 9: Percentage of the different agrosystems occupation higher than a given threshold

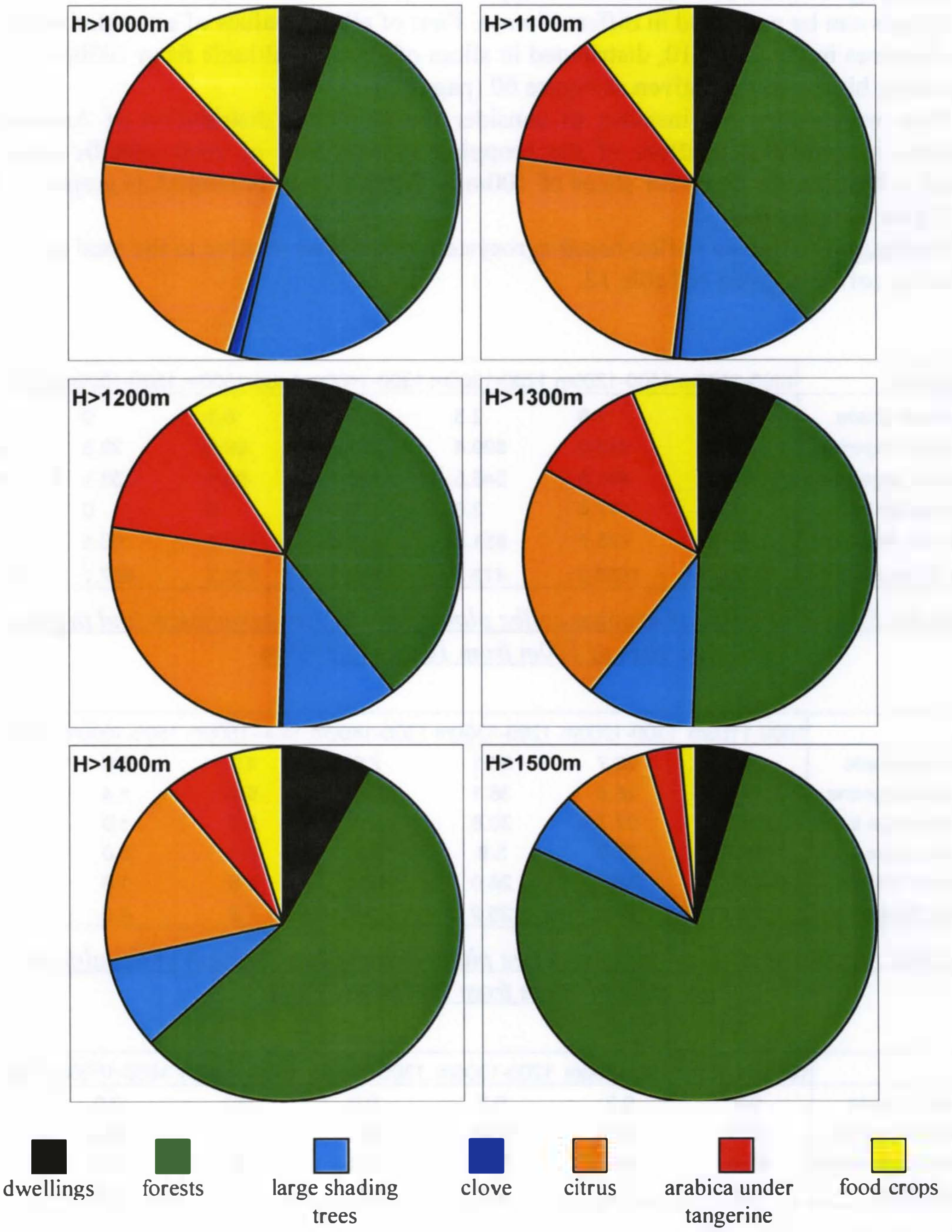


Figure 59: Distribution of the different agrosystems (cf. Table 5 p21) occupation higher than a given threshold.

- ***8.3 Evaluation of surfaces planted with Arabica coffee and analysis of their geographic distribution***

Areas finally planted with Arabica coffee can be evaluated applying to the surfaces corresponding to the agrosystems "large trees" and "clove" the probabilities of Arabica coffee occurrence under large trees (71.5%) and under clove (31.7%) estimated on the basis of the field campaign (cf. Figure 16 page 19). Although it has to be reminded that these probabilities are a bit biased by the objectives of the field enquiry (cf. Table 3 and Table 4 page 19). Areas of coffee cropped in association with citrus have been estimated to be actually only 90% of the mapped surface due to possible confusions in photointerpretation (cf.§7.3 Citrus and Arabica cultivated under Citrus page 26) and this coefficient is applied to the calculations derived from the map.

Results can be presented in different ways. First of all, the values of estimated surfaces are given in hectares in the Table 10, distributed in slices of 100m of altitude from 1000m to 1800m, corresponding histograms are given at Figure 60 (page 62).

Then we propose for instance to consider the altimetric distribution of Arabica-based agrosystems in general regardless of the cropping system, and of each specific agrosystem individually. Figures are given for slices of 100m at Table 11 and presented as graphs at Figure 61 and Figure 62 (page 63).

Finally, each Arabica coffee-based agrosystem proportion relative to the total area planted with Arabica coffee is given at Table 12.

Area in hectares	1000-1100m	1100-1200m	1200-1300m	1300-1400m	1400-1500m	1500-1800m	*1000-1800m*
Arabica without shade	2.1	1.8	2.3	0.2	0.3	0	*6.6*
Arabica under tangerine	234.2	445.0	599.4	259.5	98.8	22.5	*1659.3*
Arabica under large trees	579.5	461.6	346.5	150.1	98.1	31.1	*1666.8*
Arabica under clove	41.1	17.4	3.6	0.5	0	0	*62.7*
Total area with Arabica	856.9	925.7	951.8	410.3	197.1	53.6	*3395.4*
Total area of the region	*3842.9*	*4560.3*	*415.5*	*1836.3*	*131.2*	*807.1*	*16513.6*

Table 10: Estimated areas of Arabica coffee planted areas, per agrosystem and in general, per slice of 100m from 1000m to 1800m.

Area in %	1000-1100m	1100-1200m	1200-1300m	1300-1400m	1400-1500m	1500-1800m	*1000-1800m*
Arabica without shade	31.2	26.7	35.1	2.9	4.0	0.0	*0.0*
Arabica under tangerine	14.1	26.8	36.1	15.6	6.0	1.4	*10.0*
Arabica under large trees	34.8	27.7	20.8	9.0	5.9	1.9	*10.1*
Arabica under clove	65.6	27.8	5.8	0.9	0.0	0.0	*0.4*
Total area with Arabica	25.2	27.3	28.0	12.1	5.8	1.6	*20.6*
Total area of the region	*23.3*	*27.6*	*25.2*	*11.1*	*7.9*	*4.9*	

Table 11: Distribution of Arabica coffee planted areas as a function of the altitude, per slice of 100m from 1000m to 1800m.

Area in %	1000-1100m	1100-1200m	1200-1300m	1300-1400m	1400-1500m	1500-1800m	*1000-1800m*
Arabica without shade	0.2	0.2	0.2	0.0	0.1	0.0	*0.2*
Arabica under tangerine	27.3	48.1	63.0	63.2	50.1	42.0	*48.9*
Arabica under large trees	67.6	49.9	36.4	36.6	49.8	58.0	*49.1*
Arabica under clove	4.8	1.9	0.4	0.1	0.0	0.0	*1.8*

Table 12: Distribution of each Arabica coffee-based agrosystem relative to the whole area planted with Arabica coffee, per slice of 100m from 1000m to 1800m.

The two dominant agrosystems are dense shading by large trees (Erythrina, Leucaena, Albizia) and low shading by citrus (mostly tangerine, and grapefruit or lemon). Large trees shading is the most adopted at lower altitudes (68% for h<1100m) while citrus shading is leading the coffee culture at high altitudes (63-64% for 1200m <h <1400m). These two different agrosystems are equally distributed at intermediate (1100m <h <1200m) and very high (h>1400m) altitudes. Their distribution with altimetry is more or less lower than 1300m for large trees and 1400m for citrus and almost disappear from the landscape above 1400m (only 8% remaining in the highest altitude). Large trees are used mostly under 1100m (34%), then almost equally between 1100m and 1300m (21-28%). Citrus are rather found between 1200m and 1300m (36%), then also between 1100m and 1200m (27%) and finally equally between 1000m and 1100m (14%) and 1300m and 1400m (16%).

It seems that these two agrosystems are used in similar proportions in the region of Kintamani, and distributed more or less at the same altitude levels. Altitude and outstanding thus might not be unique characteristics to be taken into account for the delimitation of the Arabica Terroir. Amount of shading, intra-plot heterogeneity, landscape management (planting density, tree fences, rivers, dwellings proximity, terraces...) can be for instance reached out of the satellite image photointerpretation, and such information should probably be included in the "terroir" analysis.

Arabica coffee cropped under clove shading is rather anecdotal compared to the two other outstanding systems, based on large trees and citrus respectively. Clove shading is mostly found at the lowest altitudes, mainly below 1100m (68%) and 1200m (28%). This agrosystem is only found at North of the region, on the northern slopes of the mountain which might be suffering a different climate than the southern slopes, influenced by the presence of the sea (salted winds, humidity...) and the lower insolation due to the mount shadow. In addition, slopes are steeper than on the other side of the Belantih Plateau, which can be a decision factor for clove plantation in relation for instance with erosion preservation: this should be deeper investigated with the local authorities or agriculture offices. In the same point of view, soil composition might be analysed compared to the other areas of the region to understand whether there is any relationship with the presence of clove or not.

Arabica coffee is hardly ever cropped without shade in the region of Kintamani. Except isolated and exceptional plots and places where large trees were pruned enough to see the underlying coffee trees, this agrosystem is not practiced in the area and might not be taken into consideration.

In conclusion, coffee agrosystems maps alone do not allow to determine any limits to the "terroir" of the region of Kintamani. It has to be correlated to ancillary data. But it is a very useful tool to understand the spatial relationships between crops, dwellings, topography, hydrographical network (reached by forest following rivers) and so on.

It also provides with quantitative information about the surfaces planted with Arabica coffee or any crop system, giving accurate statistical data.

It also constitutes an efficient support for superimposition of any other kind of data as long as they own a geographical reference, allowing to create a Geographical Information System (GIS) dedicated to the "terroir" of Kintamani analysis.

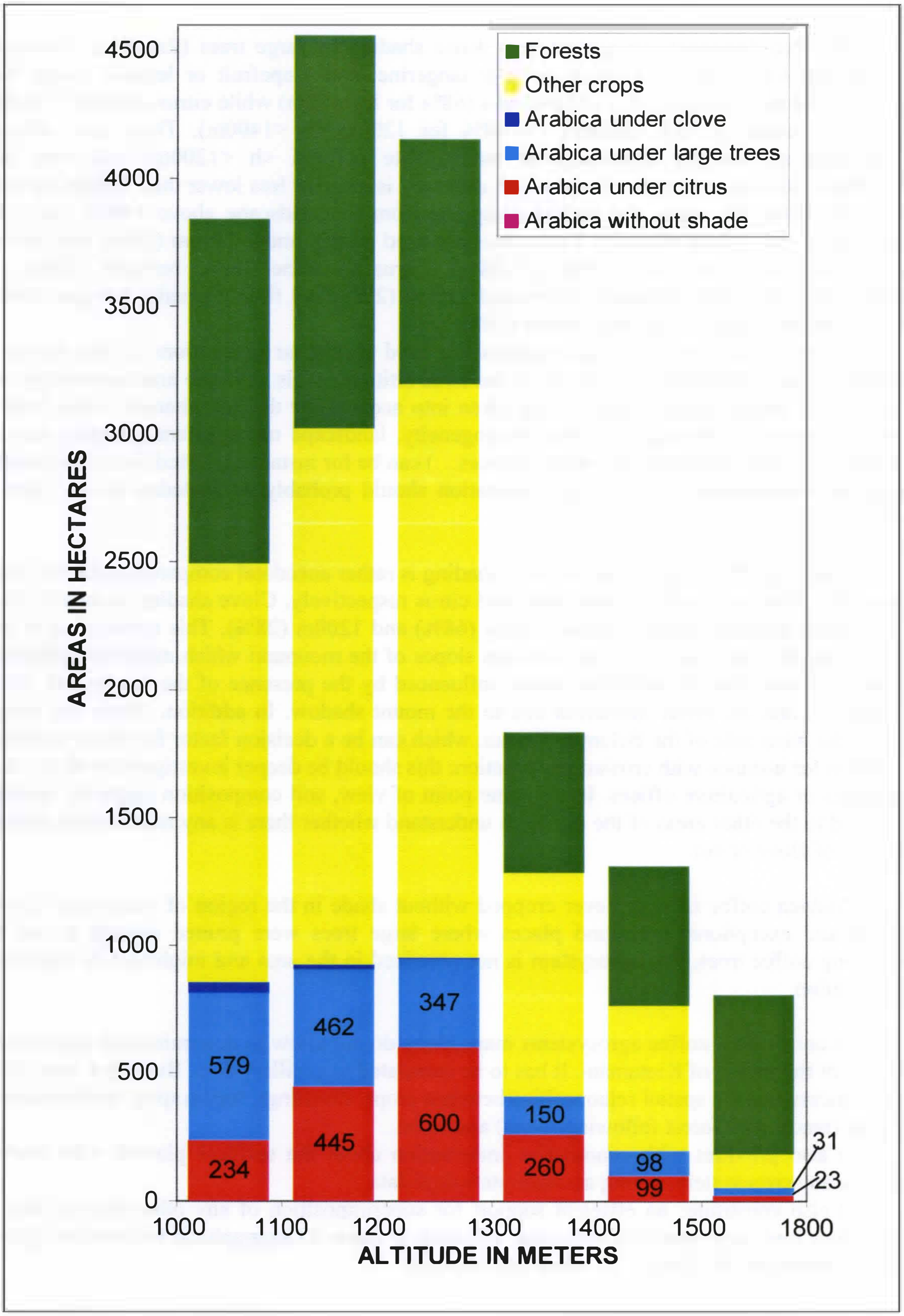


Figure 60: Estimated areas of Arabica coffee planted areas and of other crops, for each slice of 100m from 1000m to 1800m.

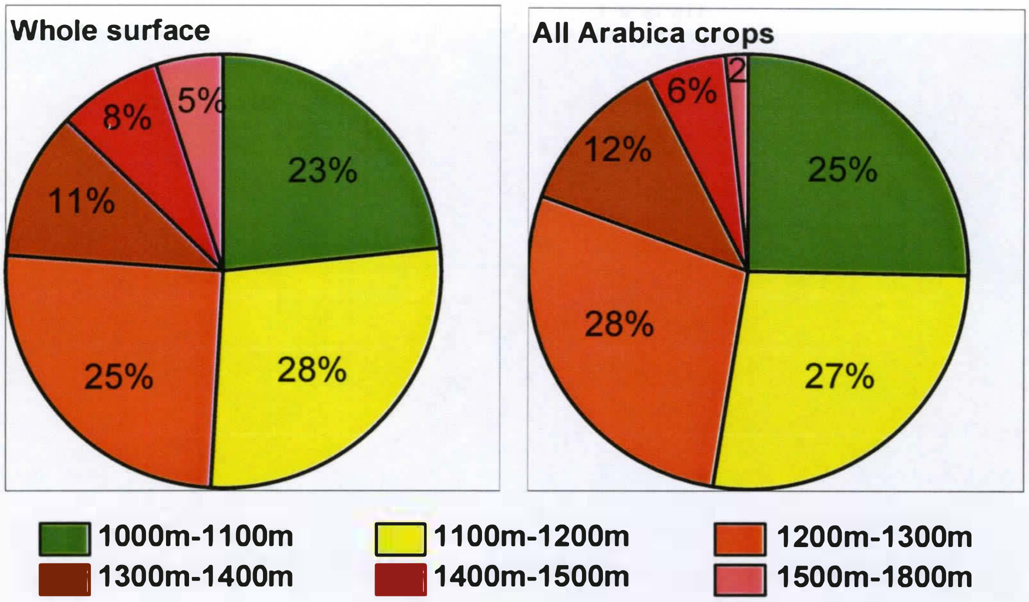


Figure 61: Altimetric distribution of the whole surface and of the Arabica coffee planted areas.

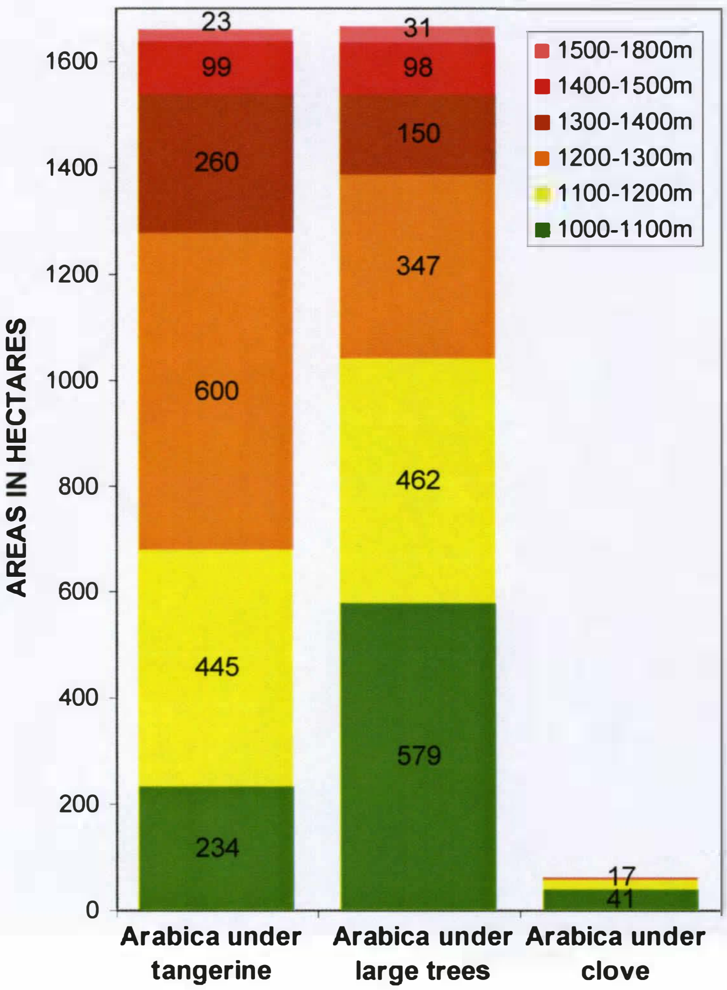


Figure 62: Altimetric distribution of the three main agrosystems based on Arabica coffee.

Figure 63: Extract of the Quickbird image displayed NIR in false colour, located at South of Banjar Mabi, East of Banjar Belantih.

9. Relationships between agrosystems map and cup sensorial quality.

Arabica coffee berries were sampled in the region of Kitamani in 2003, in different locations, agrosystems and cultivars. Sensorial quality of the coffee cup was analysed in order to classify these samples in terms of Preference, Body, Acidity, Bitterness, Fruity, Astringency, Green and Aromatic Quality characteristics (sources: Fabienne Ribeyre and Jean-Jacques Perriot, CIRAD). This analysis lead to the definition of 3 sensorial groups (SG) of coffee that can be considered to schematically correspond respectively to the good (SG1), the average (SG2) and the bad (SG3) coffees.

Statistical analysis was done on these data in order to extract the representative characters of the different groups and to correlate them to factors like altitude, variety, type and density of shading, village belonging... It appears that the sensorial group classes are not clearly dependant of the type or amount of shade, but much more to the coffee plants vigour, which is related to several other cropping practices also. Altitude seems to be an important factor of quality as more samples coming from higher altitudes (>1350m) are found in the SG1 than in the other groups, the less of them being found in SG3. But these relationships seem to depend on the considered cultivars, which do not behave identically. Establishing correlations between geographic factors and sensorial quality on the only basis of sampling data thus seems difficult.

Remote sensing provides with the opportunity to analyse these results in an integrative spatial analysis. Indeed, the GIS based on the agrosystems and the agro-region maps is a very useful tool to analyse the spatial and topographical distributions of these samples, in order to correlate geographical factors to sensorial quality and try to delimitate the Arabica "terroir" of Kintamani. The plots were coffee beans were sampled are plot over the agro-region map, providing with the values of Preference, Fruity and Acidity characteristics at the Figure 65 to Figure 67. The Preference value is plot over the topographic map at Figure 64. Each SG is displayed in a different colour (SG1 in red, SG2 in green and SG3 in blue) for quick spot. Arabica coffee processing places (geographical coordinates provided by Olivier Tichit, ECOM) are also indicated.

At first sight, it is obvious that the SG1 (good) coffees are all located inside the agro-region dominated by citrus shading, even if they are cropped under large trees. They are all found above 1100m. One can observe that the lowest sample, located at 1100m, has though been given a very high values for Preference (4.25) and Fruity (3.0).

Two thirds of SG2 (average) coffees are found in this same agro-region and the lasting third in areas of agriculture dominated by large trees shading. They are scattered in almost all the region, grown down to 1000m, except in the vicinity of Catur and Belantih villages where only SG1 coffees are found.

The SG3 (bad) coffees are only grown below 1100m in large trees shading and in food crop regions, except for one unique sample located at 1150m inside the citrus-dominated agro-region. Although, this latest sample has been given a high value of Preference and has probably been discarded from the SG1 because of a very low Fruity character (0.8). These "bad" coffees are found on both slopes of the mountain.

This representation thus confirms the quality analysis results about the dependence of quality with altitude. Good coffees are only grown at highest altitudes (>1100m) in areas where agriculture is strongly dominated by citrus associations. In addition, it helps understand the way good and average coffees are distributed inside this agro-region: average coffees are only found at the East of a diagonal line going from Ulian at South to Dausa at North of the agro-region, where good and average coffees are mixed, while only good coffees are grown at the West of this line.

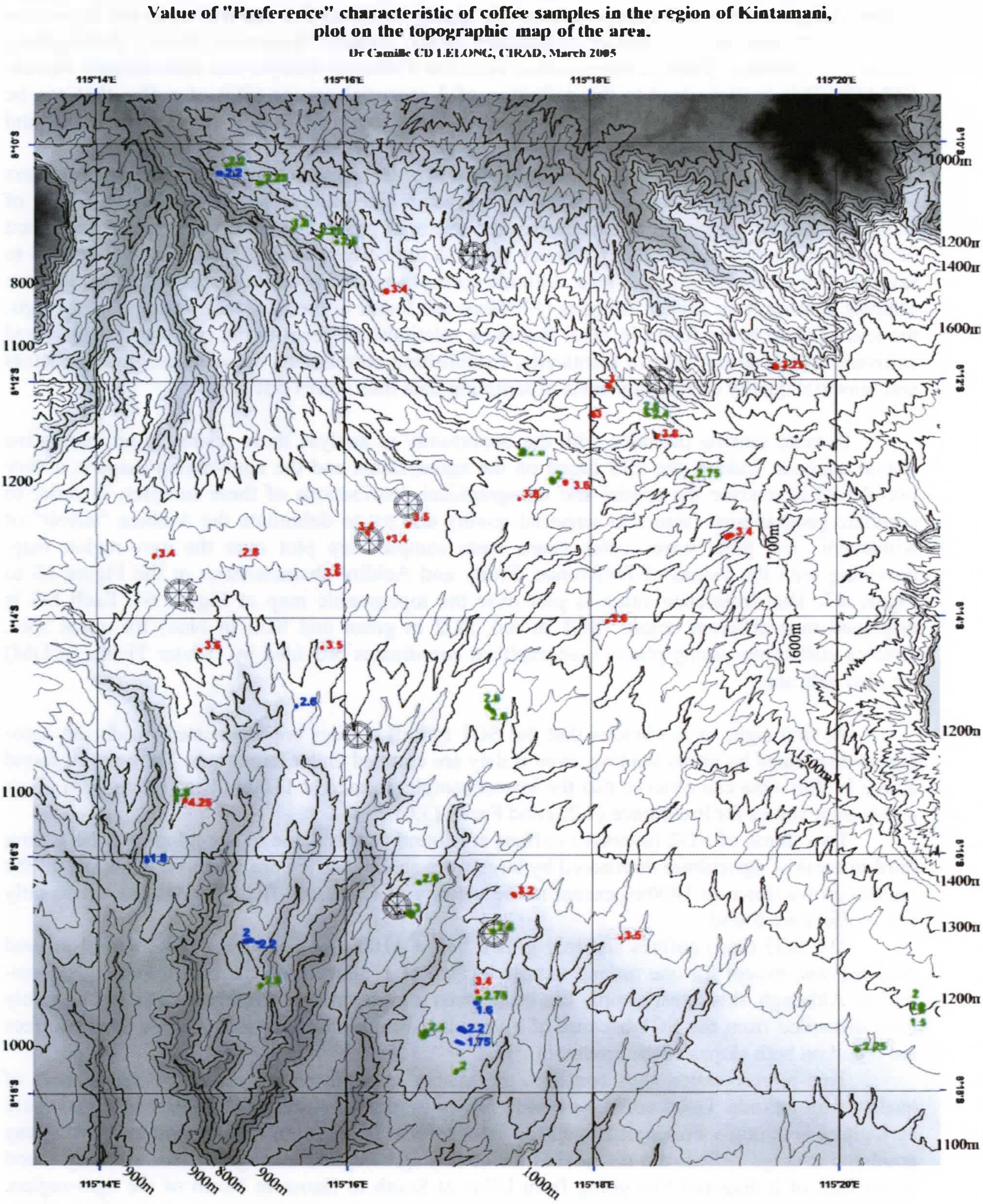


Figure 64: Value of the "Preference" characteristic of Arabica coffee sampled in the region of Kintamani in Bali, mapped over the topographic levels.

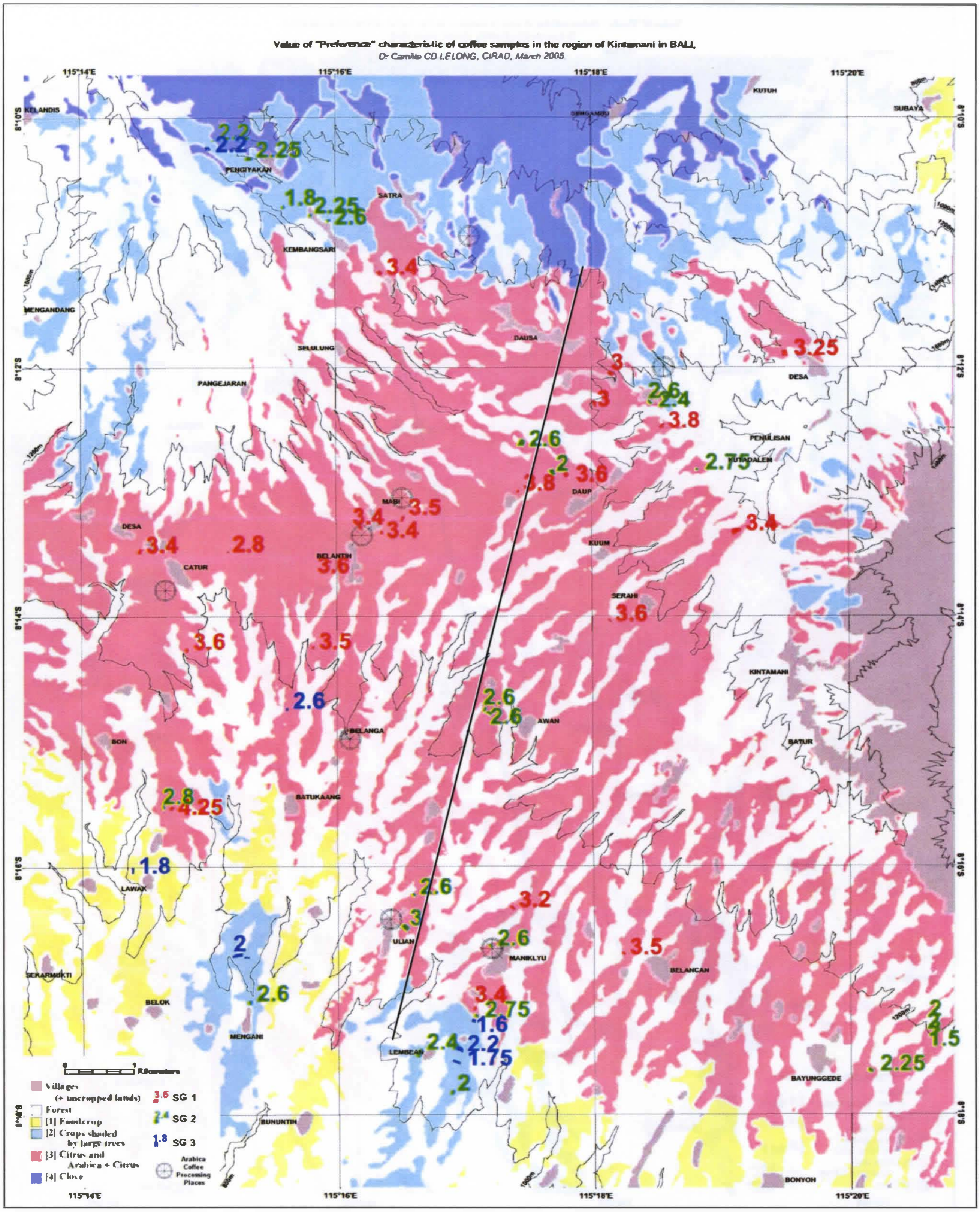


Figure 65: Value of the "Preference" characteristic of Arabica coffee sampled in the region of Kintamani in Bali, mapped over the main agro-regions of the area.

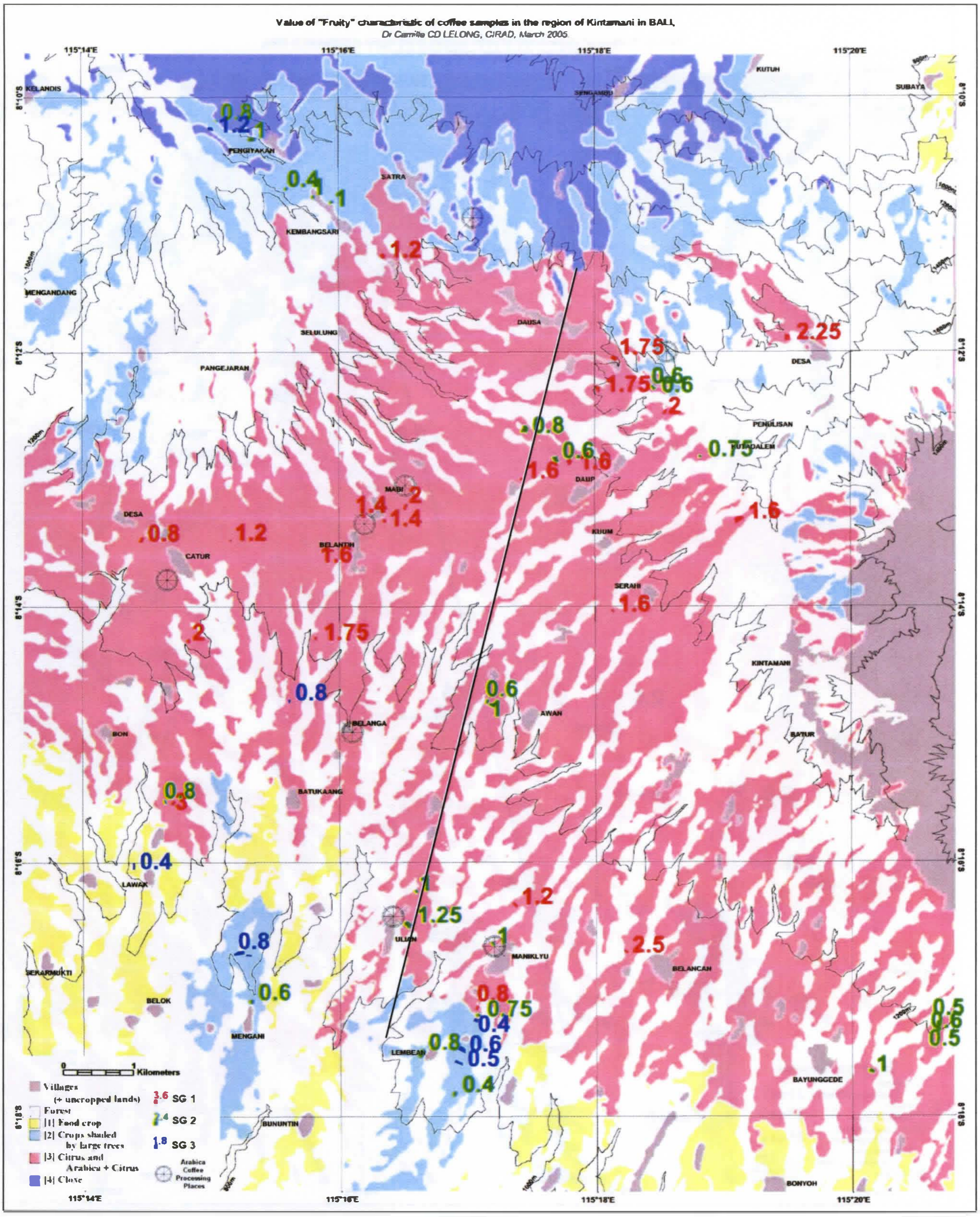


Figure 66: Value of the "Fruity" characteristic of Arabica coffee sampled in the region of Kintamani in Bali, mapped over the main agro-regions of the area.

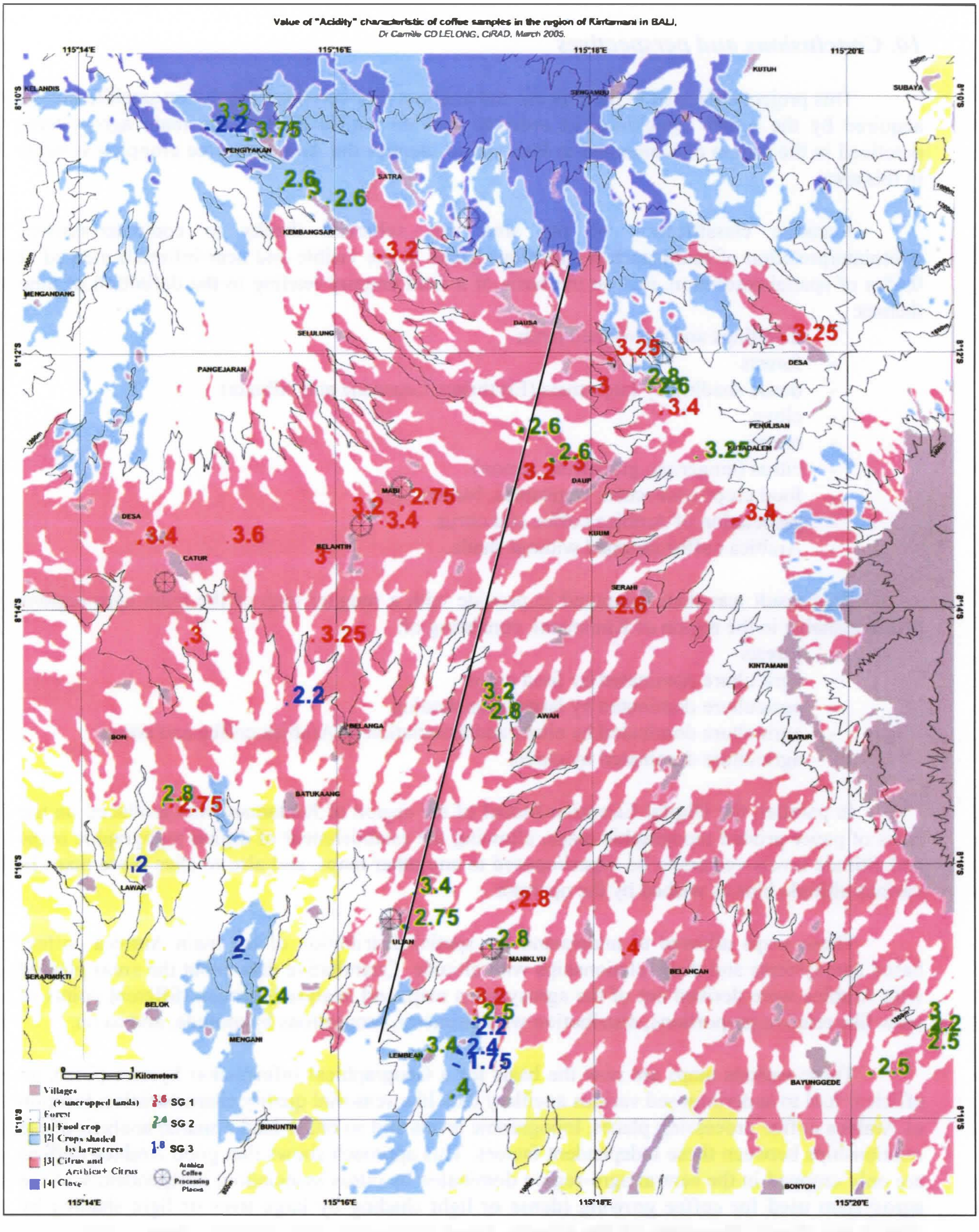


Figure 67: Value of the "Acidity" characteristic of Arabica coffee sampled in the region of Kintamani in Bali, mapped over the main agro-regions of the area.

10. Conclusions and perspectives

This project consisted in the process and analysis of a very high resolution satellite image, acquired by the sensor Quickbird, in order to provide with a map of the main agrosystems practiced in the region of Kintamani in Bali and to identify the Arabica coffee cropping systems in this area.

Accurate classification of the area was achieved thanks to computer-assisted photointerpretation of multispectral data (four bands in the visible and near-infrared) merged at 0.65m of spatial resolution, and on the basis of a field enquiry leading to the definition of nine themes:

- dwellings and uncropped lands
- forests
- dense shading by large trees (Erythrina, Leucaena and Albizia)
- clove
- cocoa
- citrus (tangerine, grapefruit, lemon)
- food crops (rice, corn, vegetables, banana...)
- association of Arabica coffee and citrus
- Arabica coffee cropped without shade.

This result was then computed to provide with a rougher map of the main agro-regions distinguishable in the region of Kintamani, consisting of:

- forests
- agriculture dominated by food crops
- agriculture dominated by large trees shading
- agriculture dominated by citrus and association of Arabica coffee and citrus
- agriculture dominated by clove.

In parallel, the Digital Elevation Model of the region of Kintamani was produced on the basis of paper-printed topographic maps, allowing the establishment of digital topographic maps and altitude levels vectors to be superimposed to any other maps, and also to slice those maps in various altitude bins as wished by the operator.

These maps allowed to understand the spatial distribution of the main Arabica coffee-based agrosystems and their relationships with altitude. Quantitative data about the areas planted with Arabica were derived out of the agrosystems map, and analysed through different points of view like relative proportions, distribution with altimetry, proportions by altitude, and so on.

These various maps are now the basis for a Geographical Information System (GIS), an efficient tool to superimposed various ancillary data like sensorial quality characteristics, location of Arabica coffee processing places, topographic levels and so on, to lead a spatial analysis of the relationships between these independent factors. This approach shows that good Arabica coffees are only cropped in the central agro-region dominated by citrus association, independently of the agrosystem used for coffee growing (dense or light shading by large trees or light shading by citrus), but clearly depending of the altitude. Good coffees are only cropped above 1100m. It is also possible to delimit inside this agro-region an area surrounding Catur and Belantih villages, at West of a line drawn between Ulian and Dausa villages, where only good Arabica coffee were sampled. The connecting region at East seems to product both good and average Arabica coffees.

Nevertheless, it seems that no trivial and restrictive limits can be extracted for the "terroir" of Kintamani Arabica coffee, neither out of the sensorial quality analysis achieved by experts of CIRAD and ICCRI, neither coupled with the spatial analysis based on the satellite image products. Additional information thus might be analysed and correlated with these first results to help leading to a conclusion about the potential limits of the "terroir".

For instance, further photointerpretation of the satellite image could be lead in order to give more detailed information about crop management inside each agrosystem. Indeed, some kind of characteristics can be of interest to help defining the "terroir" criteria like, for instance, such information that could be extracted out of the satellite image:

- presence of terraces
- presence tree fences or continuous cropping
- undercover (soil, weeds or food crop)
- planting density (spacing between trees, canopy crown dimensions)
- intra-plot heterogeneity and biomass distribution
- amount (area) and density of shading

Other management factors like addition of organic manure and pests, and plants vigour and health can be measured In the fields and geographically referenced to be integrated into the GIS.

In this volcanic and mountainous region, soil can vary a lot in composition and especially organic content, granulometry, humidity potential, and so on. Soil composition maps should then be produced (out of existing soil data or on the basis on new measurements) and added to this GIS to be correlated to any other geographical information and quality analysis to be sure that no soil effect is involved in the specificities of the Arabica coffee.

Spatial analysis can also be done concerning the distribution of dwellings and villages (isolation, size, organisation, proximity of temples, of coffee processing places...) for sociological interpretation of the agrosystems. Ancillary sociological data (for instance provided by INAO and CIRAD inquiries) should also be added to the GIS constructed in this present study. For instance it seems of huge importance to establish a map of the Subak Abian delimitations: these Subak Abian are the traditional Balinese social and religious structures ruling all the all-day life of inhabitants. For any delimitation the area unit should be whole area of a Subak Abian. Such a map could be produced in partnership with the Subak Abian chiefs and the local Dinas Perkebunan, on the basis of an enquiry combining people's declarations and GPS measurements followed by a vectorisation over the topographic map and satellite image as references for geographical limits (rivers, forests, villages...).

Finally, the produced maps give an efficient support to prepare future coffee berry samplings so that they can be representative of the variability of cropping contexts in the area, and adapted for a good determination of geographic characteristics linked to sensorial quality.

In conclusion, the analysis of very high spatial resolution satellite imagery provides with spatial and quantitative data of special interest for the knowledge and understanding of the agrosystems based on coffee practiced in the Kintamani region of Bali. It constitutes a good basis for a Geographic Information System allowing spatial analysis of relationships between sensorial quality, altitude, agrosystems and other ancillary data. It helps defining rough limits of a potential "terroir" for the Kintamani Arabica coffee. But it needs further analysis like, on one hand, more detailed photointerpretation and, on the other hand, addition of soil, crop management, sociological data and new sensorial quality data focused inside the citrus-dominated agro-region in order to improve the understanding of components of good coffee growing and their relationships with geographical indicators.

Aknowledgements

This project was funded by the French Ministry of Foreign Affairs (MAE) and by the Centre of International Cooperation in Agronomical Research for the Development (CIRAD). It was supported too by the Indonesian Ministry of Agriculture and the French Embassy in Indonesia through the larger project encompassing this one and concerning the Definition of Geographical Indications for the Arabica Coffee in Bali.

Though this report is the result of the work of a remote sensing specialist, it could never have been achieved without the contribution of the coffee experts and other participants of the overall project. I thus strongly wish to thanks all the people that have been implied more or less in this study and more especially the following persons that really helped its outcome:

- Jacques Avelino, CIRAD, raised up the idea of the use of remote sensing for the definition of geographic information in Bali: without him this study would not have been implemented,
- Bertrand Sallée, CIRAD, lead the huge task of coordinating this large project and supported this work with his accurate knowledge concerning coffee culture and with his advices and encouragements,
- Joko Sumano, ICCRI, and Nyoman Suarta, Dinas P. Kintamani II, worked actively in the fields during the ground-truth enquiry and helped me learning Bahasa Indonesia language and understand Balinese culture: their contribution has been more than essential for the work and of wonderful richness in the human point of view (Matur suksma taman-taman saya!),
- Surip Mawardi, ICCRI, and the staff of the Dinas Perkebunan in Bali gave precious help in launching the field experiment and learning about coffee cropping systems in the Kinatamani region,
- Jean-Jacques Perriot and Fabienne Ribeyre, CIRAD, provided me with their coffee cup sensorial quality analysis results,
- Valérie Keller, INAO, gave me helpful information about the assumed limits of the "terroir" to prepare the field work,
- Olivier Tichit and Uliana, ECOM, learnt me about the sociological fallout of the project and gave me the geographical data of the coffee processing places.
- Made Rede and all the inhabitant of the cooperative of Muli Sarih in the village of Mabi welcomed me during four weeks of strange but instructive typical community Balinese way of life, making the field enquiry something like an unforgettable experience.

Abstract

Very high resolution (0.65m) satellite imagery, field enquiry about cropping systems and other georeferenced information are analysed in order to provide with maps of interest for the definition of geographical indicators to help delimiting a **"Terroir" Arabica** in the region of **Kintamani in Bali**. It results in the production of several maps including: a) **map of the main agrosystems** practiced in this region: food crops, forests, systems associated with dense shading by large trees (Erythrina, Leucaena and Albizia), systems based on perennial crops (Clove, Cocoa, Citrus, associations of Citrus and Arabica coffee, Arabica coffee cropped without shade), b) **map of the main agro-regions** distinguishable in this area (agriculture dominated by food crops, by large trees shading, by Citrus and associations with Citrus, and by Clove), and c) **Digital Elevation Model** (DEM) of the region. These different products allow to implement **spatial analysis** of the Arabica coffee-based agrosystems distribution in the region of Kintamani in Bali and to derive **quantitative data** about the areas planted with Arabica in this region. These products constitute the basis of a **Geographical Information System** (GIS), enabling the superimposition of various ancillary data like sensorial quality characteristics, location of Arabica coffee processing places or topographic levels, to lead a spatial analysis of the relationships between these independent factors. This approach shows that some characteristics are clearly linked with the production of good Arabica coffees. They are located inside the central agro-region dominated by Citrus associations (and more precisely at West of the line Ulian / Dausa), and cropped only above the altitude limit of 1100m. The agrosystem used for Arabica coffee growing (e.g. shading by large trees or by Citrus) seems to have no effect on its quality. Nevertheless, it seems that no trivial and restrictive limits can be extracted for the "Terroir" of Kintamani Arabica Coffee out of this first study. Propositions are made for additional information to be collected and correlated with these first results to help leading to a conclusion about the potential limits of the "terroir". Especially there is a strong need for a map of the Subak Abian (traditional Balinese social and religious structures) that will be the area unit for any delimitation, a map of the soil composition, maps of crops management characteristics (e.g. use of terraces and fences, undercover nature, planting density, shading density and heterogeneity...) that could be extracted out of further photointerpretation of the satellite image, and additional coffee berry sampling and cup quality analysis. Integration of all these data inside the GIS and their spatial analysis should largely improve the understanding of components of good coffee growing and their relationships with geographical indicators.

Résumé

Ce projet consiste en l'analyse couplée de données issues de **l'imagerie satellitaire à très haute résolution spatiale (0,65m)**, d'une enquête de terrain concernant les systèmes de cultures et d'autres informations géoréférencées, ayant pour objectif d'apporter une dimension cartographique à la définition d'indicateurs géographiques visant à délimiter un **Terroir Arabica** dans la région de **Kintamani à Bali**. Il en résulte la production de plusieurs cartes incluant: a) une **carte des principaux agrosystèmes** rencontrés dans cette région: cultures vivrières, systèmes de culture associés aux grands arbres d'ombrage (Erythrina, Leucaena et Albizia), systèmes fondés sur des cultures pérennes (giroflier, cacao, agrumes, associations agrumes + caféier Arabica, caféier Arabica cultivé sans ombrage), b) une **carte des grandes agro-régions** distinguables dans cette zone (agriculture dominée par les vivriers, par l'ombrage sous grand arbres, par les agrumes et leurs associations et par le giroflier) et c)le **modèle numérique de terrain** (MNT) de la région. Ces différents produits permettent une **analyse spatiale** de la distribution des agrosystèmes à base de caféier Arabica et une estimation des **variables quantitatives** concernant les surfaces plantées en caféier Arabica dans la région. Ces produits constituent la base d'un **Système d'Information Géographique** (SIG) permettant la superposition de données ancillaires variées comme les résultats d'analyses sensorielles, la localisation des centres de procédés sur le café Arabica ou encore les niveaux topographiques, pour mener à bien une analyse spatiale des relations entre ces différents facteurs. Cette approche montre que certaines caractéristiques sont clairement liées à la production de bons cafés Arabica. Ces bons cafés sont localisés au sein de l'agro-région dominée par les systèmes à base d'agrumes (en monoculture ou en association) et plus précisément à l'ouest d'une ligne Ulian/Dausa, et sont cultivés uniquement au dessus de l'altitude 1100m. Le système de culture pratiqué pour la culture du café Arabica (par ex. ombrage de grands arbres ou d'agrumes) semble en revanche ne pas avoir d'effet sur sa qualité. Il semble toutefois qu'on ne puisse extraire aucune limite évidente et restrictive du Terroir Arabica de Kintamani à partir de cette première étude. On propose alors de récolter des informations supplémentaires et de les corréler à ces premiers résultats pour avancer vers une délimitation possible de ce terroir. En particulier, il ressort un fort besoin d'une carte des Subak Abian (structures socio-religieuses traditionnelles à Bali qui seront l'unité de base pour toute délimitation), une carte de la composition du sol, des cartes de caractéristiques des pratiques agricoles (par ex. utilisation des terrasses et des haies, nature de la couverture au sol, densités de plantation, densité et hétérogénéité de l'ombrage...) qui peuvent êtres obtenues par une photo-interprétation plus poussée de l'image satellitaire, et des données de qualité sensorielle de la tasse basée sur un nouvel échantillonnage de cafés. L'intégration de toutes ces données dans le SIG et leur analyse spatiale devraient largement faire progresser la compréhension des composantes géographiques d'un bon café Arabica dans la région de Kintamani à Bali.