NOVEL APPROACHES TO USE RS-PRODUCTS FOR MAPPING AND STUDYING AGRICULTURAL LAND USE SYTEMS

Dr. C.A.J.M. de Bie
ITC, Enschede, The Netherlands; debie@itc.nl

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ABSTRACT

This paper deals with novel methods that support production of agricultural land use information as required to provide timely spatial information to generate food security policies and that support land use planning studies. Options are discussed that aim at improving the quality and efficiency of required geo-spatial information production with special emphasis on agricultural land uses. Attention is drawn to use the dynamic aspects of land use systems while mapping land use by using crop calendar and crop pattern information. Similarly emphasis is put onto recognizing plots that form the primary unique sample units to survey when collecting agricultural land use data.

Shown is a method (top-down) that allows de-aggregation of available countrywide tabular statistical data on cropped area and crop production to 1km pixel crop maps by making use of 1km NDVI profile maps, agro-ecological knowledge, and thematic GIS layers. Bottom-up options discussed aim to support land use surveys; they are: merging image analysis results, classify images using crop calendar survey data, classify images using NDVI profiles and known crop calendars, surveying using mobile GIS techniques, and segmentation of images based on object-oriented analysis.

Multiple area frame land use surveys at country level use, after stratification and random selection of primary survey units, air photographs (AP's) as guide to sample plots. The novel discussed techniques require further study to replace the costly and laborious elements of preparing frames using AP's while simultaneously improving the survey quality. Use of new high resolution RS-images (e.g. Aster of 15m) and multi-temporal NDVI images (of 1km) make the discussed approaches feasible, i.e. to identify individual fields directly, to mask natural cover types present, and to differentiate types of cropping patterns followed.

1. INTRODUCTION

Population growth is leading to increasing demands for food and hence claiming more land for food production. This process threw many developing countries into a "poverty trap" characterized by expansion of agriculture into marginal lands, land degradation, declining yields, increasing frequencies of crop failures, food shortages, and conflicts between parties with different interests in how specific tracts of land are used. Drought and floods, possibly associated with climate changes, further enhance food supply problems in some areas.

Programmes or projects that address the stated sustainability issues specifically require timely and reliable (spatial) information on the productivity and sustainability of current agricultural land use systems. However, there is a general paucity of land use information in many developing countries and it is often difficult for the range of potential clients to access the information that is available. Young (1998) refers to the described vacuum as:

- "to an extent which, viewed in retrospect, is remarkable, methods for the collection and analysis of land use data have lagged behind those for natural resource surveys", and
- "…the situation with respect to land use classification was comparable with that for soils in about 1950: a large number of systems devised for national use, with no guidelines for comparison",

whilst:

> "at national level, many countries are now seeking to monitor land use change as a basis for policy guidelines and action", and "…land use is generally treated as the second most fundamental set of statistics, following population".

2. RESEARCH OBJECTIVE

The aim is to contribute to the development of compilation methods of spatial and temporal land-use data sets using existing data sources and improved GIS-based survey methods to subsequently make them available to the public with the help of recently developed data-dissemination tools.

It is envisaged that, among others, these data can be used for enhancing a broad range of studies in areas such as early warning in relation to food security, yield gap analysis studies, regional to global assessment studies, land-use planning, disaster mitigation, urban-rural linkages, the monitoring and assessment of land/ water degradation, loss of biodiversity and ecosystem functions, as well as for project formulation.

3. METHOD

Noting:

- the complexity (and back-log) of capturing and managing required land use information,
- the shortcoming to review the extent, variability, and quality of existing land use data,
- the requirements that properly geo-referenced products must soon become available,
- review of various existing land use concepts lead to further delays in producing products,

it is clear that a practical step-wise approach must follow the logic from:

'<u>quick, incomplete, and of limited use</u>',

to:

'<u>relatively laborious, flexible, and without limitations regarding applicability</u>'.

The proposed step-wise approach will initially address relatively more land use de-aggregation GIS-issues (a **top-down** approach), and ultimately more land use data capturing GIS-issues (a **bottom-up** approach”).

Topics covered are:

- Mapping and de-aggregating tabular land use statistics (**top-down**).
- Options to improve land use surveys (**bottom-up**):
    - Merging image analysis results.
    - Classify images using crop calendar survey data.
    - Classify images using NDVI profiles and known crop calendars.
    - Surveying using mobile GIS techniques.
    - Segmentation of images based on object-oriented analysis.

4. MAPPING AND DE-AGGREGATING TABULAR LAND USE STATISTICS

The presentation and use of available countrywide tabular statistical data on cropped area and crop production can be vastly improved when presented as crop maps and made available as GIS layers (Web based).

This requires preparation of geo-referenced crop maps at sub-national level that are compatible with current GIS systems. It builds on readily available (basic) agricultural statistical data. Products provide basic spatial information on cropped agricultural land. They do not provide full details on land use purposes or cover aspects of crop calendars, multiple cropping and carried out operations (inputs, dates, etc.). Products are immediately of use for integration in early warning crop monitoring activities.

The activity basically builds on readily available statistics and maps to generate through statistical inference a new GIS product.

Input data comprise of crop statistics at a sub-national level, e.g published agricultural census data and/or annual bulletins on cropped areas by administrative areas for the whole country. Annual statistics must be properly scrutinized through evaluating time series. A 5-year period update must be aimed at.

The FAO (AGL-department) is presently compiling the required statistics for many developing countries using 10-yearly Agricultural Census reports and when un-available, by compiling series of annual crop statistical publications.

Spatial GIS data comprise of RS-images, expert rules on agro-ecology and of thematic maps.

Very useful images, which are freely available through the Internet, are the SPOT-4 Vegetation 1-km NDVI images. At present a 4-years decadal global dataset exists. The data are superbly geo-referenced and allow the user full control on (de)-selecting pixels on the basis of the provided radiometric quality and cover type seen (land, water, ice, snow, cloud, shadow). Time series of images can be subjected to an unsupervised classification routine to stratify and differentiate relevant vegetation profiles (**Figure 1**). The number of required classes to prepare is evaluated through an iteration process.

Expert rules relate to evaluating Agro-Ecological Zone maps (weather and land) regarding the suitability (possibility) of each zone to grow the crop under scrutiny. Noted must be that suitable areas might be cropped by more profitable crops while areas evaluated as less suitable in the eyes of the researcher are often deemed suitable by marginal subsistence farmers. The shown example notably showed little explanatory power of the shown crop suitability map (modified FAO-product) to explain reported crop statistics by administrative area.

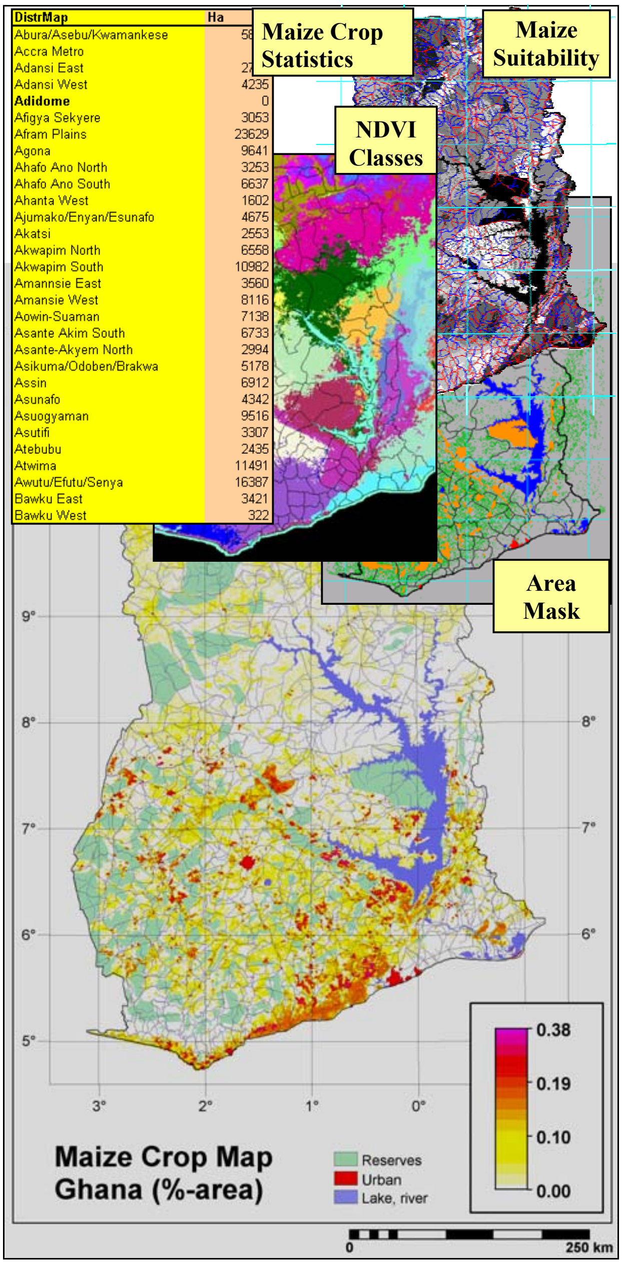


Figure 1. De-Aggregating and Mapping Crop Statistics.

- The ‘Area Mask’ comprises of the location of parks and reserves, urban areas, water, and a 100 m pixel radar image, classified by comparing it with Aster images (15 m) to identify pixels representing trees.
- The NDVI image represents a classified image (30 classes) of 4 -years, decadal, 1 km Spot Vegetation NDVI Images.
- % of area to maize = 1.9 if Mod.Suit. + 2.7 if Suit. + 6.9 if Class-11 + 3.0 if Class-15 + 32.6 if Class-25 + 17.8 if Class-26 + 12.3 if Class-27 + 34.1 if Class-29 + 15.5 if Class-30 *(N=110; Adj.R-Sq=74%)*; preliminary result.

Thematic maps are used to prepare a mask that filters out areas where the crop is surely not grown (parks, reserves, urban areas, water bodies, forests, etc.). For the example shown (Ghana; **Figure 1**), also a 100 m pixel radar image was used for the southern humid tropical areas to counter-balance cloud problems faced for that region with the NDVI images. The radar image was classified by comparing it with Aster images (15 m) to identify pixels representing trees. Such pixels were added to the mask.

Analysis is based on the GIS procedure to count by administrative area the number of pixels belonging to each of the NDVI and suitability classes while excluding pixels that are masked out. This produces a matrix of data that is tested through fore-ward step-wise multiple regression for its relation with the tabular agricultural statistics. The generated function is in turn used to generate the required crop map (**Figure 1**). An iterative procedure to re-define the number of useful NDVI classes to generate is now recommended.

One can consider to add to the generated output additional land use statistics as available in Census or annual agricultural reports, like yields, NPK use, area irrigated, etc.

5. OPTIONS TO IMPROVE LAND USE SURVEYS

This activity deals with novel methods to support gathering through surveys selected land use information, and aim to study ultimately in detail crop production land uses (where fields are present!).

Multiple area frame land use surveys at country level use, after stratification and random selection of primary survey units, air photographs (AP's) as guide to sample plots (already adopted in many developing countries). Survey preparation is costly and laborious. Use of new high resolution RS-images (e.g. Aster of 15m) and multi-temporal NDVI images (of 1km) provide options to identify individual fields directly, to mask natural cover types present, and to differentiate types of cropping patterns followed. At present Aster images are very cheap (vs. non-availability of AP's or forced use of old AP's), while decadal 1-km resolution NDVI images are completely free of costs.

The approaches aim to develop new standards that offer huge savings of time and costs while improving accuracy and detail. Clearly further research is required to fully test, explore and integrate suggested methods. Once done, improved "survey guidelines" must emerge.

To explore activities, some basic concepts must be provided.

A **Land Use System (LUS)** is defined as: "A specific land use, practiced during a known period of time on a known unit of land that is considered homogeneous in land resources" (de Bie 2000). A land use system (**Figure 2**) is composed of two main elements: land and land use. **Land Use** is defined as: "A series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources" (de Bie 2000). Land use purpose(s), i.e. the intended products or benefits of land use, and an operation sequence, i.e. a series of operations on land in order to realize one or more set land use purposes, characterize land use.

To understand the "operation sequence" better, some definitions follow:

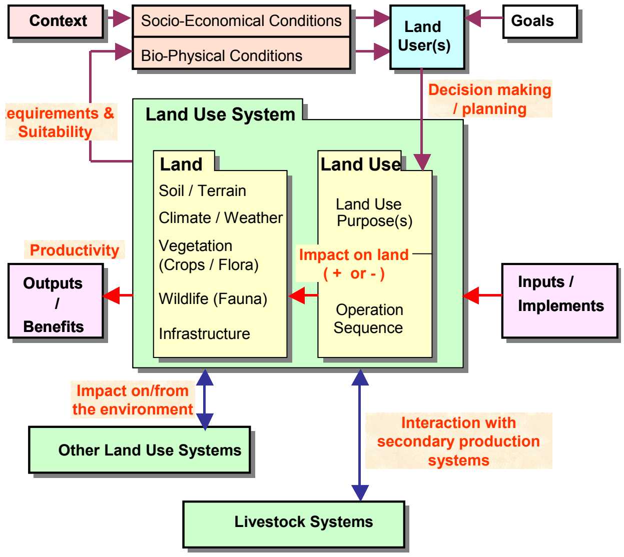


Figure 2. Conceptual Structure of a Land Use System (LUS) providing Practical 'Study Entries' (de Bie 2000).

Operations (**Figure 3**) are intended to modify land aspects, e.g. soil characteristics or land cover. Some modifications are permanent (constructing infrastructure) whereas others can be of a temporary nature, e.g. the successive land cover types 'bare soil, crop, and stubble' are brought about by 'ploughing, planting and harvesting'. Impacts of operations may exceed the intended effects resulting in, e.g. erosion, accumulation of pesticide residues, loss of soil fertility, etc. Four basic types of impact can be distinguished; they relate to soil/terrain, flora/fauna, infrastructure and air.

Observations (**Figure 3**) are defined as: "A record of one or more land conditions that are relevant to the performance of a land use system." Examples of observations are "water shortage during crop establishment", or "recorded limitation of the rooting depth of crops". Observations can be made at any moment during the life span of the land use system; the land user makes them often and information about such observations is obtained through interviews. Observations frequently provide important information on the temporal properties of the land use system; such information is not stored in databases that contain only static or generalized data on land.

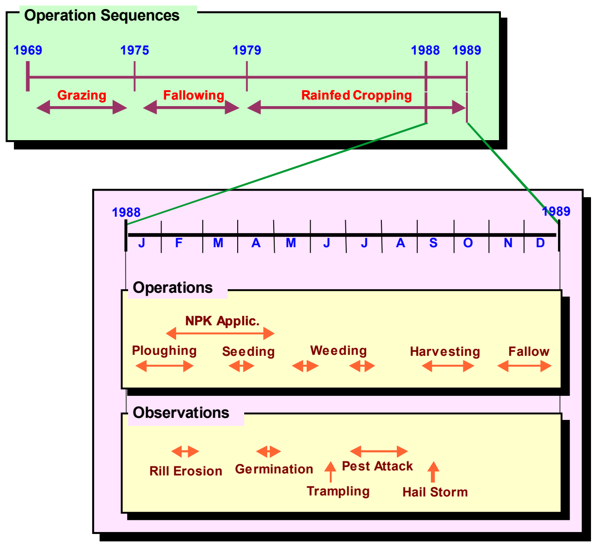


Figure 3. Illustrating Land Use Operations and Observations.

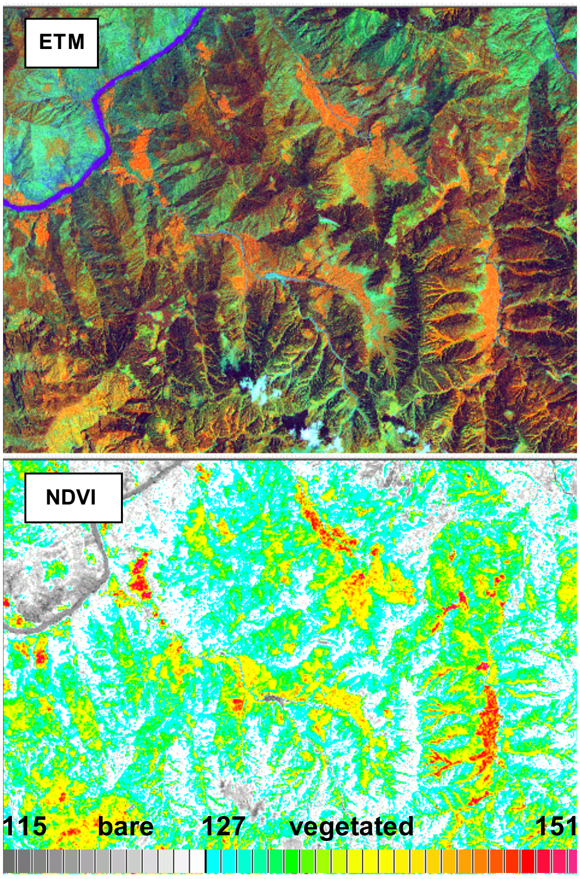
6. MERGING IMAGE ANALYSIS RESULTS

Classification of differences shown on E-TM images may be problematic due to the difficulty to differentiate categories of cover classes; often a continuum in vegetation from low to high cover is observed and class boundaries cannot be properly identified. A solution is available by converting the image to an NDVI map. Cover classes that are distinctly visible on the image, but that looses that characteristic when converted to NDVI data form a complication. Following a dualistic interpretation approach solves both problems.

An example is taken from part of the ETM-150/36 image, taken in August 1999 (**Figure 4**). An NDVI map was prepared, and based on comparing a mosaic of images, the NDVI scale was adjusted by the formula [0.70 (NDVI – 110) + 110], to reduce the level of greenness to NDVI's expected by end-Oct/early-Nov. (**Figure 4**). The NDVI map is based on a gliding scale; no attempt is made to link levels to cover classes.

Comparing the NDVI map with the original TM image shows that the dark-reddish areas do not represent active-green vegetation. Consequently information loss took place. The dark areas however comprise of pine trees and shade; pine trees have a low chlorophyll activity. Both are very distinct classes and must be re-introduced onto the NDVI map.

The ETM was subsequently classified through conventional routines to map trees and shade (**Figure 4**). Equally other cover types occurring in the area like snow, ice and clouds, were mapped. Superimposed on the NDVI image the classified image produced the merged product (**Figure 4**).



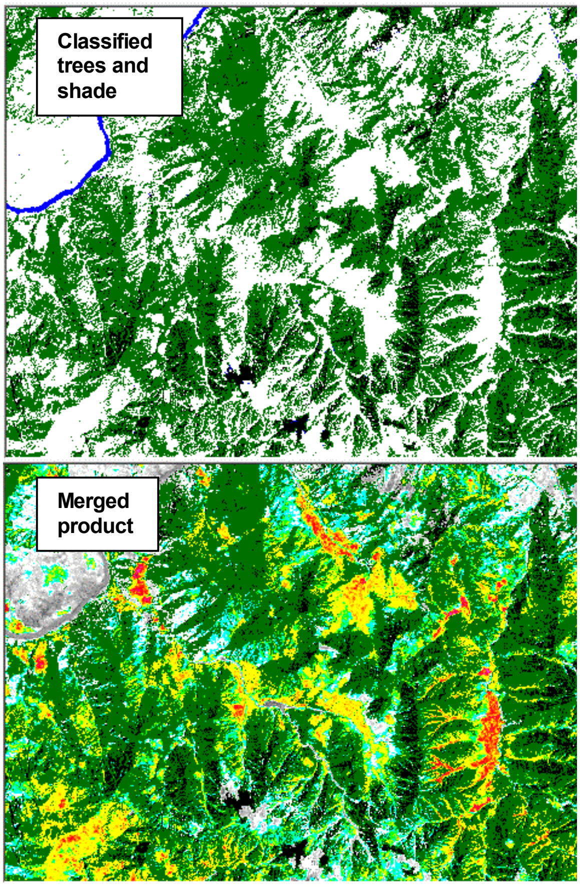


Figure 4. Merging Distinct Cover Classes with a Continuum NDVI Interpretation.

After the product is prepared, GIS features as available on topo-sheets and on other higher-resolution images (e.g. 15 m Aster images), provides a map that is ready for local-level survey and land use planning exercises. An example of a village map prepared on the above lines is shown in **Figure 5**.

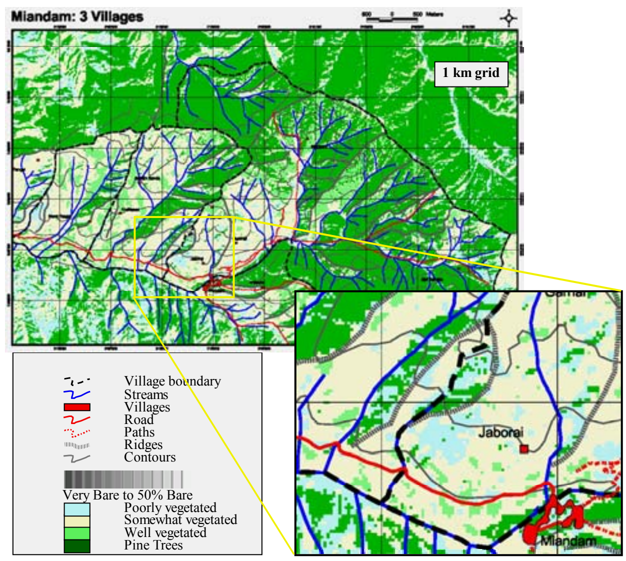


Figure 5. Adding Features to an Interpreted ETM Product.
[Miandam, located in the Swat valley, has an abundance of pine trees, especially on northern slopes. The main hillside, till the crest, has many hamlets, is less vegetated and is mainly used for grazing (cyan color on the image). Dispersed, many fields with annual crops were found (yellow); orchards are situated close to the streams (light green color).]

7. CLASSIFY IMAGES USING CROP CALENDAR SURVEY DATA

The “operation sequence” (**Figure 3**) is an essential component of any crop calendar. A **crop calendar** is defined here as: “A sequential summary of the dates/periods of essential operations, including land preparation, planting, and harvesting, for a specific land use; it may apply to a specific plot, but is frequently generalized to characterize a specified area.” Plot specific crop calendars form the key to **map** land use with the support of (multi-temporal) RS-imagery (**Figures 6 and 8**).

Note that the spatial characteristics of a land use system define its boundary. For agricultural purposes, a land use system can be limited to a plot. A **plot** is defined here as "A piece of land, considered homogeneous in terms of land resources and assigned to one specific land use."

A **cropping pattern** is traditionally defined as (ASA 1976; FAO 1996): “The yearly sequence and spatial arrangement of crops or of crops and fallow on a given area”. In view of the crop calendar definition, the **cropping pattern** definition can be sharpened to: “The spatial and temporal arrangement of crops (trees) on a specific plot.” Generally, a cropping pattern refers to a period of one year, but may also contain information on crop rotation. The definition contains spatial information (within a plot) that is not present in a crop calendar, but lacks actual date/period references as provided by a crop calendar.

Cropping pattern terminology is area a-specific and therefore often used to **classify** land use. Legends of land use maps will considerably improve when cropping pattern syntax is used (see list of classifiers in the PhD thesis of the author (De Bie 2000).

Note that the development of a universal land use classification system is not considered desirable. Instead, classifiers that define and differentiate between existing (commonly used) land use classes can develop into a standardized turn-key system that is able to merge and generalize data belonging to different classification systems. Use of “standardized” classifiers supports standardization, but should never cause users to change class boundaries unwillingly (practicality must come first!).

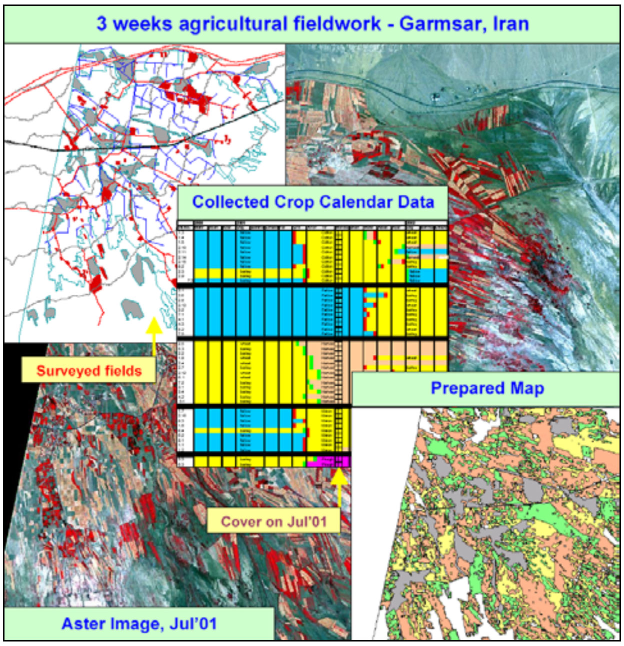


Figure 6. Generalization of Plot Specific Crop Calendar Data with the Resulting Land Use Map.

A practical example regarding ‘mapping through surveying crop calendars’ is provided in **Figure 6**. In a spreadsheet by plot collected data are made visual and sorted on the basis of differences in cover that is visual on the Aster image of July 2001. The problem of time lag between image date and survey date has thus become non-relevant.

After developing 3 groups of crop calendars, using the pixels of surveyed sites, the image was classified. The map accuracy was determined on the basis of additional plots surveyed. **Figure 7** provides the accuracy matrix on the basis of pixel counts. Accuracy and class-differentiation can be further improved by using multi-temporal images (**Figure 8**).

classification results

		cotton_melon	fallow	harvested	unagri	village	Sum	Accuracy
	cotton+melon	1043	19	8	64	42	1176	88.7%
test set	Fallow	57	191	3	29	65	345	55.4%
	Harvested	6	17	360	134	28	545	66.1%
	Sum	1115	227	371	227	135	**2066**	
	Reliability	93.5%	84.1%	97.0%				

Average Accuracy:	70.0%
Average Reliability:	91.6%
Overall acc.:	77.2%

Figure 7. Accuracy Matrix of Map Presented in Figure 6.

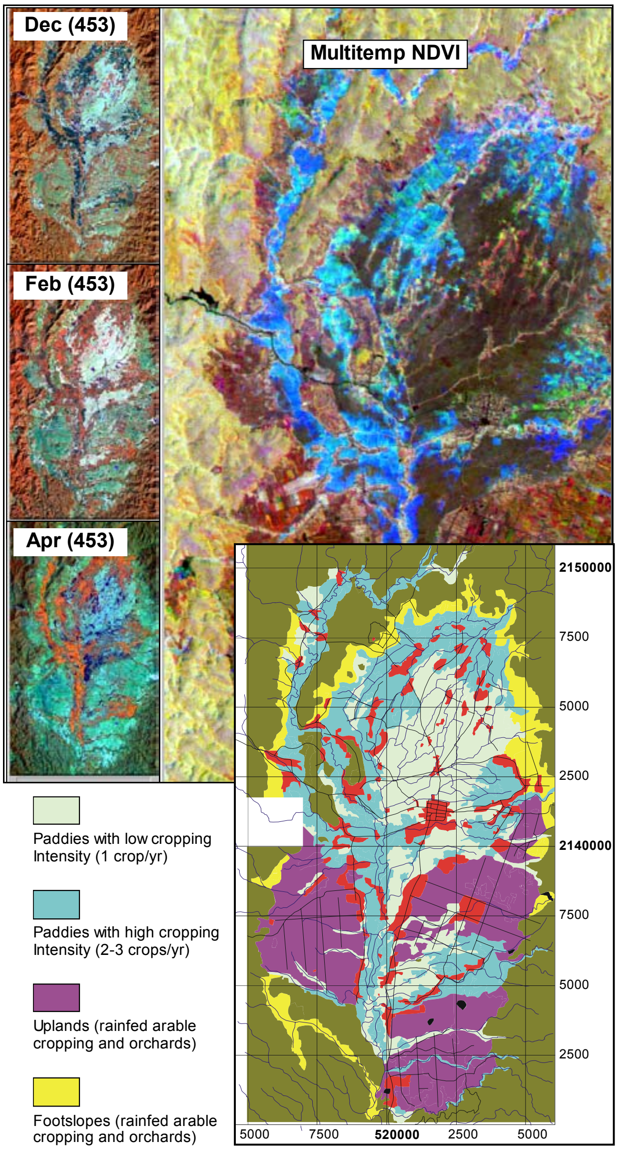


Figure 8. Example of Using Multi-Temporal Images to Map Paddies with Different Crop Intensities.

8. CLASSIFY IMAGES USING NDVI PROFILES AND KNOWN CROP CALENDARS

The approach used in §4 to stratify and differentiate relevant vegetation cover profiles using 4-years decadal SPOT-4 Vegetation 1-km NDVI images, also offers options to identify spatially areas having different crop calendars. Use of a (mosaic of) single high-resolution image lacks the required temporal information.

The relation and interpretation quality between country level and local-level classified 1km NDVI time series is explored to ascertain the link of both with crop calendar information.

For India, the available time series of images were subjected to an unsupervised classification routine to define 30 classes (**Figures 9 and 11**); the choice of class numbers relates with the number of mixed categories by pixel that will be differentiated. Similarly, also the time-series sub-set of W-Nizamabad was subjected to the routine to generate 30 area-specific classes. Profiles of the latter classes were visually compared and generalized into 14 classes / NDVI profiles (**Fig. 10 and 12**).

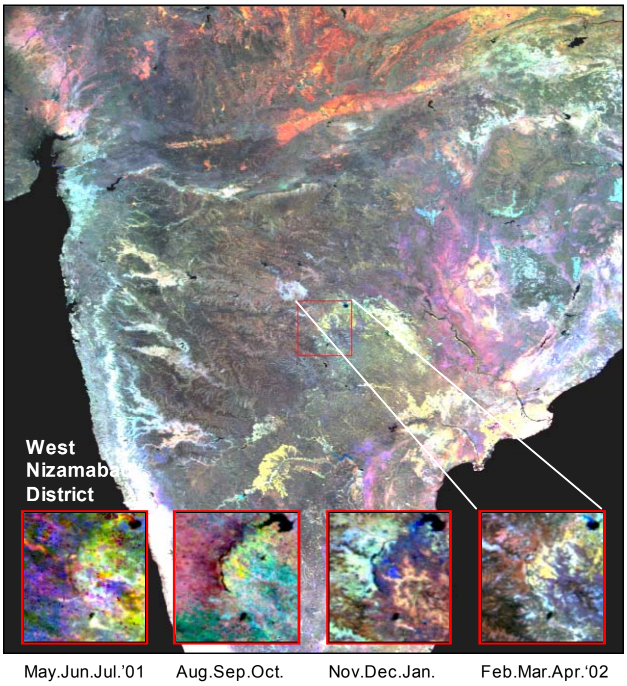


Figure 9. Location of Study Area in India on a 1km Resolution Spot Vegetation NDVI Image (RGB - Feb, Mar, Apr'02).

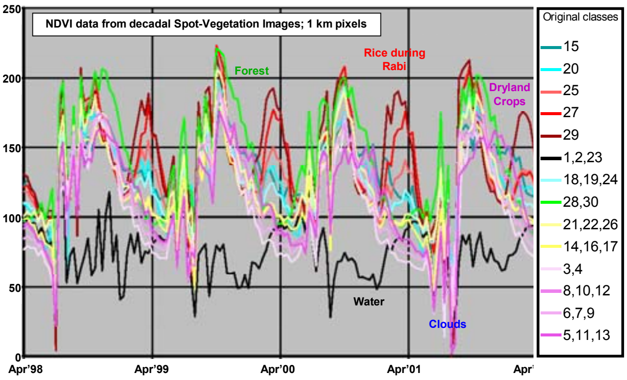


Figure 10. NDVI Curves of 14 Cover Types in W-Nizamabad based on 4 Years Decadal 1km Spot Vegetation Data.

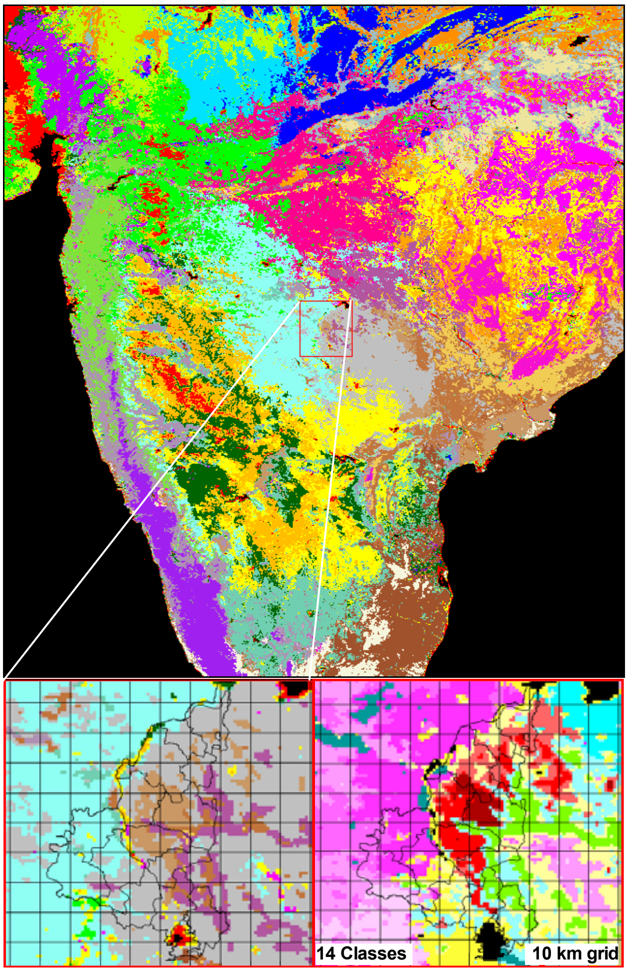


Figure 11. Unsupervised Classified Image (30 classes) of Fig.9. Enlargement of Nizamabad, and It if Classified Separately.

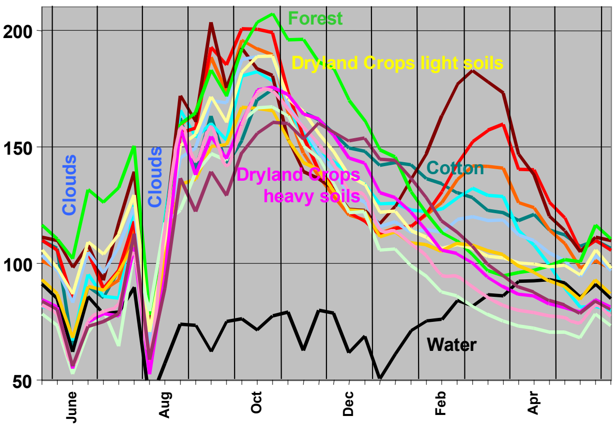


Figure 12. NDVI Curves of 14 Cover Types in W-Nizamabad.

The enlargements shown in **Figure 11** show that the spatial differentiation in classes is highly similar (colors are user defined). The area specific classification shows however (after merging classes from 30 to 14) a more likely, less-scattered, spatial stratification with more mixed categories. **Figure 13** shows that the latter interpretation is acceptable; note specifically the location of paddies (bluish on the image).

Figure 12 simplifies **Figure 10** and lends itself better for comparisons with crop calendar information. Note that several curves represent class 'mixtures' as they occur in a 1km grid.

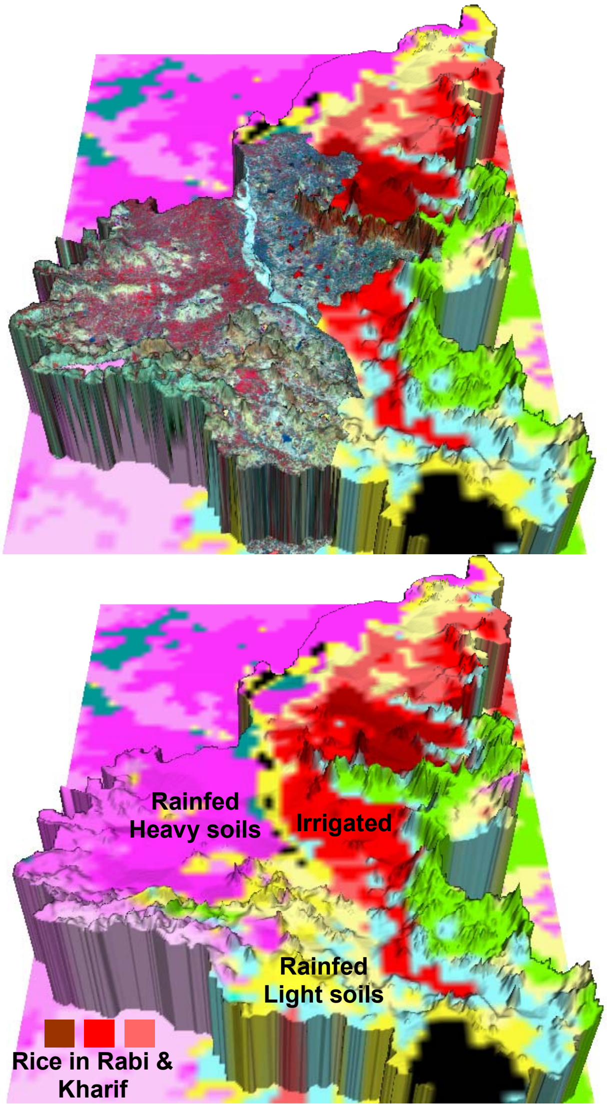


Figure 13. Part of an IRS Image (left; 18 Jan'00) and the Map of 14 Cover Types (right), draped over a DEM.

Comparing the NDVI profiles with the crop calendar data (IMSD 1995, Kameshwara Rao 1995) shows a good spatial identification of all 4 out of the 5 dominant crop calendars followed (sugarcane is grown at a limited scale in the rice area).

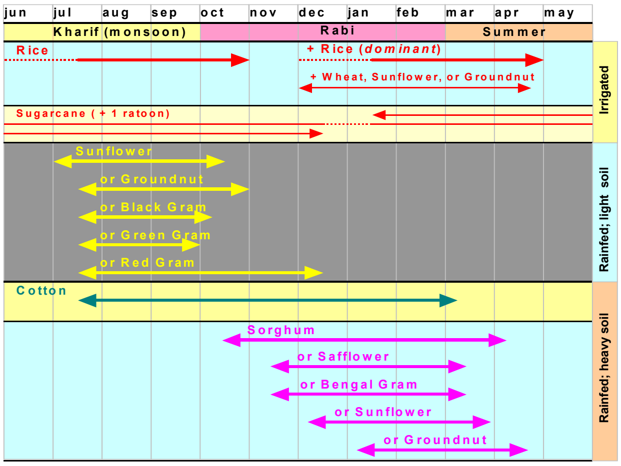


Figure 14. Crop Calendars of Nizamabad in Colors that Match those in Figures 12 and 13.

9. SURVEYING USING MOBILE GIS TECHNIQUES

Research on professional options to use in the field digital maps and to digitize by GPS points, lines and polygons, led to a relatively cheap but excellent solution (**Figure 15**).

Figure 15. The Mobile-GIS Equipment.

The Compaq-iPAQ pocket PC running at 200 Mhz under MS-Windows-CE v.3.09) is able to run Arc-Pad (v.6.0) and to connect to a GPS. The Pocket PC has backlight-features so that in bright sun the screen is still perfectly readable.

If proper software settings are adhered to, Arc-Pad is able to convert GPS readings 'on-the-fly' to the coordinate system in use. Any image, GT-Sheet, or shapefile can be displayed in Arc-Pad (on the Pocket-PC) 'as is'. The GPS position is shown on the loaded maps or images. The user can save the GPS-tracklog (as points in lat-long), or use the GPS to prepare shapefiles (point, line, or polygon features in the projection system of loaded maps). The software also allows to prepare forms (questionnaires), and to draw points, lines, or polygons directly by hand on the screen. The "iPaq–Arc-Pad–GPS" combination comprises a compact but complete set-up of digital survey equipment that can be employed in the field by car or on foot. The set-up is tested in a series of countries.

Raster images are converted into MrSID files using Erdas v5.0 or Arc-GIS; this reduces image sizes by a factor 20 with hardly visible quality loss. Arc-Pad software comes with extensions that load into Arc-View or Arc-GIS.

Most problems with the system relate to knowledge on projection systems, to the need to prepare *.prj files containing projection information, and to proper use of datum settings. Once the GPS is connected, the position accuracy on loaded maps will be within 10m pending on a proper GPS reception.

The next three examples show the gain achieved when using mobile-GIS in the field. Besides gains, also avoidance of identification errors of locations when in the field is achieved.

Figure 16 shows that roads and field boundaries can be perfectly captured by car or on foot into shapefiles. The Aster image, topo-sheet, and digitized features all match properly. Analysis done to prepare **Figure 6** is based on plot boundaries captured by GPS during the survey. **Figure 17** shows that missing features (roads) on outdated topo-sheets and which also show no contrast with its environment (rocks) on a 15m resolution Aster image can be perfectly captured while traveling around, even in mountainous areas. **Figure 18** shows that in agricultural areas, when using outdated imagery (6m IRS-Pan enhanced), sampled plots can still be perfectly mapped.

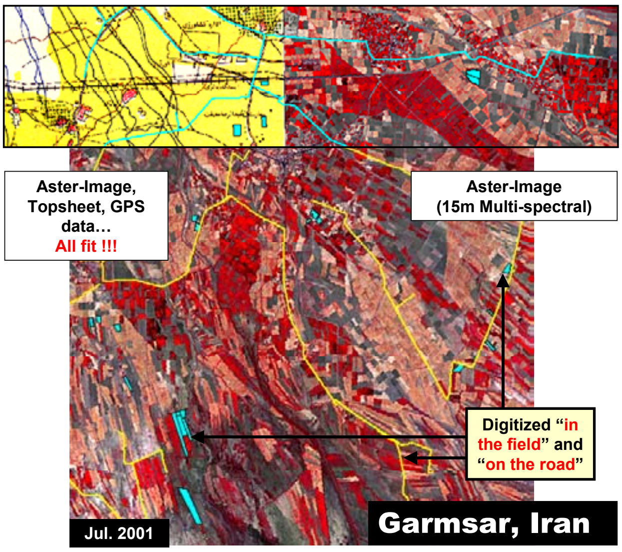


Figure 16. Capturing Roads and Plot Boundaries.

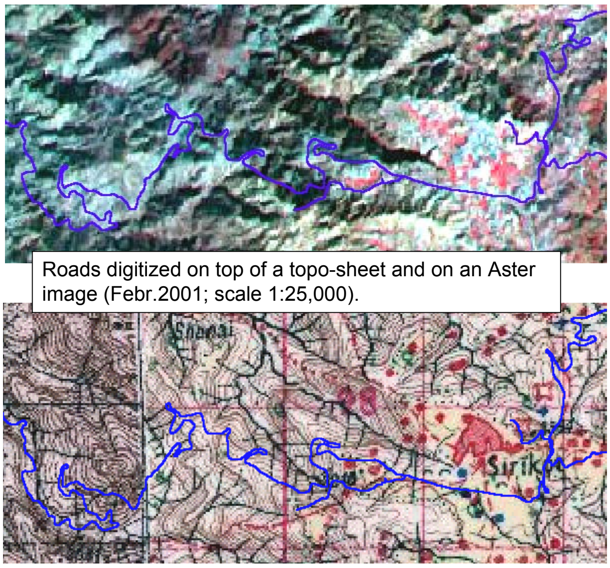


Figure 17. Capturing a Road in Mountains.

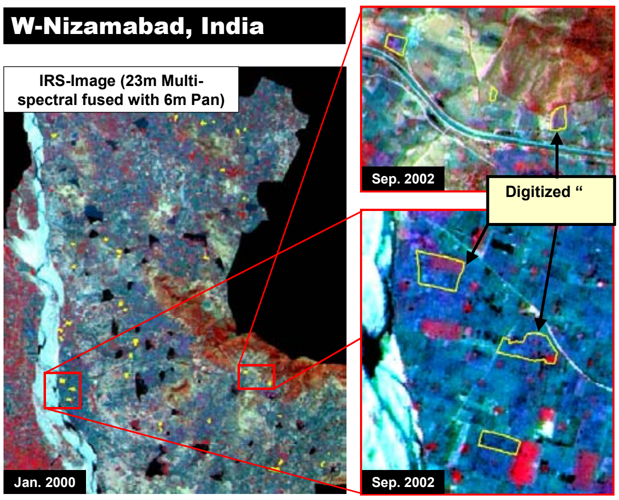


Figure 18. Capturing Plot Boundaries in 2002 while Using an Outdated Image (of 2000).

10. SEGMENTATION OF IMAGES BASED ON OBJECT-ORIENTED ANALYSIS

In agricultural land use surveys, plots form the primary unique sample units. Pixel-based image classification routines do not consider the special linear features that relate to plot boundaries and that are often seen on images. The plot boundaries are special cover features that belong to the cover type: infrastructure. In the past, only through visual interpretation, such linear features could be considered; the quality of the interpretations was however related to the knowledge and skills of the interpreter.

Better tools that map the primary survey units (plots) in a fast, standardized, and repeatable way, support survey preparation and post-fieldwork image classification (see §7; **Fig.19 and 21**).

At present, a statistically highly advanced GIS tool is available (eCognition) that is able to identify objects (fields), and that segments an image based on object boundaries (field boundaries). Spectral noise of pixels within objects is dissolved into the object's spectral statistics. **Figure 20** shows software settings that regulate object size, shape, permitted internal noise (color), and boundary smoothness.

After segmentation, through classification and use of expert knowledge (packaged into fuzzy logic relationships with other GIS layers), objects with similar spectral characteristics can be linked to a user defined cover class or to different classes when the fuzzy logic relationships dictate so. The software allows, after object classification, to merge generated object layers, generated with different software settings, pending on the object class under review.

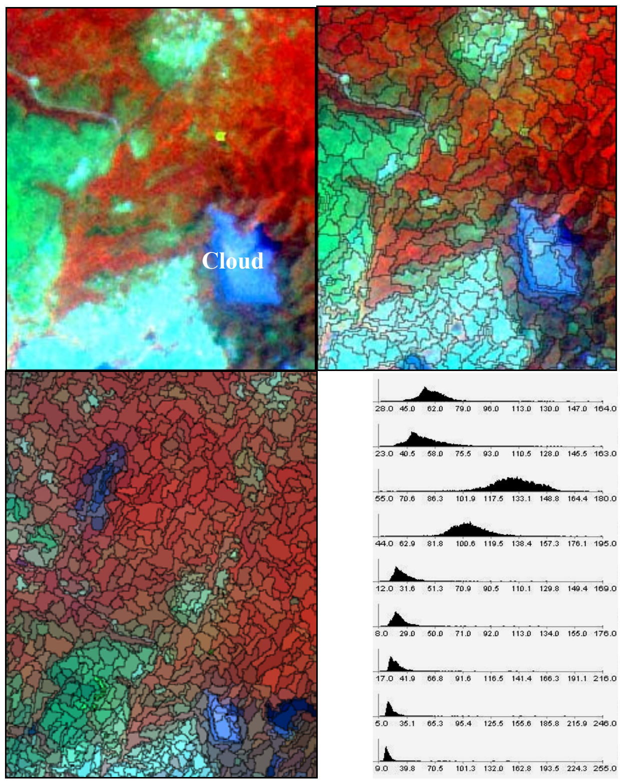


Figure 19. Segmentation of an Aster Image of a Humid Zone in Ghana; 9 Bands are Used.
Due to trees in fields, plot boundaries are hardly detected; natural boundaries of cover types are. The objects are not yet classified.

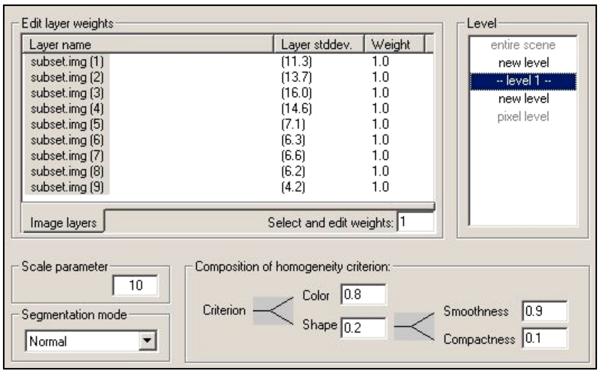


Figure 20. Software Settings that Regulate Object Identification, Size, and Shape.

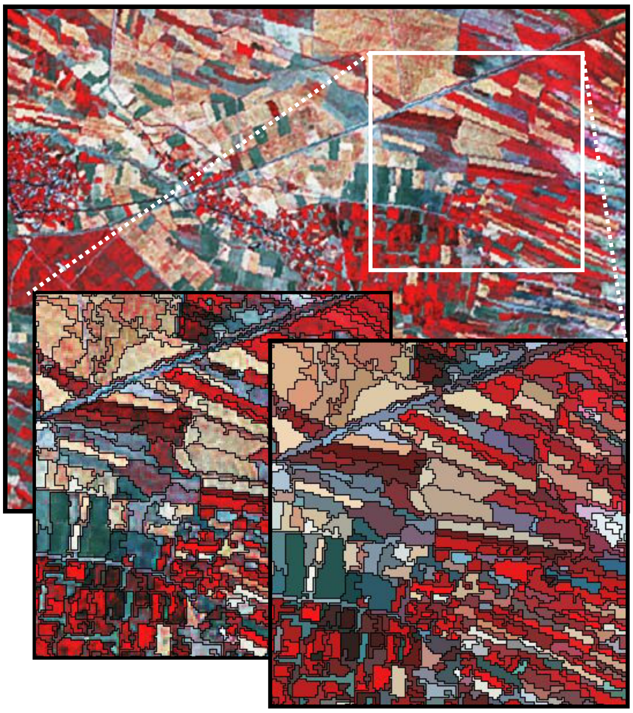


Figure 21. Segmentation of an Aster Image of Garmsar, Iran. Plot Boundaries are Easily Detected.

11. REFERENCES

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