Spatial-Temporal Mapping of Agro-Ecosystems and the need to build Thematic Legends

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ABSTRACT

During the past 10 years several inter-related topics were discussed at different forums. They were: (i) land cover and land use classification systems, (ii) geomatics, being the scientific management of spatial information, and (iii) monitoring of climate, land cover and land use changes. Simultaneously the spatial and temporal quality of remote sensing platforms and of GPS-technology improved substantially and provided new possibilities to study our environment in detail.

Progress made by the forums and the quality increases of RS-products are only worthwhile if gathered spatial GIS-information can be integrated and processed, i.e. if the used survey, generalization and classification methods are scientifically based. In other words: the quality of gathered spatial information, at various scales, must be sufficiently high to support modeling, monitoring, and preparation of decision-support systems for sustainable land management.

In spite of this, available standards for the collection, storage, generalization, classification and presentation of geo-information on climate, soil and terrain conditions, water resources, land use, land cover and bio-diversity, and on social and economic conditions, are often poorly implemented, or re-defined on a project-by-project basis. The root causes are: (i) non-familiarity with underlying concepts, (ii) use of terminology without considering their scientific definitions, (iii) complications faced when standards and rules must be followed, (iv) ignoring future uses of prepared products, and (v) institutional conservatism.

To integrate available standards, a "root" concept of a comprehensive information system is presented. Each theme presented at the root can be linked to a theme-based relational database. Joint use of each thematic layer creates a full description of an agro-ecosystem or of an agro-ecosystem class (*full descriptions help to study the system functioning*). Map legends must like-wise contain entries on a theme-by-theme basis, possibly nested, or must remain theme specific (*theme specific maps are required for monitoring*). Following this, legends covering several themes should not be based on a simple list of suggestive names that cross theme boundaries and represent an incomplete mix of class entries of the themes covered.

To further substantiate the above, the theme 'land use' is elaborated upon in some detail. Concepts to describe agricultural land use and the subsequent method to classify collected 'land use' data are presented. Shown are the key concepts: 'crop calendar' and 'cropping system' (*classification system appended*). They form important links between RS-images, land cover, land use, and the subsequent land use legend (= *classification application*). The links are demonstrated by discussing spectral classification results of multi-temporal RS-images. Derived map units link to monothematic legend classes: units having natural vegetation differ in plant phenology while units having agro-ecosystems differ in crop calendar. The used method, following only two key concepts, provides support to further improve mapping of agro-ecosystems (*e.g. by describing the operation sequences followed*), to improve crop-monitoring methods, and to build spatial information systems that adhere to sound survey, generalization and classification methods.

1. INTRODUCTION

Many scientists have conceptual problems differentiating (agricultural) land use information from information on other thematic ecosystem components, e.g. many maps, and other survey products, tend to confuse information on land use with, for instance, land cover. The impact of land use on land cover can hardly be studied if such products are used. It is a precondition for any exercise involving detection of change that causes (e.g. change in land use) and effects (e.g. change in cover) are kept apart. This principle is not open to compromise.

This paper discusses aspects to describe (agricultural) land use at plot level to optimize options to cluster, generalize and classify collected primary date, and to extrapolate the results spatially through modern RS/GIS techniques into map units that have an attached legend, in which the generalization or classification results are applied by theme.

Archiving properly collected primary land use data provides options to re-use them when new (e.g. monitoring) studies are called for. Different, study-specific classification rules can then be applied on the available primary data for alternative clustering, generalization, classification and extrapolation.

The approach followed here is intended to be both practical and conceptually correct. The bottom-up approach that was adopted leads to the holding-level where actual decision-making by individual land users takes place. Studies of biophysical land use system performance generates inputs for socio-economic evaluation, culminating in the definition of planning scenarios that conserve land resources and are rewarding for both primary and secondary stakeholders.

Agro-ecosystem (land use system) studies must include studies of the land (**Figure 1**). Management activities (operations) at plot level aim at modifying one or more aspects of land, e.g. the soil, flora/fauna, or infrastructure. Operations are carried out to support one or more land use purpose(s), e.g. to harvest a good crop but they can also have negative side effects that affects the sustainability of the system. Often, operations are pre-planned, but they can be of a remedial nature depending on dynamic land processes, for example, incidence of pests and diseases, weeds infestation, water and nutrient deficiencies, etc.

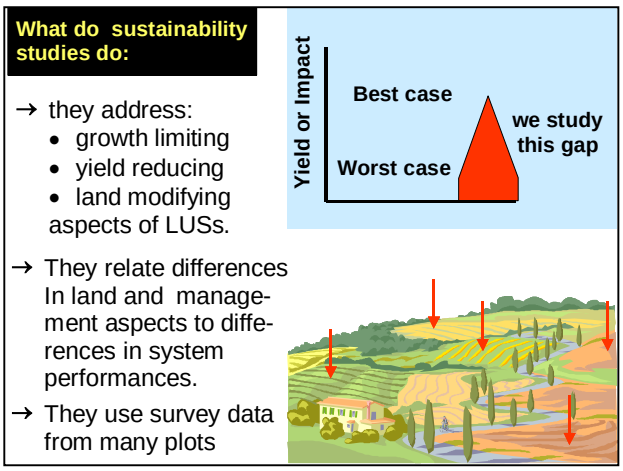

Figure 1. What do sustainability studies do?

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 (see also George and Nachtergaele, 2002):

- "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".

In short, we need good land use data to address questions as put on record by the UNCED conference in Rio (1992; Agenda 21, Chapter 10), e.g.:

- . to identify options to solve future food requirements.
- . to understand and combat environmental degradation.

and, we need practical concepts and approaches to:

- gather, manage, classify and map land use information.
- study various aspects of present day land use systems.

2. OBJECTIVES

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 proper geo-referenced products must become available in abundance, and
- that further reviews of various existing land use concepts lead to further delays in producing the required products,

the aim of this paper 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, collected 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.

Topics covered are:

- Information technology for sustainable land management
  - Geomatics
  - Quality of present day land use information systems
  - Land use information system concepts
- Use of RS for land use mapping
- Land use survey aspects
- Land use classification concepts
  - Classifiers
  - A-priori versus a-posteriori land use classification
  - Harmonizing classifiers

3. INFORMATION TECHNOLOGY FOR SUSTAINABLE LAND MANAGEMENT

Geomatics

In the early nineties, a 'think-tank' of the Atlantic Institute, representing faculties from NE-USA and E-Canada, came to the conclusion that (Beek and Groot, 1994):

- Trends in land management studies are towards geomatics, defined by the Atlantic Institute as "the scientific management of spatial information". Boundaries between formerly separate disciplines have become increasingly fuzzy;
- Developments have moved from a period of innovation (1960-1980: technology driven, little data) through a period of integration (1975-2000: building databases) to a period of proliferation (1990 -: systems integration, mass dissemination, information customer driven).

Information technology (IT) facilitates integration of information processing. This is obvious from the advent of management decision support systems that grew out of the management information systems. Geographic Information Systems (GIS) are a direct result of this integration. GIS provide the user community with tools that are unprecedented in their potential and challenge existing facilities. IT also has the capability to transform a data set at relatively low cost into new information products for specific users. An important consequence of these integration and customization characteristics of IT is that combined processing of data sets can deliver new information products with an added value over the source data sets. IT has particular significance for interdisciplinary land use planning. It facilitated decentralization of governance and progress in communication, it spurred research into sustainable use of natural resources, and it opened international markets for technology and knowledge.

Quality of present day land use information systems

Stakeholders report that the effective use of GIS technology is constrained by the limited adequacy of data on land use systems (**Table 1**). The constraints were recorded at selected (sub-) national institutes in a number of developing countries (Dalal-

Clayton and Dent, 1993) and in four European countries (Zeijl-Rozema *et al*., 1997).
The recorded statements on present day land use system information for natural resource management and planning called for (guidelines on) data harmonization. Aspects to be considered are listed in **Table 2**.

Table 1. Constraints regarding effective use of land use system information as reported by stakeholders

Data Aspect	Problem	Frequency
Availability :	what is where?	Occurs
(supply defined?)	unobtainable, restricted	Often
	limited coverage	Regular
Format :	supplier defined	Often
	data integration problems	Often
	different parcel registries	Regular
Quality :	lack of uniformity	Often
	no accuracy assessments	Regular
Documentation :	often incomplete	Occurs
	poor nomenclature	Often
Geo-referencing :	sometimes absent	Occurs
Costs :	often expensive	Regular
Updates :	poor update frequency	Regular
	no time series	Occurs
Coordination :	end users not involved	Often
	poor between organizations	Often
	no regulations	Occurs
Classification :	not tailored to user needs	Often
	no user consultations	Often
	lack of uniformity	Constant
	limited utility	Constant

Table 2. Data aspects that need attention if the quality of present day land use system information is to be improved

Data Aspect	Problem
Concepts	differentiate between land use and land cover
Data accuracy and consistency	survey methodologies
Scale and legend correctness,	observation units
Type of data	classes vs. numeric information
Class definitions	user consultations
Definitions	nomenclature
Consistency for time-series	replicability
Data formats	relational database, GIS formats
Documentation	set regulations

Land use information system concepts

At present, digital databases are being developed that form a part of the information infrastructure required for sustainable land management at various scales. The development of GIS has dramatically increased the demand for reliable geo-referenced data at all levels of detail.

UN organizations supported by specialized institutes develop standards and software for the collection and analysis of geo-referenced information on climate, soil and terrain conditions, water resources, land use, land cover and bio-diversity, and on social and economic conditions. All of these must be referenced with up-to-date and accurate topographic and cadastral information. (Inter-) national programs are needed to unite such databases in a uniform geo-information infrastructure. Examples of initiatives are GSDI (Global Spatial Data Infrastructure), EUROGI and Eurostat (Europe), and RAVI (The Netherlands). The Open GIS Consortium is a similar initiative on a world scale that was started by US-based GI-industries.

Figure 2 provides a basic "root structure" (concept) of a comprehensive land use systems (LUS) information system. Given that it was developed from the conceptual LUS-diagram provided in **Figure 3**, the part on land use is elaborated in further detail.

Figure 3 shows that a land use system is composed of two main elements: land and land use. A **Land Use System (LUS)** was defined by De Bie (2000) 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"; **Land Use** was 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". 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. Note that land use systems have both spatial and temporal dimensions. These must be understood if one endeavors to describe, classify, survey or study land use systems at the level of spatial aggregation required for solving specific natural resources management problems.

For the land use part, **Figure 4** suggests two sets of relational database files as required to capture land use descriptions. The first set is called "Actual Land Use System Data" and contains collected land use information, either primary or secondary. The second is called "Defined A-priori Classification Systems" and contains information on a-priori land use classes, i.e. class names and classifiers used to define the classes. Parameter values used in each set are derived form a "Glossary". The database files are all linked through index-keys; relevant links are presented in **Figure 4**. The various data files are:

- **Data set identifications:** Contains general information that identifies a particular data set, including the administrative area; project under which the survey takes place, names of enumerator and respondent, holder, etc.
- **Site Identifications:** Contains data that provide detailed information about the geographic location of the site(s) under study such as map unit, cadastral no., parcel size etc.
- **Land Use System Descriptions:** Contains general information about the land use system such as plot location and size, operations seq. duration, a-priori land use class, etc.
- **Operations and Observations:** Contains data on individual operations and observations.
- **Land Use Classes:** Contains information on a-priori land use classes. A land use class is defined without any temporal and spatial dimensions. It is a universally applicable land use description based on well-defined classifiers.

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

Operations (**Figure 5**) 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, plant-

ing 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 5**) 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.

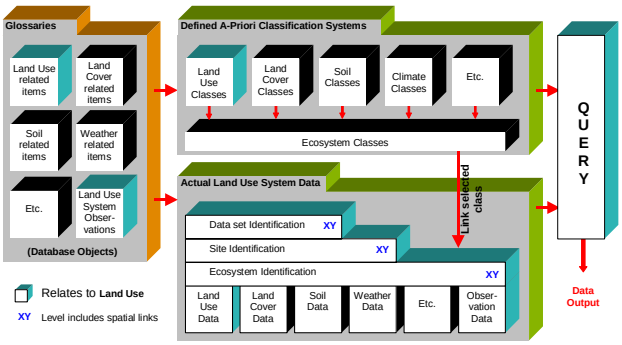

Figure 2. The basic "root concept" (structure) of a LUS- information system.

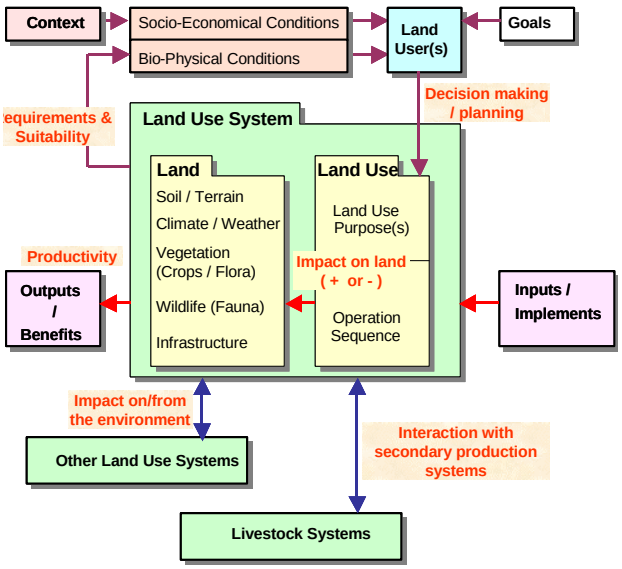

Figure 3. Conceptual Structure of a Land Use System (LUS) providing Practical 'Study Entries' (De Bie, 2000).

4. USE OF RS FOR LAND USE MAPPING

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** was defined as "A piece of land, considered homogeneous in terms of land resources and assigned to one specific land use (De Bie, 2000)."

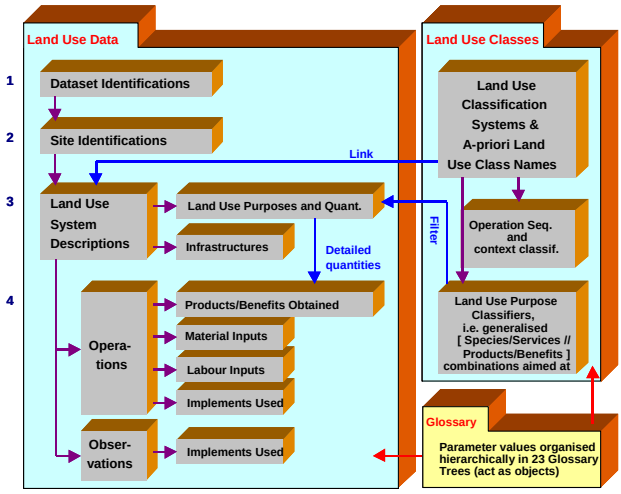

Figure 4. The underlying database files on Land Use (4 main levels); Squares represent one database file each, links from the (23) **Glossary** files to the ; **Land Use Data** and **Land Use Classes** data files are not shown in detail.

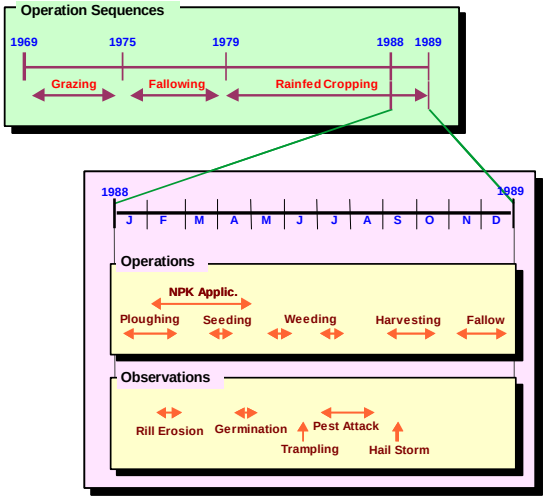

Figure 5. Illustrating Land Use Operations and Observations.

The "operation sequence" is an essential component of any crop calendar. A **crop calendar** was defined 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 (see examples below).

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 (see section 6). Legends of land use maps will considerably improve when cropping pattern syntax is used (see **Appendix**).

Land use is dynamic and operations and events take place that the surveyor cannot personally witness. The land user has that capability and is (assumed) able to recall important land use system aspects for at least the past growing season. His/her knowledge regarding those aspects can only be sampled through interviews. For land use surveys, interviews at plot level are thus essential. To complement and verify interview information, observations by the surveyor must be recorded on a field form. Interviews can be based on questionnaires or on checklists; each has its respective strengths and weaknesses. Use of checklists is recommended for scientific research to prevent that relevant site-specific operation data or occurrences are overlooked.

Table 3. Overview of 'Information Data Sets' with Specific Relevance for Land Use Surveys

RS-Image characteristics

- 1D-features (tone, color), as related to:
  - crop calendars, cropping patterns and other land use operations
  - infrastructure
- 2D-features, such as:
  - field sizes, shapes and patterns
  - internal patterns (textures, grids, mottles)
  - line features
- 3D-features (on APs): vertical structure, no. of layers

Observation / measurement data:

- plot size, coordinates, slope, position, etc.
- crops (residues) and infrastructure present in / around the plot
- land cover data (crop condition, growing stage, weed incidence, biomass, height, etc.)
- ground cover status (bare soil, mulch, crop residues, etc.)
- specific observations (soil characteristics, tillage condition, erosion status, hydrological aspects, pests / diseases incidence, evidence of grazing, etc.)

Interview data:

- holding/holder information (profile)
- site aspects (tenancy arrangement, cadastral no., distance to holding)
- land use system (plot) aspects for the period considered:
- a-priori land use class
- crops grown / services provided (% of area, numbers, etc.)
- land use purposes
- operation aspects (the crop calendar and cropping pattern):
  - operation name; species involved; % of plot involved; period / periodicity / duration and task times; main power source
  - labor and material inputs and implements used
  - products / benefits obtained
- observations by land user and indigenous knowledge:
  - soil related (workability, infiltration rate, fertility status, etc.)
  - weather related (hail storm, dry period, etc.)
  - crop related (pests, diseases, lodging, wilting, etc.)

5. LAND USE CLASSIFICATION CONCEPTS

Classifiers

There is enormous variation in land use worldwide. To map land use, compile land use statistics, and carry out land use planning, common characteristics in the wide variety of land uses must be identified. Common land use characteristics can be identified in two ways:

- By *generalizing* the descriptions of actual land use systems to a description that conforms to, e.g. land use names / descriptions in map legends; these descriptions hold only for specific areas and periods of time.
- By *classification* of land use descriptions resulting in descriptions that are not limited to a certain area or time frame.

Land use classification was defined as: "The process of defining land use classes on the basis of selected diagnostic criteria", and a **land use class** as: "A generalized land use description, defined by diagnostic criteria that pertain to land use purpose(s) and operation sequence followed; it has no location or time indications." Land use classes are exclusively based on attributes of land use in the context of a LUS.

Classification (of land use) must be based on unambiguous diagnostic criteria that are known as "classifiers". Often classifiers are not properly documented in land use (classification) reports; only names of classes are given.

A land use class is a taxon that is solely based on information on land use purpose and operation sequence. In combination with attributes of land, the land use class becomes extended to a LUS-class. Using LUS-classes does not allow assessing the suitability of a certain land unit for a certain land use or for monitoring land use changes. In spite of this, land characteristics are sometimes considered as classifiers, resulting in land use system classes such as "un-used bare soil" or "protected tropical forest".

Three types of classifiers can be applied to define land use classes (**Figure 6** and the **Appendix**):

- **Land use purpose classifiers**
  specify aimed at [Species/Service - Product/Benefit] combinations in general terms. At least one combination must be specified for each land use class. No new products or benefits can be added to define sub-classes, but existing definitions can be sharpened or split into several new definitions.

- **Land use operation sequence classifiers**
  specify (one or more) aspects of operations in general terms. For sub-classes new classifiers can be added; higher level classifiers remain valid for all sub-classes, or can be further narrowed down.

- **Land use context classifiers**
  specify (one or more) circumstantial aspects of the land use in general terms that are not a part of the land use purpose or operation sequence. Context classifiers are better not used but are mentioned to link up with existing practices. They can include: Land aspects, e.g. infrastructure, tenancy arrangements, etc.; Holding (context) aspects, e.g. origins of inputs/implements, destinations of outputs (market orientation), capital intensity, holder attitude, goals of holder, credit availability, pricing policies, etc.

The parametric method of defining land use classes employs a combination of classifiers to define a land use class. **Table 4** presents an example of a land use class defined in terms of independent classifiers. The **Appendix** contains lists of operation sequence and context classifiers that can be used to define

land use classes (land use purpose classifiers are not listed). The provided list is not exhaustive but is intended to "grow" into a standard set of classifiers for use in the preparation of land use classification systems. In addition, use of classifiers is helpful for merging of classification systems, and to correlate classes defined under different classification systems (Wyatt *et al*. 1997).

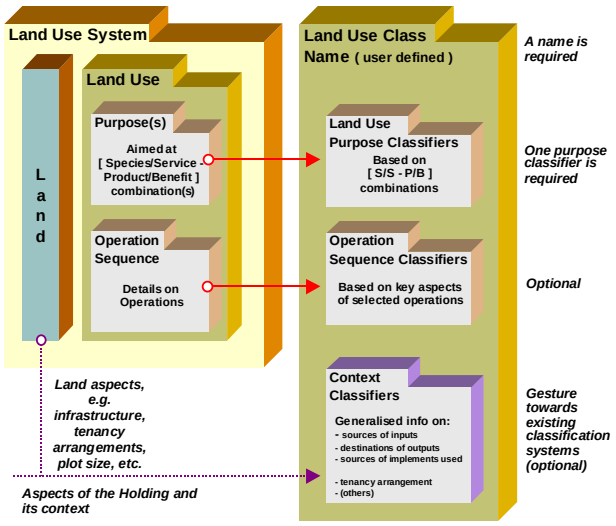

Figure 6. Classifiers used to define a land use class.

Table 4. Example of a land use class definition.

Codes (see App.)	**Shifting Cultivation**
	Purpose Classifiers
n.a. n.a.	• Plants for plant produce, *and* • Animals for animal produce.
	Operation Sequence Classifiers
A.1.1.2.1.4 B.1.4 F.0 I.2 K.1 L.1	• Agricultural production → Crop production → Temporary (arable) cropping → Multiple cropping → Intercropping → Patch ~, *and* • Extraction / Collection → Yes → Mix of hunting and vegetation exploitation, *and* • Recreation and tourism → none, *and* • Cultivation factor (R) → R < 33%, *and* • Main power source for tillage → manual power only, *and* • Material inputs → low.
	Context Classifiers
cA.0 cB.0 cF.0 cG.1 cI.0	• Tenancy arrangements / Land rights → Taken in possession, *and* without a secure title, *and* • Connectivity → poor, *and* • Market orientation → subsistence, *and* • Capital intensity → low, *and* • Secondary Infrastructure requirements → none.

A **land use classification system** was defined as: "A structured set of land use class definitions." Most land use classification systems are hierarchically structured and obey the following rules:

- The defined land use classes are mutually exclusive at each level, and
- Classes at sub-levels are a further specification of a class at a higher level.

A-priori versus a-posteriori land use classification

- **A-priori classification**
  implies that land use classes are defined before collecting the actual data. Classifiers used are based on expert knowledge, study objectives, or conform to classes defined by international organizations, national institutions etc. The main advantage of a-priori systems is that classes are standardized. Assigning class names to land use descriptions is called "identification" (Sokal 1974).

- **A-posteriori classification**
  means that land use classes are defined using classifiers that are based on (analysis of) data collected. The advantage is that classifiers can be defined that fit recorded study results.

Harmonizing classifiers

The growing demand for global assessment of land use (possibilities) generated a need for a universal classification system. Many attempts to develop a comprehensive classification system have been made (e.g. IGU 1949; UNEP/FAO 1994). Fresco *et al*. (1996) concluded that: "Yet, there is no satisfactory and commonly accepted method of defining and classifying land use globally, let alone a definition of the major classes of land use as such. This situation thwarts the systematic collection of data pertinent to use classification".

Development of a comprehensive classification system for land use is still far away. Earlier efforts were all discontinued, and there is growing recognition that different land use studies require different classification systems pending on set objectives, areas studied, and methods followed. For example: if remotely sensed images are used to map land use, classifiers used are strongly correlated with land cover whereas land use studies that center around farming system analysis will rather base their class definitions on land use purpose(s), labour inputs, etc. Each study can independently select the level at which a particular classifier is used, e.g. 'irrigated' can be a classifier at the highest level, or at any lower level, or can simply not be used.

If one universal classification system is a practical impossibility, then the problem remains that many classification systems remain in use with different classifiers at different levels. Standardization of land use classifiers would allow correlation of land use classes used in different studies. This standardization would keep the possibility to prepare user-defined classification systems open and not compromise the possibility to compare existing classification systems. It would then be possible to cross-tabulate different sets of land use classes to study their mutual (dis-) agreement.

The various criteria used around the globe to define classes form the basis to adopt an actual 'reference system'. They are the 'bridge' that can be used to compare and translate defined classes; it is thus essential that the criteria used are documented and existing classification systems are studied to define the 'basic set' of criteria.

6. FINAL STATEMENTS

This article discussed IT aspects that relates to gathering and using land use information for sustainability studies of (agricultural) land use systems. The "root concept" requires an interdisciplinary approach. Some factors that complicate the interdisciplinary IT developments are:

- The different cultures of individual disciplines,
- The kinds of knowledge involved,
- The nature of development problems,
- The institutional setting,
- Differences in the perception of problems, e.g. between producers and users of (geo-graphical) information.

The value of detailed land use descriptions to e.g. soil scientists is in the simultaneous capturing of dynamic soil characteristics so that detailed analyses of impacts by land use on the resource base can be made.

Monitoring of soil, land cover, weather and land use dynamics at different scales of time and space is on many agendas. Noteworthy are initiatives undertaken by ICASA (International Consortium of Agricultural Systems Applications), LUCC (Land Use and Land Cover Change; IGBP), and CLAUDE (Coordinating land use and land cover data and analysis in Europe; EC-DGXII).

The land use concepts discussed in this article are fully developed and ready for operational use. Comprehensive studies, especially when it concerns time series and when primary data are collected by field-staff, will benefit greatly from them. A few aspects work against their adoption:

- they require insight in the stochastic nature of land use aspects and of the underlying data model,
- analyzing and classifying generated data remains complex,
- at present no organization has a history of systematically collecting, storing, and utilizing land use data at the level of detail presented,
- they are not yet part of an operational GIS system or a comprehensive land use systems database,
- using the concepts is often not felt as a pre-requisite for land use studies.

It is to be expected that Information Technology will increasingly facilitate the development of integrated, quantitative tools for land use systems analysis based on simulation of dynamic land-use interactive processes. Already there is a strong tendency towards increased use of geo-informatics in the design of interdisciplinary geo-information systems and decision-support systems for realizing sustainable land management at different scales and for specific user groups (e.g. Chu Thai Hoanh 1996; Ceccarelli 1997). A digital geo-information infrastructure and policy framework is emerging for this purpose at global, regional, national and local levels (e.g. Eurostat 1999). This will make important research data available that are at present inaccessibly stored in archives and libraries.

Lambin *et al*. (1998) state that data compilation for land use and land cover research would benefit from harmonization and streamlining of data collection and interpretation procedures. Issues that require special attention are dataset development, integration of heterogeneous data sources, improved accessibility of data, data accuracy and error propagation, and identification of robust and meaningful indicators. Continued efforts to improve the quality, completeness, spatial and temporal consistency and compatibility of heterogeneous land use and land cover related data are thus required.

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