Integration of knowledge at different spatial scales in land use studies

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Abstract

Understanding the factors that drive agricultural land use change is of crucial importance in order to anticipate potential negative impacts on natural resources, productivity and rural living conditions. A major methodological challenge in land use studies is the integration of knowledge from different disciplines over various spatial-temporal scales in order to address issues relevant for stakeholders at different organizational levels. In eco-regional studies, a specific methodological niche can be found at the landscape level where complex spatial interactions and linkages exist. This paper describes a methodology for the analysis of land use dynamics at the landscape level. With a dynamic system model spatially explicit land use changes are simulated, using quantitative empirical information on biophysical and socio-economic land use drivers at various spatial scales. Possible near-future developments can be visualized with the model through scenarios. Application and validation in a number of Latin American and Asian countries is described. Opportunities are discussed for the combination of methodologies in tool sequences that address different objectives and scales.

INTRODUCTION

Agricultural land use is highly dynamic due to continuing technological, socio-economic and political developments. General concern exists with respect to the effects of changing land on natural resources and the multi-functionality of rural areas. In some areas, e.g. in Europe and North America, high input use has increased yields but has also caused acidification, salinization, erosion, and chemical pollution (Bouma et al. 1998a). At the same time, there is an increasing demand for high quality environmentally friendly food products, and public pressure exists for nature and landscape conservation.

Food production in many developing countries still hardly keeps up with increasing demands due to population growth and changing consumption patterns (Alexandratos 1995; IFPRI 1995). In some areas productivity is low, and there is expansion of agricultural land causing deforestation. Use of marginal land and unbalanced use of production technologies, often caused by socio-economic constraints, can deplete resources such as soil fertility (Smaling et al. 1996). These developments put the socio-economic situation of rural livelihoods under pressure, which can for example lead to migration to urban centers or colonization areas (Bilsborrow 1992). Agricultural land use is also an important factor in global change issues because of its influence on sources and sinks of greenhouse gases like CO_2, CH_4 and N_2O, on water and energy balances, and on biodiversity (Turner II et al. 1995).

Problems related to land use are thus diverse, and a number of tools have been developed to study actual and innovative forms of land use (Bouman et al. 1999; Stoorvogel et al. 1998a; Bouma et al.

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1995). Important methodological issues that have to be addressed by most land use studies are the integration of different disciplines, the handling of different spatial-temporal scales, and the involvement of stakeholders. This paper discusses some of these methodological issues with respect to the analysis of actual and near future land use and the planning of innovative land use systems. An example is given of a land use change modeling approach that focuses on landscape level dynamics of land use and their impacts on the natural resource base. We also discuss how this approach can be used in combination with other tools.

SCALES AND MULTI-DISCIPLINARITY IN LAND USE STUDIES

An important issue that has to be considered when dealing with productivity and sustainability of land use systems is that of temporal and spatial scales (Fresco and Kroonenberg, 1992; Rabbinge and Van Ittersum, 1994; Wolf and Allen, 1995; Dovers, 1995; Cocklin et al. 1997). Conclusions from a land use analysis depend on the spatial-temporal scale of analysis. With respect to temporal scales, loss of soil fertility may not affect soil productivity in the short run but could make soils unsuitable over a period of decades. An example relevant for spatial scales is that of soil erosion. The accumulated effect of erosion from individual fields in the upper part of a watershed can cause major changes at the landscape level. For example, soil mass can accumulate in lower parts of a watershed through sedimentation. Also, erosion-related depletion of soil resources may force farmers to convert land with natural vegetation, sometimes with marginal agricultural potential, into agricultural land. The accumulated effect of field-scale erosion can then be large-scale deforestation.

A fundamental challenge facing agriculture is the integration of multiple considerations across different levels in the system (Barret, 1992; Wolf and Allen, 1995). Coherent strategies are needed that aim at upper-level objectives (e.g., soil, water and biodiversity conservation) while at the same time supporting the integrity and viability of lower level sub-systems (e.g., sustainability of rural livelihoods). The considerations of actors and stakeholders in land use systems are related to spatial scales because of the level at which they take their decisions (Figure 1).

Decisions in land management depend on the objectives and perceptions of the decision taker involved. Regional and national decision takers or interest groups will take into account issues such as national food security, large-scale erosion and sedimentation (for example sedimentation in reservoirs of hydroelectric power plants), nature protection and water availability. However, rural households will in the first place try to sustain their livelihoods. For that reason, farmers living in a watershed may not consider soil erosion as their most urgent concern (Stadel, 1989) although soil loss and associated decreasing land productivity could affect their livelihood considerably over the longer term. Individual farmers will take their decisions within the conditions created by policy decisions at regional and national levels.

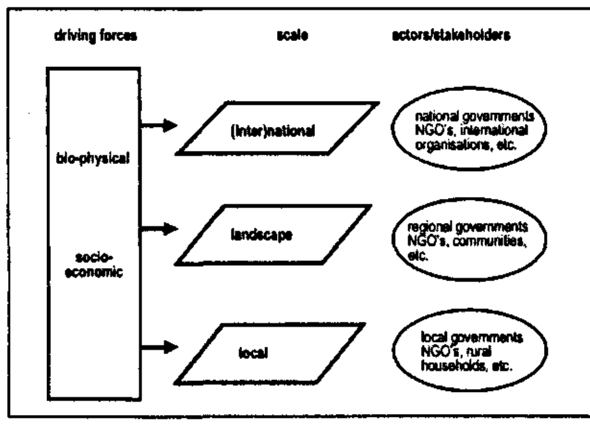

Figure 1. Different scales in land-cover and land-use change studies.

Integrated land use strategies should aim at complying as much as possible with local as well as regional and national objectives with respect to food production and natural resource management. To achieve these higher-level objectives, the problems of individual farmers have to be addressed as well, because it is at the farm level where the most direct decisions concerning land use are being taken. It is therefore crucial that rural households are offered the possibility of producing food in a sustainable and productive way.

So, insight is needed on the impacts of decisions taken at different levels. This insight can support the debate on tradeoffs in land use related objectives of productivity and sustainability at platforms involving stakeholders from regional to local levels (Crissman et al. 1998; Scoones and Toulmin, 1999; Röling, 1994). New research tools should assist stakeholders at different levels to follow a pro-active approach in the development of new strategies for sustainable and productive food production (Bouma, 1997).

These tools should not only be able to address and link the different spatial scales but also to integrate different disciplines. Land use systems are complex systems that are determined by very diverse land use drivers (Turner II et al. 1995) (see Figure 1). Land use drivers can be socio-economic (e.g. income levels, infrastructure, demographic structure), political (e.g., land tenure, subsidies, designation of protected areas), and biophysical (e.g., soil suitability, climate characteristics). In ecosystem research, it has been recognized that dominant ecological processes vary with spatial scale (Allen and Star 1982; Holling 1992; Kolasa and Picket 1991; Allen and Hoekstra 1990). In analogy, the relative importance of land use drivers in agro-ecosystems depends on the spatial scale of analysis (Veldkamp and Fresco, 1997b; Baudry, 1993; Walsh et al. 1997). While policy decisions and rather autonomous developments (e.g., population growth and consumption patterns) may dominate regional dynamics, local soil and climate conditions and farmers management cause fine scale diversity within the coarse scale patterns.

The integration of biogeophysical and socio-economic variables at the appropriate scale is still a major challenge in agro-ecosystem studies. Some propose the identification of separate disciplinary hierarchies and finding the appropriate, coherent levels at which these hierarchies can be linked (O'Neill 1988; Dumanski et al. 1998; Turner II et al. 1995; Stomph et al. 1992). Others propose the complete integration of all information and then looking for the most important processes at different nested scales (Veldkamp and Fresco 1997a).

A number of methods have been developed to study and plan actual and alternative forms of land use (Bouman et al. 1999; Kuyvenhoven et al. 1998; Stoorvogel et al. 1998a; Bouma et al. 1995; Fresco et al. 1994). These methods vary from the use of expert knowledge to detailed process models, and address different spatial scales (Hoosbeek and Bryant 1992; Bouma et al. 1998b). Land use studies can be projective, predictive or exploratory (Van Ittersum et al. 1998) or can aim at decision support and prototyping (Stoorvogel 1998b). Examples of existing tools are simulation models for crop growth and soil water and nutrient transport, multiple-goal linear programming, comprehensive decision support systems, statistical analysis and modeling, spatial system modeling and economic trade-off assessments.

Which tool to use depends on the spatial-temporal scale that is addressed, the data that are available, and the objective of the study (e.g., projections or explorations of land use changes). Single tools mostly do not address all issues that are relevant for stakeholders at the different levels of decision taking:

- Most tools address only a narrow spatial scale. While farm level case studies offer useful information on farmers' conditions, they fail to relate local developments in land use to changes that are caused by developments and decisions taken at regional and national levels. On the other hand, analyses at regional and national levels especially designed to support policy decisions, fall short in assessing consequences for local conditions.
- Integration between biophysical and socio-economic disciplines is often incomplete. Although large bodies of disciplinary literature and methodologies exist, integration of disciplines is still insufficient. This is complicated by scale dependencies in the relative importance of biophysical and socio-economic driving factors.
- A number of predictive, projective and explorative approaches exist (Van Ittersum et al. 1998). More integration of such tools is needed in order to indicate the technology trajectories and the decisions needed for a transition from existing land use systems to land use systems that comply better with multi-level objectives of individual farmers and of national and regional policy makers and interest groups.

A way to integrate spatial scales, disciplines and objectives is to combine different tools in a functional tool sequence. This implies that for each scale and research sub-question, the appropriate tool is chosen, after which these tools are combined in a coherent way.

LANDSCAPE LEVEL STUDIES

With respect to a possible tool sequence, a specific methodological niche can be found at the landscape level. Landscapes are characterized by their structure (the spatial relationships between landscape elements and patches), function (the interaction between spatial elements), and change (the alteration in structure and function through time) (Forman and Godron, 1986; Turner and Gardner, 1991). In an agro-ecological landscape structure, function and change are the result of an interaction between humans and their natural environment. Such agro-ecological landscapes are shaped by a set of interrelated and non-linear processes, causing complex linkages and interactions between different locations in the landscape (Milne 1991; Rigon et al. 1994). For example, farmers in a certain community will be influenced by developments in nearby communities or even by land use developments in quite distant places, e.g., the new cultivation of a crop in a region with a high relative advantage compared to existing production areas. This means that simple aggregation of locally observed developments to a whole region is not realistic (Easterling 1997).

At the landscape level, it is possible to investigate on-site as well as off-site processes related to land use (Veldkamp and Bouma 1999). This can be demonstrated with water, soil and nutrient redistribution processes. Land conversion, for example from natural vegetation to agricultural land, or from grassland to arable land, can have strong on-site impacts on soil chemical properties such as soil organic matter and nutrient concentration. Land use also directly influences soil nutrient status through the use of organic and chemical fertilizers, and the harvesting of crop products. Off-site effects are related to the redistribution of water and soil mass over the landscape. Water as precipitation is partly intercepted and taken up by vegetation after which the remaining water is released into the landscape by infiltration or run-off. This migrating water has the potential to change a landscape by erosion/sedimentation (run-off and run-on of water). Nutrients may be leached to the groundwater but depending on groundwater flow may appear elsewhere in the landscape. Nutrients in redistributed soil mass will be transported accordingly.

Thus, when we investigate land use dynamics at the landscape level for whole eco-regions, we can not just scale-up from the farm level because this prohibits taking into account for spatial interactions and off-site effects.

A tool that has been developed specifically for the analysis of land use change dynamics for eco-regions is the CLUE (Conversion of Land use and its Effects) model. It is a multi-scale methodology that allocates land use changes at the landscape level. It can be classified as a dynamic, empirical, spatially explicit model. The fact that landscape level dynamics are addressed dictates the chosen methodology. It is a prerequisite that the data on which the model is based cover the whole study area. Often locally observed causal relations simply can not be scaled-up to higher aggregation levels (Rastetter et al. 1992). Therefore, the dominant land use driving factors are empirically identified in dependence of spatial scale. The CLUE-model uses actual land use as a starting point to describe current and near future land use dynamics.

THE CLUE METHODOLOGY FOR LAND USE CHANGE ANALYSIS

The CLUE-model uses time steps of one year and consists of a demand module and an allocation module (see Figure 2). In the demand module, the national demands for agricultural products are calculated on the basis of population size, consumption patterns import/export developments and agricultural productivity. Yearly changes in national demands drive sub-national land use changes, assuming that total land use meets the demand. Sub-national changes are modeled in a multi-scale allocation module. The spatial units in this module are grid cells of varying sizes, this way mimicking different spatial scales. The smallest cell size depends on the size of the study area and the resolution of the available data, but in existing case studies, it varies between 2 by 2 km to 30 by 30 km. In the model, the grid cells are not treated as homogenous units; within cells the relative surface fractions of each of the studied land use types (the term 'land use type' in this paper indicates a category of agricultural crops, for example permanent crops, annual crops, etc.) are distinguished. Land use changes in the cells are calculated on the basis of the factors within cells that determine land use, the so-called land use drivers (Turner II et al. 1995). These are biogeophysical factors (e.g., biophysical and chemical soil characteristics, climate characteristics, slope), socio-economic factors (e.g., demography, income levels, occupation) and infrastructure factors (e.g., distance to roads and markets). Before using the model, the quantitative relations between land use drivers and the relative areas of different land use types within cells are determined on the basis of a stratified spatial multiple regression analysis. This analysis is done for a reference year, using a complete data set with detailed actual land use data that are normally taken from national agricultural surveys. The results of the analysis are used in the allocation module. For scenarios of changing national demands and changing local condition driving land use, land use changes in each cell are modeled in the allocation module (Verburg et al. 1999a) on the basis of:

- The comparative advantage within a cell for a certain land use type compared to all other cells within the country.

- The comparative advantage of a certain land use type within a cell compared to the other land use types within that same cell.

These comparative advantages are determined for each year by the actual biophysical and socio-economic conditions in each cell (Figure 2) and the relation between these conditions and land use as determined in the statistical analysis for the reference year (De Koning et al. 1999a).

Increasing national demand for areas of certain land use types will generally push the increase of that land use type within cells. However, area decrease can also take place due to competition effects between land use types, or due to adverse local conditions. Yearly, spatially explicit changes in the drivers of land use are taken into account.

The CLUE model describes multi-scale land use change dynamics under certain assumptions of possible future developments, defined as scenarios. Therefore "what if" situations are described. Results of CLUE are not meant to be predictions, but possible spatial outcomes of feasible land-use developments. This offers information that can be used to evaluate the range of possible outcomes for land use changes and when coupled with impact assessment models, their effects on the natural resource base.

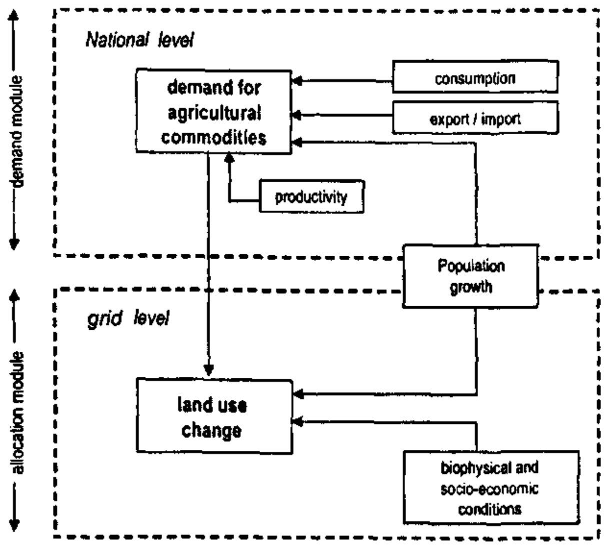

Figure 2. *General structure of the CLUE modeling framework* (source: De Koning et al. 1999a).

SELECTED RESULTS OF CASE STUDIES

The CLUE model was first developed for and applied to Costa Rica (Veldkamp and Fresco 1996, 1997a, 1997b). Recent and current applications are those for Ecuador (De Koning et al. 1998, 1999a, 1999b), Central America (Kok et al 1999), China (Verburg et al. 1999b) and Indonesia (Verburg et al. 1999c). In this section, selected results of land use change scenarios are presented, as well as results from validation studies.

Modeling of land use dynamics

For China, with a total extent of 9.5 x 106 km2, a minimum cell size of 32 by 32 km was used in the land use allocation module (Verburg et al. 1999b). The choice for this resolution was based on the spatial detail of the available data regarding land use and socio-economic and biophysical variables. Recent changes in Chinese land use have been dominated by losses of agricultural land due to urbanization and desertification. At the same time, demand for agricultural products is rising as result of population growth and changing consumption patterns. For China, a scenario was defined at the national level, taking into account some major issues in Chinese land use: changing population size and structure, growing food demand, increase of urban built-up areas, reforestation and desertification (Verburg et al. 1999b). Spatially explicit land use changes in this scenario were simulated for the period 1991 to 2010, using stratification into seven regions. Figure 3 shows the model results, expressed as changes over the simulated period, for two land use types: cultivated area (mainly arable crops) and unused area. Changes are biggest on the Ordos plateau and the Loess plateau in central China. For these areas, the model results indicate that substantial parts of formerly cultivated land become unusable because of land degradation, and that other areas are reforested. Cultivated land is also lost to increasing urban areas in Eastern and Southern China. This land has a higher productivity than average, so these area losses have relatively stronger consequences for total crop production volumes.

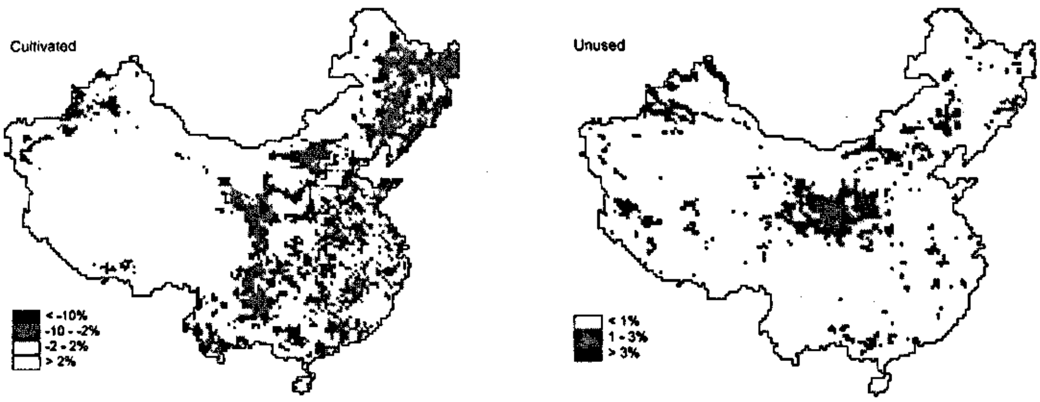

Figure 3. Simulated changes (%) in the spatial pattern of cultivated land and unused area in China during the period 1991-2010 (source: Verbug et al. 1999b).

For Ecuador, with a total extent of 260 x 10^3 km^2, a minimum cell size of 9 by 9 km was used (De Koning et al. 1999a). The reference year 1991 was used to quantitatively determine the drivers for the land use types: permanent crops, temporary crops (annuals), grassland and natural vegetation. The country was stratified into three regions: the Andean mountain range, the tropical coastal lowland (west of the Andes) and the Amazonian lowland (east of the Andes). A variety of scenarios were formulated for the period 1991 to 2010. At the national level, different developments in national food demand were defined on the basis of assumptions for population growth; consumption patterns and exports developments (De Koning et al. 1999b). At the sub-national level, the protection of nature parks and land use limitations due to land degradation were evaluated with respect to their possible spatial impacts on the land use change dynamics within the country. In contrast to China, in most scenarios, the area agricultural land expanded significantly, resulting in more use of land in existing agricultural areas and frontier-type expansion into areas with rather undisturbed natural vegetation. The patterns of change depended on the increase in demand, competition between land use types, changes in land use drivers, and the area of land that was excluded from agricultural use. Figure 4 indicates the modeled area changes for three land use types in a base-line scenario, taking into account growing demands and stagnating yield developments. In this scenario, changes in grassland area are the most widespread, especially through expansion in the Northwest, the Northern Amazon and the Andean footslopes. Areas in permanent crops (mostly export crops) also increase. These crops are mainly grown in the lowlands west of the Andes, and to a lesser extent east of the Andes. In the central fertile coastal plains, the strongest competition between different forms of land use takes place, especially between permanent crops and temporary (annual) crops.

Possible soil fertility impacts of modeled land use changes in Ecuador were estimated using the NUTMON (NUTrient MONitoring) methodology (Smaling and Fresco, 1993). With NUTMON, nutrient balances of cropping systems are estimated on the basis of the inputs (mineral fertilizer, organic fertilizer, atmospheric deposition, biological N-fixation and sedimentation) and the outputs (harvested product, removed crops residues, leaching, gaseous losses and water erosion). The inputs and outputs are quantified using a combination of expert knowledge, empirical information and process knowledge. In Table 1, the reported areas of permanent crops and temporary crops in 1991 are classified according to the associated nitrogen balance. The modeled area increases in the base-line scenario are also classified. The results of Table 1 indicate that relatively more of these new areas fall within the classes of the highest nitrogen losses. These results suggest that the best soils are already being used and that expansion into marginal areas depletes resources at a faster rate.

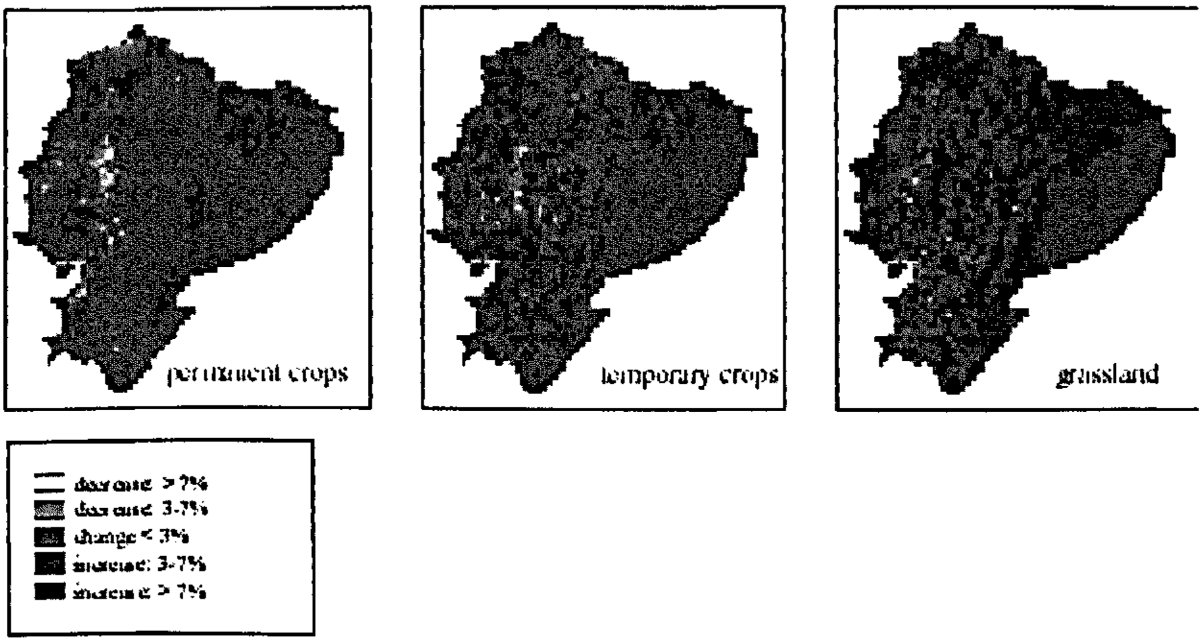

Figure 4. Simulated changes in land use (%) for permanent crops, temporary crops and grassland in Ecuador during the period 1991-2010 (Source: De Koning et al. 1999b).

Table 1. Areas of permanent crops and temporary crops classified according to the annual nitrogen balance. Percentage area in each class is given, with the total of the 4 classes summing up to 100%. For 1991 the total area is classified. For the base-line scenario, the area increases between 1991 and 2010 are classified as: class 1 (losses smaller than 10 kg/ha); class 2 (losses between 10 and 35 kg/ha); class 3 (losses between 35 and 60 kg/ha); and class 4 (losses larger than 60 kg/ha).

Nitrogen	1991		Base-line scenario	
balance class	Permanent crops	Temporary crops	Permanent crops	Temporary crops
1	25	31	4	14
2	20	25	0	11
3	21	15	21	21
4	34	29	75	54

The highest resolution was applied in a study for the Atlantic Zone of Costa Rica, with a total extent of 5 x 10^3 km^2, using cell sizes of 2 by 2-km (Kok et al. 1999a). In this study, CLUE was used for the first time at sub-national scale. Spatial patterns of land use change between 1984 and 2005 were modeled for different scenarios. Among the factors that were included in these scenarios were government policies with respect to protection of natural parks and the designation of agricultural settlements. Particularly relevant for this region are import and export developments. Different market-liberalization scenarios were defined. These determine exports, mainly of bananas and animal products, and imports, mainly of subsistence crops and animal feed products. Distances to urban markets were considered, as well as the proximity to major infrastructure such as the national seaport. Different domestic food demand developments were described on the basis of income and price levels. Furthermore, changes in crop yields and crops losses were included.

Figure 5 shows the results of a base-line scenario for natural vegetation and banana plantations (Kok et al. 1999a). In this scenario, current developments in food demand and banana exports are projected. Protection of natural parks is not taken into account. The results show a substantial replacement of natural vegetation by pasture. Natural vegetation becomes limited to areas unfavorable for agricultural land use because of drainage problems and unfertile soils. The area of banana plantations expands in this scenario, especially along the main road from San Jose to the seaport.

Validation of model results

In the case studies, the model results are validated. Figure 6 shows the validation results for country-level studies for Costa Rica and Honduras executed by Kok et al. (1999b). Model results calculated for individual cells were aggregated to the level of administrative units and compared with an independent set of data for these units from an agricultural census. For Costa Rica the land use changes were modeled and validated for the period 1973-1984 and for Honduras for the period 1974-1993. Figure 6 shows the modeled changes in pasture areas versus the actual changes for Costa Rica and Honduras. The lines indicate the hypothetical one to one relation between modeled and actual changes. The results indicate that increases as well as decreases in areas are rather well captured by the model, especially for Costa Rica. Correlation coefficients between actual and modeled changes were 0.80 for Costa Rica and 0.60 for Honduras ($p < 0.05$).

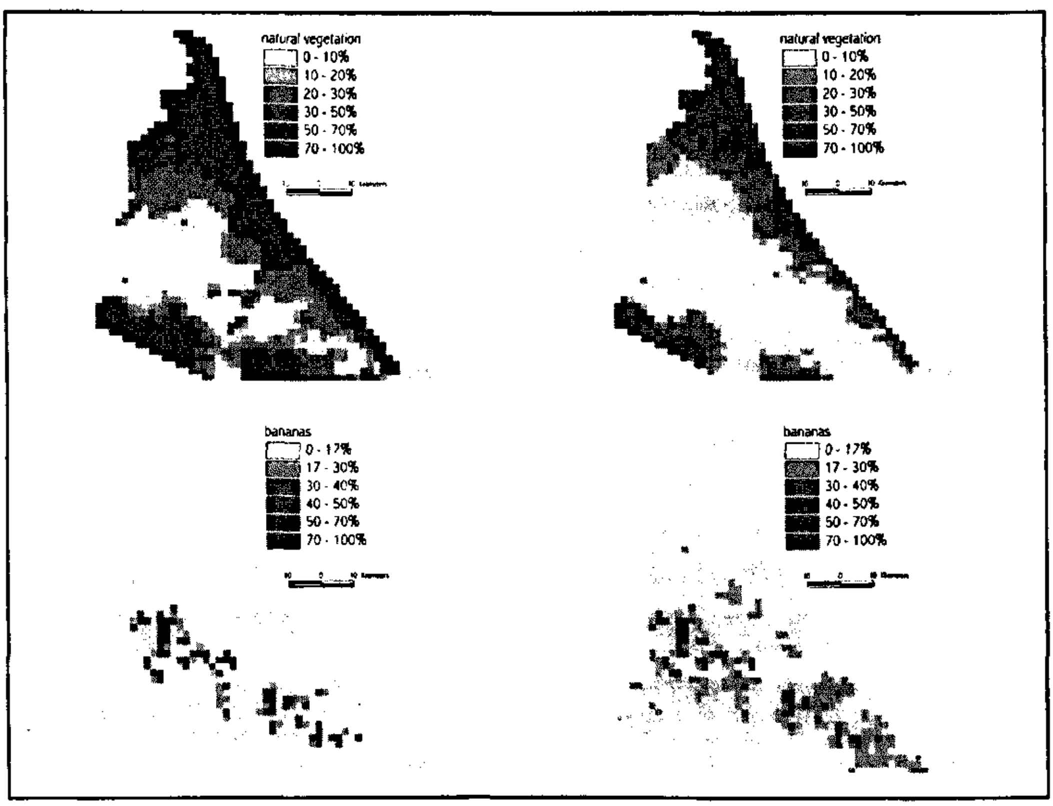

Figure 5. Actual land use distribution in 1984 (left side) and modeled distribution in 2005 (right side) for natural vegetation (top) and bananas (botton) in Costa Rica (source: Kok et al. 1999a).

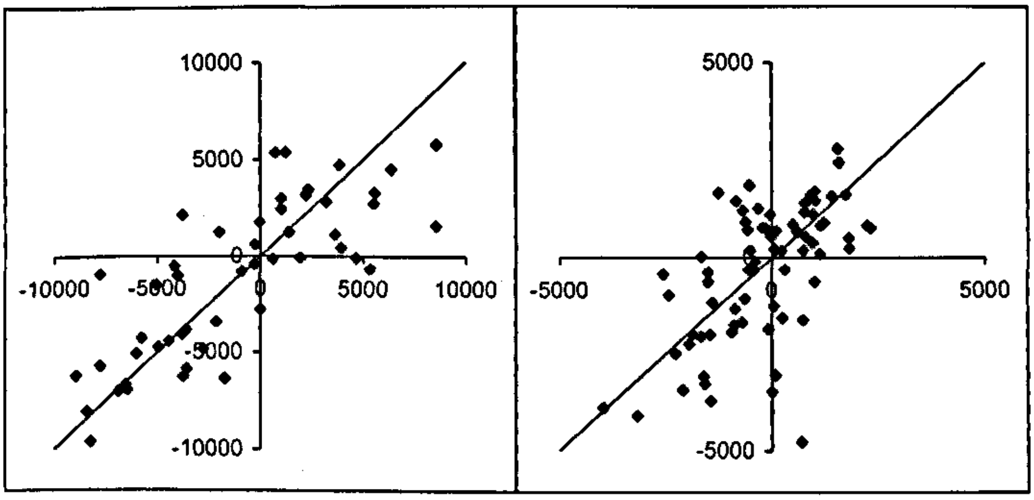

Figure 6. Simulated (y-axis) vs. observed (x-axis) change in pasture areas (ha) for administrative regions in Costa Rica (left) (n=50) and Honduras (right) (n=72) (Source: Kok et al. 199b).

A validation for modeled land use changes on the island of Java in Indonesia was executed by Verburg et al. (1999c). The land use types considered were shifting cultivation, paddy fields, dry agriculture, housing and gardens, and estates. Spatially explicit changes between 1979 and 1994 were modeled and compared with changes as reported in agricultural surveys. At the level of individual grid cells (40 by 40 km), the correlation between modeled and actual area changes varied between 0.22 and 0.66 ($p < 0.05$) for the different land use types. Figure 7 presents the results of the validation at the level of agro-ecological zones. For these zones, the modeled and actual changes are highly correlated (0.93). A trade-off can thus be observed between resolution and accuracy. At lower resolutions the spatial detail becomes less, but the accuracy of the model results increases.

CHARACTERISTICS, LIMITATIONS AND OPPORTUNITIES

The CLUE methodology has been specifically designed with the objective of addressing landscape-level land use dynamics. Several spatial scales from landscape to national level are considered in order to capture top-down as well as bottom-up processes.

The approach allows for the quantitative analysis of the main land use drivers. Through scenario studies the effects of changes in drivers on land use change are evaluated. Drivers can be diverse, for example food demand, nature protection policies, land degradation, migration patterns, and production technologies and export developments. A spatially explicit approach is followed that includes landscape-level land use interactions. When coupled with impact assessment models, effects of land use change on natural resources can be investigated, as was demonstrated with an analysis of soil nutrient balances.

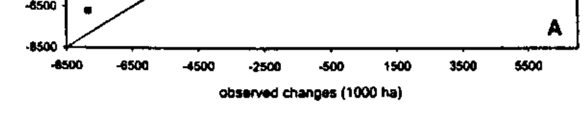

Figure 7. Simulated vs. observed land use change for agro-ecological zones in Java (source: Verburg et al. 1999c).

The spatial domain of the methodology is determined by the extent of the study area and the chosen grid resolution. Normally countries or rather large regions are studied and the grid cells vary in size from 2 by 2 to 30 by 30 km. The grid cells are not treated as homogenous units, but information on the exact location of attributes within a cell is unknown. This means that field and farm level dynamics can not be captured. The time step of one year and the time horizon determine the temporal domain of the model. The time horizon is considered to be maximally 20 years, aiming at an evaluation of short-term to mid-term developments. Although somewhat arbitrary, this time horizon is considered reasonable given that actual land use is the point of departure. Veldkamp and Fresco (1997) showed for Costa Rica that the quantitative relations between land use and its drivers are rather robust over such periods of time. The approach is of an empirical nature. The reason for this is that process-based knowledge from detailed scales can not just be scaled up, especially when combining socio-economic and biophysical information. Biophysical and socio-economic information is integrated by empirically analyzing their relative importance at different scales. The empirical basis means that the model can not be used for very long time horizons and that quantitative information on land use drivers is specific for the study area. For new study areas, the model has to be parameterized on the basis of information on land use and socio-economic and biophysical conditions. Hardly any model parameters have to be estimated or calibrated.

The approach can play a specific role in a tool sequence that addresses different scales and research questions. At the landscape level, it detects so-called "hot-spots" where land use is dynamic and where problems with respect to sustainable land management are expected. Local studies can then be nested within this landscape level analysis of land use dynamics. The local level offers the possibility of collecting specific biophysical and socio-economic data for more process-based tools. Such a tool could be a crop growth model for the determination of biophysical potentials and limitations to crop production. These are especially useful when socio-economic conditions allow for the use of the required innovative production technologies, as is the case in some of the areas in China investigated with CLUE. In Ecuador, many regions have very low production levels compared to the biophysical potential. Here identification of socio-economic constraints might be the main focus at the local level. In any case, more specific assessments of agricultural productivity, water and nutrient fluxes, erosion and sedimentation processes, soil compaction and nature values can be made at the local level, using the appropriate tools. Exploratory models can be applied to determine so-called "windows of opportunities" or "agro-ecological utility spaces" (Bouma et al. 1998b, van Ittersum et al. 1998). This was done, for example, in Costa Rica though optimization with a linear programming model (Bouman et al. 1999). Through a combination of likely developments with desired developments, new land use management strategies can be defined. In this process, prototyping of new cropping or farming systems can be applied, as was demonstrated for Costa Rica by Stoorvogel (1999b).

Nesting tools for local level analyses within tools that address the landscape and national levels can contribute to a better evaluation of the impacts of decisions from national to local scales. This offers information that can be used by platforms of stakeholders from different levels when negotiating trade-off between productivity and sustainability objectives in land use.

CONCLUSIONS

Integration of disciplines over different spatial-temporal scales is necessary in order to address the issues relevant for actors and stakeholders at different organizational levels in land use and natural resource management. Existing tools for systems analysis in agricultural research should only be used within their spatial-temporal domain. New opportunities lie in the coherent combination of different tools in a tool sequence. The methodology that was demonstrated in this paper offers an analysis of land use change dynamics at the landscape level and can form a link in a nested research approach from national to local levels.

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