MULTI-SCALE LAND USE SYSTEMS ANALYSIS : A BRIDGE BETWEEN RESEARCHERS AND STAKEHOLDERS : AN EXAMPLE FOR SEMI-ARID WEST AFRICA

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SUMMARY

To incorporate existing variability in agro-ecological and socio-economic conditions, in evaluating options for (agricultural) development in West Africa, an interactive approach to land use planning dubbed "Multi-scale Land Use Systems Analysis (MLUSA)" is proposed. It covers scales of household, village and district, and provides guidelines for managing resources to satisfy changing human needs without degrading the environment.

The components and functioning of land use systems are analysed in six steps to provide land use options at different levels of aggregation that are relevant to both farmers and policy makers. The steps are *(i)* goal setting, *(ii)* multi-scale characterization, *(iii)* selected research, *(iv)* scenario analysis, *(v)* evaluation of technologies and interventions, and *(vi)* impact assessment. The method is illustrated with examples from semi-arid Burkina Faso, Mali, and Niger.

1 INTRODUCTION

In semi-arid West Africa, agro-ecological and socio-economic conditions vary considerably in both space and time. In addition to the environmental variability, farmers use a wide range of production systems with modern and traditional technologies often existing side by side within one household. This results in a large variation in productivity across and within agro-ecological zones. Major constraints for development are low soil fertility, erratic rainfall, and population growth rates that exceed the annual growth rates of agricultural production. Over the last two decades, the annual increase in output of production systems has been about 1.3% (Cleaver and Donovan 1995). The increase in food demand is about 2.8% (Club du Sahel 1991). Currently 20% of total food requirements have to be imported (FEWS 1997).

Hence, options are urgently needed for an integrated development strategy addressing the needs of various stakeholders, based on sustainable production systems and with increased yields. Research by National Agricultural Research Systems (NARS), international and other agricultural research institutes has developed improved technologies. However, adoption by farmers is far below expectations for several reasons. Among them are *(i)* the improved technology does not match the farmers' ability and financial resources, nor the strategies of both crop and livestock farmers which tend to focus on extensive agriculture, *(ii)* limited co-ordination by groups that intervene in a given region, *(iii)* low availability of inputs, and *(iv)* incompatibility with land tenure (Marcussen 1994, FAO 1995, INSAH 1997).

Another limiting factor seems to be the focus of research and development projects to find solutions at the field scale. It might be true that a (technical) solution, such as fertilizer application, is efficient at the field scale. But at higher level of aggregation (household, village, district, region) adoption may be constrained or the technology may cause constraints of a different kind. For example, in a modeling study for the Fifth Region of Mali (Veeneklaas *et al.* 1994) soil nutrient mining was excluded through fertilizer and manure application, but maximization of marketable grain production required more fertilizer for that region alone than the total national imports (van Duivenbooden 1993). Application of the proposed sustainable land use systems was thus limited by budgetary and infrastructural constraints at a higher level of scale.

Research should aim for better short-term solutions at the lower scale levels when these constraints cannot be lifted. It is also clear that up-scaling and down-scaling to examine the consequences of both constraints and solutions is needed before attempting to transfer technologies.

Finally, low availability of spatial information about land resources (e.g. detailed soil maps) and the often poor linkages between research institutes and stakeholders (farmers, extension services, non-governmental organisations (NGOs), policy makers, and development projects) have considerably limited the targeting and adaptation of technologies to the site-specific bio-physical and socio-economic environments.

Thus there is a need for holistic land use planning to identify appropriate land use systems, i.e. the match of land use and land. Land use systems, with their principal components and flows, can be defined at any level of aggregation. For instance in Niger we have defined them at the level of the agro-ecological zone (the rainfed mixed agro-pastoral system and at the canton level, the extensive millet-based system).

The purpose of this paper is to present a multi-scale research and development method that integrates and capitalises existing information from a wide variety of sources, and that identifies options for development which can be discussed with stakeholders at different levels of aggregation. It is illustrated with examples from semi-arid regions in Burkina Faso, Mali, and Niger.

2 MULTI-SCALE LAND USE SYSTEMS ANALYSIS (MLUSA)

2.1 Approach

The procedure proposed includes elements of various existing methodologies which have been evaluated against the criteria of land use planning (Table 1).

The main disadvantages of most of these approaches are the absence of spatial and temporal analysis, and results referring mainly to one level of scale. Hence, in addition to a multi-scale approach, land use planning should include *(i)* integration of disciplines and possible stake-holders' goals and visions, and involvement of all stake-holders in the design, implementation and evaluation stages, *(ii)* identification and quantification of the most important constraints or limiting processes of land use systems, *(iii)* reliable and 'easy to understand' presentations of trade-offs between various development options that attract stake-holders into participating in scenario analyses, *(iv)* consideration of present land use systems and technologies, *(v)* identification of the interval and path between actual and future situation, and *(vi)* monitoring of progress.

Various research disciplines can be linked through the formulation of development scenarios (or options for development) which requires the identification and quantification of the interactions (e.g. inputs and outputs). The scenarios relate to the various stakeholders at each aggregation level (i.e. farmers, village heads, regional and national decision-makers).

In multi-scale land use systems analysis (MLUSA), the components and the functioning of land use systems are analysed in six steps (Figure 1) to give quantified and clear land use options at different aggregation levels (household, village and district).

Table 1
Main characteristics of various current methods and of the proposed method, concerning the development of sustainable production systems (van Duivenbooden 1995)

AC = Agricultural Census, LE = Land Evaluation, FSR = Farming Systems Research and Farming Systems Analysis, LEFSA = Land Evaluation and Farming System Analysis, AAD = Agro-ecosystem analysis and development, EIA = Environmental Impact Assessment, RRA = Rapid Rural Appraisal, FESLM = Framework for Evaluating Sustainable Land Management, AEC = Agro-ecological characterization

Characteristic	AC	LE	FSR	LEFSA	AAD	EIA	RRA	FESLM	AEC
Advantages									
multi-disciplinary	+/-	+	+	+	+	+	+	+	+
multi-scale	-	-	-	+	-	+/-	-	+	+
systems approach	+/-	-	+	+	+/-	-	-	+	+
geo-referenced	-	+	-	+	-	+/-	-	+/-	+
identification of constraints	-	+	+	+	+/-	+	+	+	+
scenario analysis	-	+/-	+	+	-	-	-	-	-
effect analysis	-	-	-	-	-	+	-	-	-
farmers' goal included	-	-	+/-	-	-	+/-	+	-	-
visually clear presentation of results	+	+	-	+	+/-	-	-	-	+
Drawbacks									
huge time requirements	+	+	+	+	+	+	-	+	+
huge data requirements	+	+	+	+	+	+/-	-	+	+
qualitative nature	-	+/-	+	+/-	+	+/-	+/-	-	+/-
no spatial analysis	+/-	-	+/-	+/-	+/-	-	+	+/-	-
no temporal analysis	+/-	+	+	+	+/-	-	+	+	+/-
organisational aspects	-	+	+	+	-	-	-	+	-
limited information	+	+	+/-	+	+	+/-	+	-	-
Tools	3	3,5,6	1,3,4	3	3	3	1,3	1,2	1-6

Note : multi-disciplinarity merely implies that at least two of the relevant disciplines are included. +: true, -: not true, +/-: not always true. Tools : 1 = literature review, 2 = remote sensing, 3 = survey and interview, 4 = experiments, 5 = modelling and 6 = GIS application.

Figure 1
Possible research and development activities at various levels of aggregation of the Multi-scale Land Use Systems Analysis (AEZ = agro-ecological zone).

Steps	AEZ	District	Village	Household	Plot
1. Vision and goals setting		—	—	—	—
2. Characterization					
satellite images	—	—	—		
air photos		—	—	—	—
transects			—	—	—
interviews			—	—	—
3. Selected research					
literature review	—	—	—	—	—
policy, markets		—	—		
surveys			—	—	
simulation modeling			—	—	—
technology formulation			—	—	—
experiments				—	—
4. Scenario analysis		—	—	—	
5. Technology and intervention validation			—	—	—
6. Evaluation of outcomes		—	—	—	—

The main steps are:
1. Definition and formulation of vision and goals of researchers and stakeholders. 'Where do we want to go? What do we want to achieve?'
2. A comprehensive description of the actual agro-ecosystems at different scales of aggregation; 'Where are we at this moment?'
3. Research restricted to the most important components and flows of land use systems; 'What do we have to understand better?'
4. Analysis of development scenarios with a multi-criteria programming model or multi-scale decision support system (MDSS) or linked to geo-

graphical information systems (GIS). 'What are the possibilities? What outcome can we logically expect?'

5. Evaluation and validation of technologies and interventions by researchers and stakeholders; 'Does it really work? Is it feasible under farmers' conditions?'

6. Evaluation of outcomes; 'Is it adopted by farmers? Has a policy really changed?'

Steps 3 to 5 are closely linked and are carried out more or less concurrently. Figure 2 shows the flow of data use and the integration of GIS, process and multi-criteria programming models.

2.2 Vision and goals setting

The definition of vision and goals at each level of scale enables us to set criteria and milestones. It is so important, at the outset, that all stakeholders are able to express what they need from each other and what they can offer in return.

Common or aligned goals among stakeholders, of course, will increase efficiency and effectiveness because the stakeholders are not all pulling in different directions. If stakeholders have conflicting goals, the efforts of each may be less effective or even lost.

Against the background of disparate biophysical and socio-economic endowments at household level, setting common goals is an almost impossible task. However, goals upon which a measure of consensus may be achieved may be defined as sets of multiple objectives that are in minimum conflict with one another. Examples of goals at various levels of aggregation are given in Table 2. The most important goal is to meet the demand for food. The other goals are not ranked.

The goals will focus research and development, and will assist in defining indicators that guide the process of change towards sustainable land use systems. This step takes some time at the beginning but, after formulation of goals, the efficiency of the following steps is much greater than without such a focus.

2.3 Multi-scale characterization

The essential elements for assessing the potential of an area for agricultural development are the physical properties of the natural environment (i.e. climate, soils, water availability, and form of the landscape) and the socio-economic components and processes (labour, capital input, management, land tenure, temporary

Table 2
Selected general goals of various stakeholders at three levels of scale in the semi-arid regions of Burkina Faso, Mali, and Niger

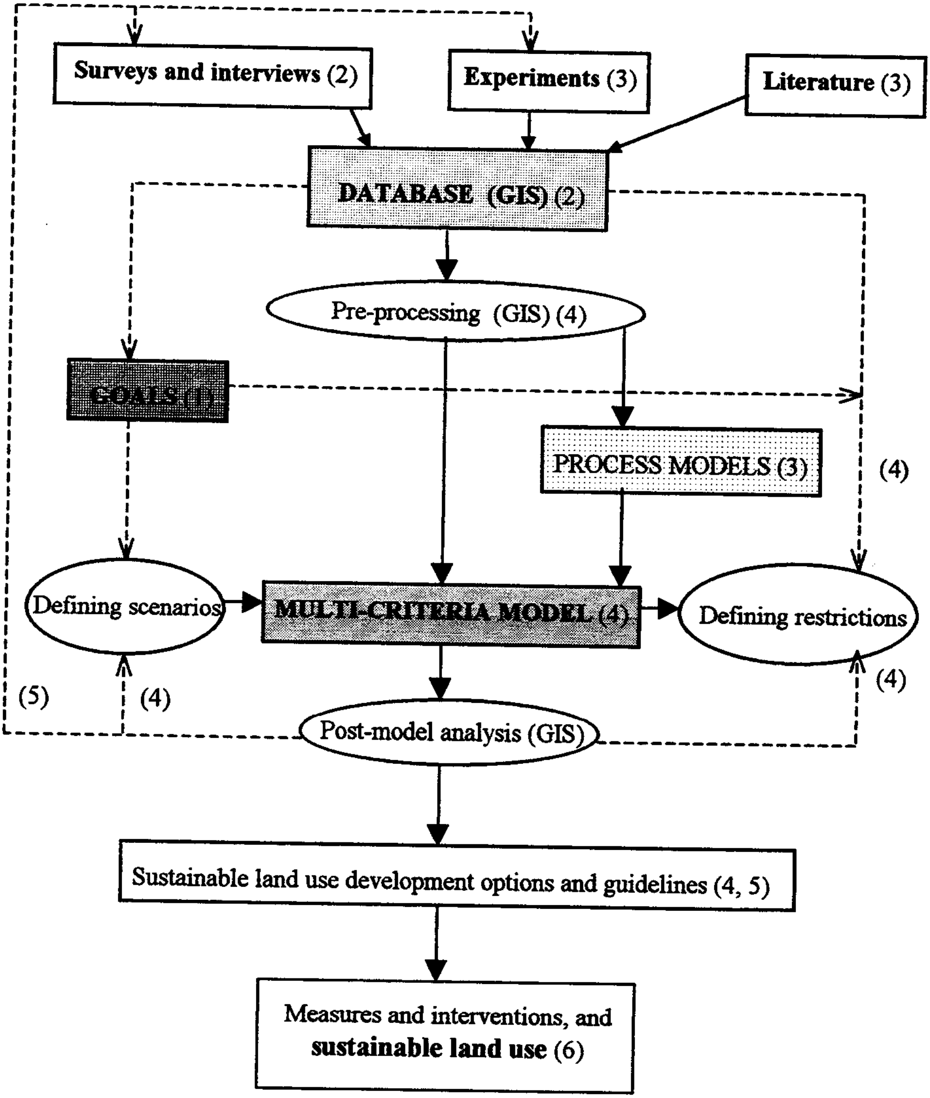
GOAL	Household	Village	District
Meeting food demands	—	—	—
Increased revenues	—		
Social status	—		
Production and revenue security	—	—	
Improved natural resource management			
Maintained and improved soil fertility	—	—	—
Sustainable use of wood		—	—
Sustainable exploitation of fishery		—	—
Increased fodder production		—	—
Reduced water and wind erosion		—	
Improved use of agricultural by-products			—
Infrastructure (roads, school, health)		—	—
Environmental / biodiversity protection		—	—
Avoidance of conflicts		—	—
Increased milk and meat production			—
Organization of socio-economic groups			—
Reduction of labour exodus			—

migration) and their spatial differences. For instance, income generation from migration in the Sahel amounts to 10% compared to 2% in the Sudan Savanna and 1% in the Guinea Savanna zone (Reardon 1994).

Multi-scale characterisation is the comprehensive description of land use systems at different scales. Five major levels are distinguished (Figure 1): macro (e.g. agro-ecological zone with scales between 1:1000000 and 1:500000), re-connaissance (district at 1:100000-1:250000), semi-detailed (village at 1:25000-1:50000), detailed (household at 1:5000-10000), and micro (e.g. plot at 1:1-5000). With the change in scale from macro to micro, the unit of analysis (used for comparison within a scale) and the degree of detail of information also changes.

Each level of scale has a different unit of analysis with its own boundaries. In general, two schools exist for the selection of the boundaries : (*i*) using biophysical or morphological units (e.g. watershed or other more scientific units),

Figure 2.
Information and data flow, showing the integration of geographical information system, process and multi-criteria programming models. Straight lines: data. Dotted lines: information. Numbers in brackets refer to steps in MLUSA (see text)



and (*ii*) using units at which decisions are made (e.g. administrative boundaries). Each has its own advantages and disadvantages, but it is beyond the scope of this article to discuss those in detail. Here the administrative boundaries are used because they relate better to the various stakeholders who have to take the decisions (district governors, village heads, household chiefs).

The success of the analysis depends on the availability and reliability of the basic data. These data should preferably be collected over a long period in order to enhance the validity of the information. Standard methods include satellite imagery and aerial photos, transect surveys and interviews. A geo-referenced multi-scale database (Figure 2) is needed for reference by the various stakeholders.

In this process of characterization, constraints for development are identified (e.g., Ogungbile *et al.* 1998). They include, for instance, at the household level: cash, labour, drought, and land tenure system; at the village level: availability of land, and institutional framework; and at the district level: budget, land availability, political institutions, and infrastructure (Table 3).

Table 3.
Selected general constraints at three levels of scale in the semi-arid regions of Burkina Faso, Mali, and Niger

Constraint (specification)	District	Village	Household
Political institutions	———		
Budget	———	———	———
Land (availability and quality)	———	———	———
Infrastructure (roads, etc.)	———	———	
Extension (quantity, quality)		———	———
Market access / price risk		———	———
Land tenure system		———	———
Timing of farm activities			———
Labour (availability and price)			———
Inputs (availability and price)			———
Rainfall (quantity, distribution)			———
Health (gender, age group)			———
Education (gender, age group)			———

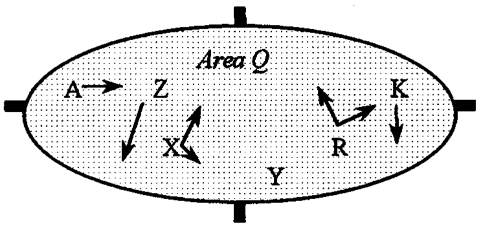
During this step, indicators have to be identified to measure sustainability and development, e.g. organic matter and phosphorus content (Herweg *et al.* 1998).

2.4 Selected research activities

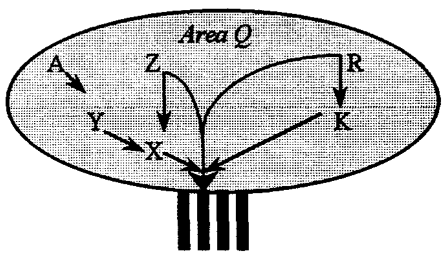
To complement existing results or fill in the gaps (i.e. outcome of characterization phase), research might be needed. Review of existing information and data is also an important activity of this step as, too often, research continues without taking stock of available knowledge. A recent example is the inventory of technologies already available for transfer to farmers in Niger (Ly *et al.* 1998). This process is being continued in other countries taking part in the Desert

Figure 3
Schematic diagram showing the difference in output without and with alignment in goals. The letters represent institutions or projects (van Duivenbooden, 1997)

With 'individual' goals (except for Y having no clear goal), but without alignment:



With common goals and alignment:



:goals; : amount and quality of output.

Margins Program (DMP), a research program to stop desertification in sub-Saharan Africa. Another example is the review carried out by NARS on their research on the theme of optimizing soil water use (OSWU), as an activity of the similarly named consortium under the umbrella of the Soil Water Nutrient Management Program.

Experimental work on various units of analysis should be carried out on representative (benchmark) sites selected on the basis of the characterisation. It is also executed in partnership between research institutes and stakeholders. Joint planning and priority setting is a prerequisite and the output increases when the activities of one partner contribute to the output of another (Figure 3).

Finally, surveys and analyses with crop simulation models and GIS will help to identify possibilities and match technologies (e.g. improved crop varieties) to specific environments.

2.5 Analysis of development scenarios

The question ‘Where do we want to be, and when?’ (e.g. self-sufficiency at 75% in dry years by 2005) may be addressed using multi-criteria programming (de Wit *et al.* 1988) as being used by a number of Dutch research workers in West Africa (e.g. Veeneklaas *et al.* 1994, Bakker *et al.* 1998, Maatman *et al.* 1998).

Goals and constraints on the system at a given level of scale form the basis of such a model.

The earlier defined stakeholder-goals need to be translated into quantifiable objectives, referred to as ‘model-goals’ (Fig. 2). A model-goal is a function, i.e. something to maximize (e.g. profit, consumption) or minimize (e.g. risk). Optimizing (maximizing or minimizing) this goal subject to the constraints (restrictions) placed on the system, will result in suggested activities or interventions. Constraints limit possible activities and achievements. There are, for instance, resource limits (e.g. land), process limits (e.g. yields as functions of physical and chemical characteristics and inputs), and activity limits (e.g., institutional factors). Processes are links between activities. They can refer to consequences (e.g. land degradation) or they can describe feed backs (e.g. land use practices may cause degradation which in turn reduces crop yield and influences land use practices). The impact of these interventions can be explored through different scenarios. These scenarios test the efficiency and acceptability of the interventions.

In a MDSS model, goals, constraints, and processes will appear in the form of equations. Quantifying these relationships (equations) determine the data requirements to make the model operational. Data availability will often determine what goals can be examined and the reliability of the results. Depending on the issue or strategy to be evaluated, models can be static, multi-period or dynamic. Linking models to a GIS helps to display the various outcomes of the modelling.

Sustainability (e.g. in terms on equilibrium soil nutrient balances, absence of erosion losses) should be one of the goals. However, the chance for adoption is much larger when the options are consistent with market-oriented development. If farmers don't get any additional income from adopting improved management practices, they will not adopt them. Furthermore, non-farm income should be considered at the household level, since this determines to a large extent the ability of the household to invest in agricultural production systems. Hence, geo-referenced socio-economic information is needed to see how attractive a land use system can be under different pricing and income scenarios. With this information, policy makers can judge whether it makes sense to promote a technical option in a particular area at that point in time, or to promote market development first.

This comparison of options is illustrated with two cases. Firstly, is the case of the goals to obtain equilibrium soil nutrient balances and to reach the agri-cultural production potential in terms of marketable grain production in the Fifth Region of Mali. Table 4 shows for the district level the effect of increased fertilizer avail-ability (scenario B) compared to the restricted availability in the early 90's (scenario A). Except for the change in amount required (see earlier remarks in the introduction), there is also a clear shift in relative amounts of nitrogen, phosphorus and potassium caused by changes in land use patterns.

Table 4

Total millet production and total ('000 ton) and relative requirements of N:P:K (in elementary form), fertilizer requirements in selected agro-ecological units in the Fifth Region of Mali while maximizing marketable grain production and avoiding soil nutrient mining. Scenario A is restricted fertilizer availability, and Scenario B unlimited fertilizer availability (adapted from van Duivenbooden 1993)

Agro-ecological	Scenario A			Scenario B		
unit	Millet	N:P:K	Fertilizer	Millet	N:P:K	Fertilizer
Delta Central	18	26:1:8	2.0	45	12:1:6	8.0
Mema Dioura	8	1:0:0	0.2	20	7:1:5	2.0
Plateau	40	1:0:0	0.3	84	6:1:4	8.0
Sourou	39	14:1:2	0.9	94	6:1:4	10.0
Seno Bankass	40	5:1:1	0.3	49	6:1:4	4.0

Table 5
Selected results of the linear programming model for a representative household in an 'average' rainfall year in North Burkina Faso under two scenarios, (a) without rock bunds or the possibility to apply zaï (i.e. dug holes with a diameter of 15-20 cm and 10-15 cm depth, in which manure is applied), and (b) with rock bunds and zaï (adapted from Maatman *et al.* 1998)

Characteristic	No rock bunds; no zaï	With rock bunds and zaï
Total surface (ha)		
Sown	3.59	3.56
Sown with zaï	-	0.67
With intensive weeding: timely and efficient weeding	2.71	2.75
Extensive weeding: superficial	0.88	0.81
Harvested	3.59	3.56
Production (kg)		
Cereals	1343	1357
Groundnuts	69	230
Cowpeas	33	44
Sales (kg)		
Cereals	75	5
Groundnuts	37	82
Cowpeas	18	34
Purchases (kg)		
Cereals	378	399
Groundnuts	0	0
Cowpeas	0	0
Reserve stock (kg cereals)	0	125

The second example, for the aggregation level of a representative household in Burkina Faso seeks to maximize crop production. It illustrates the need for applying water and nutrient conservation techniques (Table 5). Both examples show again the importance of aggregation levels for the consequences of proposed technologies at the plot level.

Discussions with stakeholders on preliminary results and a post-model analysis are essential to further verify the obtained results and, if necessary, adapt the model. In a subsequent phase of a project, researchers and stakeholders can then sit together and run the model for different scenarios.

2.6 Evaluation and validation of technologies and interventions

Based on the outcome of the modelling exercises, several technologies and/ or interventions can be identified as apparently favourable and affordable to farmers. Since many of them have already been tested on-station and on-farm (and their results have been incorporated in the model), the need for validating or testing is considerably reduced. However, some on-farm experimentation may be required to validate simulation models and the interaction of different component technologies. This experimentation will be done at the field level (i.e. household-level experiments), but it is important to involve a number of villages to compare different socio-economic variables. Moreover, in some villages all farmers should take part to obtain a village-level experiment. Consequences of household- and village-level experiments can then to be analysed for village and district, respectively. Eventually, as new technologies and recommendations are adopted (or not) by the actual land user, the computer simulations can be judged for their usefulness and predictive capability.

2.7 Evaluation of outcomes

The final step in MLUSA is the assessment of the achievements, such as adoption of technologies by farmers and NGOs, interventions by policy makers, and improvement of indicator values. For certain indicators, this evaluation may not be an easy task because of the length of time before changes are obtained. This analysis should give feedback to research to policy makers, and should address different levels of scale.

3 DISCUSSION AND CONCLUSION

In this paper, an interactive land use planning methodology has been advocated. It could be a next step in *(i)* the capitalisation and integration of stakeholder goals and current knowledge of land use systems, *(ii)* the planning of sustainable agriculture, and *(iii)* the increase of labour and fund efficiencies in natural resource management. It allows the effects of certain decisions or developments (e.g. population growth, soil mining, climate change) to be illustrated, e.g. by smart-maps which can easily be understood by policy makers. In addition, it links different levels of scales. As a consequence, it proposes a logic chain of possible measures and interventions to be taken by the various stake-holders at the different levels of scales. The procedure requires alignment of research and development activities to avoid duplication of efforts and provides a way to quantify and integrate knowledge of various disciplines.

Compared with the current methods in Table 1, it scores positively for all advantages and suffers none of the drawbacks except that it still requires a great deal of data, as do other methods. The development and availability of verified geo-referenced multi-scale databases are key factors but, once created, they can be used to analyse multiple scenarios and lead to overall time savings.

The innovations are the importance given to stakeholder goals from the beginning and the focus on addressing different levels of aggregation. The approach tries to bridge the gap between regional and national decision-makers, farmers, extension services, and researchers.

The land use planning method addresses different issues at each level of scale because at each level of aggregation the characteristics of land use systems and their inherent variability are different. It acknowledges that, in order to attain a goal, action is often required at a different level of aggregation, whether higher or lower. It is noted that the process of zooming in from a higher to a lower scale is much better known than the opposite, i.e. extrapolation. The latter, however, is needed to facilitate the framing of policies that are based on research results and geo-referenced information obtained at a lower scale. This is part of the research being carried out by NARS and ICRISAT in Burkina Faso, Mali, and Niger (van Duivenbooden 1997, van Duivenbooden *et al.* 1998).

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