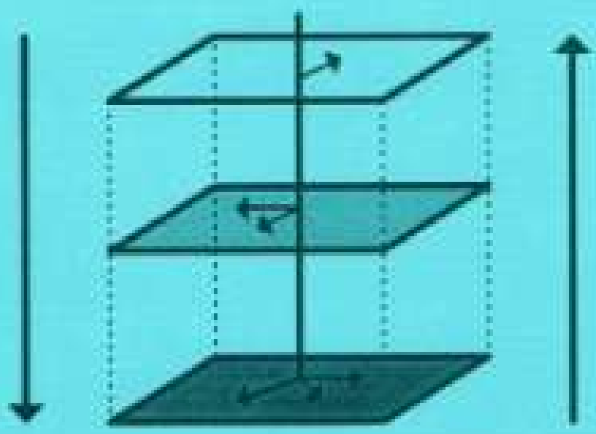
Integrated Systems Project
Report Series no. 1

Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa (MUSCLUS)



In collaboration with:
INRAN, INERA, IER, NGOs, and development projects in Niger, Burkina Faso, and Mali, and the C.T. de Wit Graduate School of Production Ecology (PE) in the Netherlands

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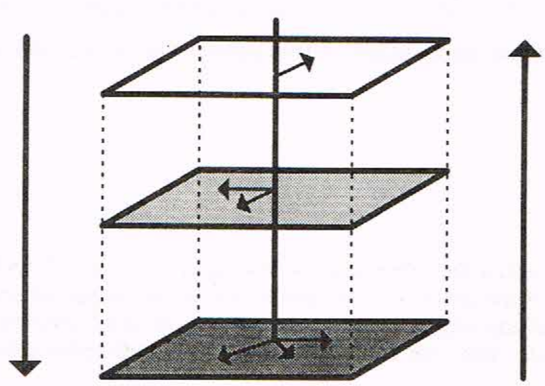
Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa (MUSCLUS)

Methodology and work plan

N. van Duivenbooden

1997



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Abstract

The impact of research on the agricultural development and sustainability of millet and sorghum based systems in the semi arid tropics of West Africa is low. One reason is the considerable variability of land use systems that occurs on different scales. Hence, appropriate recommendations for stakeholders at every scale need to be formulated. To do this, a joint project has been initiated between national agricultural research systems in Mali, Burkina Faso and Niger, with scientific support from various institutes in Wageningen, the Netherlands. The objectives of this project are to: *(i)* improve natural resource management by targeting technologies for specific environments and by the exploitation of multi-scale variability in the biophysical and socioeconomic conditions; *(ii)* formulate pragmatic recommendations on integrated natural resource management (INRM) for both regional level decision makers and farmers; and *(iii)* develop a methodology for 'up-scaling' research results obtained at a field level. The research approach includes four levels of scale: the household, village, district, and agroecological zone. After characterizing each scale, simulation and multi-criteria models linked to a geographical information system will be used to explore the niches of sustainable land use systems and examine development options to target technologies and interventions. The methodology and work plans of this project are presented in this report.

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Executive summary

In the semi-arid tropics of West Africa, agroecological and socioeconomic conditions differ considerably in both space and time. As a consequence, farmers use a wide range of production systems that cause a large variation in productivity across and among agroecological zones and farm types. Due to soil mining and other inappropriate management practices, most production systems are not sustainable. The delineation of scales now allows a systems analysis that defines options for agricultural development (e.g., measured as an increase in rates of self-sufficiency) based on sustainable production systems and their corresponding technologies. At each scale, the characteristics of land use systems (and their inherent variability) are different. Lower scales include more details than higher scales. Variation in the characteristics of land use systems as a function of scale is called "multi-scale variability". This multi-scale variability can be exploited to understand better the key processes in the functioning of land use systems, to analyze risk in current and alternative land use systems, and to specifically target technologies and interventions.

The project "Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa" or MUSCLUS is a joint research activity of ICRISAT and national agricultural research systems (NARS) in Mali, Burkina Faso and Niger, with scientific support from various institutes in Wageningen, the Netherlands. It is planned for 5 years (1996-2000) and is partly financed by the Directorate General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs. MUSCLUS falls within the framework of ICRISAT's Integrated Systems Projects and will make optimal use of the institute's experience in the region.

The objectives of this project are to: *(i)* improve natural resource management by targeting technologies for specific environments and by the exploitation of multi-scale variability in the biophysical and socioeconomic conditions; *(ii)* formulate pragmatic recommendations on integrated natural resource management (INRM) for both regional level decision makers and farmers, based predominantly on existing research information; and *(iii)* develop a methodology for 'up-scaling' research results obtained at a field level.

The research approach used in this project is land use systems analysis (LUSA). It aims to cover the successful management of resources to satisfy changing human needs without degrading the environment or the natural resource base. Components and the functioning of land use systems are analyzed in five steps, in an interdisciplinary way, to give quantified and clear alternative land use options on different scales. The main steps are: *(i)* the definition and formulation of common goals of farmers, researchers, and land use planners, *(ii)* a comprehensive description of the actual

agroecosystems on different scales, *(iii)* research restricted to the most important components and flows of land use systems, *(iv)* the analysis of development scenarios with a multiple goal linear programming model linked to a geographical information system, and *(v)* the evaluation of new technologies and management practices by both farmers and scientists. Four levels of scale are distinguished, guided by the decision-making process: agroecological zone, district, village, and household.

Outputs comprise a decision support system that assists in targeting technologies and interventions to specific environments, guidelines for stakeholders for development of improved production and sustainable land use systems, management options for farmers, and a methodology for extrapolation and transfer ("regionalization") to the district level of research results and information obtained at a field level.

Main collaborators are Institut National de Recherche Agronomique au Niger (INRAN), Institut d'études et de recherches agricoles (INERA in Burkina Faso) and Institut d'Economie Rural (IER in Mali) and the C.T. de Wit Graduate School of Production Ecology (PE) of the Wageningen Agricultural University (the Netherlands). In the near future this group will expand with other NARS, non-governmental organizations, international agricultural research centers, advanced research institutes, and development projects. Collaboration takes place through linkage to on-going activities, and on the basis of the "alignment principle", i.e.,, activities of this project are carried out in such a way that results of the one or more partners contribute to results of others ("win-win" situation).

The emphasis is on millet- and sorghum-based production systems in the southern Sahelian and northern Sudanian zones of West Africa in the rainfall zone of 400-700 mm, or with a length of growing period of 60-125 days, in Mali, Burkina Faso, and Niger. The key sites are located in the south Sahel (400-500 mm) and north Sudan Savanna zone (600-700 mm). The selected districts and villages are in Niger: Tillabery (Banizoumbou) and Dosso (Tanda); in Burkina Faso: Banh (Madougou) and Fada (Kouaré); and in Mali: Mopti (Lagassagou) and Sikasso (M'Peresso).

Keywords: sub-Saharan Africa, scales, up-scaling, down-scaling, characterization, land use systems analysis, multi-criteria model, simulation modeling, integration of disciplines, alignment, consortium approach

Introduction

Background

In the semi-arid tropics of West Africa, agroecological and socioeconomic conditions differ considerably in both space and time. Annual rainfall ranges from 400 mm in the central-northern Sahel to 700 mm in the north Sudanian zone (Sivakumar 1989). Soils range from clay in inland valley bottoms to sand on the slopes. Due to selective fertilization, the predominantly sandy soils with inherent low fertility (Bationo and Mokwunye 1991), are more fertile near the compound than in the bush fields (Prudencio 1993). Within a field, differences in soil characteristics in the course of the year are also observed (Brouwer and Powell 1995). Differences exist in labor availability, presence of markets, and in the policies that support agricultural development (e.g., development of cotton in south Mali). As a consequence, farmers use various types of animal and crop production systems, resulting in high variations in yield in time and space, across and among agroecological zones and between farm types. In addition, due to soil nutrient mining and other inappropriate management practices, production systems are no longer sustainable. Not unexpectedly, the self-sufficiency rate in these countries is low, and the increase in annual output of these production systems (1.3%, Cleaver and Donovan 1995) lags behind the increase in food demand (2.8%, Club du Sahel 1991).

The present aim for West African agricultural development is to intensify agricultural production systems that are sustainable and obtain an annual growth rate of 4%. New or improved technologies are available (e.g., Shetty et al. in press), but their adoption is low because they are inappropriate to the socioeconomic conditions of farmers. Low availability of fertilizer and seeds, poor extension services, land tenure problems, and non-compatibility with the individualist strategies of crop and livestock farmers are among some of the reasons cited (Dugué 1994; FAO 1995). In addition, consequences of on-farm field experiments are not generally calculated to a village or district level. Finally, links between farmers, researchers, extension agencies, and regional decision makers are tenuous, so that each group is most likely to pursue its own goals rather than work with the others.

To identify strategies that enhance crop production and are sustainable, and to target technologies to specific environments in West Africa, two key issues need to be considered in regional agricultural research: variability of land use systems characteristics and integration of disciplines and institutes (van Duivenbooden 1995). Land use is defined as human activities that are directly related to land, make use of its resources or have an impact on it. A land use system is thus the combination of specified land uses (or production systems) practiced on a given land unit (FAO 1976). Figure 1 gives a schematic presentation of the main flows and components of land use systems. A land use system is sustainable when output, output stability and resource use efficiency are maximized, while maintaining or improving the production potential of the natural resource base. The output is a function of genetic resources, abiotic and biotic environments, and management practices. Output stability is considered a function of the variation in these same four factors. The resource use efficiency describes the efficiency with which a particular input (natural resource or external) is used for production (Almekinders et al. 1995).

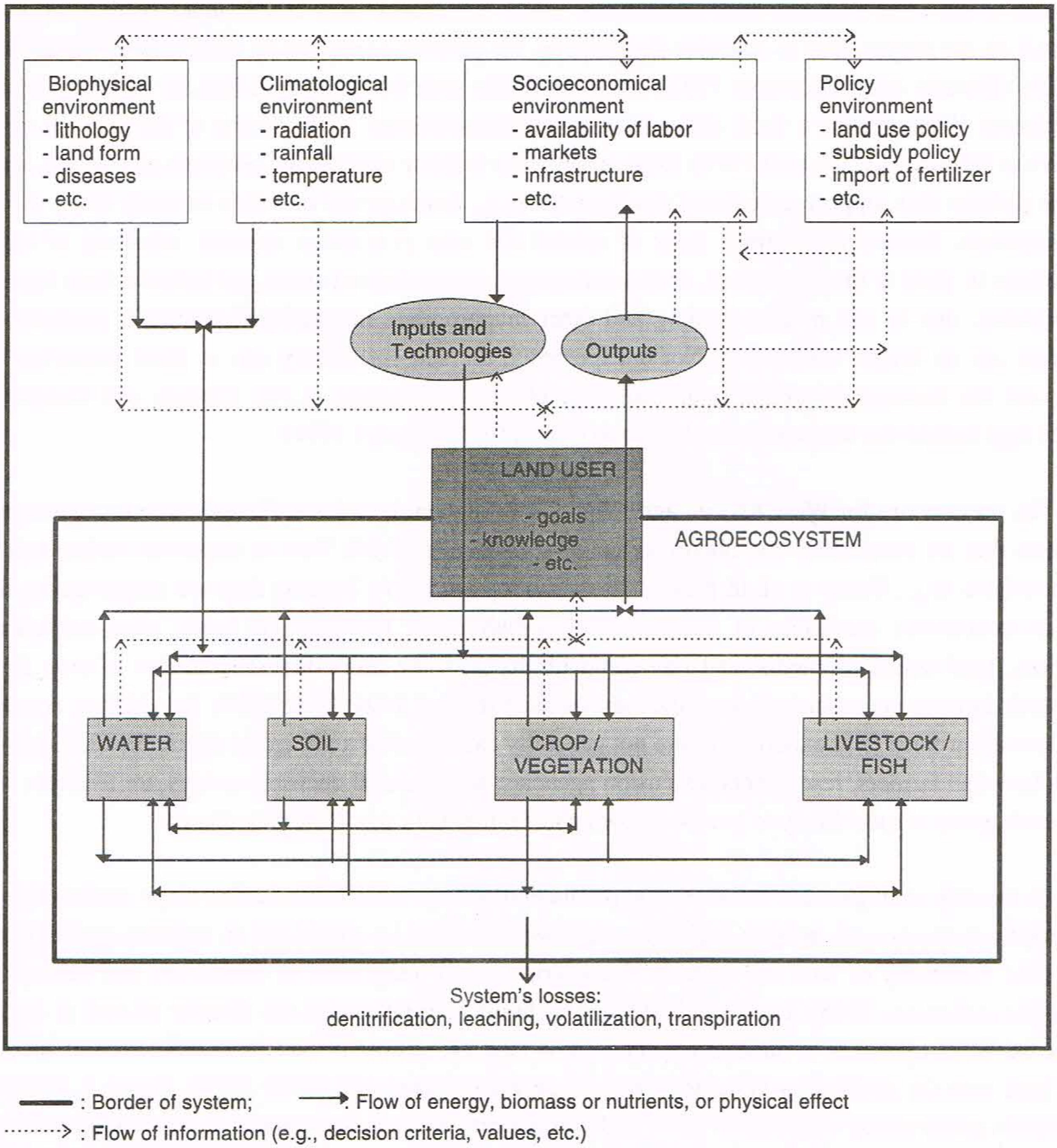

Figure 1. Schematic representation of a land use system (van Duivenbooden 1995).

To address variability, scales that create more or less homogeneous units of analysis should be identified, as the heterogeneity observed at a scale is the result of inadequate resolution. Working at different scales is also needed because: *(i)* characteristics of agroecological processes (e.g., temperature) can be at the same time exogenous forces as well as variables of the system (Fresco 1995); *(ii)* patterns seen at one level may be explicable only on the basis of processes functioning at a lower level (Izac and Swift 1994); *(iii)* characterization and data are linked only to one level of scale (Andriesse *et al.* 1994), *(iv)* the type of processes that influence the production potential of a land use system is scale-dependent (Kruseman et al. 1996), *(v)* risk is a phenomenon with spatial and temporal dimensions (Fresco 1995); *(vi)* an understanding of relations within the system and extrapolation of results requires a systematic approach (Andriesse *et al.* 1994); and *(vii)* a (technical) solution may be efficient at one scale (e.g., field), but at a lower level of resolution causes constraints of a different kind (e.g., socioeconomic; van Duivenbooden 1993, 1995). Finally, it must be realized that statistical studies have only limited value, if any, when the scale is not given.

Working at different scales implies that at each scale, the characteristics of land use systems and their inherent variations are different (Andriesse *et al.* 1994; Fresco 1995), and at smaller scales (e.g., at 1:2 000 000) less detail is presented than at larger scales (e.g., at 1:100 000). The variation in characteristics of land use systems among scales and their variability as a function of scale is called "multi-scale variability".

Instead of avoiding or ignoring existing variability, multi-scale variability can be exploited to *(i)* understand better the key processes of land use systems, *(ii)* analyze risk of the current and alternative land use systems in terms of improved production and sustainability, and *(iii)* avoid a mismatch of technologies and interventions. This exploitation may comprise, for instance, optimization of crop production on a field that has plots with different soil physical and chemical characteristics through crop diversification and/or plot specific management. Or, at district level, it may comprise optimization of production systems among villages (exploiting the comparative advantage of a village), so that options for development and niches for sustainable land use systems can be presented to farmers and regional decision makers. It is noted that the process of zooming in (i.e.,, from a higher to a lower scale) is much better known than the reverse, i.e., extrapolation. The latter, however, is needed to facilitate the framing of policies that are based on research results and information obtained at a lower scale.

To link various research disciplines, formulation of development scenarios of sustainable land use systems is considered an effective mechanism. These must be defined according to stakeholders (i.e., for farmers, village heads, regional and national decision makers) and for each scale (van Duivenbooden 1995). While exploiting the multi-scale variability of land use systems, formulation of such development scenarios permits identification of technologies and interventions at different scales and different moments, and of the priorities of agricultural research. This will lead to an improved impact of research.

The MUSCLUS project

The project "Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa", or MUSCLUS, is part of the research agenda of ICRISAT, and is partly financed by the Directorate General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs. It is a joint project between ICRISAT and several institutes in Wageningen: the C.T. de Wit Graduate School of Production Ecology of the Wageningen Agricultural University (WAU-PE), DLO Institute for Soil Fertility and Agroecological Research (AB-DLO), and the Working Group on Sustainable Land Use and Food Security in the Tropics (DLV). It is the follow up to the joint ICRISAT-Wageningen project working on soil and crop growth variability (Brouwer and Bouma in press).

As the title suggests, the project addresses natural resource management issues, in particular, the development of Integrated Natural Resource Management (INRM), i.e., management of soil, water, nutrients, crop, trees, natural vegetation, and livestock as related to the biophysical and socio-economic environments in this region.

As ICRISAT only has comparative advantage on the international strategic aspects of this study, cooperation with national agricultural research systems (NARS), non-governmental organizations (NGOs), other international agricultural research centers (IARCs), development projects and farmers groups is a prerequisite for its successful execution in particular locations (Figure 2). A special feature of this project is that it attempts to link its activities with the on-going ones of its partners to avoid fragmentation of national research and development capacities. Furthermore, a discussion with regional decision makers is envisaged so as to bring agricultural research more in line with policies. At the same time, MUSCLUS falls within the framework of the Integrated Systems Projects of ICRISAT on strategies for enhanced and sustainable production in millet/ sorghum/legumes based production systems (Table 1).

This document (also available in French; van Duivenbooden in press) includes the results of discussions with the various institutes in Wageningen, the First MUSCLUS Workshop with participants from ICRISAT, INRAN, IER, INERA, and University of Hohenheim (van Duivenbooden 1996), ICRISAT's Internal Workshop (March 1996), and other field visits and discussions with partners.

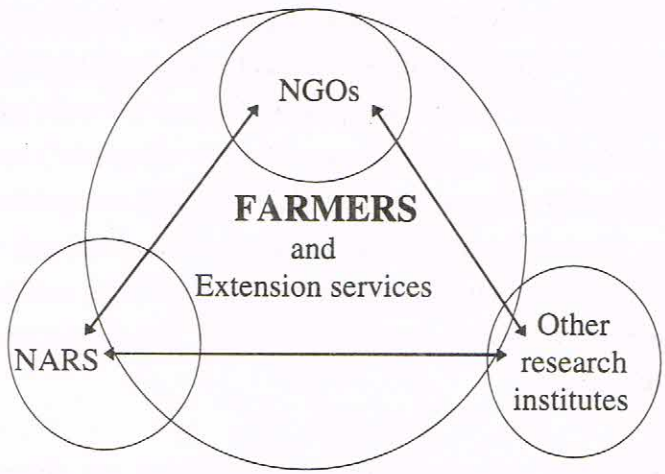

Figure 2. Proposed interactive collaboration between the various institutions that are involved in agricultural development.

Table 1. Main objectives and goals of ICRISAT's Integrated Systems Projects for West Africa (ICRISAT 1995).

Title	Objectives and goals
Strategies for enhanced and sustainable productivity in	to develop and evaluate strategies for enhanced and sustainable production; to improve productivity in land use systems and arrest degradation of the natural resource base;
S1. Rainfed short-season (60-100 days) millet/legume based production systems	to develop improved genotypes, better management of nutrient and drought stresses, sustainable resource management technologies, and integrated management methods for for pests, diseases and weeds
S2. Short- to intermediate season (100-125 days) rainfed millet/sorghum/legume based production systems	to characterize production systems; to focus on introduction and evaluation of improved genetic materials, improvement of soil, water and nutrient management, integrated management of pest, weeds, and diseases, and impact assessment
S3. Low to intermediate rainfall (90-150 days) rainfed cereal/legume based production systems	to improve soil, water and nutrient management and socioeconomic constraints, crop intensification in soils of high water-holding capacity; crop production on low water-holding capacity; and the integrated crop and soil management for post-rainy season crops.

In this project, the emphasis will be on millet- and sorghum-based production systems in Niger, Burkina Faso, and Mali. Research will be carried out in the rainfall zone of 400-700 mm yr^{-1}, or in terms of the length of growing period (LGP) of 60-125 days (the regions of S1 and S2; Figure 3). These zones are called the southern Sahelian and northern Sudanian zone, respectively.

Four scales are distinguished, guided by the decision-making process, to focus research activities. The highest level is the agroecological zone (comparable to the Production Systems as defined by ICRISAT; ICRISAT 1995). Within an agroecological zone, a district is selected as the next level of scale, as translation of scientific results into practical terms for units governed day to day by stake-holders is required. In this district, a village area ("terroir villageois") can be selected, and within the village area, a household cultivating a set of fields, each field comprising plots (Figure 4). In case of pure livestock holders, the two lowest levels are the herd and animal, respectively. In the different countries, the district size is set between 500 and 1000 km^2. This results in a different nomenclature of the district is the selected countries. In Niger and Mali, the district is called "Arrondissement" and in Burkina Faso, "Département".

As many research results and other relevant information are already available from ICRISAT, NARS, other IARCs, NGOs and development projects in the region, analysis of these data and extrapolation of the field level to higher scales by crop simulation and multi-criteria models and geo-graphical information systems (GIS) will be the starting point. In the past, results of simulation and other computer models had only a limited impact on farmers. Hence, the focal point of this project is the translation of analytical results in practical terms. This implies the formulation of alternative crop production systems with their technologies which will be evaluated by NARS and NGO's on farmer's fields.

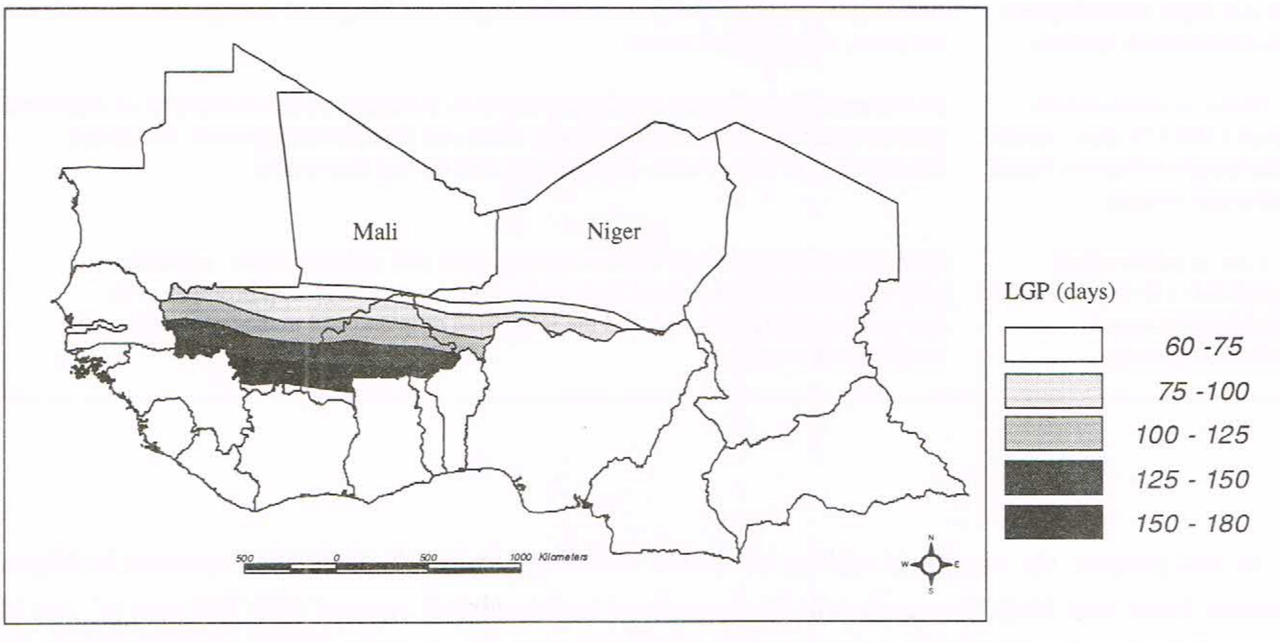

Figure 3. Map of West Africa showing Mali, Burkina Faso and Niger and their Length of Growing Period (LGP) zones (FAO 1984).

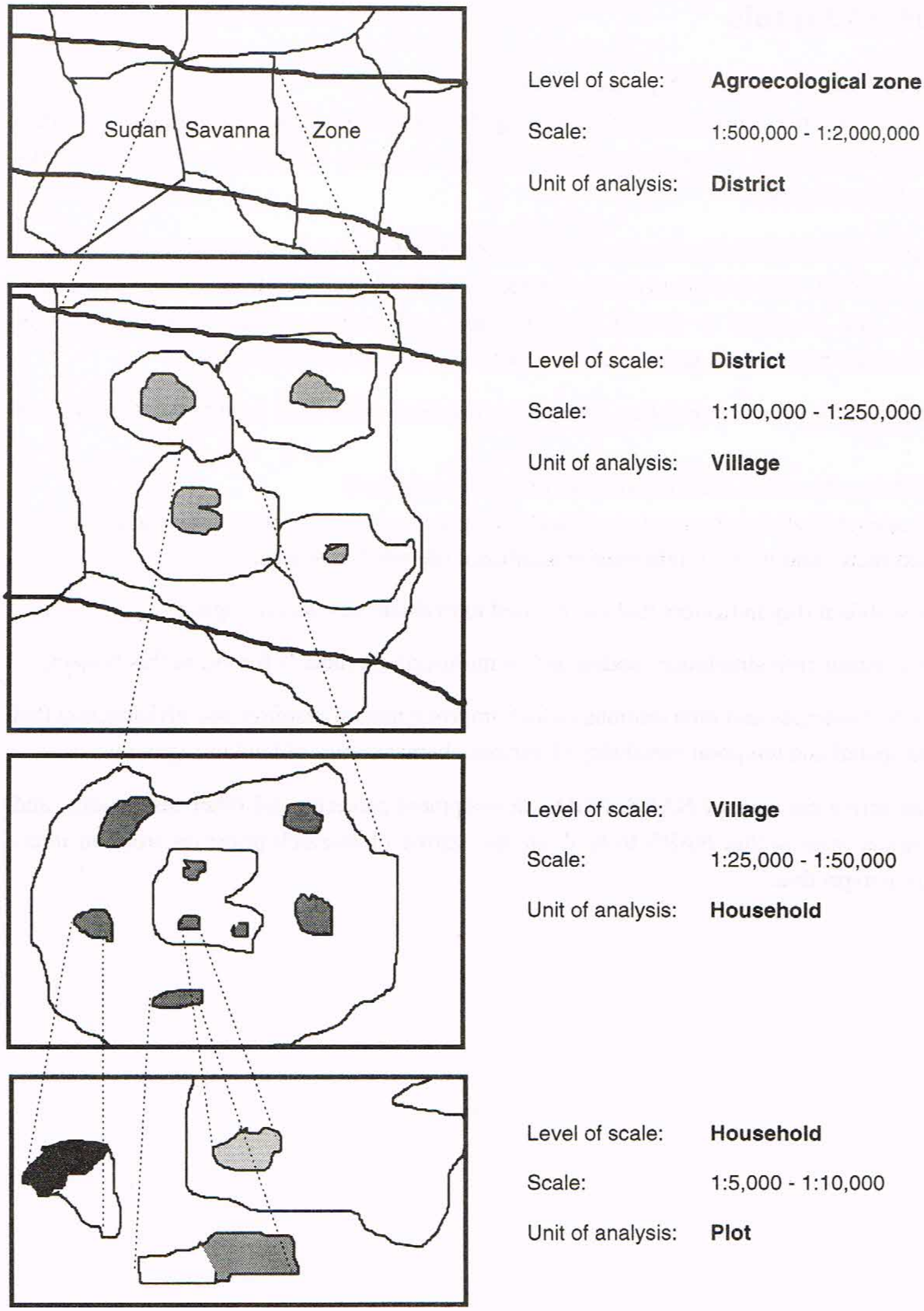

Figure 4. Schematic diagram of the four levels of scales and their unit of analysis distinguished.

Objectives and goals

The main objectives of the MUSCLUS project are to:

- improve natural resource management by exploiting the variability of land use systems (with their biophysical, socioeconomic and policy environments) and targeting technologies for specific environments at different scales
- formulate options for development and pragmatic recommendations for integrated natural resource management (INRM). This is defined as the management of soil, water, nutrients, crop, trees, natural vegetation and livestock as related to biophysical and socioeconomic environments. The options will reflect the common goals of both farmers and regional decision makers
- develop a methodology for extrapolating information obtained at the field level to the district level

On the basis of these objectives, the following set of goals are defined:

1. to identify at each scale key parameters of land use systems on which technologies and interventions should focus, and which might require additional (detailed) research;
2. to identify sustainability indicators that can be used to evaluate new technologies;
3. to validate existing crop simulation models and/or multi-criteria models for use in this project;
4. to evaluate technologies and interventions (which improve natural resource use efficiencies) that address the spatial and temporal variability of various characteristics of land use systems;
5. to create an active network of NARS, NGOs, development projects, and other institutions, and build a critical mass within NARS to facilitate the setting of research priorities from an interdisciplinary perspective.

General research approach

The approach to be used in this project is Land Use Systems Analysis (LUSA; van Duivenbooden 1995). LUSA aims to govern the successful management of resources to satisfy changing human needs, without degrading the environment or the natural resource base. It analyses in five steps the components and functioning of land use systems in an integrated and multi-disciplinary fashion, and presents land use options along with a quantified allocation of the required resources at different scales.

Land Use Systems Analysis

The main steps in LUSA are illustrated in Figure 5, and are discussed in more detail in the following subsections. Since existing data will be used whenever possible, it may be possible to cut short some of the steps enumerated below.

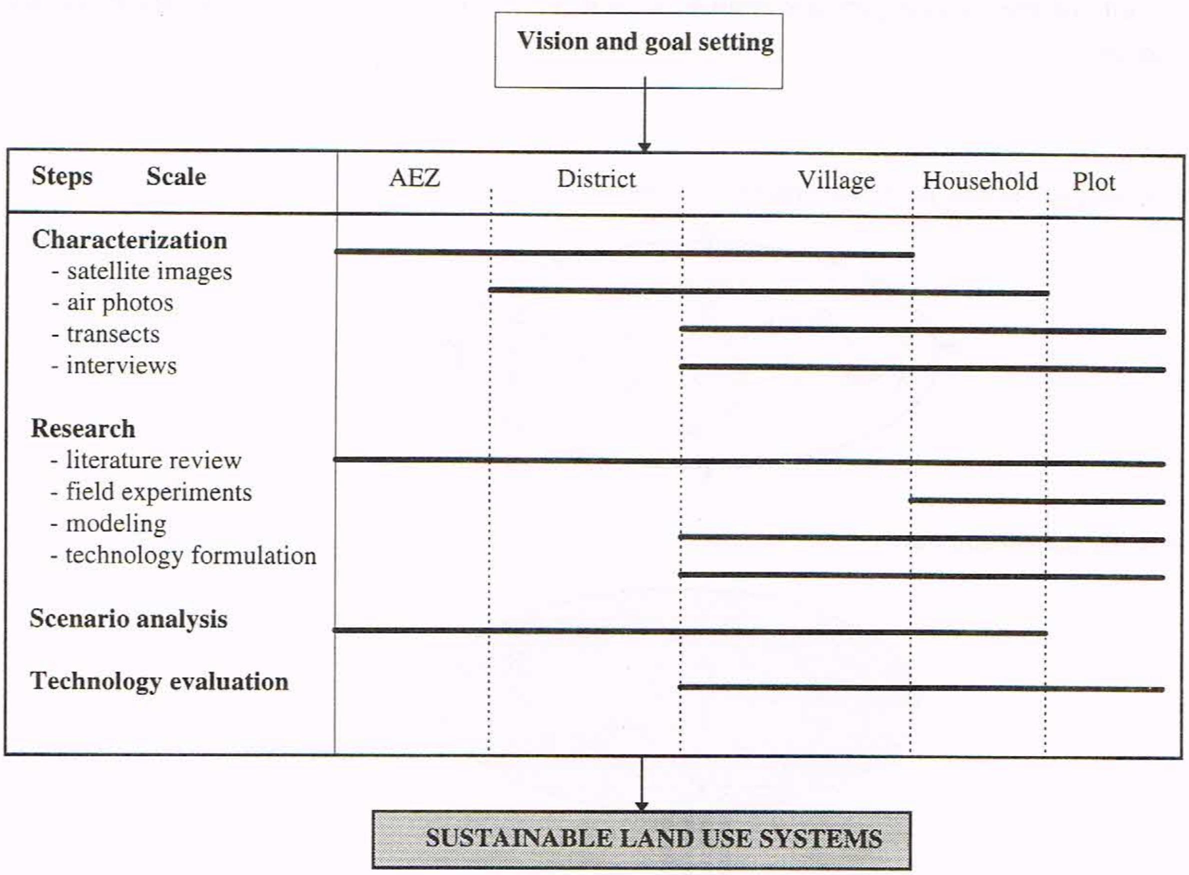

Figure 5. Simplified diagram of possible research activities in each step of Land Use Systems Analysis and their degree of detail. AEZ: agroecological zone (van Duivenbooden 1995).

Setting visions and common goals

The definition of visions and common goals is a prerequisite of LUSA, because a vision of the future environmental conditions and state of well-being of people and institutions enables us to set criteria and milestones. Moreover, if stakeholders at one level do not have a common goal, they may never achieve sustainable development because they are all pulling in different directions. If decision makers have conflicting goals, the efforts of each may be less effective or even lost. Against the background of non-uniform biophysical and socioeconomic endowments at the household level, setting common goals may seem a near-impossible task. Therefore, common goals may be defined as sets of multiple objectives that are in minimum conflict with one another. They will further focus research and development, and will assist in defining indicators that guide the process of change towards sustainable land use systems.

This step may appear to take some time at the beginning, but after formulation of goals the efficiency of the following steps will be much higher than without such a focus. Setting of goals is also done on the basis of the "alignment principle", i.e., the activities of a project are carried out in such a way that results of the various partners contribute to results of others ("win-win" situation) as illustrated in Figure 6.

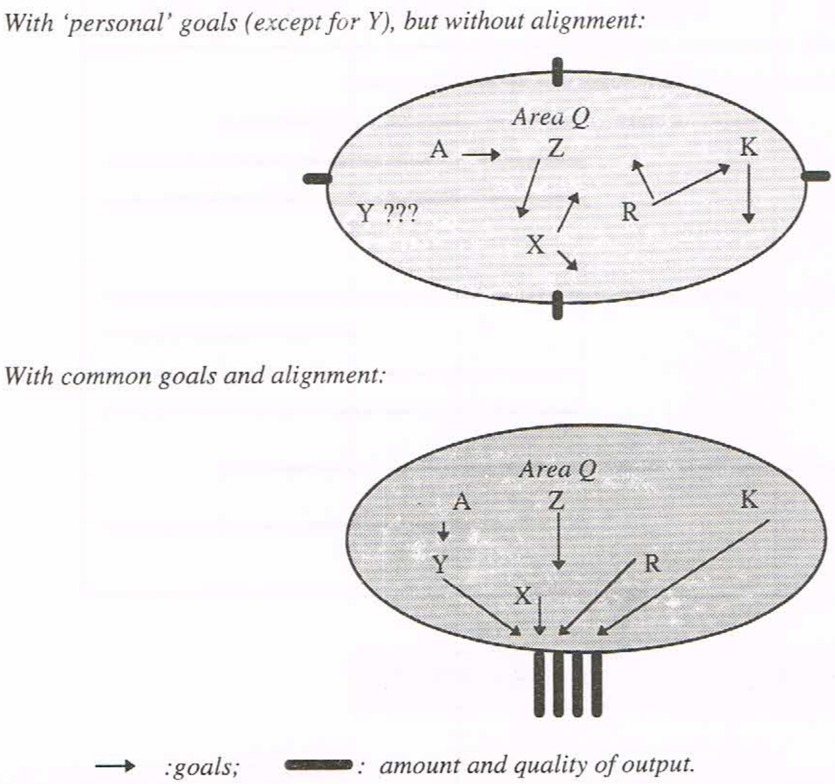

Figure 6. Schematic diagram showing the difference in output without and with alignment in goals.

Multi-scale characterization

Characterization is a comprehensive description of the agroecosystems at different scales on the basis of biophysical parameters (climate, lithology, land form, soils and hydrology, land cover; Andriesse et al. 1994) and socioeconomic identifiers (labor, capital input, and management). In this multi-scale characterization, four levels are distinguished: macro (scales between 1:1 000 000 and 1:5 000 000), reconnaissance (1:100 000-1:250 000), semi-detailed (scales 1:25 000-1:50 000), and detailed (1:5 000-10 000; Andriesse et al. 1994). In this study, the agroecological zone is at the macro level, and telescopes down to a district, village, and household level (Figure 4).

With the change in scale from macro to detailed, the unit of analysis (used for comparison within a scale) and the degree of detail of information to be gathered changes (Appendix 1). Zooming in (or scaling down, or disaggregating), implies a higher degree of detail and an increasing number of dynamic parameters. Parameters that are common to different scales become more dynamic as the scale becomes more detailed, but certain macro-level parameters remain more or less static (e.g., climate and lithology at detailed level). On the other hand, during scaling up (or aggregating), details distinguished for variables at a lower level (e.g., crop rotations) are disregarded at a higher level. Land use involves far more dynamic variables than soils or climate, such as cropping and farming systems. At the detailed level, characterization of land use systems includes the sequence of operations, their timing, the applied inputs, the implements and traction sources used, and the type of output (Stomph et al. 1994).

To a certain extent, information on relevant key parameters is already available, e.g., at IARCs, NARS, NGOs, and development projects, often in so-called "gray" literature. However, specific information needs to be collected or verified in new surveys.

Research activities

Applied and basic research will be carried out on representative sites selected on the basis of the characterization. Research will be restricted to the most important components and flows of land use systems. It will also be carried out on the various units of analysis (Figure 4) and executed in close collaboration with NARS, NGOs, IARCs, development projects, and farmers.

Analysis of development scenarios

The analysis of prospective development ("where do we want to be") scenarios (i.e.,, self-sufficiency at 80% in dry years) can be done with multi-criteria models. An example is a multiple goal linear programming(MGLP) model. To better display the spatial differences of the outcomes, the model will be linked to a GIS. While taking into account spatial and temporal (year to year) relations, results reveal the type of the required technical and political measures to bridge the gap between present and commonly defined future land uses and their effects for a region. In such studies, the 'best' option for land use systems is calculated under different scenarios (e.g., x ha of traditional millet; y ha of millet with high rates of manure, and q ha of fallow when no fertilizer can be used, or z ha of millet with inorganic fertilizer when it is assumed to be available; van Duivenbooden 1993).

Natural, human and financial resources are allocated to land use systems, and outputs of certain systems may be inputs for others, as illustrated by Figure 7. Options for land use are further determined by the relationships between production, consumption/trade, and saving/investing. Sustainability should be one of the goals to calculate the tradeoff between current, non-sustainable land use systems and alternative, sustainable systems.

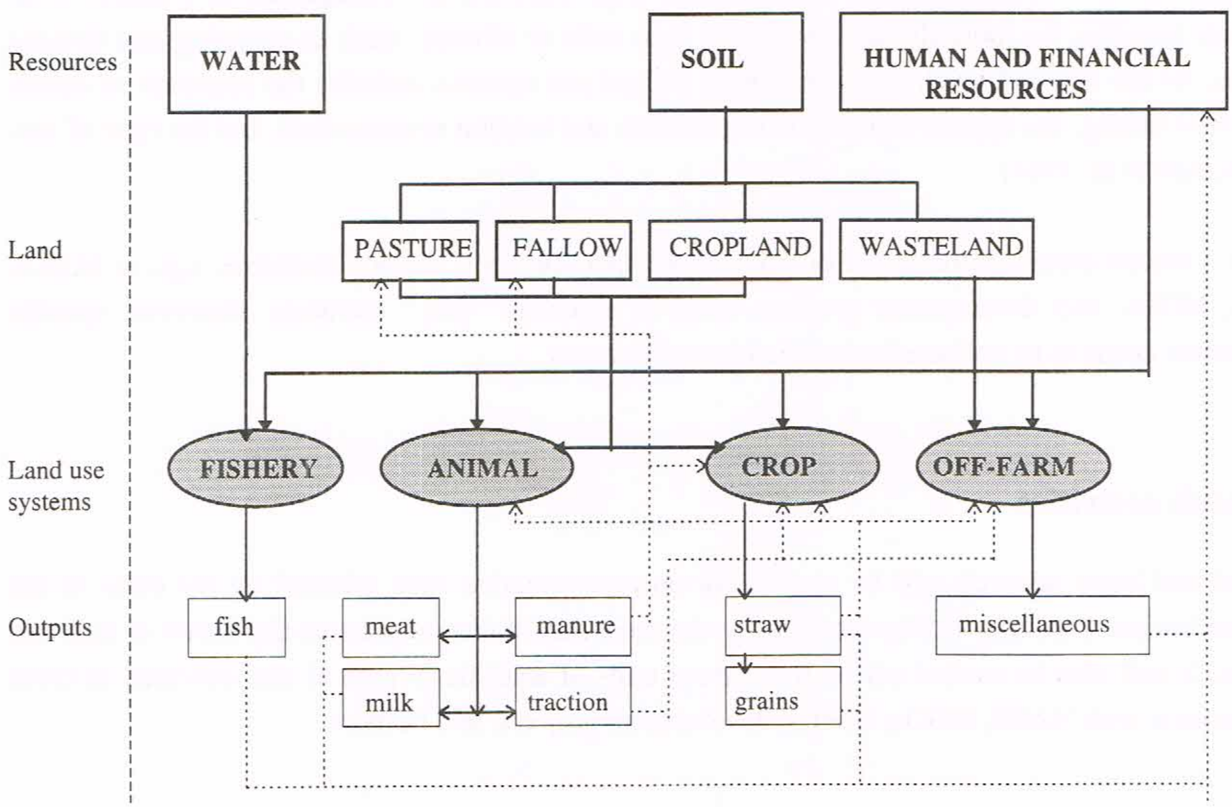

Figure 7. Schematic diagram showing distribution of natural, human and financial resources, and interactions between land use systems (i.e. outputs are also inputs) in a multiple goal linear programming (MGLP) model.

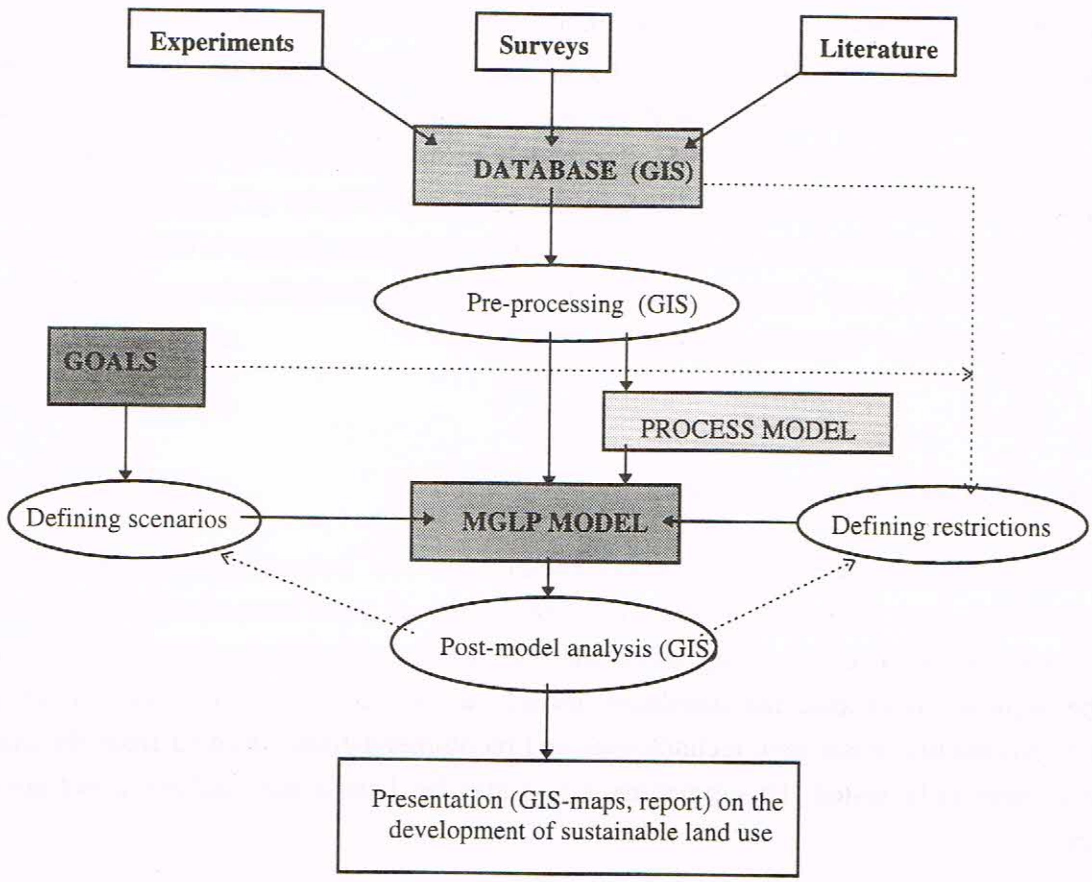

Figure 8. Schematic diagram of the integration of Geographical Information System, process and optimization models.

This MGLP approach has been used at different scales: for instance in Mali, at a regional scale (Veeneklaas et al. 1991; van Duivenbooden 1993), sub-regional level (Sisokko et al. 1995) and household level (Kruseman et al. 1995).

The data to "feed" this MGLP model can be derived from literature, and field experiments, or generated with various tools, such as crop simulation models or databases (GIS). Figure 8 shows the flow of data use and the integration of GIS, process and optimization models. This type of integration has only been researched for less than a decade, but is a prerequisite for environmental assessment studies in general (Bregt 1993) and natural resource management in particular. The figure also shows that development goals determine on the one hand the development scenarios, but on the other hand also the restrictions of the area ("right-hand side") in which the solutions need to be calculated. Restrictions are also defined in terms of land suitability, socioeconomic factors, and the output feasibility of the model (post-model analysis: "can this really be achieved?").

Simulation models, important among other things for extrapolation of results, land use planning, and insight into key processes, can not currently be developed by the partners in Africa. Therefore existing models will be used as much as possible, for instance those from the School of de Wit (Bouman et al. 1996; Verberne et al. 1995), the models being developed by Collaboration on Agricultural Resource Modeling and Applications in the Semi-arid Tropics (CARMASAT) which is a cooperation between ICRISAT and Agricultural Production Systems Research Unit (APSRU) on the APSIM model (McCown et al. 1996), or through the world-wide simulation consortium International Consortium of Agricultural Systems Applications (ICASA).

Validating alternative technologies

Based on the outcome of the MGLP modeling exercise, several technologies can be identified as apparently favorable and affordable to farmers. Since many of them have already been tested on-station and on-farm, the need for testing is considerably reduced. However, some field experimentation may be required to validate the simulation models and the interaction of different component technologies. Eventually, some new technologies and recommendations, derived from the computer analyses, may have to be tested. This experimentation may be done at the field level, but also at the village level.

General remarks

Research, scenario analysis and technology testing are closely linked, hence they can be carried out more or less concurrently. In this way the viewpoints of various stakeholders for development of sustainable agroecosystems are also taken into account, the complementarity of their view-points and research methodologies is also used. As mentioned earlier, the research in this project is carried out within the framework of the Integrated Systems Projects of ICRISAT (Table 1).

To increase exchange of research results, results should be made available to the various users. As the five steps will result in a large amount of data, storage of information per agroecological zone (or part thereof) in a GIS-linked database is indispensable. For soils, the SOTER database will be used (UNEP et al. 1994), for characteristics of land use systems, the Land Use Database (de Bie and van Leeuwen 1996). These databases are then used to establish relations between parameters at different scales and from different disciplines. The efficiency of data exchange is further increased when common research and laboratory methodologies are used.

Project implementation

Definition of key issues and common goals

The project started with the first workshop with participants from NARS from Niger, Burkina Faso and Mali (February 1996; van Duivenbooden 1996), during which key issues of natural resource management and common goals were defined (Table 2). Certain key issues were used as criteria for selection of the next representative scale. In addition, possible research methodologies were identified (Table 2). Work in the countries started only later in 1996 after the required administrative procedures.

Table 2. Key issues, selection criteria for zooming in to the next level of scale (c), common goals and possible methodologies defined during the workshop. AEZ: agroecological zone.

		Scale			
		AEZ	District	Village	Household
Key issues					
Availability of data (quantitative)		X	X	X	X
Variability of production system		X(c)	X	X	X
Climate	- Variability of rainfall	X(c)	X(c)		
Soil	- Variability of soil type	X(c)	X(c)	X(c)	
	- geomorphology		X		
	- soil characteristics				X
Crop production					
	- variability of vegetation	X			
	- cropping techniques			X	X
Animal production					
	- carrying capacity		X		
	- herd composition		X	X	X
	- animal requirements				X
Management					
	- rights of use	X			
	- type of management of village area			X	
	- size, type and localization of household fields			X (c)	
Inputs (availability, quality, price)				X	X
Level of knowledge					X
Owner rights					X
Human resources					
	- variability of population	X	X(c)		
	- ethnic		X		
	- social structure			X	
	- labor (availability - requirements)			X(c)	X
Miscellaneous					
	- infrastructure	X			
	- market		X(c)		
	- buying capacity			X	

Table 2. Continued.

	Scale AEZ	District	Village	Household
Common goals				
Developing data bases	X	X	X	X
Understanding of variability	X	X	X	X
Land use planning	X	X	X	X
Evaluating potentials	X	X		
Developing strategies	X	X		
Determining constraints for adoption of technologies		X	X	
Securing food requirements		X	X	
Proposing alternative NRM[1] options		X	X	X
Contributing to welfare			X	
Contributing to improvement of farmers' knowledge			X	X
Evaluating cropping techniques			X	X
Proposing alternative technologies				X
Possible methodologies				
Characterization	X	X	X	X
Literature review	X	X	X	X
GIS	X	X	X	X
Agroecological zoning models	X			
Satellite image interpretation	X	X		
Inventory		X		
MGLP model		X	X	
Air photos		X	X	X
Simulation models		X	X	X
Interviews		X	X	X
Experiments			X	X

[1]) alternative NRM: natural resource management technologies contributing to more sustainable production systems with increased production.

Activities

The common goals of Table 2 and the objectives of the project are reached through a number of activities, which are clustered on the basis of the level of scale they refer to (Subsections 4.2.1 - 4.2.4). In addition, possible activities for training are defined (Subsection 4.2.5).

Macro-level: Sudano-Sahelian zone of West Africa

Problem definition. Many results on improved crop production systems have been obtained on-station and on-farm, but stability, sustainability and economic feasibility of these crop production system under farmers' conditions are partly subject of further research. On the other hand, technologies are available, but the translation of results to larger areas (extrapolation) has been very limited. Climate, soil conditions, farm resources, technology adoption criteria, inputs and product market systems, and institutional arrangements and policies have imputed large scale adoption of improved technologies.

Therefore, more strategic and applied research to fine-tune and diffuse technologies is necessary, and appropriate strategies and techniques to specific agroecological and socioeconomic conditions should be identified at this level of scale.

Working goals and activities. The working goal at this scale is:

- To characterize in general terms the agroecological zones with emphasis on constraints identification for intensification of sustainable crop production system and transfer of improved technologies.

Two activities are defined:

A1.1 Multi-scale characterization of the selected agroecological zones

A1.2 Identification of constraints of intensification of production systems

Methodology. The agroecological zones will be characterized in general terms (e.g., crop species, soil types; see also Appendix 1) to address questions as "what type of constraints in the different regions?", and "which production systems can be emphasized in the different district?". In this way, variability among production systems can be exploited. In addition to already existing databases at ICRISAT (linked to a GIS) on rainfall, soil types, main production systems, other characteristics will be included, such as population density (Snrech 1994). An inventory of existing digitized databases is one of the first steps to be taken in each country.

Alternative production systems will eventually be matched with these biophysical and socio-economic environments, while taking into account different policies and price settings when possible. Although not part of this project phase, it may be decided in the future to use also at this scale a MGLP model to allocate land use for the entire agroecological zone. Such a study should be compared to that of land use allocation in the European Community (WRR 1992; de Koning et al. 1995).

Characterization will be based on existing data available at the various institutes and projects. If lack of information is observed, some additional surveys will be carried out by NARS. The unit of analysis is the district (a political defined area; about 30 in each of the 3 countries).

Expected results and milestones. The results of these activities will be:

- maps of West African Semi-arid Tropics showing where what type of millet production systems can be applied (first version: early 1997)

- maps showing where what aspect of the biophysical, socioeconomic or political environment should be changed to allow specific millet production systems (first half of 1997);
- synthesis report (late 1997);
- recommendations for research at lower levels of scales (1998).

Reconnaissance level: districts

Problem definition. As the entire region is too large to investigate in more detail the applicability of production systems and to define development scenarios, for a few key-districts the production systems and their links to soil units and to other characteristics (depending on availability; e.g., market and labor availability) will be worked out in more detail.

Working goals and activities. The working goal at this scale is:

- To formulate development scenarios for the district level and definition of alternative farmers' practices.

Six activities are defined:

A2.1 Characterization of biophysical and socioeconomic environment and of production systems

A2.2 Realization of land use maps with boundaries of village grounds

A2.3 Construction and use of a MGLP model, and proposition of alternative (towards sustainable production systems with increased production) development scenarios

A2.4 Evaluation of development scenarios (i.e., post-model evaluation) with emphasis on putting into practice the alternative cropping techniques

A2.5 Identification of constraints of intensification of production systems and analysis of the possible demands of farmers

A2.6 Identification of (quantified) development goals

Methodology. The MGLP model to be applied should be of a 'crude and practical' type. The model should preferably be multi-period (10-20 years). If both existing non-sustainable and alternative sustainable production systems are included, formulation of development scenarios for the transition from non-sustainable to sustainable production systems would be feasible. An additional requirement is a model interface that should permit also non-experts to learn about the consequences of human decision-making on ecological systems and to understand the trade-off underlying those decisions. Use of a GIS will facilitate clear presentation in, for instance, showing where which production systems can be expected, to researchers and stakeholders in the region (e.g., Stoorvogel 1995). At this level of scale, the unit of analysis is the village.

With respect to the 'crude type', in the past very much time was spent on definition of parameters. Furthermore, different models exist that are based on sustainable production systems (e.g., Veeneklaas et al. 1991), but their practical value remains under-exploited. Therefore, here a different approach is envisaged. The MGLP model (not-multi-period) being developed by DLV, or the model developed for training purposes (not multi-period; de Ridder and van Ittersum 1994) in Wageningen could be a good starting point. An alternative is the multi-period model QUEST (SDRI 1995), but detailed information and the model itself are not yet available at ICRISAT. Finally, it is repeated that the model should take into account current production systems, as to investigate how we have to proceed towards sustainable systems. Hence, the selection of the model need some more time.

The required data for research at this scale are presented in Appendix 1. In addition to existing data, agroecological zoning models will be used.

Expected results and milestones. The results of these activities will be:

- development scenarios for the key-districts, presented among others through maps (GIS made) (first version: early 1998);
- a MGLP model (or equivalent) and simulation models that can be used by IARC, NARS, NGOs and decision makers as a tool to target integrated development research and interventions (early 1998);
- recommendations for alternative farmers practices, i.e., actions for development agencies and areas of research for various institutes (mid 1998).

Semi-detailed level: villages

Problem definition. Over 90% of the population in the West African Semi-arid Tropics lives in villages and the conscious and organized local efforts to durably maintain or increase the regenerative capacity of local natural resources at this level are often referred to as local resource management (LRM; den Breemer and Venema 1995). However, transfer of new or improved technologies to villages have often failed, due to a number of reasons (see Introduction). Other reasons are that fields are supposed to be homogeneous, and recommended fertilizer rates are generally based on general soil types and not on the land use system. Brouwer and Powell (1995) have demonstrated that soils within fields are very heterogeneous for soil fertility, hydrology, and soil physical characteristics. Prudencio (1993) has documented the decrease in soil fertility when going outwards from a village. These phenomena are well recognized by farmers who have their own classification for fields in their village (Taylor-Powell et al. 1991; van Gent and Mohamed 1993; Kante and Defoer 1995; Lamers and Feil 1995), although the correlation between these field types and millet production is not always observed (Krogh 1995). Nevertheless, it is clear that the potentials for crop production in a village is a function of these type of soils, and use should be made of indigenous knowledge and the existing variability to optimize the outputs (e.g., by using comparative advantages of households combined to soil types). Furthermore, since the adoption of improved technologies is not successful, alternative angles into research need to be taken. Therefore, and for practical reasons, alternative technologies should be geared towards these farmer-classified' soils, referred to as 'ethno-soil units'.

At this moment, research results obtained at the field level by various research institutes can be investigated for their validity. After such model exercises, some recommendations can be made towards those researchers, and alternative crop production system can be tested on farmer's fields. Thereafter, a plan for development can be formulated with extension services, village heads and farmers.

The unit of analysis at this scale is the household (i.e., set of farmers fields). In this way links with general socioeconomic studies can be established, and results from other studies can be used (if required extrapolated to the level of a district).

Working goals and activities. The working goal at this scale is:

- To formulate development scenarios for a village in different agroecological zones, and recommendations for farmers practices related to ethno-soil units, and for researchers for their targets.

Seven activities are defined:

A3.1 Characterization of biophysical environment and construction of maps of *(i)* soil types, *(ii)* land use (cultivated, fallow, infrastructure, etc.) and *(iii)* vegetation

A3.2 Characterization of production systems

A3.3 Identification of constraints of intensification of production systems and analysis of the possible demands of farmers

A3.4 Construction and use of a MGLP model, and proposition of alternative (towards sustainable production systems with increased production) development scenarios

A3.5 Identification of (quantified) development goals through interviews

A3.6 Testing and evaluation of alternative cropping techniques

A3.7 Organization of open days at the institute for farmers

Methodology. The first step is the characterization of the village and its households (Appendix 1). On the basis of existing data, actual production systems will be described in terms of inputs-outputs (cf. van Duivenbooden and Gosseye 1990; van Duivenbooden *et al.* 1991).

As field experiments to study all variables, such as different soil conditions (especially P availability) within the fields, effects of different planting densities and planting times, outbreak of pests and diseases are, however, impossible, application of validated crop simulation models is then the only alternative. Existing data from on-farm field experiments and these simulation modeling exercises will then be used to define alternative production systems. In addition, data could be obtained through new surveys (cf. van Duivenbooden et al. 1996), or through data exchange with the "Consortium for Sustainable Use of Inland Valleys in sub-Saharan Africa" (Bouaké, Côte d'Ivoire; WARDA 1993), and the VARINUTS project (SC-DLO *et al.* 1995). Field work will consist of characterization of farmers fields, and to quantify the existing ethno-soil classification. Cooperation with IER (Sikasso) seems very relevant, given their experience. GIS will also be used for the analysis of results.

For the formulation of development options, a simple MGLP-model (or equivalent) will be used. In the MGLP model, the restriction of the set of farmers fields can be removed to investigate the potentials of the village as such, i.e., without the individual households while optimizing the potential of the 'village'hold on the basis of existing soil types. Use can be made from MGLP modeling experiences in the region, e.g., in Mali (Sisokko 1996; Breman and Sissoko, in press), Burkina Faso (Deybe *et al.* 1993) and Niger (Williams, pers. comm.).

Expected outputs and milestones. The results of these activities will be:

- development scenarios for key-villages, presented among others through maps (GIS made) (late 1998);
- a MGLP model (or equivalent) and simulation models that can be used by IARC, NARS, NGOs and decision makers as a tool to target integrated development research and interventions (mid 1998).
- recommendations for testing certain types of alternative technologies, or for development of farmers technologies (mid 1998);
- tested alternative technologies (land use systems) (end 1999);

Detailed level: households

Problem definition. At this level of scale, variability also plays a major role in the potential of agricultural production. For instance, soil surface (physical) characteristics as well as soil chemical characteristics vary considerable within a plot and within a year (Brouwer and Powell 1995). Consequently, variability exists in space and time in farmer's fields: e.g., for millet total above-ground biomass ranged from 27 to 13954 kg ha^{-1} and for cowpea from 0 to 666 kg ha^{-1}, as measured in 5 * 5 m subplots. Variability was correlated with differences in soil fertility, hydrology, and soil physical characteristics (Brouwer and Powell 1995). The presence of trees (e.g., *Faidherbia albida*) and parasites (e.g., *Striga hermonthica*) in the plots have also impact on the variability. Animals are another component of the agroecosystem that influence the spatial and temporal variability within farmers' fields and the surrounding rangeland through the removal of biomass and excretion of manure and urine (Powell et al. 1995). It is, however, still unknown how the farmer makes use of, or avoids this variability and what the determining factors are.

So far, agronomic research implicitly assumed that soils are generally homogeneous and that a given agronomic treatment or a physical or chemical technology, allows clear conclusions to be drawn with respect to the processes that are operating, and which are assumed to apply to larger units of area. This approach has been the norm in Western agriculture, and, in retrospect, erroneously applied to agriculture in developing countries. Clearly, conditions in farmers fields do not correspond to theoretical assumptions of homogeneity. Site-specific management has so far not been considered in research in sub-Saharan Africa, as attention was mainly focused on the characterization and interpretation of the spatial and temporal variability of soil and plant parameters. Hence, techniques are needed to adequately describe the variability of the biophysical environment and to make use of them to improve natural resource management. It is evident that new site-specific management technologies should be applicable (technically and socioeconomically) by farmers. In this project site-specific management refers to plot-specific management because of practical reasons.

Operations for site-specific management, such as plot's soil type - crop specific fertilizer application and treatment of pest and diseases, are generally underestimated in land evaluation exercises. It is noted, however, that experiments can not be carried out for each plot type, so that (crop simulation) modeling becomes necessary. Especially models that take into account rotation schemes, water, and nitrogen and phosphorus balances are envisaged. Some of those have, however, to be developed. In the past, alternative sustainable land use systems are defined by means of theoretical and simulation modeling approaches (e.g., van Duivenbooden and Gosseye 1990), but these land use systems need to be tested on-farm.

Working goals and activities. The working goals at this scale are:

- To formulate site specific technologies that allow for increased resource use efficiencies;
- To test alternative land use systems.

Six activities have been identified:

A4.1 Characterization of plots (location, subdivision, chemical and physical characteristics, size, number, etc.)
A4.2 Characterization of production systems
A4.3 Testing and evaluation of alternative cropping techniques
A4.4 Identification of constraints of intensification of production systems
A4.5 Validation of already existing models with water, N and P balances

A4.6 Identification of (quantified) development goals through interviews
A4.7 Development of simulation models (Wageningen and/or CARMASAT)

Methodology. After characterization of the fields in the key-village (Subsection 4.2.3), representative plots can be selected for site specific management research. In the past, Brouwer and Powell (1995) have used for his spatial variability analysis blocks of 5*5 m. Since his results do not clearly show the needs for such a small scale, and for farmers this may be too detailed at this stage of agricultural development, where farmers think in more in fields or in parts thereof , it is tried here to develop a site-specific management on a somewhat larger scale in the order of 0.4 to 0.5 ha. For research purposes an area of (50*50 m =) 0.25 ha will be used as starting point. Data, as defined in Appendix 1, will be collected from various (past and current) projects at ISC. Additional on-farm experiments will contribute to filling gaps of required data (to be specified in a later stage).

Research is conducted in selected plots of farmers in the selected key-villages. In Niger, Mr M. Gandah (soil scientist of INRAN), is working at this level of scale, as part of his PhD thesis (Gandah 1995). ICRISAT and WAU-PE are also collaborating on the development of a simulation model that describes the growth of Striga as a function of soil fertility (van Ast 1996). Pot experiments in Wageningen (the Netherlands) and field experiments in Samanko (near Bamako, Mali) are being planned.

Expected results and milestones. The results of these activities will be:
- Tested site-specific management options (end 2000);
- Fertilizer recommendations on a plot basis for selected alternative land use systems (end 2000);
- Simulation model on Striga (end 2000).

Training course in use of development scenarios

Problem definition. In the past in West Africa, a disciplinary approach dominated research approaches. At present, most researchers from various disciplines realize that this is not the approach required for solving the problems. A so-called 'multi-dimensional' approach (i.e., various disciplines, various institutes, taking into account dynamics) seems more appropriate. This requires a change in thinking and working. A course in this field may facilitate this process. This course will be used to train researchers from NARS and other institutes in multi-scale approaches and the required integration of disciplines.

Goals. The goals of this project are:
- to increase multi-dimensional thinking and working;

- to increase the awareness of the power of target-oriented working.

Course materials to be developed. At present, a multi-criteria course is being developed at WAU-TPT/TPE (de Ridder and van Ittersum 1994; de Ridder et al. 1994; van Ittersum et al. 1995). This course seems an appropriate starting point for a course (workshop) to be given in West Africa. The textbook that has to be made should give ample illustrations for semi-arid regions including past experiences with these or related models. Recently, FAO has asked AB-DLO to give a similar course in West Africa. It is clear, that such a training course should be a joint effort of various institutes, because of its regional character.

Expected results. The results of this activity will be:

- Increased ability to work in interdisciplinary teams;
- Increased ability to prioritize work.

Prioritization of work and site selection

As the work described in the preceding sections can not be executed to its full potential (in all agro-ecological zones, villages, etc.) due to limited manpower, a selection has to be made. During the workshop it was decided that two districts would be selected, i.e., one in the rainfall zone of 400 to 500 mm (dominated by millet/cowpea/livestock production systems, addressed also in S1 and DMP), and the other from 600 to 700 mm (sorghum/groundnut based production systems; addressed also in S2). On the basis of representativitiy of the district, the availability of data, and the presence of a number of active organizations that can contribute to this project, six district and villages were selected (Figure 9).

Collaboration with NARS, NGOs, IARCs and development projects

Potential regional partners

During the first MUSCLUS workshop (February 1996) not all potential partners could be invited. Table 3 list the institutes which are identified as potential partners. As a consequence, the collaboration with the various partners can only be described to a certain extent.

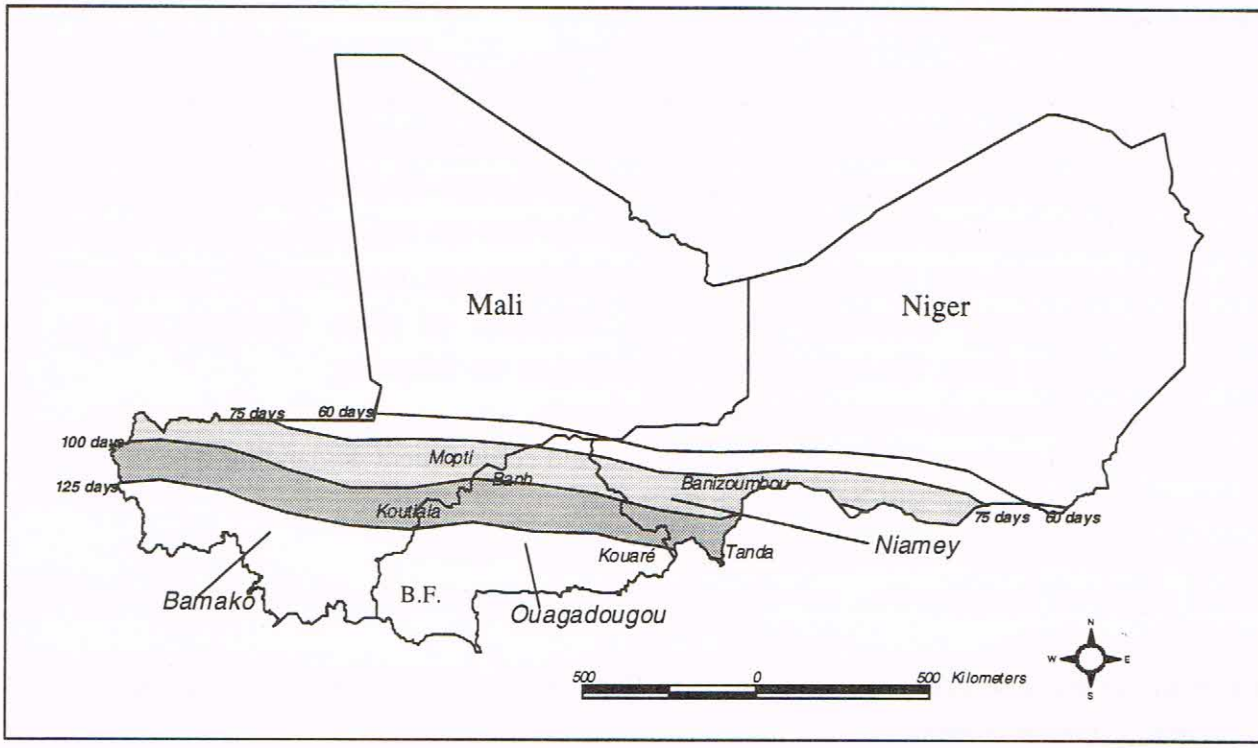

Figure 9. Map of Mali, Burkina Faso and Niger showing their capitals and the six villages selected in the various LGP- zones.

Table 3. List of potential partners which whom the MUSCLUS project may establish links (the next level gives only additional institutes), and between brackets their possible methodologies (numbers correspond to those in Table 2).

Scale	Country	Organization
Agro-ecological zone	Niger:	ICRISAT, ILRI, ICRAF (1,2,3), INRAN (1,2), AGRHYMET, ACMAD (3,4,5), IGN, GTZ, DA, FEWS
	Burkina Faso:	INERA (1,3,4), ORSTOM (5), CIRAD (4,5), BUNASOLS (1), CRPA (4), PSB, SAFGRAD (1), PATCOV, IGB, CCI/DSAP, CRTO, PNGT, DRP
	Mali:	IER (1,3,4), DMN (4), DNCT (5), CIRAD, ORSTOM, USGS
District	Niger:	Univ. of Hohenheim, PASP, Projet Ronneraie, Programme Hydraulique Villageoise, BRGM, PGRN
	Burkina Faso:	PVNY, PDRIs, TINTUA, WAU-Antenne Sahélienne
	Mali:	CMDT, ESP/GRN, LaboSEP, CRRA, PGT
Village	all	CVD, Cooperations, NGOs, extension officers
Household	all	farmers

Institutes in Wageningen

Collaboration with institutes in Wageningen (Agricultural University and DLO-agricultural research institutes) will take place through the C.T. de Wit Graduate School of Production Ecology of the Wageningen Agricultural University (WAU-PE), the DLO-Institute for soil fertility and agroecological research (AB-DLO), the working group on "Sustainable land use and food security in the tropics" (DLV), and the research and training program for sustainable land use in tropical countries of the Wageningen Agricultural University (WAU-VF). Members of these institutes act as the 'Wageningen' support group. The role of Wageningen may be the following:

- Ad hoc backstopping (e.g., commenting on draft papers);
- Guidance of PhD students, being the most efficient and commitment demanding type of cooperation: as is already the case with Mr. Gandah (INRAN);
- Supply of crop simulation models and MGLP models upon request;
- Active supply of literature (i.e., new relevant articles, reports and books will be sent at earliest convenience to ISC);
- Active information on new research projects in West Africa (i.e., proposals, proceedings, etc.) to avoid duplication of efforts;
- Upon request of ICRISAT, students can be asked to carry out some field work in West Africa as part of their study for a period of 4 to 6 months.

In addition, the Wageningen Agricultural University has for its VF-program an office in Ouagadougou (Antenne Sahélienne), and students are also working in the district Fada N'Gourma (Burkina Faso; Niemijer and Mazzucato 1995). As the Antenna Sahélienne seeks further collaboration with ICRISAT and with INERA, this project seems an appropriate form.

Additional linkages with institutes and projects

With some institutes linkages have already been established to collaborate within the framework of this project. In the future other institutions may join, if alignment can be established.

INRAN. In addition to the MUSCLUS activities they committed themselves to, collaboration with INRAN has already started through the work of Mr. Gandah, who is working on his PhD thesis with on-station experiments in Oallam, Sadoré, and Tara (started in 1995), and planned on-farm experiments in two sites (started in 1996).

IER. Considering the links of MUSCLUS to existing research by IER, the following points should be noted: *(i)* DLV is working together with ESPGRN on MGLP model for Koutiala at household level, and *(ii)* a MGLP model at village (and to a certain extent also at the district) level is developed by K. Sissoko, working on his PhD (promoters Prof. A. Kuyvenhoven and Prof. H. van Keulen both of WAU).

ILRI. At ISC, the International Livestock Research Institute (ILRI) has also its offices. ILRI has also projects in the area around Niamey, especially in the villages around Banizoumbou. A detailed digitized land use map (for 1994 et '95 at 1:15.000) exists of Banizoumbou. Reports on livestock, crops and socioeconomic issues are available. The collaboration with ILRI has primarily started through the work of Mr. Gandah (INRAN), but is expected to extent in the near future.

University of Hohenheim. At ISC, the University of Hohenheim (UH) is also active with various PhD student projects. Of relevance to the MUSCLUS project is the work of Frieder Graef. He is working on land use planning on a district- and a village level in Niger. The selected district is Tillabery, and the villages are Kirtachi (100 km south of Niamey) and Banizoumbou. For Kirtachi, UH is carrying out several agronomic and socioeconomic studies. Emphasis of this project is on characterization of the biophysical environment, using satellite image interpretation (Landsat TM 1986 and 1988) and transects surveys. As data are stored in the soil and terrain database SOTER (UNEP *et al.* 1994), a soil inventory of the study area is being build. Special attention is drawn to the collection of existing soil data in local national and international institutions. For this purpose a local soil scientist is employed. Outputs will be SOTER unit maps, suitability maps, productivity and risk estimations for different crops under certain innovation scenarios (1998).

The Desert Margins Programme (DMP). Improving natural resource management as a means to combat desertification is seen as an important, if not essential, step forward in this initiative. It gives a much clearer focus to defining the problem at a local scale and highlights the need for more effective integration of local, national, and regional institutions responsible for natural-resource management. This imperative for more effective utilization of resources to address common problems has brought together the following nine countries of sub-Saharan Africa: Niger, Burkina Faso, Mali, Senegal, Botswana, Namibia, Zimbabwe, South Africa, and Kenya into forming a consortium called DMP. This "bottom up" approach is the basic premise for the development of the DMP as an integrated national, sub-regional, and international action research program for developing sustainable natural-resource management options to combat desertification in sub-Saharan Africa.

The key overriding goal of the DMP is to increase the food security of poor, rural populations and contribute to poverty alleviation by halting or reversing desertification. Its mission is to unravel the complex causative factors climatic and human-induced and formulate appropriate holistic solutions and develop integrated approaches to halt the process and reverse degraded lands.

Collaboration will be in multi-scale characterization and development of methodology for working at different scales and an integrated decision support system.

Social and Environmental Relations in Dryland Agriculture (SERIDA). The aim of the project is to build a comprehensive environmental history, alongside data on land degradation and livelihood strategies. A longer term aim is to provide a multi-disciplinary base-line where change, adaptive strategies, and environmental processes can be monitored. Research activities will be carried out by a working group of a) Brunel University (BU), Department of Geography and Earth Science, b) Institute of Hydrology (IH), and c) University College London (UCL), Department of Geography near the village of Banizoumbou in Niger. Research assistants and students will collect socioeconomic and biophysical data, respectively, that can be used in the model to be developed.

Climate Impact on Water Resources and Dryland Agriculture (CLIWARDA). Climatic variability affects water resources and agriculture through agricultural, social and economic processes which develop to mitigate the impact of physical factors, so climate cannot be related solely to physical factors, e.g., varying precipitation. The goal of the network CLIWARDA is to integrate the evaluation of physical, agricultural and socioeconomic factors in assessing the impact of past and of forecast climatic variability. This can be done by establishing a cooperation mechanism among reading research organizations, active in representative drylands of four continents and with a long-standing tradition and a known record of successful performance. The network members (coordinated by SC-DLO, Wageningen) have contributed to develop innovative solutions to manage natural resources in the regions where they operate and to introduce new concepts and technologies in these regions. In Niger, research activities will be carried out predominantly by ACMAD.

Tentative agenda of project activities

In addition to continuous research activities, the following regional meetings and courses may be organized (Table 4). Table 5 summarizes the foreseen activities in the coming 5 years.

Table 4. Tentative activities during the MUSCLUS project.

February 1996:	First MUSCLUS workshop
April:	National meetings at NARS
August/September:	Visit to districts by N. van Duivenbooden
March 1997:	Regional meeting "Multi-scale natural resource management research in the Sudano-Sahelian Zone of West Africa, a re-orientation"
'97 - '98:	Workshop on the use of MGLP models (in cooperation with AB-DLO/ FAO ??)
February '98:	Regional meeting "Multi-scale natural resource management research in the Sudano-Sahelian Zone of West Africa: how to bring the message to farmers?"
February '99:	Regional meeting "Multi-scale natural resource management research in the Sudano-Sahelian Zone of West Africa: evaluation of MGLP-results"
February '00:	International Conference "Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian Zone of West Africa

Table 5. Tentative calendar of activities.

Activities	1996	1997	1998	1999	2000
Agro-ecological zone level					
A1.1 Characterization	—	—			
A1.2 Non-adoption analysis	—	—			
District level					
A2.1 Characterization	—	—			
A2.2 Elaboration of maps		—	—		
A Course in MGLP modeling		—			
A2.3 Develop MGLP model		—	—		
A2.3 Use MGLP model			—	—	—
A2.4 Evaluation of develop. scenarios				—	—
A2.5 Non-adoption analysis	—	—			
A2.6 Identification of development goals		—	—		
Village level					
A3.1 Characterization	—	—			
A3.1 Elaboration of maps		—	—		
A3.2 Description of production systems		—	—		
A3.3 Non-adoption analysis	—	—			
A Course in MGLP modeling		—			
A3.4 Develop MGLP model			—		
A3.4 Use MGLP model			—	—	—
A3.4 Evaluation of devel. scenarios				—	—
A3.5 Identification of devel. goals		—	—		
A3.6 Test of technologies				—	—
Household level					
A4.1 Characterization		—	—		
A4.2 Description of production systems		—	—		
A4.3 Tests of technologies				—	—
A4.4 Non-adoption analysis		—	—		
A4.5 Validate simulation models		—	—		
A4.6 Identification of devel. goals		—	—		

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Appendix 1. Data required for characterization of land use systems at different scales

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Macro level: Agro-ecological zone (unit of analysis: district)

Average annual rainfall [mm yr^{-1}]
Length of growing period (LGP; min-max) [d]
Soil types (FAO classification)
Production systems [type and kg $district^{-1}$; km^2 $district^{-1}$]
Major constraints (e.g., Striga, area of degraded soils)
Population density [person $district^{-1}$]
Food requirements [kg millet, rice, meat, vegetables $district^{-1}$]
Availability of rock phosphate [t $district^{-1}$]
Size of districts [km^2]

Reconnaissance level: district (unit of analysis: village)

Average annual rainfall [mm yr^{-1}]
Length of growing period (LGP; average) [d]
Soil types (FAO classification)
Production systems [type and kg $village^{-1}$; km^2 $village^{-1}$]
Population density (actual and future; e.g., Club du Sahel) [person $village^{-1}$]
Food requirements [kg millet, rice, meat, vegetables $village^{-1}$]
Social organization [person ethnic $group^{-1}$]
Number of animals [type and TLU $village^{-1}$]
Land use intensity [ha cultivated ha $available^{-1}$]
Size of villages [km^2]
Presence of markets
Presence of roads
Presence of cooperations
Development goals

Semi-detailed level: village (unit of analysis: household; set of farmers fields)

Daily weather data:
- rainfall [mm]
- min and max temperature [°C]
- radiation [J m^{-2}]
- wind speed [m s^{-1}]
- length of growing period [d]

Soil:
- soil type (ethno-classification; FAO) [ha]
- texture
- physical characteristics (e.g., pF curves, bulk density)
- chemical characteristics (e.g., N, P, CEC, OM)
- depth [m]
- subdivision in cultivable soils, soils for pasture and wasteland

Population:
- number of persons per ethnic group, stratified by age
- family structure [person $household^{-1}$]
- labor availability [md], men and women [adult equivalent] for the periods of:
  - field preparation and sowing of millet

- first weeding
- rest of the season up to harvest
- harvest of millet
- harvest of cowpea
- harvest of rainfed rice
- rest of the year

food requirements [kg person^{-1} period^{-1}]
wood requirements [kg household^{-1}] for:

- construction
- fuel-wood

Crop production systems (including vegetables, fodder crops, fallow and pasture)

soil type potential usable by this production systems [ha]
soil type occupied (1995-6) [ha]
growing period [calendar and number of days]
classification of crop production
biomass production of grains, straw, rest of cobs, roots [kg ha^{-1}] (if possible)
Outputs:

- yield of grains, etc. [kg ha^{-1}]
- biomass production of roots (if possible) [kg ha^{-1}]
- biomass production of straw, fodder:
  - quantity [kg ha^{-1}]
  - quality [g N kg^{-1}]
  - availability in the course of the year
- wood production [kg ha^{-1}]
- nutrient uptake [kg ha^{-1}]
- Subdivision of use of straw and wood for feed, construction, miscellaneous

Inputs:

- manure, chemical fertilizer [type and kg ha^{-1}]
- straw on the field before sowing [g N kg^{-1}, g P kg^{-1}, g K kg^{-1} and kg ha^{-1}]
- labor [md ha^{-1}] for
  - cleaning of field
  - transport and application of manure
  - basic dressing
  - land preparation
  - sowing
  - first weeding
  - first top dressing
  - first spraying of insecticides
  - second weeding
  - second top dressing
  - second spraying of insecticides
  - harvest
  - transport to house
  - threshing and winnowing
  - transport to market (return)
  - marketing
  - water collection
  - wood collection
  - meal preparation
- fallow [ha ha^{-1}]
- animals for traction [TLU ha^{-1}]
- donkeys [TLU household^{-1}]
- equipment (sowing machine, donkey chart, etc.)

prices of inputs and outputs [FCFA], for e.g.,:
- plough
- small equipment
- sowing machine
- spraying machine
- seeds
- pesticides
- insecticides
- grains
- straw
- wood

Animal production system
- Type of animal and actual number [TLU]
- Herd structure (male, female, age)
- Outputs:
  - milk [kg TLU-1]
  - meat [kg TLU-1]
  - increase in herd [TLU TLU-1]
  - manure [kg TLU-1]
- Inputs:
  - fodder, concentrates [kg TLU-1 per quality class of g N kg-1]
  - labor [md TLU-1]:
    - herding
    - milking
    - watering
    - feeding
    - vaccination
  - monetary inputs [FCFA TLU-1]:
    - materials
    - vaccines
    - supplementary feeds (e.g., concentrates
    - salt bricks
    - water

Alternative production systems
- e.g., with new variety, but with lower fertilizer recovery or with higher yields but higher inputs
- description as above

Off-farm activities:
- Number and ethnic group for specified periods of the year [md]
- Income [FCFA md]

Miscellaneous:
- Development goals
- Village policies for land use, users' rights
- Water availability for specified periods of the year

Detailed level: household (unit of analysis: plots)

The same as in A1.3, but additional information (generally now measured), such as variety, uptake of same and other nutrients, within plot variation of soil characteristics etc. Important details can be added

Appendix 2. Abbreviations and acronyms

AB-DLO	= DLO Institute for soil fertility and agroecological research (the Netherlands)
A/D	= District: 'arrondissement' or 'département'
AEZ	= AgroEcological Zone
APSRU	= Agricultural Production Systems Research Unit (Australia)
CARMASAT	= Collaboration on Agricultural Resource Modeling and Applications in the Semi-arid Tropics
CLIWARDA	= Climate Impact on Water Resources and Dryland Agriculture
CRPA	= Centre Régionale de Promotion Agropastorale (Burkina Faso)
CSIRO	= Commonwealth Scientific and Industrial Research Organization (Australia)
DLV	= working group on sustainable land use and food security in the tropics (the Netherlands)
DMP	= Desert Margins Programme
DRP	= Direction Régionale du Plan (Burkina Faso)
DSAP	= Direction des Statistiques AgroPastorales (Burkina Faso)
ICASA	= International Consortium of Agricultural Systems Applications
ICRAF	= International Center for Research on AgroForestry
ICRISAT	= International Crops Research Institute for the Semi-Arid Tropics
IER	= Institut d'Economie Rural (Mali)
IFDC	= International Fertilizer Development Center (USA)
IGB	= Institut Géographique Burkinabé
IH	= Institute of Hydrology (UK)
IITA	= International Institute of Tropical Agriculture (Nigeria)
ILRI	= International Livestock Research Institute (Ethiopia)
INERA	= Institut d'études et de recherches agricoles (Burkina Faso)
INRAN	= Institut National de Recherche Agronomique au Niger
IUCN	= World Conservation Union
ISC	= ICRISAT Sahelian Center (Niger)
GIS	= Geographical Information System
LUSA	= Land Use Systems Analysis
LGP	= Length of Growing Period (days)
MGLP	= Multiple Goal Linear Programming
NARS	= National Agricultural Research Systems
NGO	= Non-Governmental Organization
ORSTOM	= Institut francais de recherche scientifique pour le développement en coopération (France)
PDRI	= Projet de Développement Rural Integré (Burkina Faso)
PNGT	= Programme Nationale de Gestion de Terroir (Burkina Faso)

PSB	= Programme Sahel Burkinabé
PVNY	= Projet Vivrier Nord-Yatenga (Burkina Faso)
SC-DLO	= DLO Winand Staring Centre for Integrated Land, Soil and Water Research (the Netherlands)
SERIDA	= Social and Environmental Relations in Dryland Agriculture
UNDP	= United Nations Development Program
WAU-PE	= C.T. de Wit Graduate School of Production Ecology of the Wageningen Agricultural University (the Netherlands)