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Land Use Systems Analysis, a Multi-Scale Methodology to Explore Options for Development of Sustainable Agricultural Production Systems

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1. Abstract

In many developing countries, limiting factors for development of sustainable production systems include variability in agro-ecological and socio-economic conditions, poor access to geo-referenced data and information, and poor relationship between the civil society, researchers and decision makers Working with Interactive Development Scenarios (IDS) models may provide a way to plan (agricultural) development This tool can integrate results of various methods that assist in land use planning Nine methods are briefly discussed and evaluated All methods depend on reliable basic data, but many display inadequate planning procedures, static approaches and neglect of socio-economic aspects Therefore, an alternative methodology "Land Use Systems Analysis (LUSA)" is being presented 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 analysed in five steps, in an inter-disciplinary way, to give quantified and clear alternative land use options on different scales Based on this approach, ICRISAT has started in 1996 a joint research project based on this approach with NARS in Mali, Burkina Faso and Niger, entitled "Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa (MUSCLUS)" Four levels of scale are distinguished agro-ecological zone, district, village land, and household Its goals and expected outputs are presented in this paper

Keywords sub-Saharan Africa, scale levels, characterisation, land use systems analysis, multi-criteria model, simulation modelling, and integration of disciplines

2. Introduction

In many developing countries agro-ecological and socio-economic conditions differ considerably in both space and time On top of this variable environment, farmers use a wide range of production systems, resulting in a large variation in productivity across and among agro-ecological zones, and among farm types Additionally, the low availability of geo-referenced data and information, and the often poor relations between the civil society (farmers, extension services, and Non-Governmental Organisations (NGOs) and development projects), research institutes, and decision makers have considerably limited the targeting of technologies to the specific environments, and consequently the development of sustainable agricultural production systems for larger areas in these countries Considering that in most countries the population growth rates exceed largely the annual growth rate of agricultural production, and soil mining is almost a rule, options for agricultural development based on sustainable production systems with increased yields are urgently needed Research has yielded alternative technologies, but transfer to villages has often failed, due to a number of reasons Among them are the non-adaptation of technology to farmer's ability, financial

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constraints, low availability of inputs, poor extension services, land tenure problems and the non-compatibility with the extensive, individualists strategies of both crop and livestock farmers (FAO, 1995) Land use planning, being an integral part of farmer's practice ever since people started to cultivate crops, may provide a way to solve many of these problems At present land use planning means almost implicitly the development of sustainable production systems for a given region Interactive Development Scenarios (IDS) models may be tools that outline options for development through identification of appropnate land use systems, i e the combination of specified land uses (or production systems) practised on a given land unit that can be geo-referenced Figure 1 shows the principal components and flows in land use systems

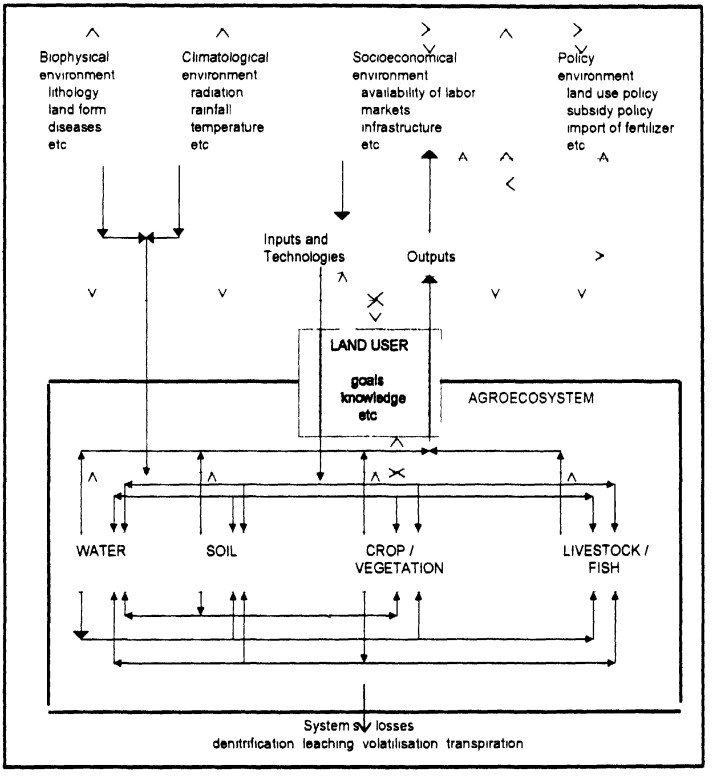

Figure 1 Schematic representation of a land use system (van Duivenbooden, 1995).

The purpose of this paper is to evaluate briefly various methods that assist in giving alternative options for land use, and to present an alternative multi-scale approach that is being applied in three West African Countries

3. Evaluation of Various Existing Methods

For land use planning different aspects of land use systems need to be included Various methods exist either through the collection of land use data, analysis of data and options for development (i e scenarios), or their combination As it is beyond the scope of this paper to present details of all existing methods, nine major methods are briefly described in Table 1

Table 1. Current methods that can be used (partly) for land use planning, and the proposed alternative (van Duivenbooden, 1995)

Method	Description
Agricultural census (AC)	A method to collect data on relatively stable agricultural structures and to provide a sampling frame for other surveys on agricultural holdings An AC involves collecting processing and analyzing data from a large number of agricultural holdings and provides essential structural data for small areas to prepare plans and formulate policies for rural development (FAO 1986)
Land Evaluation (LE)	A physical land suitability assessment method including socio-economic aspects in which properties of a given geo-referenced land unit are compared with the requirements of a specific land use The aim is to examine the consequences of change and guide planning decisions LE focuses on future predicted or potential land use for which purpose land units are classified (Fresco et al 1990) However translation into practice is limited because of the rather qualitative suitability classifications and the absence of formalized procedures for selecting land use systems (Dent, 1993)
Farming Systems Research (FSR) Farming Systems Analysis (FSA)	Deal with entire farms of resource-poor farmers and farm components They are generally carried out by multidisciplinary teams of agronomists and socio-economists FSA gives insight into the improvements that are possible and necessary whereas FSR concentrates on experimental methods to test adapted technologies Both focus on the present situation on the basis of land units (Fresco et al 1990) Due to the absence of relations with the landscape and with higher levels of spatial integration (agro-ecological zone) and the limited amount and accuracy of quantitative data acquired it does not provide a basis for spatial or pattern analysis
Land Evaluation and FSA (LEFSA)	This has been developed on the basis of LE and FSA This method considers the regional agricultural system and cropping or livestock systems in alternation and integrates agronomic and socio-economic aspects (Fresco et al 1990)
Agro-ecosystem analysis and development (AAD)	Deals with all levels of agro-ecosystems on a multidisciplinary basis It studies interactions between people and natural resources often at the community level and includes identification of trade-offs between different land uses (Lightfoot et al 1989)
Environmental Impact Assessment (EIA)	An environmental analysis and is merely a tool and a set of procedures to ensure that adequate environmental considerations enter into the decision-making process EIA is an instrument for shaping policies programs and project decisions (World Bank 1991)
Rapid Rural Appraisal (RRA)	A systematic activity carried out in the field by a multidisciplinary team designed to acquire quickly new information and new hypotheses about possible interventions in the rural environment (Fresco et al 1990)
Framework for Evaluating Sustainable Land Management (FESLM)	Defined as a pathway to guide analysis of land use sustainability and connect all aspects with the multitude of interacting conditions (environmental economic and social) whether that form of land management is sustainable or will lead to sustainability It does not include planning or development (Smyth et al 1993)
Agro-Ecological Characterisation (AEC)	A comprehensive description of agro-ecosystems on the basis of physical and biotic parameters Land use is described including its socio-economic identifiers The degree of detail of information collected in agro-ecological characterization is strongly related to the scale of characterization (FAO 1978 Andriesse et al 1994)
Land Use Systems Analysis (LUSA)	Aims to cover the successful management of resources to satisfy changing human needs without degrading the environment or the natural resource base and to give quantified and clear alternative land use development options on different scales (van Duivenbooden 1995)

Their characteristics referring to data and scenario analysis are evaluated in Table 2. This latter table shows that only some of them use spatial analysis. It is obvious that the success of land use planning depends on the availability and reliability of the basic data.

Table 2. Main characteristics of various current methods and of the proposed method, concerning the development of sustainable production systems (van Duivenbooden, 1995)

Characteristic	AC	LE	FSR	LEFSA	AAD	EIA	RRA	FESLM	AEC	LUSA
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	3	3	3	3	1,3	1,2	1-6	1-6

AC = Agricultural Census, LE = Land Evaluation, FSR = Farming Systems Research & 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, and LUSA = Land Use Systems Analysis. +: true, -:not true, +/-: not always true. Tools: 1 = literature review, 2 = remote sensing, 3 = survey and interview, 4 = experiments, 5 = modeling and 6 = GIS application.

Other difficulties presented by these methods include technical, socio-economic and political constraints, of which Table 3 gives three categories. The large number of references (29) used to construct this table emphasises the wide-spread occurrence in West Africa. Finally, the rapidly changing social and economic values, and the emerging conflicting goals of different stakeholders and decision makers in many countries can only be handled by the listed methods to a certain extent, if at all.

Table 3. Main characteristics and consequences in an African region of three categories of difficulties that hampered land use planning (van Duivenbooden, 1995)

Category	Problem characteristics	Practical consequences
Inadequate planning procedures and implementation	Contradictory and conflicting nature of land use policies lack of co-ordination among planning agencies top-down approach focus on one sector/scale planning period too short no co-operation with local people neglect of requirement for maintenance of infrastructure and for resource management	soil mining salinisation erosion land use planning only applicable for a limited area and period of time
Neglect of the population growth rates	underestimating effect of growth rate of 3-4% in West Africa (versus globally 1 7%) often no spatial and temporal analysis	no self-sufficiency in food market disturbed by imported and aid foods uncontrolled grazing vegetation burning and settling investment in survival rather than in land resource management inappropriate land ownership
Neglect of socio-economic aspects	exclusion of land tenure rights price policies tribal and gender issues institutional and organisational arrangements under-estimating land as source of income through crop production	loss of traditional land use practices and certain agro-ecosystems insufficient participation of the local population land use plans that cannot be implemented

4. An Alternative Approach

The analysis of the presented problems in and associated practical consequences of land use planning leads to the conclusion that the 'ideal' method for land use planning should take into account the following criteria

- integration of disciplines, possible farmers' goals and planners' visions and involvement of researchers, extension agents, NGOs, and policy makers in the design, implementation and evaluation stages
- identification and quantification of the most important processes of complex land use systems
- presentation of trade-off between various land use options in such a way that planners and decision makers really do understand them and wish to participate in scenario analyses
- consideration of present land use systems
- identification of the interval and path between actual and future situation In addition, working at different levels of scale is a prerequisite for land use planning for different reasons (Table 4) This implies, among other things, up and down scaling of problem formulation and of analysis results related to spatially referenced sites Since at each scale level, the characteristics of land use systems and their inherent variations are different, land use planning should address different issues at each level of scale

Table 4. Reasons for working at different levels of scale in land use planning (Andriesse et al., 1994; Izac & Swift, 1994; Fresco, 1995; van Duivenbooden, 1995; Kruseman et al., 1996)

- to create more or less homogeneous units of analysis, the heterogeneity observed at one scale level is a result of inadequate resolution
- characteristics of agro-ecological processes can be at the same time exogenous forces as well as a variable of the system
- patterns seen at one level may only be explicable on the basis of processes functioning at lower level
- characterisation and data are linked to one level of scale
- statistical studies have only limited value, if any, when the scale is not given
- risks is a phenomenon with spatial and temporal dimensions
- an understanding of relations within the system and extrapolation of results requires a systematic approach
- the type of processes that influence the production potential of a land use system is scale dependant
- a (technical) solution may be efficient at one scale (e.g. field), but at a higher level of scale causing constraints of a different kind (e.g. socio-economic)

To link various research disciplines, formulation of development scenarios of sustainable land use systems is considered an effective mechanism, because it requires the identification and quantification of inputs and outputs from the one and the other. The scenarios must be defined according to stakeholders (i.e. for farmers, village heads, regional and national decision-makers) and for each scale (van Duivenbooden, 1995). Formulation of such development scenarios permits identification of technologies and interventions at different scales and moments, and of the priorities of agricultural research. This will lead to an improved impact of research.

Based on the requirements described above and experiences in various projects on land use planning, "Land Use Systems Analysis (LUSA)" is introduced as an alternative methodology. 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 analysed in five steps, in an interdisciplinary way, to give quantified and clear alternative land use options on different scales (Table 5).

Table 5. The five steps in Land Use Systems Analysis

Action steps	Answering
1 Definition and formulation of vision and common goals of farmers researchers and land use planners	"Where do we want to go?"
2 Characterisation of the actual land use systems at different levels of scales	"Where are we, what do we know?"
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 simulation and optimisation models linked to a GIS	"What can we logically expect?"
5 Testing of a new technologies and management practices by both farmers and scientists by putting them into practice	"Does it really work?"

The main steps are

- the definition and formulation of common goals of farmers, researchers and land use planners
- a comprehensive description of the actual agro-ecosystems on different scales
- research restricted to the most important components and flows of land use systems
- the analysis of development scenarios with a multiple goal linear programming model linked to a geographical information system (GIS)
- the evaluation of new technologies and management practices by both farmers and scientists (Figure 2)

The last three steps are closely linked hence they are carried out more or less concurrently In this way the viewpoints of various stakeholders for development of sustainable agro-ecosystems are also framed, while making use of the complementarity of their viewpoints and research methodologies It is, however, not possible to solve at the same time some of the drawbacks (e g time and data requirements) of previous methods (Table 2) It is furthermore 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 geo-referenced information obtained at a lower scale

4 1 Setting visions and common goals

The definition of visions and common goals is a prerequisite of LUSA 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 socio-economic 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", based on the crux of a clear expression of what you need from the other and what you can offer, and looking for ways how to strengthen each other ("win-win" situation)

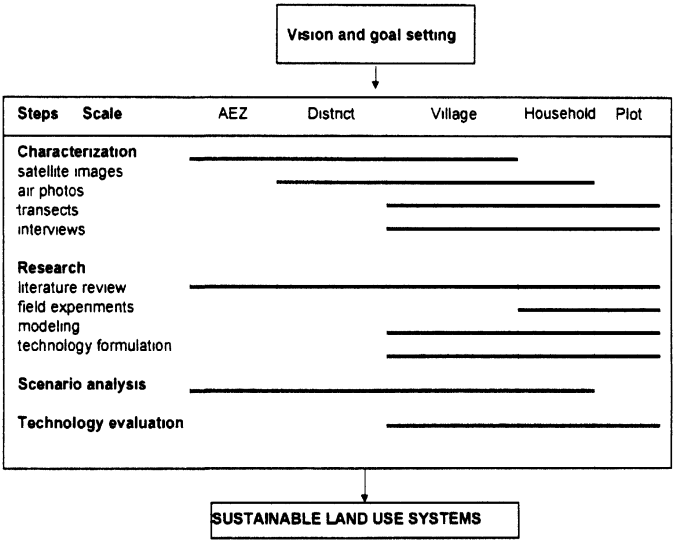

Figure 2 Simplified diagram of possible research activities in each step of Land Use Systems Analysis and their degree of detail AEZ agroecological zone (van Duivenbooden, 1997)

4 2 Multi-Scale Characterization

Characterization is a comprehensive description of the agro-ecosystems at different scales on the basis of biophysical parameters (climate, lithology, land form, soils and hydrology, land cover), socio-economic identifiers (labour, capital input, and management), and policy schemes (credit, subsidies, fixed farm gate prices) In this multi-scale characterisation, 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, Andnesse et al , 1994) 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 Building of or completing the geo-referenced multi-scale database is thus an important associated activity

4 3 Research Activities

Applied and basic research will be carried out on representative (benchmark) sites selected on the basis of the characterisation Research will be restricted to the most important components and flows of land use systems, merely to complete the existing knowledge It should be carried out on the various units of analysis and executed in close collaboration between National Agricultural Research Systems (NARS), International Agricultural Research Centres (IARCs), and the civil society

4.4 Analysis of development scenarios

The analysis of prospective development ("where do we want to be and when?") scenarios (e.g., self-sufficiency at 80% in dry years) can be done with multi-criteria models. An example of such models is the multiple goal linear programming (MGLP) model (de Wit et al., 1988). To better display the spatial differences of the outcomes, the model need to be linked to a GIS. For the temporal (year to year) aspect, the model should be dynamic. Then, while taking into account spatial and temporal relations, results will 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.

Natural, human and financial resources are allocated to land use systems, and outputs of certain systems may be inputs for others. Figure 3 shows the flow of data use and the integration of GIS, process and optimisation models. 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 in which the solutions need to be calculated. Restrictions are also defined in terms of land suitability, socio-economic factors and the output feasibility of the model (post-model analysis: 'can this really be achieved?'). 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 trade-off between current, non-sustainable land use systems and alternative, sustainable systems. However, the chance for adoption is much larger when the options are consistent with market oriented agricultural development. If farmers don't get any additional income from adopting improved management practices, they will only adopt them under stress (van Duivenbooden et al., 1997). Hence, geo-referenced socio-economic information need to be used to see how attractive a land use system can be under different pricing scenarios. This information can then help to let policy makers know whether it makes sense to promote a technical option in a particular area at that point in time or establish first a market.

The data to 'feed' this MGLP model can be derived to a certain extent from literature, field experiments, or generated with various tools, such as crop simulation models and GIS. One constraint may be that in most developing countries geo-referencing has not been done, and a multi-scale database is lacking.

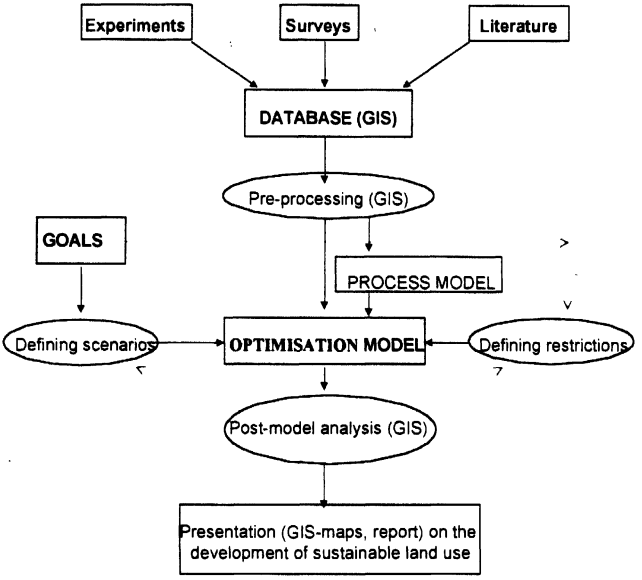

Figure 3. Schematic diagram of the proposed Interactive Development Scenarios (IDS) model, the integration of Geographical Information System, process and optimisation models (van Duivenbooden, 1997).

4.5 Validating Alternative Technologies

Based on the outcome of the multi-criteria modelling exercise, several technologies can be identified as apparently favourable 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 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.

5. The MUSCLUS Project

Instead of avoiding or ignoring existing variability in the characteristics of land use systems as a function of scale, or called multi-scale variability, it can be exploited to

- understand better the key processes of land use systems
- analyze risk of the current and alternative land use systems in terms of improved production and sustainability
- avoid a mismatch of technologies and interventions in specific (geo-referenced) sites.

This exploitation may comprise, for instance, optimisation 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 optimisation 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.

ICRISAT has started in 1996 a new collaborative research project with NARS in Mali, Burkina Faso and Niger, entitled "Exploiting multi-scale variability of land use systems to improve natural resource management in the Sudano-Sahelian zone of West Africa (MUSCLUS)" (van Duivenbooden, 1997). As ICRISAT only has comparative advantage on the international strategic aspects of this study, co-operation with other IARCs, and the civil society is a prerequisite for its successful execution in particular locations. 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.

The objectives of this project are to:

- Improve natural resource management by exploiting the variability of land use systems (with their biophysical, socio-economic 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 socio-economic 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.

Four scales are distinguished, guided by the decision-making process, to focus research activities. The highest level is the agro-ecological zone. Within an agro-ecological zone, a district (about 500 to 1000 km^2) is selected as the next level of scale. This level requires the translation of scientific results into practical terms for units governed on a day to day basis by stakeholders. In this district, a village area ("terroir villageois") can be selected, and within a village an exploitation cultivating a set of fields, each field comprising plots. The emphasis is on millet- and sorghum-based production systems 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 one key site is located in the Sahel (400-500 mm) and one in the Sudan Savanna zone (600-700 mm).

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 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 into practical terms. This implies the formulation of alternative crop production systems with their technologies, which will be evaluated by NARS and NGOs on farmer's fields, and through the MGLP model recommendations to policy makers need to be formulated. Outputs comprise, among other things:

- An Interactive Development Scenarios (IDS) model that assists in targeting technologies and interventions to specific environments;
- Guidelines for stakeholders and management options for farmers for development of improved production and sustainable land use systems;
- A methodology for extrapolation and transfer ("regionalisation") to the district level of research results and information obtained at a field level.
- Multi-scale geo-referenced databases fore selected sites.

6. Conclusion

In this paper, a methodology has been advocated that could be seen as a next step in the capitalisation of current knowledge of land use systems, the planning of sustainable agriculture, and the increase of labour and fund efficiencies in natural resource management. It requires alignment of researcher activities to carry it out, but it avoids duplication of efforts, and it gives a way to integrate quantitatively disciplines. Because of the multi-scale approach, the method tries to bridge the gap between, on the one hand the decision-makers, and on the other hand the farmers, extension services and researchers, although not all answers of how to do so are already solved. It is this mix of characteristics and activities, which distinguishes Land Use Systems analysis from previous methods. National geo-referenced multi-scale databases seem to be a key factor in further development of sustainable agriculture. The MUSCLUS project initiated by ICRISAT in Mali, Burkina Faso and Niger will be a next step in the development of national geo-referenced multi-scale databases, and in formulation of sustainable natural resource management.

7. Acknowledgements

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8. References

Andriesse, W., L.O. Fresco, N. van Duivenbooden & P.N. Windmeijer, 1994. Multi-scale characterisation of inland valley agro-ecosystems in West Africa. Neth. J. Agric. Science 42: 159-179.

Dent, D., 1993. From land evaluation to land use planning. In: D.L. Dent & M.E.F. van Mensvoort (Eds), Selected papers of the Ho Chi Minh City symposium on acid sulphate soils. Ho Chi Minh City, Vietnam, March 1992. Publication 53, ILRI, Wageningen, p. 289-298.

de Wit, C.T., H. van Keulen, N.G. Seligman & I. Spharim, 1988. Application of interactive multiple goal programming techniques for analysis and planning of regional agricultural development. Agricultural Systems 26: 211-230.

FAO, 1978. Report on the agro-ecological zones project. Volume 1. Methodology and results for Africa. World Soil Resources Report 48. FAO, Rome, 158 p.

FAO, 1986. Programme for the 1990 World Census of Agriculture. FAO Statistical Development Series 2. FAO, Rome, 119 p.

FAO, 1995. Akosombo principles. Proc. FAO Workshop "Adoption of sustainable land manage-ment technologies: challenges and opportunities", Ghana 6-10 February 1995, 45 pp.

Fresco, L.O., 1995. Agro-ecological knowledge at different scales. In: J. Bouma, A. Kuyvenhoven, B.A.M. Bouman, J.C. Luyten & H.G. Zandstra (Eds), Eco-regional approaches for sustainable land use and food production,

Proc symp on eco-regional approaches in agric research. 12-16 December 1994, ISNAR, The Hague Kluwer, Dordrecht, p. 133-141

Fresco, L.O., H. Huizing, H. van Keulen, H. Luning & R. Schipper, 1990. Land evaluation and farming systems analysis for land use planning. FAO Guidelines: Working Document. FAO, Rome, 207 p.

Izac, A.-M.N. & M.J. Swift, 1994. On agricultural sustainability and its measurement in small-scale farming in sub-Saharan Africa. Ecological Economics 11. 105-125.

Lightfoot, C., A. Bottrall, N. Axinn, G. Conway & P. Singh, 1989. Training resource book for agro-ecosystem mapping. Process documentation of an experiential learning exercise in Agro-ecosystem mapping, held at Rajendra Agric. Univ., Pusa, Samastipur, Bihar, India, 7-10 March 1989. IRRI, Philippines/Ford foundation, India, 55 p.

Kruseman, G., R. Ruben, A. Kuyvenhoven, H. Hengsdijk & H. van Keulen, 1996. Analytical framework for disentangling the concept of sustainable land use. Agricultural Systems 50: 191-207.

Smyth, A.J., J. Dumanski, G. Spendjian, M.J. Swift & P.K. Thornton, 1993. FESLM: an interna-tional framework for evaluating sustainable land management. A discussion paper. World Soil Resources Reports 73. FAO, Rome, 74 p.

van Duivenbooden, N., 1995. Land use systems analysis as a tool for land use planning, with special reference to North and West African agro-ecosystems. PhD thesis Wageningen Agricultural University, 176 p.

van Duivenbooden, N. 1997. 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. Integrated Systems Project Report Series no. 1. ICRISAT, Patancheru, India, 40 pp.

van Duivenbooden, N., E. Freud, L. Cissé, and A. Bationo, 1997. Resource management research in semi-arid West Africa: Challenges and new opportunities. In: Proceedings of International Workshop on 'Soil fertility in west African Land use systems', 1-4 March 1997, Niamey, Niger (in press).

World Bank, 1991. Environmental Assessment Sourcebook. Vol. I, II, III. Worldbank Technical Paper numbers 139, 140, 154. World Bank, Washington.