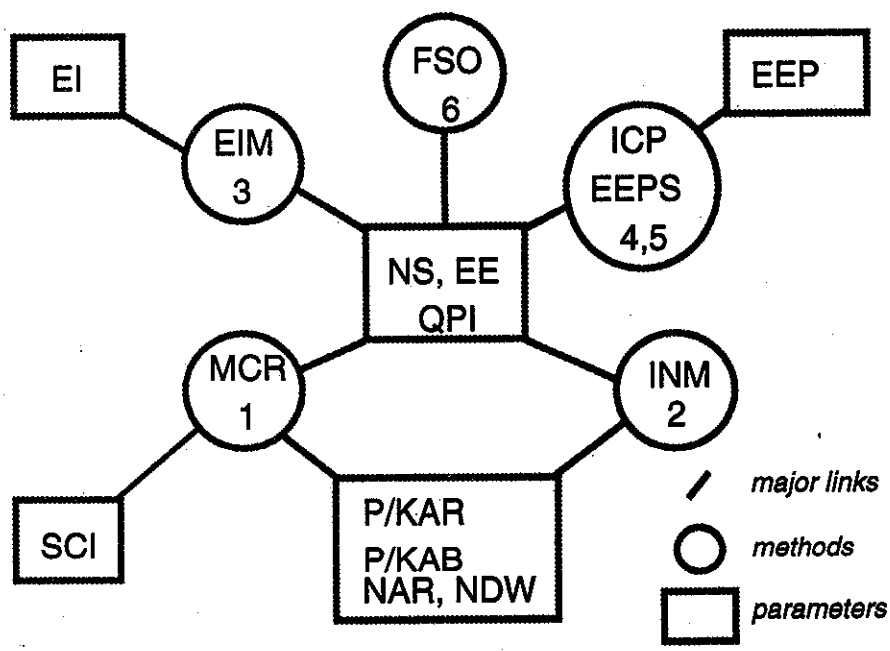
Proceedings

Workshop on Ecoregional Research at ILRI

ILRI, Addis Ababa, 5-8 October 1998



International Livestock Research Institute
PO Box 30709, Nairobi, Kenya

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Edited by

P.K. Thornton and A.N. Odero

International Livestock Research Institute
PO Box 30709, Nairobi, Kenya

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Ecoregional Workshop, 5–8 October 1998

International Livestock Research Institute (ILRI), P.O. Box 5689, Addis Ababa, Ethiopia

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PREFACE

Over the past few years, increasing recognition has been given to the need to improve agricultural productivity while protecting or enhancing the natural resource base. In 1992, the Technical Advisory Committee (TAC) recommended ecoregional research as a fundamental activity for the Consultative Group on International Agricultural Research (CGIAR) to address improvements in agricultural productivity and natural resource management. TAC acknowledged that the global research community did not have an appropriate paradigm for natural resource management research. The identification of a conceptual framework, together with appropriate research methods, was regarded as a goal of truly international relevance.

Since then, various ecoregional initiatives have been organised throughout the world. They have been convened by sister CG centres and have involved various consortia of partner institutions, both international and national, including NGOs and universities. ILRI is participating in several of these consortia with varying degrees of success, as approaches, methods, mechanisms, institutional participation, expertise and funding have been quite diverse. It is recognised that ecoregional research is following an evolutionary process, that builds on past experiences in farming systems research and other research frameworks.

A workshop on ILRI's ecoregional research activities was convened at ILRI's facilities in Addis Ababa from 5-8 October 1998. The workshop had three major objectives:

1. To sharpen the focus of ILRI's ecoregional research.

2. To further identify commonalities in tools and new methods that can enable ILRI to do effective transregional research.

3. To identify improvements to the way in which ILRI does ecoregional research.

Scientists from the ILRI Projects whose activities include a substantial portion of ecoregional research (now and in the future) were invited to present a paper on their current work, with some emphasis on tools and methodologies. Visitors from CIAT (the International Centre for Tropical Agriculture), CIP (the International Potato Centre), ICRAF (the International Centre for Research on Agroforestry), Wageningen Agricultural University, the University of Edinburgh, the UK and Australia were invited to present a paper on their ecoregional activities. These papers were presented over three mornings. The afternoon of each day and the fourth morning were given over to discussion groups, who addressed three issues:

- What should be the underlying themes for ILRI's ecoregional research?

- What are the major activities of these themes, and where globally should ILRI be working on them?

- What does ILRI need to do to address these themes?

These proceedings contain written papers based on all the presentations made at the workshop. An introductory paper provides an overview of what ecoregional research is, and describes ILRI's current ecoregional activities. This is followed by six ILRI Project papers and by the seven presentations made by visitors to ILRI. The final paper, on agro-climatic classifications, was written for the workshop but was not able to be presented then. The papers are followed by summaries of the discussion sessions and a short summary of the entire workshop, with a list of future activities to help refine the prioritisation process. The papers have been edited only very lightly, primarily so that these proceedings could be produced and distributed rapidly.

We would like to thank the European Development Fund for sponsoring the workshop, the participants from ILRI and elsewhere for their papers and their active participation in the workshop, Letty Padolina for doing much of the organisation of the workshop, and Margaret Morehouse for facilitating the discussion sessions.

Philip Thornton and Andrew Odero
Nairobi, 16 February 1999

WORKSHOP PRESENTATIONS

ECOREGIONAL RESEARCH AT ILRI: BACKGROUND

Hugo Li Pun, Mohammad Jabbar and Philip Thornton

Summary

This paper looks briefly at ecoregional research: what is commonly meant by the term and how it may be carried out. ILRI's involvement in various ecoregional consortia is discussed, together with problems and constraints that have been faced to date. The paper ends by listing a number of issues that require resolution if substantive progress is to be made in ecoregional research at ILRI and if the potential benefits of small teams of scientists located in different regions are to be realised. The object of the workshop is to work towards solving some of these issues, by sharpening both focus and methods of ecoregional research at ILRI.

Introduction

Since the 1970s, the Consultative Group on International Agricultural Research (CGIAR) has focussed on research to improve agricultural productivity. Increasingly, sustainability of agriculture, especially degradation and loss of soil, water and other natural resources, has become a concern, especially in developing countries where agriculture is the driving force for food security and poverty alleviation.

The CGIAR approved the support to ecoregional research in 1992. Ecoregional initiatives were promoted by the Technical Advisory Committee (TAC) of the CGIAR as a vehicle for:

a) Increasing research on the conservation and management of natural resources, linking agricultural productivity with the sustainable use of natural resources, and

b) Rationalising CGIAR centre contacts with the National Agricultural Research Systems (NARS)

In *Priorities and Strategies for the CGIAR* (1992), the TAC recommended improving natural resource management through ecoregional research as a fundamental goal for CGIAR research along with improving agriculture productivity. An ecoregion was regarded as an agro–ecological zone, regionally defined. The focuses of natural resource management research are the agro–ecozones, which share common characteristics of soil, water, climate, etc. However, TAC also recognised the significant differences within and between agro–ecozones in agricultural practices and markets that are influenced by socio–economic, political, cultural and other non agro–ecological factors.

TAC also acknowledged that the global research community did not have an appropriate paradigm for natural resource management research. Thus

identifying a conceptual framework and effective methods for ecoregional research were regarded as goals of truly international relevance.

The following were identified as international outputs of ecoregional research:

1. Effective research and development approaches for natural resource management that bring sustainable improvements in productivity to rural communities.

2. Understanding of the principles of management of soil, water, and biological processes, and their interactions in different ecologies.

3. Effective mechanisms to link decision–making and policy formulation and implementation, with technological opportunities and social organisations as instruments of change, at different levels.

4. Understanding of the principles of farmer and community decision–making, particularly the trade–offs between short–term gains and long–term sustainability of production.

5. Human resource capacity to help national research systems implement an effective research approach to natural resource management.

Following TAC's recommendations, different ecoregional initiatives have been organised by the CGIAR. TAC designated a CG Centre to take the lead role to develop consortia of NARS, Advanced Research Institutes (ARIs) and other International Agricultural Research Centres (IARCs). It was left to the different consortia to define their mandate, their scope of activities and the roles of the different partners. These consortia then engaged in constraint analysis, priority–setting, agreement on responsibilities, and development of proposals for funding.

The Nature of Ecoregional Research

What is ecoregional research?

Ecoregional research has been thrust high on the research agendas of IARCs and associated ARIs and NARS. The response of the sceptic is to dismiss it as old wine in new bottles, while to the convert it represents a paradigm shift in the way in which much agricultural research and development is conceived and implemented. As usual, the truth lies in between. There is undoubtedly a real need for ecoregional research, but there is not (yet, anyway) a cohesive *modus operandi* for doing it.

While it is not worth attempting to define "ecoregional research" with any precision—the term is rather like "sustainability" and "gender", whose meaning is now surrounded in a mist of imprecision—we can certainly identify some characteristics associated with it. For example, Rabbinge (1995), a tireless proponent and philosopher of the approach, writes that:

1. It deals with the region, not the farm and not the continent.

2. It bridges the gap between basic science and applied science.

3. It bridges the gap between the biophysical sciences and the socio–economic sciences.
4. It rectifies the common and erroneous assumption that the environment is an independent forcing variable.

5. It permits the systematic study of changes in land–use and in agricultural systems.

This concept clearly goes much further than the idea of an ecoregion as an agro–ecological zone, regionally defined. Such a list makes it easy to see what is not. It is not Farming Systems Research (FSR), for instance. FSR never generally dealt with 1 and 5, often included only token appreciation of 4, but did attempt 2 and 3. It is not the same as systems research; systems research deals with systems in general at every level in the hierarchy (but we may well say that ecoregional research is a subset or special case of systems research).

Much of the confusion about ecoregional research probably arises because of the notion of "region"—what is it, and how is it defined. Rabbinge (1995) defines the region "... in terms of its natural, administrative or socio–economic boundaries, within which the main rural and land development issues are made explicit" (the second half of this sentence is not very clear). So what is an ecoregion? Is it an agro-ecological zone, a recommendation domain, a natural resource management domain? Is an ecoregion contiguous, or simply made up of parcels of land of particular characteristics? Clearly, an ecoregion may be any of these; it depends purely on the purpose of the agglomeration and the analysis proposed. In this respect it is just like a "system": it is defined purely for the purpose of the analyst. In the same way that it makes no sense to collect data in the absence of an underlying hypothesis, it makes no sense to define an ecoregion in the absence of a purpose.

There are two ramifications of this. First, there is no such thing as The Ecoregion—it is explicitly a dynamic idea, a construct to facilitate analysis. Second, it forces the agricultural researcher to think about the level of analysis. For any field–based research activity, the idea of extrapolating from the particular site where the experiment was done to the ecoregion, where the ecoregion is defined (say) as the semi–arid regions of Africa, will often be meaningless. It is quite likely that at such disparate scales, the very processes being investigated at the plot level are of no relevance (or do not even operate) at the continental scale. Agricultural research is making tentative movements towards encompassing the notions and concepts that have been used in ecology for years. As in many traditional disciplinary areas, there are tremendous synergies to be gained from swapping and adapting tools and concepts, particularly amongst agriculture, ecology, geography and economics. Ecoregional research has a vital catalytic role to play in all of this. The scale issue is of central concern to ecoregional

research. Somehow, results of experimentation at the plot, parcel, and watershed levels have to be generalised to much wider regions, if the process is to work. For the basic biophysical processes, such as the transformations of Nitrogen in the soil, for example, this is comparatively straightforward: good, reasonably mechanistic models exist of such processes that are independent of environment, and can thus, with appropriate input data, be applied in environments in general. There are many other processes that are either at higher levels in the hierarchy or for which understanding is much less complete. For processes such as these, generic and generalisable models lie considerably in the future.

How is it done?

Two important questions are, can ecoregional research actually do the things listed above, in the list distilled from Rabbinge (1995), and if so, how?

It may be useful to think of ecoregional research as an agriculturally–orientated extension (or subsystem) of systems research. Seen in this light, an illustrious forerunner was the FAO (Food and Agriculture Organization of the United Nations) meeting of 1986 (Bunting, 1987), and even then they were grappling with the issues of data availability and databases, modelling, and identification of minimum data sets for studying biophysical and socio–economic processes. Another forerunner, at a higher scale, was the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project and the DSSAT (Decision Support System for Agrotechnology Transfer) set of crop models; this project also sought to identify biophysical minimum data sets to facilitate comparison and extrapolation (Tsuji *et al.*, 1998).

The issues of natural resource management at the regional level were clearly to the fore by the late 1980s, even if the tools to address such issues were not as well developed as they are today. The ideas of compatible global databases, linking socio–economic factors into recommendation domains, and linking detailed biophysical models with resource economic models, have a surprisingly long history. It is still the case that tools outstrip data (data really are critical to the approach), and until we have more extensive compatible, global–level biophysical and socio–economic databases, ecoregional research is going to be severely constrained in its effectiveness.

As noted above, continual consideration has to be given to the level in the system hierarchy at which the analysis is being carried out; the processes are different, and the tools required to study them are also different (Figure 1). In agricultural science, at least, the ways in which level of detail, system level, the processes operating, and appropriate models to study them, have not been very well elucidated, despite some attempts in this direction (e.g. Fresco, 1995; Bouma and Hosbeek, 1996).

Wherever in the hierarchy studies are undertaken, agricultural research is often represented as an iterative process, from characterisation and diagnosis through technology generation, technology testing, delivery, adoption and impact on appropriate target beneficiaries (Figure 2). The characterisation and diagnosis phases, if concerned with agricultural systems or component

systems, will often involve some form of formal or informal modelling, as a theory about how the system works, to enable (or at least to help) constraints to be identified and interventions assessed.

Ecoregional research does not, however, necessarily encompass all the steps in the process (Figure 2). In fact to define whether particular research is truly "ecoregional" is not always easy—but if it addresses the five points from Rabbinge enumerated above, then it probably is (or could usefully be considered) ecoregional research.

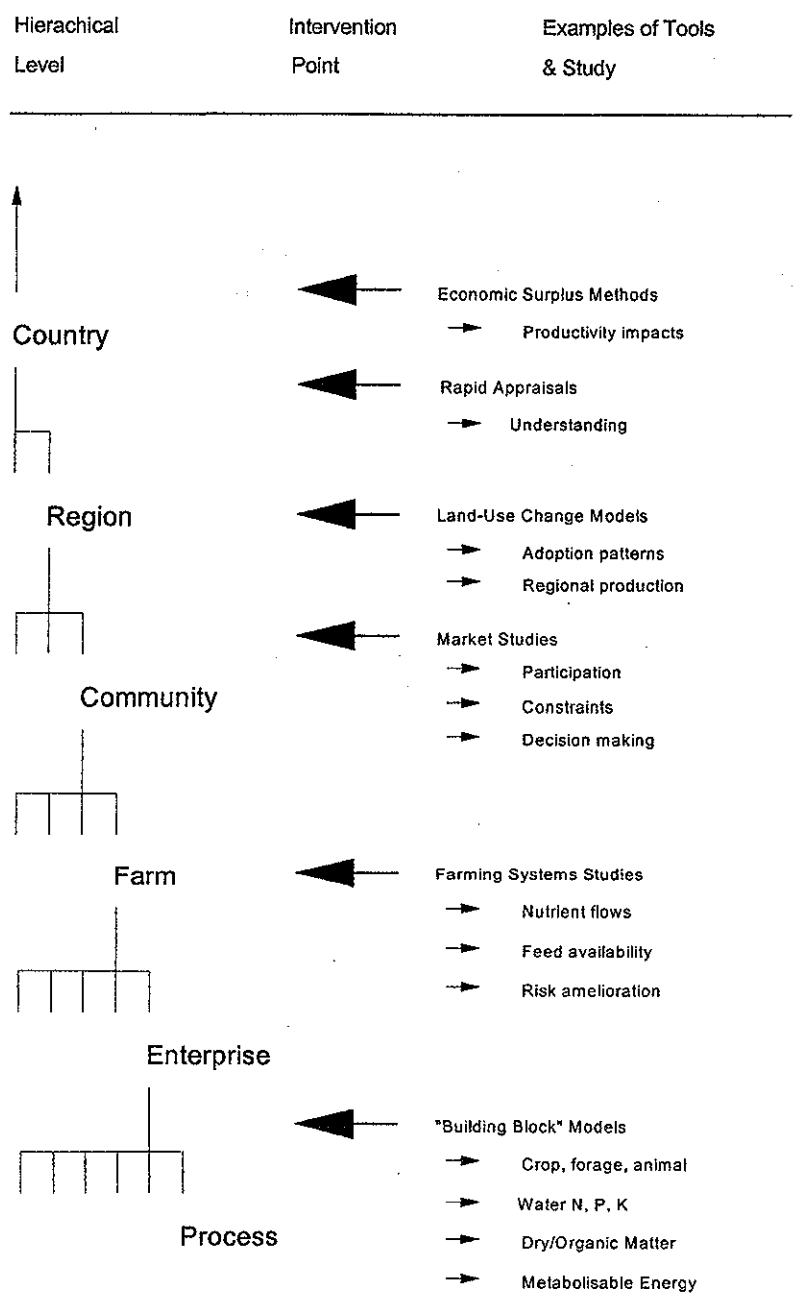

Figure 1. Some of the levels in the agricultural system hierarchy.

The Tools and Activities of Ecoregional Research

Some brief comments follow on particular aspects of various tools and activities of ecoregional research.

Ecoregional characterisation

Ecoregional characterisation need not be limited to spatial characterisations in terms of climatic or edaphic conditions, for example. As noted above, it has to be related to some purpose, and the socio–economic factors are likely to be the most problematic in the characterisation, principally for two reasons: first, because social factors are not generally spatially contiguous (unlike soil types in a landscape, for instance); and second, because although economics is at bottom about the geography of money, with one or two exceptions economics has not yet really dealt with its spatial and geographic roots. The latter is changing, but the former reason is a stumbling block, because the analytical treatment of contiguous and non–contiguous variables is different. This is presumably one more reason why so little progress has been made (or even can be made) with respect to definition of a minimum data set of socio–economic variables that parallels the relative success of a minimum data set for crop modelling purposes, for instance.

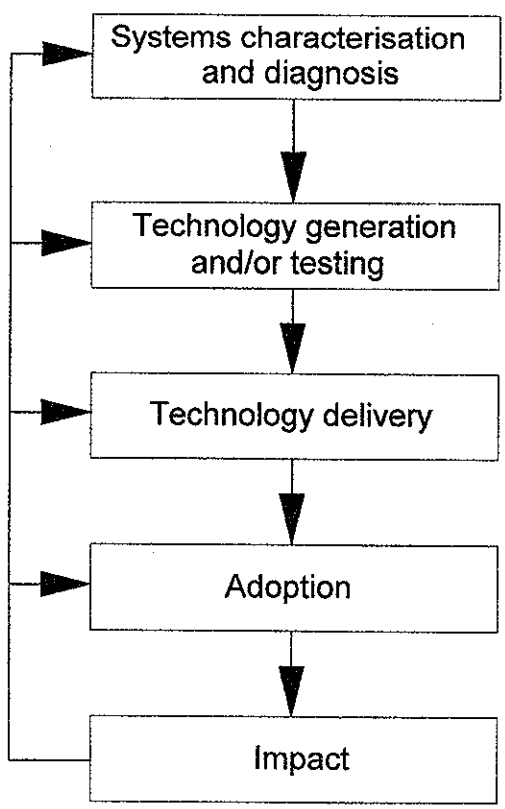

Figure 2. Agricultural research as an iterative process.

Ecoregional characterisations may use rather gross proxies of certain socio–economic variables, such as human population density, to add to the climate, soil type, elevation, slope and aspect data from digital elevation models,

infrastructural data and land–cover/land–use maps that are often overlaid and treated to provide agro-ecological zonations. The problem of data remains; the mountains of time and effort required to collate and treat appropriate census data to form many of these coverages are known well only to those people who are actively involved in doing this (and this does not include the collection of these data at the primary level). Much more work is required on suitable socio–economic indicators that can serve as proxies for a wide variety of variables. Being able to target particular potential beneficiaries (of a certain wealth or poverty class, for example) is becoming increasingly important.

The issue becomes more complex with respect to transregional relevance. Many agricultural technologies have some degree of locational specificity that limits returns to scale in research and makes adaptive research a prerequisite for diffusion. In these cases, farmer preferences, attitudes and other stakeholder–related considerations become increasingly important for defining recommendation domains.

Ecoregional modelling

It is hard to see how ecoregional research can proceed very far in the absence of models. It is possible to envisage that just about any model could be used for ecoregional studies, particularly in a step–wise approach (such as using detailed biophysical simulation models to generate input–output coefficients for mathematical programming models). These models may operate at nearly any level in the hierarchy (Figure 1), from detailed plot–based biophysical models to multisectoral economic models. We might make an initial distinction between non–spatial and spatial models, although as usual in such distinctions, there is often overlap.

For non–spatial models (or models that are not spatially explicit), there is a wide variety available. Thorne (1998) reviews some existing crop and livestock simulation models, with a view to elucidating the ease or otherwise with which they could be put together to investigate crop–livestock interactions in the various regions where ILRI works. There are examples of such models being put together to study natural resource management issues at the household and watershed levels—Hansen (1996) is a notable example.

Much of the Dutch work in ecoregional research has revolved around the use of mathematical programming at the regional level—a good example of a hybrid approach that can generate useful information. Mathematical programming models are not of themselves spatially explicit, although optimisation problems can be formulated in such as a way as to take account of space at a fairly coarse scale. Tools such as crop models, GIS and goal/linear programming have been linked quite successfully to study how various socio–economic, ecological and agricultural objectives can be achieved and traded off against each other (Rabbinge and van Latesteijn, 1992; van Keulen and Veeneklaas, 1993; van Latesteijn, 1995) Such methods are currently being used to look at land–use options in West Africa (van Duivenboden, 1998) and Asia (Roetter and Hoanh, 1998).

It is likely that spatially–explicit models will be of particular value in ecoregional research. Such models include land–use models, systems analysis models, and other types of models linked in some way to spatial databases. Models of biophysical processes (rainfall, hydrology, plant growth, nutrient dynamics, livestock productivity) are commonly linked to spatial databases in order to demonstrate change. As noted above, socio–economic processes have been neglected because they are less amenable to modelling in the same fashion. Nevertheless, it is possible to portray social, cultural and economic processes in space; the challenge is to find a way to link the two, in a spatial framework. To this end, simple and well–focussed models based on typologies or qualitative relationships, for instance, may be more practicable at present than complex diagnostic models.

Much spatial modelling originated in spheres other than agriculture; its application to agriculture–related questions can be expected to result in substantial cross–fertilisation of concepts. Much of this modelling work may be described as "exploratory", in the sense that the ultimate utility of these models is uncertain; if they are useful, then the methods and models can be developed further; if not, then that particular line of inquiry can be abandoned before too much time has been spent on it, and something else can be attempted.

The importance of spatial arrangements and relationships in many of the processes that define the environment within which human activity is carried out (including agriculture) is receiving increasing attention. A wide variety of methods that seek to have an impact on problem solving has been developed. Examples include: spatial models of herbivory including SAVANNA (reviewed by Coughenour, 1991); landscape ecology models (Turner, 1990; Turner *et al.*, 1996); human and livestock population distribution models (Deichmann, 1996; Wint, 1996); static and dynamic systems analysis models (Shepherd and Soule, 1996); semi–econometric models to explain deforestation patterns (Chomitz and Gray, 1996); and simple Markov rule–based models of land–use dynamics in a watershed (Thornton and Jones, 1998; Stoorvogel, 1995). In addition, there is a whole array of regression, statistical, economic, and ecosystem models that contain some spatial components for studying land–use and deforestation processes (reviewed by Lambin, 1994).

The reviews cited above provide excellent overviews of what has been done and what remains to be done in these various modelling areas.

Ecoregional adoption and impact

Assuming that an ecoregion has been characterised in some way, constraints and interventions identified, technology tested on the ground, and subsequently delivered to target beneficiaries somehow (assumptions of heroic proportions), then adoption and impact should follow, together with studies showing these. So far as we are aware, there are as yet no studies of ecoregional adoption and impact emanating from ecoregional research *per se*, but presumably this will change in the future. The tools and techniques for adoption and impact studies are likely to be the same as for non–ecoregional studies, except that if the characterisation work has been done, then

appropriate baseline data exist with which to analyse "before" and "after" scenarios. The provision of good baseline data to carry out adoption and impact work is increasingly important. It is generally far preferable to do a time series impact assessment ("then" and "now") rather than a cross–sectional assessment involving "adopters" and "non–adopters", in an attempt to minimise the confounding of survey data.

Transregional analysis

This is probably the "holy grail" of ecoregional research: the point at which the research carried out in one ecoregion is transferable and applicable to another ecoregion. The practicalities are currently formidable. A detailed mechanistic crop growth and development model is, in a sense, a good metaphor for transregional research, since it should be applicable anywhere, with minor modifications and extensions. How this operates at higher levels in the agricultural system hierarchy, or in situations where we do not understand very well the processes going on (thus precluding the idea of a mechanistic model for the time being), is much harder to say.

Livestock in the Ecoregional Context

Livestock are of particular importance in the ecoregional context. They are often the key to maintaining productivity and sustainability of agricultural systems. However, the specific role and the relative importance of livestock in production systems and natural resource management vary across agro–ecozones (e.g. from the dry to the wetter regions). Moreover, livestock products are increasingly important as urbanisation, income growth and population expansion stimulate markets for meat and milk. In some ecoregions, livestock are often the important "cash crop" available to smallholders; while in others they contribute to subsistence crop agriculture through the use of traction and manure.

ILRI is participating in the ecoregional initiatives in which livestock play a critical role in the production systems and natural resource management. They include the following:

1. The ICRISAT–co–ordinated Desert Margins Programme (DMP) through ILRI Project 15 (Semi–arid Areas) based in Niamey.

2. The IITA–co–ordinated Ecoregional Programme for the Humid and Sub–humid Tropics of sub–Saharan Africa (EPHTA), through ILRI Project 14 (Sub–humid Areas) based in Ibadan. Three consortia are operate under this umbrella:

   a) The Moist Savannah Consortium. This is the main focus of ILRI's activities linked to ILRI Project 14 (Sub–humid Areas).
   b) The Inland Valley Consortium (IVC).
   c) The Humid Forest Consortium.

3. The ICRAF (International Centre for Research in Agroforestry)–coordinated African Highlands Initiative (AHI), through activities of ILRI

Projects 11 (Systems Analysis and Impact Assessment), 13 (Highlands) and 19 (Market–Oriented Smallholder Dairy).

4. The CIP (International Potato Centre)–coordinated Consortium for Sustainable Development of the Andean Ecoregion (CONDESAN), through ILRI Project 16 (Latin America) based in Lima and Addis.

The System–wide Livestock Programme for which ILRI has lead responsibility is organised expressly to work through ecoregional research consortia on feed production and utilisation and on livestock–related natural resource management.

Status

The degree of participation of ILRI and the implementation of collaborative research activities have been quite variable. In all cases, ILRI has been involved in technical meetings, consultations, and preparation of research proposals submitted to donors.

The System–wide Livestock Programme has also contributed resources for research activities of the consortia (formal and informal) led by ICRAF, CIAT (International Centre for Research in Tropical Agriculture) and ICARDA (International Centre for Agricultural Research in the Dry Areas). Specific research activities include:

DMP (Desert Margins Programme)

- Biodiversity with relevance to climate change and land degradation. ILRI–DMP.

- Resource–uses optimisation at village and district levels in the desert margins of West Africa. ILRI–DMP–GEF (Global Environmental Facility)

EPHTA (Ecoregional Programme for the Humid and sub–humid Zone)

- Development of sustainable crop–livestock systems in the lowland moist savannas. ILRI–IITA–NARS (Nigeria, Ghana, Côte d'Ivoire, Benin).

- Developing a crop–livestock geographic information system. ILRI–IITA–NARES (National Agricultural Research and Extension Systems in Nigeria, Ghana, Côte d'Ivoire).

- Estimating the contribution of livestock to farming systems of the moist savannah ecozones. ILRI–IITA–NARES (Nigeria, Ghana, Côte d'Ivoire).

- Crop–livestock reciprocal benefits: crop residues/biomass as mulch, feed and/or manure. ILRI–IITA–NARES (National Animal Production Research Institute (NAPRI), Institut Des Savanes (IDESSA), Institut National De Recherche Agricole Du Benin (INRAB)).

- Characterisation of dairy production sub–systems in the inland valleys of Côte d'Ivoire, Mali and Nigeria. ILRI–WARDA/IVC–NARES (NAPRI, IDESSA, Institut d'Economie Rurale–IER).

- Testing of *ex–ante* models targeted at the production, management and utilisation of forages grown on residual moisture for dairy production. ILRI–WARDA/IVC–NARES (NAPRI, IDESSA, IER).

AHI (African Highlands Initiative)

- Development of legume–based feeding systems for smallholder dairy systems. ICRAF–KARI (Kenya Agricultural Research Institute)–ILRI funded by the SLP.

CONDESAN (Consortium for Sustainable Development of the Andean Ecoregion)

- Livestock in ecoregional research (LAC). ILRI–CIP/CONDESAN–NARS–IDRC–EDF (European Development Fund). It includes several experiments and studies, including the development of feeding systems, *ex–ante* assessment of technologies, modelling of production systems, testing of alternatives, policy research (particularly related to credit), and training

Constraints

The various ecoregional consortia are facing a number of constraints:

1. Relatively high transaction costs associated with awareness creation, formation of partnerships, definition of research agendas, and proposal preparation.

2. Restricted additional finances.

3. Over–expectations from partners.

4. Limited use of appropriate frameworks and definition of tools to be used in ecoregional research for integration of partners and information generated.

5. Lack of understanding of the new approach with implications for expanding partnerships.

6. Inadequate linkage between field–, laboratory– and station–based research activities at IARCs and among partners to address the R & D continuum.

Progress is being achieved to overcome these constraints, especially those numbered 1–3. The fourth is a critical one, not just for ILRI but for ILRI's partners too, because it is only through definition of a common framework and utilisation of common methods that comparison of results can take place, including analysis across ecoregions of similar ecological conditions.

ILRI and its predecessors have a history of being involved in systems research. Originally, it started as ecozonal research. The idea was to select areas representative of broad regions of similar ecological conditions (rainfall, vegetation, temperature, soils, etc) in order to conduct farming systems research that would be applicable to the broader ecozone (recommendation domain). Jahnke (1982) has synthesised this work, based on the ecozone classification of FAO.

Various driving forces are combining to suggest that in future ecoregional research is going to develop considerably and have substantial impact:

a) Availability of tools. This relates particularly to developments in geographic information systems that allow the incorporation of socio–economic and bio–physical data, remote sensing, computers and communication technologies that allow more extensive storage of databases and faster analyses, transferability of information, simulation modelling of systems, and accessibility to end–users and stakeholders.

b) More experience in multidisciplinary research. Multidisciplinary research has often been a time–consuming process, partly because of perceived conflicts between reductionist and holistic approaches. These are two sides of the same coin, and must proceed in tandem to attack complex problems. Effective solutions to smallholders' problems are more likely to be forthcoming when stakeholders participate in problem identification, design of solutions and their testing. A greater critical mass of scientists with the skills for multidisciplinary research now exists.

c) Better knowledge of biophysical and socio–economic constraints. Past farming systems research tended to look at problems at the farm level, and mostly from a technological perspective. Many constraints are related to inappropriate policies, lack of markets for inputs and outputs, ineffective institutions, etc.

d) Financial constraints. In the past, relatively plentiful resources for research brought scientists the freedom to experiment and conduct long–term research. Current financial constraints impose a need for careful planning and targeting of efforts to solve problems of broad relevance, which can be identified with the help of *ex–ante* impact assessments.

e) Environmental concerns. Past research efforts have tended to emphasize production and productivity gains, with sometimes mixed consequences for the environment.

f) Social concerns. Emphases on societal, familial and intergenerational equity are very much to the fore, and research for development needs to address these concerns.

Given the evolving goals for research for development and financial constraints, it is not yet clear how ecoregional research can best respond to the challenge. Our toolbox certainly needs to be expanded considerably if

ILRI is to become highly effective and efficient in carrying out natural resource management research at a regional level at spatially dispersed sites.

Conclusions

Ecoregional research should be considered to be evolutionary. While some initiatives have undertaken a long preparatory phase (Desert Margins), others have taken a more pragmatic approach and have progressed much more quickly to the research phase (CONDESAN). Support to these initiatives will presumably increase, but probably not in a very dramatic way. In the future, participants will increasingly be expected to invest matching funds.

Given considerable pressures from donors, environmentalists and others about impact from livestock–related research, and more specifically their relation to natural resource management and the environment, ILRI will be expected to strengthen efforts in this area. Not doing so will have serious effects in terms of potential impact of ILRI's research, credibility with partners and donors, and overall future financing of the institute. There are some difficult questions to grapple with, however, including the following:

1. Do we require a framework as such, or is it more important to identify with considerable precision the focuses of ecoregional research at ILRI, from which a coherent framework can be derived?

2. Are the Sustainable Production Systems Programme teams located in the different regions necessarily "ecoregional teams"—in other words, is there a need for all (or even most) of their research to be ecoregional in scope?

3. To what extent do we require standardised data collection protocols and standardised methodologies and models for what ILRI is trying to do?

4. What is the most effective way to manage spatially dispersed research teams to ensure compatibility between activities, in the search for technologies of transregional relevance?
5. Which are the gaps in ecoregional methodology that are particularly relevant to crop–livestock systems, and how might these be plugged effectively?

Resolution of these issues will go a long way towards helping to strengthen the linkages between ecoregional and more strategic research at ILRI and helping to enhance the effectiveness of natural resource management research in the context of crop–livestock production systems.

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ILRI'S RESEARCH IN THE HIGHLANDS ECOREGION

M.A. Mohamed Saleem

Summary

This paper outlines the evolution of ILRI's highland ecoregional research programme from the 80s to its current form. It highlights the shift in the programme focus from food improvement in the 1980s to embrace the sustainability goals of the CGIAR (Consultative Group on International Agricultural Research) of the early 90s and most recently, the global concerns associated with ILRI's new global mandate. The concomitant changes in the research approaches from farming systems research to natural resources management and sustainable agriculture are also highlighted. A matrix for analysing production constraints within the highlands and ILRI collaborative research is also presented. In concluding, the paper underscores the importance of stakeholder analysis to harmonize the different concerns of stakeholders in natural resources management and sustainable agricultural research.

Background

The manner in which ILRI's highlands research is currently operationalised has been influenced by three major shifts in emphasis since the time ILCA (International Livestock Centre for Africa) considered the highlands (area above 1500 m asl) a priority zone for livestock research twenty–five years ago. Although farmers' needs and problems have been the major driving force, global political concerns and donor preferences have also significantly influenced the highland research and development agenda at ILRI.

Early Period

The pioneers at ILCA justified research in the highlands on the basis of the following:

- Rapidly rising human population, which in some countries in the region is increasing at more than 3% annually.
- Increasing pressure on land for growing food crops.
- Increasing soil erosion and permanent loss of agricultural land.
- Increasing dependence of livestock on crop residues as natural pasture availability declines.
- Low productivity of livestock, which, with some exceptions, have not been subjected to selection for milk and meat yields.

At its inception, the principal thrust of the highland research was "to develop and test low–input techniques for increasing the contribution of livestock to farm production for resource–poor African smallholders" (ILCA,1983).

Global concern over famine in the early 80s, particularly in Ethiopia, and donor enthusiasm to play a humanitarian role made funds available for efforts

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that had the potential to increase food production in the shortest possible time. ILCA had access to such funds from Swiss Development Co–operation (SDC). Starting in 1986 ILCA highlands research changed focus and initiated a collaborative project with different NARS (National Agricultural Research Systems) and international organisations for the improvement of vertisol management, which gave the "donor–desired" emphasis to food improvement. Research on draft animals and animal–powered implements was the entry point for ILCA in these efforts. ILCA adopted a farming systems approach to research. This involved identifying constraints from baseline surveys, designing new systems on the experiment station to replace part whole of the local or traditional systems, and on–farm validation/popularisation of technologies.

Jumping on the Band Wagon

Starting in the early 90s, we entered the era of the "sustainability movement" with the CGIAR slogan of increasing food security, alleviating poverty and protecting the environment. This had three implications for research approaches in the highlands at ILRI:

- Values of natural resources such as ecosystem maintenance, biodiversity, water recharge, and bequeath value became as important as obtaining high yields of crop and livestock products.

- To manage natural resources, we had to take into account the vertical delineation of land forms, and the impact of one type of land–use upstream on the health and production of another type of land–use downstream. Until then, the issue of vertical differentiation was not an important consideration in our farming systems research model.

- Sustainability needs to be measured over a period of at least 10 years. The benefits of sustainable agriculture in the long–term do not fit within most farmers' decision–making horizon. In some respects, sustainability and short–term impacts seem contradictory. However, demands from donors for immediate and measurable impacts have not changed.

- Long–term benefits from natural resource management improvements do not fit within the new shift in research emphasis on sustainability. This required a shift in our approaches to address agricultural sustainability in the highlands as indicated in Table 1.

We also realised that there was a dearth of published literature on sustainable production and a well–tested framework for long–term assessment of aggregated benefits of technologies and policies in space and time.

ILRI's Global Mandate and Highland Ecoregional Research

With the global mandate of ILRI, it was recognised that work in the highlands needed a change in research priorities and approaches that could be used to select relevant experimental sites and could lead to extrapolation of results. We also realised that although ILRI priorities changed in 1995 to reflect global issues, implemented activities had to accommodate the on–going work that started when sub–Saharan Africa was the mandate area. This was necessary because ILRI had commitments to donors and on–going collaborative partnerships.

Table 1. Research considerations when shifting from a farming systems to a natural resources focus.

Parameter	Farming Systems Research	NRM & Sustainable Agriculture
Temporal	Field–Village	Watershed, ecoregion
Beneficiary	Farm households (on–farm)	Multiple groups (on– & off–farm)
Technology	Whole–farm system	Complex, ecosystem Sensitive
Purpose	Farm profits, improved income	Monetary and non–Monetary (nutrition & health)
Role of farmer	Provider of information to researcher	Participatory, indigenous knowledge
Policy	Marketing products	Marketing & Individual and Society empowering
Equity	Gender/benefits to poor	Gender/benefits to poor/inter generational

Adapted from Rhoades (1997).

Access to global data sets, characterisation and GIS expertise would have helped us a great deal in priority–setting. These are expected to be available through collaboration with ILRI's System Analysis and Impact Assessment project in the future. However, we realised that there was a great deal of confusion in research concepts to address NRM issues and sustainability. This arose from varying perceptions of the problem and different scales in which research was being carried out without reference to the spatial and socio–demographic hierarchy.

Across the globe, the highlands form the water towers and functionally they play a major part. Unlike the plains, the highlands contain several sub–

ecozones with characteristic vegetation communities, which are governed by complex interactions of precipitation, solar radiation, temperature and edaphic factors. Within short distances, differences in altitude gradients are responsible for distinct variations. Highland farmers exploit separate levels of the vertical landscapes, and from a household point of view survival depends on interdependent multi–zonal exploitation of the land.

Based on the literature and expert knowledge, we developed a matrix that delineated major land–use systems using altitude, land slopes and climatic and edaphic characteristics (Table 2). Although this delineation is crude, it has provided the basis for analysing production constraints in each of the sub–ecozones. In order to refine this matrix and enable inter– and intra–regional comparisons, we needed more data on:

- History and land–use trends.
- Boundaries and extents of production by crop types, livestock, grassland and forest cover.
- Productivity of land–use types and seasonalities.
- Farming knowledge and technological base.
- Infrastructural changes etc.

General production constraints encountered at the different vertical levels in the highlands are also given in Table 2. Some technologies can provide direct benefits to individual farmers by alleviating constraints in a given vertical zone or "niche", while others can provide collective benefits when farming communities are brought together.

Examples of Technological Options to Address "Niche"–Related Problems

Land potential and land–use practices differ when the gradient and altitude are taken into consideration. Major constraints to improving productivity and arresting degradation of the resource base of the Ethiopian highlands were found to be:

- Seasonal waterlogging restricting the full use of lands on the lower slopes.
- Land fragmentation, disappearance of fallows, negative soil nutrient balance, low crop/fodder yields, and food deficit in the medium slopes and altitudes.
- Because of increasing population and the resultant pressure on land for cropping, very steep slopes and high altitudes were overstocked at the risk of widespread of soil erosion.

Possible technological options identified as suitable for different "niches" are given in Table 2. The ILRI collaborative research undertaken in the highlands can be grouped into the following areas:

a) Intensified food /feed production strategies.
a) Feed utilisation strategies.

b) Livestock–mediated soil, water and nutrient management strategies.
c) Spatial integration of system improvement strategies.

Intensified food/feed production strategies

Land productivity is low, land holdings are small, household food and feed requirements are high compared to what an average household can produce, and crop/forage/livestock biogenetic production potentials are not achieved. Intensification of land–use to increase feed production per unit of land (in terms of quality and quantity) and to minimise the effects of seasonal feed availability, without affecting the food production potential of the land, is the major challenge. Associations of food and forage crops have been achieved by manipulating spatial and temporal resource–sharing attributes of the crops and forages. Research includes:

- Selection of forages based on growth requirements.
- Assessment of resource (light, water and nutrients) sharing at various spatial and temporal associations of food and forage crops.
- Improved tillage practices for alternative cropping schemes.
- Assessment of nutritive quality and harvest time to maximise quality and quantity of usable feed.
- Household land allocation for different crop–forage mixtures to balance year–round grain and feed requirements.

Preparation of broadbeds and furrows using an animal–powered broadbed maker improved drainage of vertisols. These soil types are normally found on the lower slopes and in the valleys and often remain waterlogged during most of the growing season. Making broadbeds and furrows can improve drainage, which allows early sowing of crops, followed by another crop sown later in the season after harvesting the first crop. This has opened up opportunities for growing different crop/forage types and their combinations in the same year.

Feed utilisation strategies

Available feed for livestock is inadequate. Seasonality and inter–year variability in feed quality and quantity aggravate the farm feed–shortage problem. Even if feed production can be improved, what are the relative nutritive values for livestock: when, with what type, how much and in what form (fresh, wilted, dried, chopped, etc.) should the needs of livestock be supplemented? What should be the feeding package for dairy cows or small ruminants (fattened strategically for markets) or for draught animals (to keep them in good body condition before the onset of the ploughing season)? These are questions addressed in this area of research. We are also studying whether crossbred dairy cows can perform multiple functions (milk production and draught power) without affecting reproductive ability over the animal's life span.

Livestock–mediated soil, water and nutrient management

Nutrients are lost from production systems through harvested products, and purchased inputs for nutrient replenishment are often expensive. Efforts to

Table 2. Land–use practices and technological options in the highlands.

High ← Altitude → Low

Steepness of slope	>2,500m	1,500–2,500m	< 1,000m
High (> 15°)	• Forests • Shallow rooted • Pasture & grazing	• Forests • Tea / coffee • Pasture & grazing	Permanent crops Horticultural crops Pasture & grazing
8–15°	• Forests • Pasture & Grazing • Horticultural crops	• Wheat / Barley • Horticultural crops & pulses • Mixed crop – livestock • Specialised dairy	• Maize / Sorghum • Horticultural crops • Mixed crop – livestock • Specialised dairy
4 – 8°	• Pasture & grazing • Horticultural crops	• Wheat / Barley • Horticultural & pulses • Mixed crop–livestock • Specialised dairy	• Maize / Sorghum • Horticultural crops • Mixed crop–livestock
Low (0 – 4°)	• Horticultural crops • Pasture & grazing	Intensive • Wheat • Pulses • Horticultural • Grazing • Teff	Intensive • Rice • Pulses • Grazing

Problems	Solutions	Technologies
• Erosion • Overgrazing	1. Improve vegetative cover 2. Reduce nutrient loss and improve water retention	1. Grazing frequency and intensities 2. Manure management and increased soil protective cover
• Land / (food/feed) shortage • Erosion • Draft power	1. Intensify land–use 2. Tree in systems 3. Improve energy & nutrient use efficiency 4. Prevent livestock diseases of intensification	1. Food/forage crops 2. Alley cropping/fence lines MPT • Manure & fertilizer use 3. Dairy/draft cows • Feed supplementation • Improved fiber digestion • Breed selection
• Waterlogging	1. Improve drainage 2. Reduce soil loss 3. Increase grain and fodder	1. Broadbed maker 2. 2 & 3. Multiple food/forage crops

improve livestock production in smallholder farming systems include the efficient use of crop residues and manure, and introduction of herbaceous/tree forage legumes. This has opened up opportunities for managing nutrients in the production system through:

- *In–situ* recycling nutrients through manure.
- Accumulation and spatial concentration of nutrients.
- Planted fallow and leys.

What is the quality of manure, how does it vary seasonally and with feeding strategies (e.g. grazing versus penned); which weed species accumulate, through undigested seeds, when crop fields are manured and what is the impact of these weeds on crop yields or in changing species composition in grazing lands? How much manure will be required, and what are the complementary effects of mixing manure and inorganic fertilizers on crop nutrient uptake? For how long will the application effects of manure last in the soil, and how much of the applied nutrients will be retained in surface and sub–surface water? What are the relative benefits of natural and planted fallow to livestock and to food crops that follow the fallow? These are questions addressed in this research.

In the highlands, livestock are spatially and temporally associated with grazing lands and crop lands. Livestock spend considerable amounts of time on crop lands, particularly after grain harvest, grazing crop residues, recycling nutrients, and compacting the soil. Crop lands are periodically ploughed and fertilised, while actions of the hoofs of grazing animals are accumulated, often compacting the grazing lands. Common grazing lands in African countries are not fertilised to improve biomass productivity.

With increasing cultivation of steeper slopes, livestock are pushed further on to very steep slopes. Hence, lands where animals graze during the cropping season are overstocked and overgrazed. Soil structural changes under varying grazing pressures influence soil erosion, water infiltration, water retention, subsurface flows, and runoff rates.

An understanding of the influence of grazing on biophysical processes, including vegetative and hydrological changes, is a prerequisite to developing better resource management strategies that can contribute to intensification of mixed crop–livestock systems in the highlands. Long–term investigations in this research area include:

- Assessment of seasonal variation in grazing pressure, potential biomass production and biomass availability.
- Vegetative cover, run–off rates, soil erosion and soil water infiltration.
- Biomass requirements for meeting grazing demands and soil protection on varying slopes.
- Surface and sub–surface faunal and floral diversity.
- Grazing land productivity with and without manure deposited during grazing.

Sustainable Agricultural Development in the Highlands

Traditional agricultural practices in the highlands are no longer sustainable with the increasing population pressure and disruption of social systems that are occurring in the spirit of modernisation. However, new production technologies *per se* may not themselves provide all the answers. People have different needs, with implications for food security, poverty alleviation and environmental protection beyond individual farms. Different land–use systems, therefore, are required to meet the multiple needs of people but they will have to be integrated at a bigger landscape level to assess their benefits in terms of food security and environmental protection. Multi–zonal land–use arrangements in the highlands do not allow individual decision–making and action without consideration of the broader community. Therefore, appropriate policies also need to be in place to enable farmers to adopt new technologies for development and management of common resources.

We have identified two watersheds that exhibit many of the production, human and environmental features of the East African highlands. Intensive work at Ginchi is being carried out with different partners to generate public goods by combining various technologies. A second site at Chefe Donsa was identified, and characterisation work is to be completed soon. This site provides a contrast to the Ginchi watershed in terms of agro–ecology, population pressures and cropping systems while also providing opportunities for testing the same technologies as in Ginchi.

Lessons Learnt

Integrated assessments at the household and community levels are linked to various external conditions. Farming decisions are made according to available assets and natural resources, and external forces at the national, regional and global levels can significantly influence decision–making. Benefits (reduction in erosion, siltation, flood control, etc.) from NRM at the watershed level actually occur outside individual farmers' fields. It is often assumed in market economies that individuals usually have short planning horizons for decision–making. Therefore, even if the farmer is aware of the long–term benefits, the sustainable agricultural options that have the highest likelihood of being adopted are those that increase yields and decrease risks to compensate for the yearly costs of implementing those options. The time and investment required of individual farmers to implement many of the practices proposed to improve sustainable agricultural production may be inappropriate. This is where stakeholder analysis will be very important, and in our experience we have found that farmers, policymakers, planners, development agents, and donors are all stakeholders. But the farmers have a bigger stake than the others, and they are the ones directly linked to the natural resource base. Reconciling the different concerns of local people with the other stakeholders is one of the major challenges, and there seems to be no well–tested paradigm yet to address this. The major challenge for resource management research is to aggregate individual economic considerations and individual resource–use objectives for the benefit of the entire community. This is an aspect that the highlands research team at ILRI has embarked upon, starting in 1998.

Agro–ecosystems are complex, but their complexity is largely attributable to the interaction of socio–economic and ecological processes. To evaluate agro–ecosystems and to aid in their improvement, the ultimate impact on the people who depend on them will have to be considered. Data are being collected across different highland sites in Africa and Asia on different components at spatial and temporal scales. This includes data on the elementary processes in different ecozones to isolate impact of livestock on the natural resource base and anticipate development of natural resource and land–use trends. We hope these will provide the necessary technical background for designing alternative options for livestock production systems across different highland ecoregions, and this effort is being pursued with the International Centre on Integrated Mountain Development (ICIMOD). There is as yet no satisfactory framework for facilitating an integrated evaluation of these multi–faceted data sets. We have considered the use of an agroecosystems health framework.

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CROP–LIVESTOCK SYSTEMS RESEARCH IN THE ANDEAN REGION: ECOREGIONAL APPROACH, METHODS AND PROCEDURES

Carlos León–Velarde and Roberto Quiroz

Summary

Increased population, low agricultural productivity, pressure on land and overexploitation of natural resources, are current problems in the Andean ecoregion. Knowledge of the region is vast, but results from site–specific research have seldom been integrated. A holistic ecoregional research approach is required to solve the problems and contribute to regional development. To this end, the appropriate definition of the term ecoregion and the proper use of methods and procedures to generate and adapt technology are necessary for sustainable development. This paper aims to present the integration and management of knowledge in a holistic way for the effective application of systems analysis research in an ecoregional context.

Introduction

Agricultural researchers apply the scientific method to overcome factors limiting agricultural productivity. Appropriate technology and financial resources are key limiting factors, particularly on resource–poor farms. A close look at the scientific method raises the issue of whether this method *per se* may be applied to solve technological and policy problems that constrain agricultural productivity. In a restrictive sense, the scientific method can be seen as a process that utilizes knowledge to generate new knowledge (Figure 1, adapted from Cañas and Lavados, 1989).

Problem–solving requires adaptation of knowledge to overcome limiting factors. The successful use of technology to solve major constraints to agricultural production relies upon adequate experience with the problems within a specified context, and appropriate application of available knowledge. When this is used to address the agricultural problems of smallholder farmers with their active participation, this is generally described as Farming Systems Research (FSR). Many of the reasons are presented elsewhere (Dent, 1993; Thornton, 1991).

This paper attempts to contribute to the definition of ecoregional research and the integration and management of resources in a holistic way, for more effective application of systems research. It is not the intention to present a comprehensive review of the methods and procedures used to solve problems. Some examples from experience in the Andean region are presented to show how the application of different tools and procedures can help in the context of ecoregional research.

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Towards a Framework for Ecoregional Research

There is no consensus about the meaning of ecoregion (Li Pun *et al.*, 1998). However, the ecoregional approach addresses explicitly the choices among different agricultural land–uses and the unavoidable trade–offs among objectives (Rabbinge, 1991). Consequently, the first step is to define the meaning of ecoregion. The definition of a system (a group of physical components that have a structure and function) helps to understand the concept of ecoregion. Fundamentally, a system has limits, components, inputs, outputs, and relationships among components. The relationships among components of the defined system and the environment need to be studied to understand better the behaviour of that system.

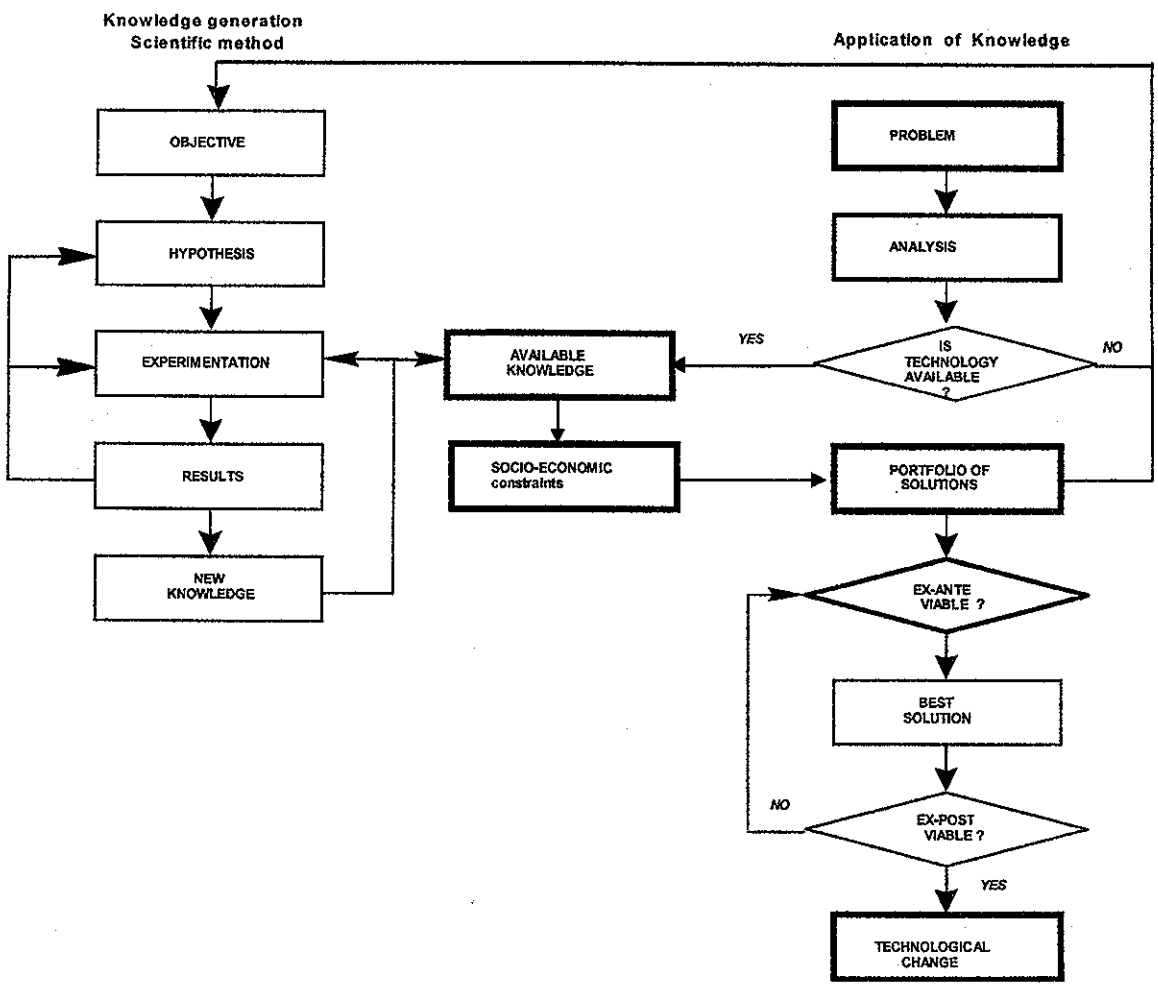

Figure 1. Linking scientific method with knowledge use in FSR (adapted from Cañas and Lavados, 1989).

An ecoregion can be defined as an area that shares biological and socio–economic characteristics within administrative boundaries. These characteristics help to identify biophysical and socio–economic opportunities and constraints for development. Therefore, an ecoregional research

approach is a way of carrying out quantitative and integrative research on ecoregions. Ecoregions contain a diversity of soils, water resources, crops and livestock, and people in diverse social and economic conditions, who presumably attempt to use resources in a sustainable way for agricultural development. Consequently, ecoregional research requires integration across disciplines, particularly of biophysical and socio–economic sciences.

The Andean region can be considered a system with sub–regions, each with particular biological, economic, social and climatic characteristics. The Northern sub–region (green Andes), Central sub–region (high altitude and narrow valleys), and the Altiplano (yellow or dry Andes), can be considered ecoregions of the Andean region (PISA, 1993; ILRI, 1997; CONDESAN, 1997). The classification is based on rainfall, altitude and temperature, among other bio–economic and social factors. The sub–regions considered include Ecuador, Peru and Bolivia, and southern Colombia.

Ecoregional research in the Andean region is shown in Figure 2. The right–hand side of the figure shows the phases of Farming Systems Research. The central section shows the systems analysis approach, whose goal is to generate, adapt or use knowledge to improve a particular system through adequate technological alternatives. These are generated by identifying the comparative advantages and market opportunities in the ecoregion. The research pays particular attention to improving or maintaining the natural resource base.

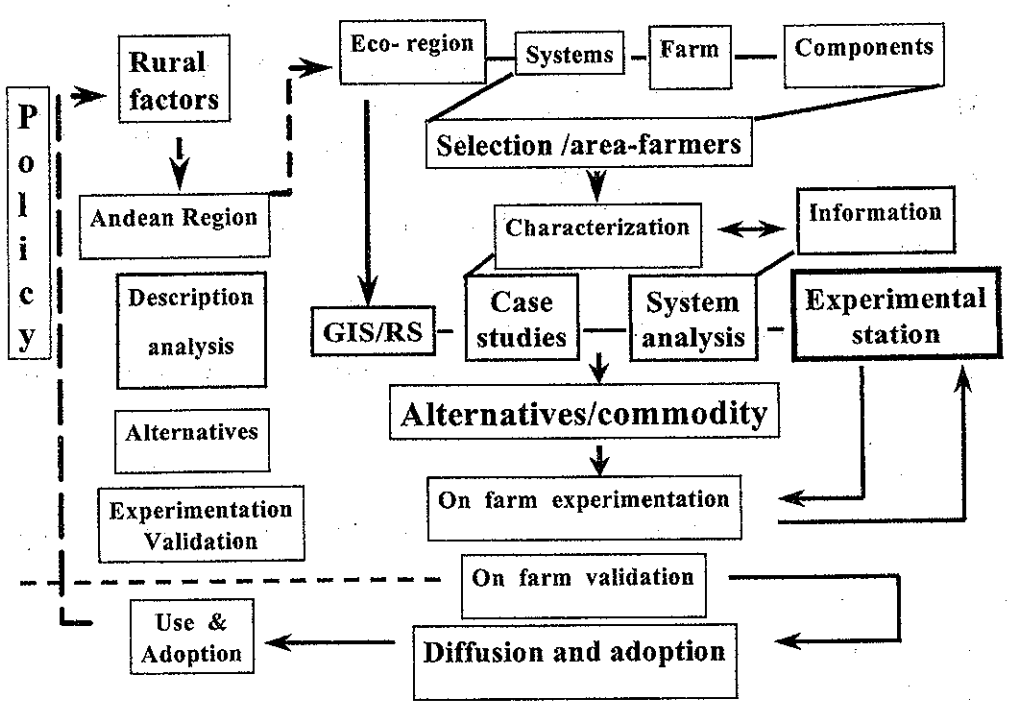

Figure 2. Ecoregional research approach in the Andean region integrating systems analysis within Farming Systems Research.

Experimental work is conducted on–farm or at a research station. The concept of on–farm research needs to be clarified. It can be done with direct or indirect farmer participation but this depends on the scientific rigour

required and on how advanced the technological alternative is. Usually, this issue becomes a discussion between experimentation and validation, which should be resolved by researchers and extension agents.

The dotted line in Figure 2 indicates the diffusion phase, which is the responsibility of the national institutions. Duplication of effort should be avoided. However, it is necessary to establish strong linkages between research institutes and extension agents to obtain impact. In the Andean region impact is measured as the number of NARS (National Agricultural Research Systems) that are delivering a technological alternative generated through ecoregional research.

Bio–Economic and Social Information to Define an Ecoregion

For a clear definition of an ecoregion, it is necessary to delineate the region (e.g. Andean). The research should then be orientated to define benchmark sites that are representative of the ecoregion. However, it is necessary to recognize that there are likely to be large differences in socio–economic dynamics. The benchmark site is where research activities are carried out, but the appropriate hierarchical levels need to be clearly defined. The interactions between the various economic levels in particular need to be considered.

The main factors, parameters and variables to be considered in a characterization include the following:

Biophysical factors:

- Soil, topography and slope; type of soils and erosion rate.
- Water sources: quantity; seasonality; quality expressed in terms of sediment residues and salinity. Water use for irrigation, domestic, commercial and industrial purposes.
- Vegetation: Normalized Difference Vegetation Index; pasture, crops and forestry.
- Climate: Temperature (maximum and minimum); rainfall variability; radiation; hours of light; wind velocity.
- Agricultural production: crop and livestock production and productivity.

Social factors:

- Index of human development: income, education, and life expectancy.

Economic factors:

- Gross national product, per–capita income.
- Price of local products at farm– and market–level.
- Price of imported products.
- Access to market: distance and quality of infrastructure (access roads).
- Estimation of value–added through transformation of agricultural products.

Institutional factors:

- Institutions and human resources.

Table 1 summarizes the main parameters and indicators considered in most crop–livestock production systems. In the Andean region, a combination of crops, livestock and forestry is found. However, forestry as well as native grasslands require intervention to avoid or control the rate of natural resource degradation.

Research in an Ecoregion

Research in an ecoregion requires biophysical, economic, social and institutional information. Table 2 shows the biophysical factors along with the parameters and variables needed to define and classify areas of intervention. Biophysical indicators can be used to determine three types of zone:

1. Degraded.
2. Vulnerable.
3. Zones with potential for intensification or diversification.

Table 1. Major parameters and indicators considered in the analysis of a crop–livestock production systems.

Parameter or component	Sub–system components[1]		
	Crop	Rangelands	Forest
Soil properties	Organic carbon content Nutrient content Cation exchange capacity Erosion rate	Salinity Organic carbon content Nutrient content	Nutrient contents
Water quality and quantity	Salinity Seasonality Pollutant concentrations	Precipitation patterns Pollutant concentrations	Seasonality Evapotranspiration fluxes Pollutant concentrations Base flow
Biological diversity	Species richness and diversity of indicator groups Population size of keystone species Crop diversity Soil and pest organism diversity	Species richness and diversity of indicator groups Population size of keystone species Forage diversity	Species richness and diversity of indicator groups Population size of keystone species Forage diversity
Production of goods and services	Crop productivity (output/input) Crop genetic reserves	Stocking density Forage productivity	Wood and non–timber product yield
Energy and nutrient flow	Parent rock nutrient mobilization Nutrient (fertilizer) input fluxes Energy efficiency and quality	Nutrient mobilization	Primary productivity Nutrient mobilization
Landscape, composition and patterns	Field size and mix Land–use conversion rate	Grazing gradients Land–use conversion rate	Spatial variation of vegetation types Land–use conversion rate
Atmospheric composition	Acid precipitation UV–B irradiation Troposphere ozone concentration Carbon dioxide concentration	Acid precipitation UV–B irradiation Troposphere ozone concentration	Acid precipitation UV–B irradiation Troposphere ozone concentration Carbon dioxide concentration
Climate	Temperature mean and variability Precipitation mean and variability	Temperature mean and variability Precipitation mean and variability	Temperature mean and variability Precipitation mean and variability

1. Does not include wildlife/ wild–lands; freshwater fisheries; wetlands/groundwater; coastal resources and marine fisheries (adapted from Munasinghe and McNeally, 1995).

Interaction of socio–economic and biophysical indicators with institutional capacity result in a biophysical and socio–economic characterization. Usually, ecoregional research will be carried out in degraded and vulnerable zones. Research activities on soil conservation and forestry are likely to be important for degraded lands. Zones 2 and 3 will often overlap, and in some cases will also have degraded areas. In such cases, research becomes a particular challenge, especially for the short–term. Links with policy research are then likely to be highly important.

Figure 3 shows in schematic form the institutions, methods and efforts for rural development from the farm level to higher hierarchical levels such as the ecoregion or region. Much research addresses the farm level but not the ecoregion. Efforts will often lead to a point where discussions with decision–makers at the policy level are needed. In such cases, the results of scenario analysis from model simulations can be of prime importance. Table 3 describes the phases of ecoregional research based on system analysis.

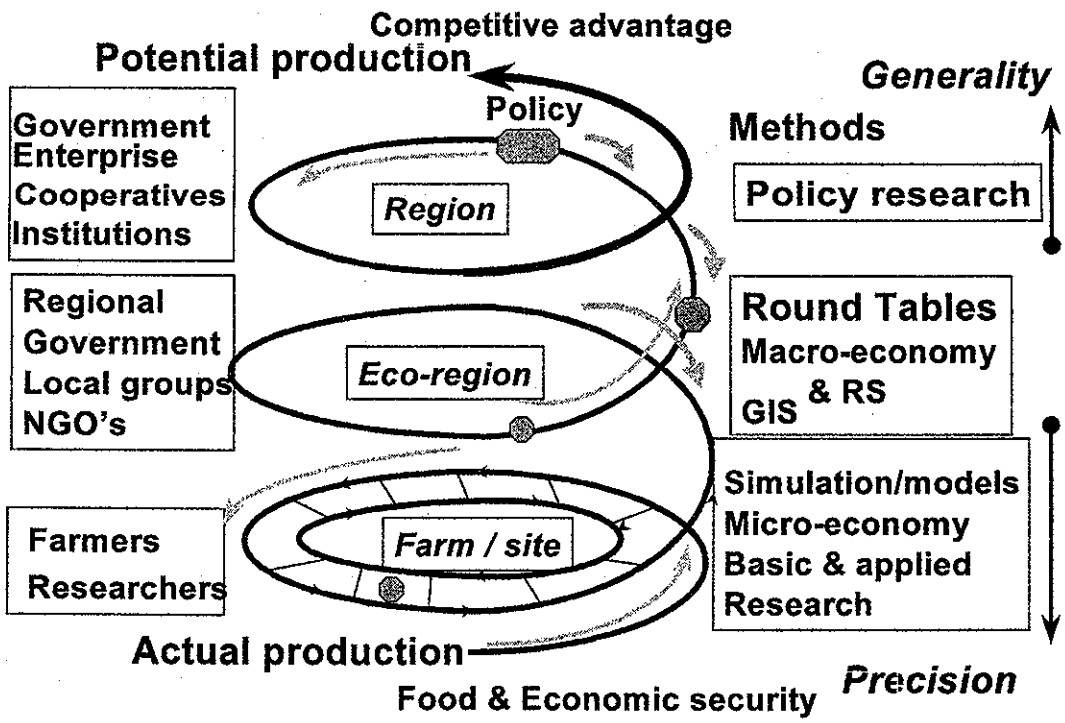

Figure 3. Schematic representation of rural development based on ecoregional research.

Analysis of Scenarios and Site Selection

Quantitative information plays an important role in the selection of a site. However, because of external influences that are usually beyond the control of researchers, a balance between research and development is required. Mathematical programming models and computer simulation models such as ALES (Rossiter and van Wambeke, 1994), DSSAT (Bowen *et al.,* 1993; Tsuji *et al.*, 1994) and others (León–Velarde and Quiroz, 1994; León–Velarde *et al.*, 1997; Quiroz *et al.*, 1995), have a large role to play in helping to analyze current and potential scenarios. Results from such scenario analysis can provide information concerning changes and impacts at selected sites or of

particular technological alternatives (Pandey and Hardaker, 1995; Quiroz *et al.*, 1998). One important tool is the response surface (Montgomery, 1984). This tool, constructed with results from factorial experiments in the field or with simulation models, can be used to evaluate the effect of several factors on system performance over time.

As an example, Figure 4 shows a response surface of the dynamics of cattle herds in the Andean region. There are more possibilities for intensification for those herds with less than five cows. Herds with between two and five cows with management effects from 50–60% indicate a *status quo* for animal production in the Andean region. Herds with more than five cows have more possibilities for intensification if there is an adequate level of management (>60%) and an adequate farm size with market orientation. Similar examples are described for Alpacas (León–Velarde and Quiroz, 1994) and dairy production (León–Velarde *et al.*, 1994).

Table 2. Information that may be required for biophysical characterization of an ecoregion.

Type of information	Variable	Frequency	Unit	Format	Process
Soil					
• Secondary information	Soil types	1		Digital map	Make map
	Slope	1		Digital map	
• Local classification	Soil types	1		Digital map	Make map
Vegetation					
• Secondary information	Covered vegetation	1		Digital map	
• Aerial photography	Covered vegetation	1		Photo/Digital	Make map
• Satellite image	Covered vegetation	1	RD	Digital map	Make map
Water					
• Secondary information	Sources of water	1		Digital map	
	Caudal river	By season	m^3/s	Chart/Digital	
	Sediments/residues	By season	μ/λ	Chart/Digital	
	Salinity	By season	μ/λ	Chart/Digital	
	Use of water	By season		Chart/Digital	
Weather					
• Secondary & primary information	Temperature (max/min).	Daily	°C	Chart/Digital	Probabilities &
	Precipitation	Daily	Mm	Chart/Digital	Annual pattern
	Radiation/hours light	Daily	J	Chart/Digital	Annual pattern
	Wind	Daily	m/s	Chart/Digital	
Agricultural production					
• Secondary information	Crop production	Annual	t/ha	Chart/Digital	Link–map
	Livestock production	Annual	t/ha	Chart/Digital	Link–map
	Forestry	5 years	RD	Chart/digital	Link–map

Linking Ecoregional Research with Sustainability and Adoption of Technological Alternatives

The goals of the ecoregional approach dictate the methodology and the tools that can be used. Case studies aim at the exploration of possibilities from studies that investigate what is expected in the near future. In many of these studies, a time horizon is needed. Trends based on secondary information

can give information concerning the near future. Different trend models can be applied to observe the rate of improvement over time. In the case below, sustainability is measured as the increased rate of a particular parameter, be it biological, economic or social. Searching for a composite index with which to measure sustainability is a challenge. The approach taken here is to use gross or net income over a number of years. Simulation models that include several factors can help to measure farm–level or ecoregional sustainability. At the same time, these models allow the user to observe the effect of a particular factor such as soil or pasture sustainability.

Figure 5 shows a scenario of income accrued by Alpaca farmers over time by adopting new pasture management and herd techniques (based on 80 ha farm size in the Altiplano). The logistic curve used shows three phases: initial sustainability, a technical increment, and bio–economic sustainability (Quiroz *et al.*,1998). A similar pattern of milk production and herd productivity, comparing estimated and real data, was demonstrated in Guyana (León–Velarde *et al.*, 1994).

Table 3. Methods and procedures utilized in ecoregional research in the Andean region based on farming systems analysis.

Phase	**Methods**	**Observations/procedures**
Characterization	Secondary information Static and dynamic surveys Rapid rural appraisal GIS & Remote sensing	Statistic/compilation; charts, figures. Farmer participation; depend on the dynamic of the variables Farmer participation Satellite images; ground truthing; maps
Analysis	Principal component & cluster Analysis. Linear and non linear mathematical models Simulation models Econometric models Cost–benefit analysis	Definition of farmer strata & target population Trends; sustainability (logistic, linear and non–linear models) Comparison of scenarios (current and potential); risk analysis Economic response; linear programming, multiple–goal programming. Profitability; risk analysis
On farm/station Experimentation and validation	Experimental design (classic) Composite central design Trials farmer *vs* alternative	Cause–effect response Response surface; scenarios Validation on farm/linking adoption
Diffusion/farmers Researchers and Extension agents	Fields days; short courses Publication; manuals Seminars; workshops Communication media	Farmers participation/linking adoption Description of technological alternatives Researchers and extension agents Radio; television (tapes–short and case studies)

In a similar way, the alternatives generated for a production system in the ecoregion need to be incorporated into farms through an adoption process.

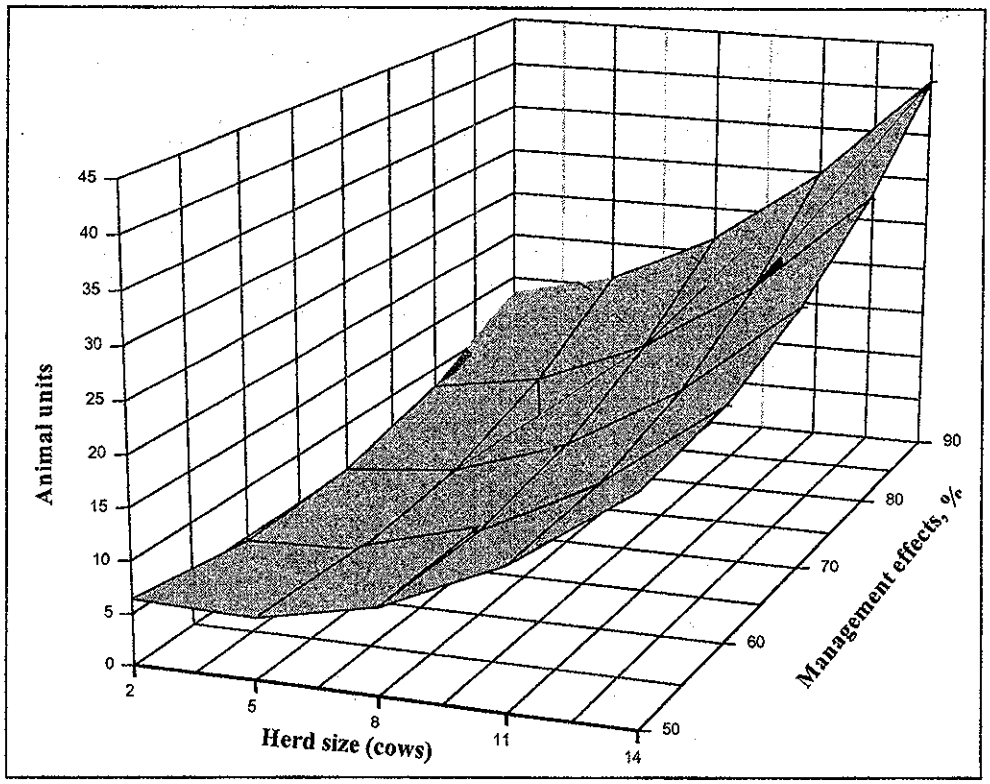

Figure 4. Relationship between herd size and herd management effects (calving rate, mortality, age at first service) in the Andean region. Response surface is simulated over ten years.

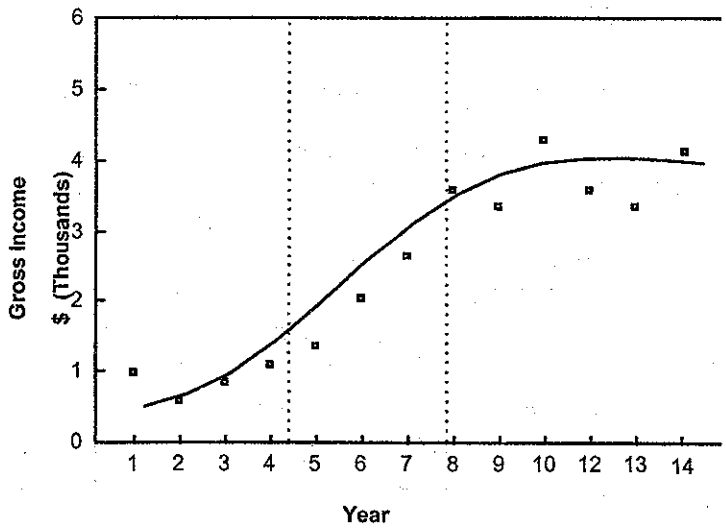

Figure 5. Simulated gross income accrued by Alpaca farmers overtime by adopting new pasture management and herd techniques (based on 80 ha farm size in the Altiplano). $Y= b_0/(1+b_1e^{-b2t})$; b_0=3,891.2, b_1=22.2, and b_2=0.57.

During this process, the main constraint is capital; consequently; the degree of adoption needs to be measured. There are various algebraic forms of the adoption curve that can be used to measure or estimate the adoption process.

Figure 6 shows the numbers of farmers adopting a particular alternative to produce seed potato in rustic greenhouses. As far as the project was concerned, a target level of adoption was reached during the life of the project. However, the time required for adoption to reach its asymptote is close to ten years. The issue of how this adoption process is managed and implemented once a project has terminated is an important one, and solutions call for strengthening the links with national institutions.

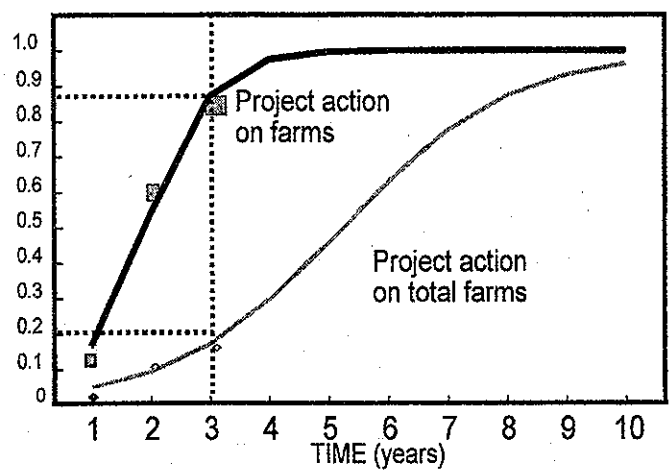

Figure 6. Impact of adoption of potato seed production in rustic greenhouses. SEIMPA project, Puno, 1995.

Research in the Andean Ecoregion: Conceptual and Operational Scheme

Ecoregional research in the Andean region is based on the conceptual framework described above. Activities are set up at various levels that distinguish the biophysical, economic and social environment within administrative boundaries, such as the country and watershed. The coordination is done by different institutions. For each site there is a research or education institution (national research institutions or university) linked with an extension institute such as an NGO. Table 4 summarizes the sites within ecoregions. Each site presents special characteristics; the problems are of the same nature, but their magnitudes are different. Consequently, for each site within an ecoregion, the priorities change in relation to market opportunities. In some cases subsistence is important, with the surplus production going to market. For other sites, intensification of crop–livestock systems with a clear market orientation is the priority.

Table 5 shows the orientation and focus of research planned in the Andean region, based on the conceptual framework shown in Figure 7. All the work is being done in collaboration with different agencies. Among these are Spanish Agency of International Cooperation (AECI), International Development Research Centre (IDRC), International Potato Centre (CIP) and the

Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN). The main goal is to improve family income through sustainable land–use based on crop–livestock systems. The gray shaded areas represent the work components, while the non–shaded areas show the operational research issues carried out with the national institutions. Table 4 shows the links of each participating institution with the operational research areas shown in Figure 7.

Studies, Results and Perspectives

Livestock–related ecoregional research in the Andean region is just starting. However, results noted above are based on previous work done in collaboration with other projects. Table 6 summarizes the most important results achieved.

Perspectives

The perspectives considered in ecoregional research can be summarized as follows:

- Integration of crop–livestock activities; subsistence and commercial; promotion of micro–enterprises.
- Improved livestock products; establishing micro–enterprises with orientation to aggregate value through product transformation.
- Linkage of partners in horizontal collaboration, and a research network of livestock research is being promoted.
- Training of researchers, students, extension agents and farmers.
- Publications (manuals and papers).

Table 4. Livestock ecoregional research in Latin America within the Andean region; countries, agro–ecological sites and partners.

Country	Site/ecoregion	Characteristics	Institution	Type
Colombia	La Miel	Hillsides Inter- Andean valleys	Caldas Universitv IGALA	R & T NGO/C-E
Ecuador	El Carchi Chimborazo	Inter-Andean valleys	INIAP ESPOCH	R & E E
Peru	Cajamarca	Inter- Andean valleys Rainfed	Cajamarca ASPADERU	R & T NGO/E-C
	Junin	Inter- Andean valleys high	Agrarian SAIS Tupac	R & T Coop.
	Mañazo	Altiplano wet dry	CIRNMA Puno	NGO/E R & T
Bolivia	Aroma	Altiplano dry	ASPROLP San Simon	Coop. R & T

R=research; T=teaching;C=credit;E=extension.

Table 5. Livestock ecoregional research in the Andean region; research and constraints.

Focus of research	Constraints
Credit studies with technical assistance	Capital & Technology
Pasture management; research activities / nutrient cycling	Forage availability
Non traditional animal feeding; use of Andean products	Lack of demand
Minimization of climatic risk	Altitude & conform zone
Integration of crop-livestock activities with market orientation	Products & transformation
Health & diseases	Management effects

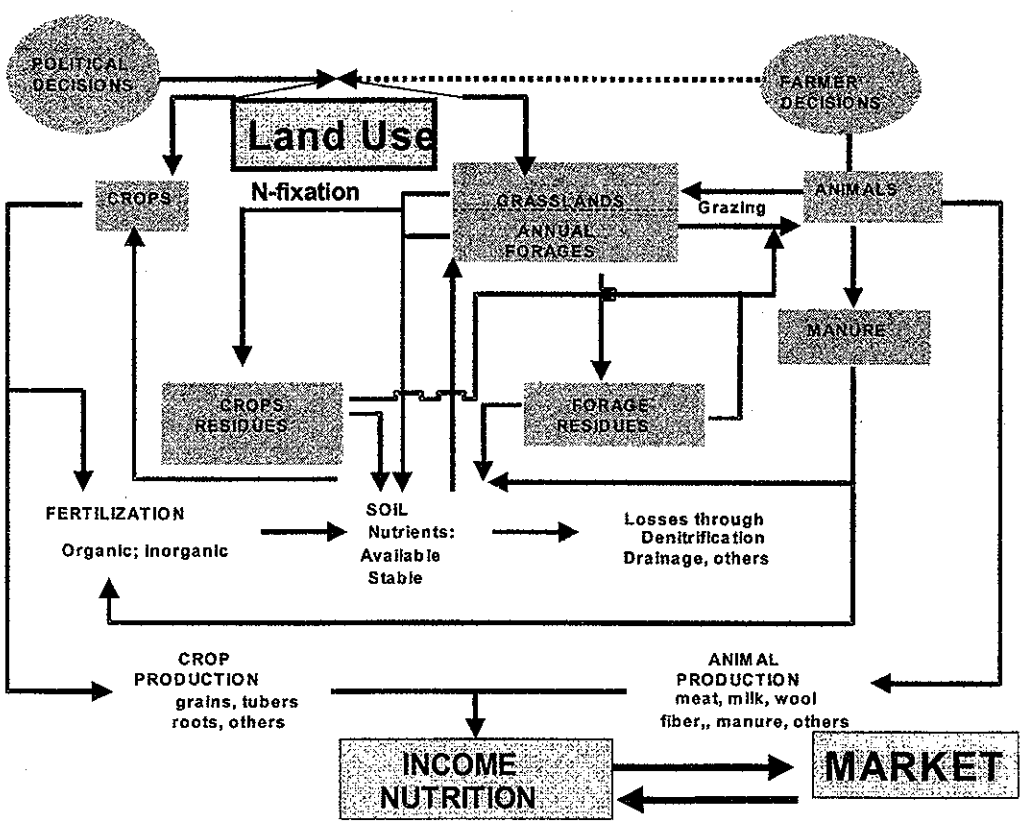

Figure 7. Scheme of the conceptual framework of ecoregional research in the Andean region.

Table 6. Studies and main results of livestock ecoregional research in the Andean region.

Component	Procedure/research	Observations/comments
Forage availability • Use of aquatic forage • Risk minimization • Annual and perennial • Use of native pasture	Shelter and pre–dried llachu & totora Shelter and forage base / calf Combination of barley, winter wheat, oats with alfalfa Increase of grazing area (bofedales)	Weight gain 0.854 kg/day; 142 % Weight gain 72 % on calves Improve forage base; 38–76% D.M Improve stocking rate and production.
Herd management	Alpaca herd Cow herd management Model simulation	Improve fibre characteristics by using index selection; 16–22% Use of records/milk production and reproduction Dual purpose and dairy; scenarios
Bio–economic analysis	Risk analysis	Model to compare alternatives
Credit studies	Revolving funds/credit	Improve forage base and herd
Family income	Integration of portfolio of technological alternatives	US$ 1,980; 55–104% Potato,2.8 kg/m^2; commercial greenhouses/vegetables
Soil/land–use	Nutrient cycling studies	Forage–manure; 12–26%

Acknowledgements

The authors acknowledge the helpful comments of Dr. Victor Mares; his suggestions are greatly appreciated.

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EXISTING AND PROPOSED ECOREGIONAL RESEARCH IN SOUTH ASIA

Ercole Zerbini

Summary

This paper attempts to highlight the major components of an established regional research consortium in South Asia, the operational difficulties, and proposed improvements needed in implementing this regional research. The components and the lessons learned from this mode of research will be very useful when establishing crop–livestock regional research as proposed in the second part of this paper.

An Established Research Consortium:The Rice–Wheat Consortium for the Indo–Gangetic Plains

Introduction and rationale

The main objective is to promote research on issues that are fundamental to enhance the productivity and sustainability of rice–wheat cropping systems in South Asia. Rice–wheat systems cover an area of 12 million ha in South Asia (30% of rice and 45% of wheat produced) and 12 million ha in China.

The Rice–Wheat Consortium (RWC) was initiated to find solutions to the following problems in the rice–wheat production systems in the Indo–Gangetic Plains (IGP–Pakistan, India, Nepal and Bangladesh):

- Yield stagnation and factor productivity decline.
- Degradation of natural resources supporting rice–wheat systems.

The main causal factors for the total factor productivity decline were attributed to:

- Declining water tables where tubewell water is used but water–logging/salinity/alkalinity in canal irrigated areas.
- Declining soil organic matter.
- Increasing incidence of pests, diseases and weeds in rice–wheat rotations.
- Nutrient imbalances (excess of Nitrogen and Phosphorus application, induced nutrient deficiencies).

Establishment of the consortium

The Rice–Wheat Consortium, established in 1993, is a collaborative research initiative involving the NARS (National Agricultural Research Systems), the IARCs (International Agricultural Research Centres), and other relevant institutions. A systems approach to tackling rice–wheat problems was initiated through an African Development Bank project (1992–94) conducted in the region by NARS of IGP, CIMMYT (International Centre for Improvement of Maize and Wheat) and IRRI (International Rice Reseach Institute). An output of this project was the development of a proposal for collaborative

research that outlined the basic structure and mechanisms of the present rice–wheat consortium.

In 1993 TAC (Technical Advisory Committee) recommended that IRRI, CIMMYT and NARS in the IGP region would form this consortium within an ecoregional initiative for the warm arid and semi–arid tropics. The World Bank convened a meeting in New Delhi in 1993 with the Heads of NARS and the Directors General of IRRI and CIMMYT indicating the need for a concerted and coordinated approach to rice–wheat problems. ICRISAT (International Crops Research Institute for the Semi–arid Tropics) was originally appointed as the convenor of RWC as it was located in the target region. It would provide administration and logistic support, as well as some technical input relating to its own mandate (e.g. role of legumes in alleviating soil problems). The RWC Facilitating Unit (FU) was based at the ICRISAT office in Delhi supported by funds from IFAD (International Fund for Agricultural Development) and the government of Sweden.

Role of FU

The facilitating unit is the implementing agency governed by the research steering committee (RSC) and the Regional Technical Coordination Committee (RTTC), it is the communication node among partners, and it coordinates training and attempts to generate donor support (RTTC, 1997).

Technical Role of IARCS

- CIMMYT: tillage and crop establishment theme and socio–economic analysis.
- IRRI: integrated nutrient management theme (with Cornell University).
- ICRISAT: Legumes in rice–wheat systems; IPM (Integrated Pest Management) themes and GIS (Geographic Information System).
- IWMI (International Water Management Institute): water management.

The approach followed to achieve these objectives included:

- Locating the specific areas most seriously threatened.
- Identifying the biological, physical, and socio–economic constraints of the production system.
- Developing, testing and promoting the implementation of strategies that will impart greater sustainability and enhance system productivity.

Expected outputs

- Better understanding of the areas and extent of problems.
- Reports of diagnostic surveys on existing practices.
- Better understanding of changes in soil.
- Improved soil, water and crop management practices.
- Increase availability of implements.
- Tested nutrient management practices.
- Effective soil nutrient supply assays/tests.
- IPM research at selected sites.

- Database and modelling.
- Mechanism for information exchange.
- Enhanced NARS capabilities.

Problems encountered

- Very different R&D capacity among participating NARS.
- High transaction costs because of large number of involved organizations.
- Difficult transition from component, single commodity mode (rice–wheat research imposed on existing rice–wheat research) to interdisciplinary, system–oriented research mode.
- Need for additional funding.

Recommendations for improvement

- Rotate location of the FU between the 4 participating countries.
- Use electronic meetings to reduce numbers of the RSC and RTTC meetings.
- Establish more transparent joint priority–setting mechanisms that balance needs and opportunities against comparative advantages of partners.
- Clearly set out the roles and responsibilities of the FU.
- Taking full advantage of emerging electronic dissemination technologies, establish a well–defined periodic reporting system.
- Assist partners to better define the joint work plan in terms of shared objectives, milestones and outputs; and uniform means of monitoring progress.
- Build a RWC identity by devising means for regular publications identified with the RWC and crediting the donors and partners involved.

Funding

Funding mechanisms involve multi–donor participation either directly or through the IARCS involved.

1994–1997 (Sweden, IFAD, Switzerland, Netherlands, World Bank, ACIAR–Australian Centre for International Agricultural Research) through the FU: $1.1 million.

1996–2000 (ACIAR, DFID–Department For International Development, USAID–United States Agency for International Development) through CIMMYT, IRRI and Cornell: $3.4 million.

Present status

The convening role of RWC was transferred from ICRISAT to CIMMYT from the end of October 1998.

A Proposed Research Consortium: Increasing Livestock Productivity in Mixed Crop–Livestock Farming Systems in South Asia

An ICRISAT–ILRI proposal addressing crop–livestock systems issues and problems in South Asia, encompassing the establishment of a regional consortium, is reported here as an example of how ILRI could conduct ecoregional research through partnerships in the South Asia region.

Statement of the problem

Crop-livestock systems in South Asia are vital for the security and survival of large numbers of people. In these systems livestock generate cash income, draught power and manure, they utilise crop residues and by–products, and they are important for the maintenance of crop yields and sustainability of the farming systems.

During recent decades there have been significant changes within these systems, but little is known about the relative contribution of the agro–ecological, technological and socio–economic factors affecting these changes. Furthermore, there is a paucity of information on farming systems research that incorporates animals interactively with cropping systems. Too often, research has emphasized component technologies that did little to influence policy–makers or provide a foundation for sound policy development. Policies and research and development programmes can be more effective if they are based on a recognition of the strong nexus between crop and animal production; an appreciation of the complexity of the systems; the need for differential interventions in the different systems; and a better understanding of the rationale for prevailing patterns of animal ownership and management that account for the striking variations that occur in mixed farming systems in the sub–region (Devendra *et al.*, 1998; Kelley *et al.*, 1997).

The proposed project is an attempt to correct these deficiencies. The development of a mixed farming typology and the classification of systems will provide a foundation for the introduction of more appropriate technological and policy interventions in these systems in the future to benefit resource–poor farmers and protect the environment. The study will provide a link between the nature of these systems and the research and institutional management approaches required to deal with them. Equally important for this project will be the critical assessment of the impact of various interventions implemented in the past; the rationale for their use; the effects on the natural resource base; and the manner in which they were implemented. The aim is to obtain a better understanding of the reasons for the success or failure of these interventions. As a consequence of this analysis, it should be possible to suggest more appropriate intervention strategies in the future and the institutional arrangements required to implement them effectively.

Purpose and objectives

The purpose of the project is to develop a crop–livestock typology that will ultimately improve the effectiveness of technical and socio–economic interventions aimed at improving animal performance and protecting the natural resource base at the farm level in South Asia. The objectives of the proposal are:

- To construct a mixed crop–livestock farming systems typology for South Asia, and to characterise each system.
- To understand the relative importance of agro–ecological, technological and socio–economic factors in influencing the evolution of these farming systems.
- To assess the impact on the farming systems of external technical and socio–economic interventions implemented by state organisations, non–governmental organisations and international agencies.
- To test on–farm specific external interventions and assess their impact on animal productivity and the natural resource base, and interactions with other components of the farming systems in selected priority crop–animal systems.

Indication that the project is demand–driven

The proposal is a collaborative, multi–disciplinary effort across the six countries of South Asia involving natural and social scientists at two international centres, seven national agricultural research systems (NARS) and selected non–governmental organisations (NGOs). The concept was developed from discussions with colleagues working on animal production–related issues in the NARS and NGOs. They have endorsed the initiative and indicated their willingness to participate in the consortium. Through on–farm trials, farmers will participate in the research work.

Implications of the project

Through the construction of the typology, the characterisation of the farming systems, the improved knowledge of factors influencing the evolution of the systems, and the reasons for the success or failure of external interventions, it will be possible in future to introduce more effective policies and more appropriate technological and socio–economic interventions at the farm level to benefit resource–poor farmers and protect the environment.

Project location

The project secretariat will be located at ICRISAT, Hyderabad, India. The various studies will be undertaken in the six countries of South Asia, namely Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka.

Project focus

In the first instance, the main beneficiaries will be the NARS and NGOs, intermediate users in the uptake pathway. Membership of an international consortium will allow improved interactions between the participants from the different countries and improve their understanding of farming systems from a

sub–regional perspective. The study will also contribute to capacity–building for systems analysis in the NARS. Ultimately, resource–poor farmers as end–users will benefit from the more effective transfer of appropriate, environmentally–friendly interventions that will improve livestock production. Since women play an important part in animal production in South Asia, the development of the livestock sub–sector is of relevance to the promotion of gender equity.

Collaborators

The consortium will consist of natural and social scientists from ICRISAT, the International Livestock Research Institute (ILRI), the Bangladesh Agricultural Research Council (BARC), the Research, Extension and Irrigation Division (REID) of the Ministry of Agriculture in Bhutan, the Indian Council of Agricultural Research (ICAR), the National Dairy Development Board (NDDB) of India, the Nepal Agricultural Research Council (NARC), the Pakistan Agricultural Research Council (PARC), the Department of Animal Production and Health, Ministry of Livestock and Rural Industries (MLDRI) in Sri Lanka, and selected NGOs. The project will run for five years.

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INCREASING THE PRODUCTIVITY AND SUSTAINABILITY OF CROP–LIVESTOCK SYSTEMS IN SEMI–ARID WEST AFRICA: RESEARCH APPROACHES AND METHODS

Salvador Fernández–Rivera, Pierre Hiernaux and Timothy Williams

Summary

Rapid population growth and periodic drought are steadily influencing the traditional systems of crop and livestock production in Semi–arid West Africa (SAWA). Farmers, in their quest to produce more food for an expanding population, are cropping marginal lands, cultivating more land permanently, and abandoning the traditional practices that formerly allowed land to rejuvenate naturally. The extension of cropping into marginal lands has reduced the area of natural rangeland and increased the risk of environmental degradation in this zone. Partly as a consequence of these changes, crop production and livestock rearing are increasingly being integrated. To support this evolution, research is needed to develop innovative crop, livestock and land management strategies that will lead to increased agricultural production, improve the economic well–being of producers, and promote more effective natural resource management.

The International Livestock Research Institute (ILRI) has an ecoregional research programme in SAWA. This programme, based in Niger, follows a systems–oriented, interdisciplinary approach and collaborates with other international, regional and national institutions in addressing problems of regional importance related to animal agriculture and natural resource management. The goals of the project are (i) To develop technologies that would increase the productivity of mixed crop–livestock production systems and allow for sustainable use of available natural resources, and (ii) To determine economic incentives, policies and institutional options that would ensure that the developed technologies are adopted and improve farmers income and welfare.

Specifically, the key interactions between plants, animals and soils are investigated, and farmers' perceptions and priorities are factored into the research process. The research agenda focuses on identifying, using a farmer participatory approach, the different types of livestock production systems in the region, determining the economic and ecological role of livestock in mixed farming systems, improving the nutrition of livestock in these systems and modelling the crop–livestock interactions using mathematical programming, simulation and Geographic Information Systems (GIS) techniques.

It is expected that the technologies and management interventions that emanate from the ILRI's research project in Niger will contribute to meeting the increasing demand for food of animal origin, alleviating poverty, and maintaining the production potential of the natural resource base.

Background

Increasing population pressure and periodic drought in Semi–arid West Africa (SAWA) have partly prompted a shift from nomadism and shifting cultivation to more sedentary forms of livestock and crop production. What used to be exclusively cropping and pastoral systems are now incorporating livestock and cropping activities, respectively. The integration of crops and livestock stabilizes food availability in a climatically risky environment. A variety of economic and biological interactions between livestock rearing and crop production make mixed systems attractive to producers. Some of these interactions have beneficial as well as potentially detrimental consequences. For example:

1. Mixed farming is a risk diversification strategy with ruminant livestock providing an important investment opportunity, stabilizing food availability during poor crop production years.

2. The application of livestock manure sustains crop yields in many areas. Rangelands and fallows provide nutrients for livestock, and through manure, for crop land.

3. As demographic pressure increases, more intensive modes of agricultural production involving increased use of manual labour per unit of land are sometimes adopted. The use of animal power at this stage can alleviate labour shortages and increase productivity. The tillage of some soils by animal traction may also increase the risk of wind and water erosion.

4. Overgrazing during the wet season can occur as a result of the reduction in rangeland and shortening of fallow periods due to increased cultivation. This reduction in rangeland area also jeopardizes the sustainability of nutrient transfers.

5. The excessive removal of vegetative cover through grazing and/or harvesting of crop residues, as well as the trampling of the soil surface by animals, may adversely affect soil properties and decrease the production potential of both crops and livestock.

Given this situation, research is needed to maximize the complementary and minimize the competitive relationships between crops and livestock in order to improve the productivity of mixed farming systems in SAWA. This research needs to take into account the effect of climatic factors as well as the demographic, social and economic changes currently taking place in SAWA, and their implications for agricultural productivity, poverty alleviation and sustainable natural resource management. To contribute to the solution of these problems, the International Livestock Research Institute (ILRI) established a research programme in Niger. This paper describes the history, objectives, research agenda, collaborative efforts, and expected outputs of ILRI's research programme in SAWA.

Goal

The goal of the research programme of ILRI in SAWA is to develop improved technologies and management interventions and identify economic incentives, policy options and institutional arrangements that would improve crop–livestock production in mixed farming systems and ensure the maintenance of the production potential of the natural resource base.

Research Strategy

Devising successful technologies and management interventions for rural development requires an effective research strategy. To ensure that the limited resources available for research are used effectively and that the research activities are relevant, the programme follows a systems and farmer participatory approach, and employs an inter–disciplinary research team of natural and social scientists to work in collaboration with colleagues from other international and national institutions.

Systems oriented and farmers' participatory research

The research project employs a holistic approach to identify the main components and interactions found in mixed farming systems, and to determine appropriate points of intervention. Studies are conducted to gain a better scientific understanding of the key interactions between plants, animals and soils and their effects on primary productivity. At the same time participatory rural appraisals are conducted to determine the cultural, institutional and economic factors that condition farmers' resource–use and management decisions. This on–farm work also solicits the active participation of producers in problem identification and technology evaluation. Villages in areas with differing demographic pressure, rainfall distribution, and access to markets are selected in order to capture a wide range of climatic and socio–economic conditions. Whole–farm and spatial models, involving GIS techniques, have also been developed to serve as tools to evaluate changes in the production systems.

Interdisciplinary approach

The complex nature of the cultural, technical, and socio–economic issues involved in livestock and land management in SAWA necessitates an interdisciplinary research approach. The research project of ILRI in the semi–arid zone is strongly supported by the collaboration of scientists in the areas of animal science, range ecology and agricultural economics. Additional expertise is assured through consultancies in the area of human ecology. ILRI scientists also collaborate closely with other centres' scientists in various plant science disciplines (agronomy, genetic enhancement, physiology), soil science and agroclimatology.

Multi–institutional collaboration

The research programmes based at ICRISAT (The International Centre for Research in the Semi–Arid Tropics)–Niamey bring together researchers in climate, plant, animal, soil and social sciences. This provides a unique forum for multi–institutional collaboration and interdisciplinary research. For instance, research on millet–based systems involves various institutes and scientific disciplines. Whereas issues pertaining to millet production are of principal concern to ICRISAT, ILRI focuses on improving the feeding value of millet stover and IFDC (The International Fertilizer Development Centre) on issues pertaining to stover use for soil conservation, with all three institutes participating in the definition of target production systems, nutrient cycling research, and ways to mitigate the competition between crop and livestock production.

In addition to collaborating with ICRISAT in improving the feeding value of crop residues, the programme collaborates with ICRAF(International Centre for Research in Agroforestry) in research on the fodder value of multi–purpose trees, with ORSTOM, AGRHYMET and several NGOs on the land–use in village study sites, and with ICRISAT in the use of GIS for evaluating natural resource management. National collaborators in Niger include those from the National Institute of Agricultural Research of Niger (INRAN), Abdou Moumouni University (AMN), and the Ministry of Agriculture and Livestock. The three national institutes have played an important role in initiating the on–farm research activities of ILRI and have benefited from ILRI's research programme in training young professionals and scientists. Scientists from INRAN and AMN are active members of a number of research networks coordinated by ILRI.

The programme has developed collaborative research links with INERA (Burkina Faso), IER (Mali), INRAN (Niger) and ISRA (Senegal) and well as with ICRISAT and IFDC in the preparation and execution of a project funded by the International Fund for Agricultural Development (IFAD) and the International Development Research Centre (IDRC, Canada) on the improvement of crop–livestock productivity through improved nutrient management. The programme executes a project on improving livestock marketing and regional trade in six West African countries with financial support from the Common Fund for Commodities (CFC).

Partnerships with ecoregional and systemwide programmes

ILRI researchers in SAWA collaborate with the Desert Margins Programme (DMP) and the Systemwide Livestock Programme (SLP). With the DMP, a proposal on the role of livestock in the ecological and economic linkages between the arid and semi–arid zones is under review. The proposal identifies three key research areas that need to be investigated. The first concerns the identification of technologies, policies and institutional innovations that can be used to sustain livestock–derived income in the arid zone and to improve the effectiveness of indigenous coping mechanisms to minimize production and capital shortfalls. The second relates to the potential for improving the beneficial inter–zonal interactions in order to improve

regional livestock and crop productivity. The third is the development of livestock management practices that preserve biodiversity and resilience of natural vegetation in the arid zone and minimize land degradation caused by livestock production in the semi–arid zone.

The present focus of the SLP on feed resources provides ILRI's research project in SAWA with an opportunity to further expand on–going work on this theme in collaboration with other IARCs and NARs within the region. In collaboration with ICARDA (International Centre for Agricultural Research in Dry Areas), ICRAF, ICRISAT and the national research institutions of Burkina Faso, Mali, Niger and Senegal, studies are being undertaken on the utilization of multi–purpose trees as feed for livestock and the evaluation of genetic variation in fodder quality of various accessions of Sahelian trees and shrubs. The project is also part of a consortium led by ICRISAT to develop a research proposal on the production and utilization of farm residues in mixed crop–livestock systems.

Research Agenda

The research issues in mixed farming systems of SAWA are numerous and complex, and demand urgent solutions, yet the programme's resources and those of its partners are limited. Therefore, ILRI's project in Niger and its partners identify those research themes that are relevant, of highest priority, and for which ILRI is best positioned to conduct research. Emphasis is also placed on research issues that are likely to have a positive impact on the systems under study.

The research project strives to maintain a balanced portfolio of strategic and applied research. Earlier work developed a typology of livestock production in crop–livestock farming systems and identified constraints and opportunities within the existing mixed farming systems found in SAWA. This work demonstrated the critical feed deficiency that occurs during the latter part of the 6– to 8–month dry season and the continuing importance of manure as a soil amendment in the region. Based on these findings, on–station and on–farm studies were initiated to search for techniques to optimize the use of available feed resources, reduce nutrient losses and synchronize the release of nutrients from plant residues and manure with crop demands. Farmers' feeding and manure management practices were studied in order to obtain information to design, test and evaluate alternative animal management strategies. These initial biophysical and socio–economic studies focused mainly on the field level. Results emanating from this work, however, indicate that manuring and animal feeding practices observed in a farmer's field or household are not only determined by the resources at the disposal of the individual farmer, but also by institutional structures, land–use patterns, and management decisions at higher spatial and social organizational levels.

Current research activities are designed to build upon previous work by linking work done at the household level to new activities aimed at the village scale. Additional information gathered from current research activities will improve the project's capability to generate livestock management techniques and

policy interventions that will enhance livestock productivity and natural resource management in SAWA. On–going research activities are grouped into three projects: (1) Socio–economic analysis of livestock production and natural resource management in SAWA; (2) Dynamics of livestock–mediated nutrient transfers in SAWA landscapes and their implications for resource management; and (3) Feed resources and nutrition of ruminants in crop–livestock systems of SAWA. The main objectives, work programme and expected outputs of these projects are briefly described below.

Socio–economic analysis of livestock production and natural resource management in SAWA

Improvement of livestock production and natural resource management demands a better understanding of not only the biological factors related to soil–crop–livestock interactions, but also the processes by which farmers gain access to and use natural resources for crop and livestock production. Imperfect understanding of the social and institutional processes that govern resource–use at the farm level have inhibited the development of appropriate policies to combat unsustainable resource–use practices. New institutional arrangements and policies are needed to complement technical interventions to improve livestock production and promote sustainable use of natural resources. The objectives of this project are: 1) To identify and characterize existing resource–use and resource management practices on mixed farms in different agro-ecological zones; (2) To identify village–level institutional arrangements and broader administrative laws governing access rights, use, and management of common–pool resources, and to determine how these have adjusted to both internal and external changes over time; and (3) To identify economic incentives, policy options and institutional arrangements that can be used to promote the adoption of technical interventions that will improve crop–livestock integration and natural resource management in SAWA.

To accomplish these objectives, participatory rural appraisals are being conducted in several villages located in areas with differing population density and access to markets. Information has been gathered on customs and rules governing resource–use and management at the community level, utilization of own and common–pool resources, and strategic manipulation of herd size and composition to match exigencies of changing resource availability. Work is also envisaged on a number of issues where more detailed localized data collection is required. Such issues include the study of changes in transhumance organization in response to agricultural encroachment, and the quantification of utilization of organic material by farmers.

Existing results from cross–sectional and process–oriented studies are being used to develop whole–farm models to examine the impact of alternative resource management practices on soil fertility, output, and income of farmers. Whole–farm models that incorporate climatic, crop, livestock and socio–economic components of the farming systems can help in elucidating the complex nature of crop–livestock interactions and the complementarities and trade–offs inherent in the production system. These models will enable the programme to evaluate the potential of new management techniques to

ensure that they represent better and more appropriate alternatives to existing management practices.

Dynamics of livestock–mediated nutrient transfers in SAWA landscapes and their implications for natural resource management

Livestock are major vectors of nutrient transfers in SAWA. Livestock contribute to the recycling of nutrients from natural vegetation and crop residues through manure and urine. Livestock grazing also affects soils and the production and species composition of vegetation. These effects depend on the intensity and time of grazing, and are mediated by the grazing behaviour of the different animal species. Studies of the spatial and temporal variations in grazing intake and manure–urine deposit, and their impact on vegetation production and composition are needed to assess the sustainability of animal–mediated nutrient transfers from range and fallow lands to crop lands. The implications for nutrient cycling of livestock management variables such as stocking rates, herd composition, seasonal transhumance, herd nocturnal location, and daily grazing itinerary need also to be investigated. The objectives of this project are (1) To assess the impact of livestock on nutrient cycling and natural resource management in crop–livestock systems of SAWA; and (2) To develop management options that optimize resource–use and improve livestock output.

To initiate this work, three village lands located within the same area of Western Niger (similar base geomorphology, vegetation and rainfall) but with contrasting cultivated fractions and livestock presence were selected as study sites. An inventory of households permanently or seasonally using village natural resources was initially established. Agro–ecological units and land–use in the three village territories (including approximately 500 km^2) were mapped at the scale of 1/15,000 using aerial photographs. These maps have been digitized and constitute the first layers of the spatial database or GIS that will be used to model the nutrient flows in the village agro–ecosystems.

The amounts, spatial distribution, and seasonal variability of forage on offer in three villages have been monitored since July 1994. Feed intake and excretions by ruminants are also assessed in the three village lands. Livestock populations and activities are characterized with respect to GIS–based geographical units. Grazing itineraries of all herds in village territories are monitored through map–facilitated interviews at three–weekly intervals. Grazing itineraries of selected herds are also monitored in each of the villages at least once per season. During the grazing day, voiding events, characterized by type, size and location, are recorded for one selected animal together with other activities (e.g. grazing, browsing, walking, resting). Intake and faecal excretion using faecal collection bags and oesophageally fistulated animals are measured for cattle, sheep, and goats in an 'experimental herd' based in one of the villages and managed by a local herder together with his animals. Rumen nutrition characteristics are monitored over the season using rumen fistulated animals in this herd.

The impact of herd management practices (e.g. diurnal or nocturnal grazing; different stocking rates and browser:grazer ratios) on nutrient ingestion and

excretion are studied in experiments conducted on–station. The effects of livestock grazing on soils, vegetation production and species composition have also been monitored on–station.

The information emanating from this project will provide an empirical basis for spatial modelling work that will evaluate the productivity of crop and livestock production systems at village to regional scales under different management, land endowment, cultivation fraction and livestock population combinations.

Feed resources and nutrition of ruminants in crop–livestock systems of SAWA

Poor nutrition is the main cause of the low productivity of ruminants in crop–livestock systems of SAWA. The most critical period is the latter part of the eight–month dry season. Opportunities to improve livestock nutrition in these systems include the development of supplementation techniques, the improvement of available dry season feeds such as crop residues and fodder trees/shrubs, and the identification of grazing management practices that can result in higher nutrient supplies to animals. In mixed farming systems of SAWA livestock play an important role in soil fertility maintenance through the provision of manure. Herds are managed so as to facilitate manure collection. Improved feeding strategies can result also in increased crop production through the provision of better quality manure and a more efficient cycling of organic matter, nitrogen and phosphorus. The objectives of this project are: 1) To increase meat and milk production in crop–livestock systems of SAWA through improved feeding strategies, 2) To improve the cycling of nutrients by livestock in mixed farming systems through better use of feed resources and herd management.

Work undertaken in this research area includes a collaborative study with ICRISAT and IITA (International Institute for Tropical Agriculture) to evaluate the forage quality of residues from improved and local varieties of pearl millet, groundnut and cowpea, as well as the impact of the introduction of genetically controlled traits on agronomic traits and feeding value of millet stover. Experiments have been conducted to study seasonal variation in rumen environment and diet quality of grazing animals in order to understand the nature of nutritional constraints to cattle, sheep and goats grazing in rangeland and crop residue fields. The effects of supplementation, with protein and non–protein nitrogen, metabolizable energy, and phosphorus on forage intake and growth rate of grazing ruminants are being studied in collaboration with INRAN. Grazing experiments are being conducted to identify herd management practices that improve the production of livestock and enhance their contribution to the maintenance of soil fertility. Where appropriate (e.g. in experiments on stocking rates and supplementation) economic analyses are conducted to determine economically optimal stocking rates and supplementation levels.

The expected outputs of this research include: 1) Supplementation strategies that increase meat and milk production and improve the cycling of nutrients by livestock in mixed farming systems, 2) Grazing management practices that increase the supply of nutrients and improve livestock production, and 3)

Improved feeding value and use of available crop residues and fodder trees/shrubs.

Expected Outputs

It is expected that the research project of ILRI in SAWA will develop improved technologies and management interventions and will identify policy options and institutional arrangements that will enhance the productivity of livestock in mixed farming systems, ensure the long–term conservation of the natural resource base, and improve welfare of farm families.

ECOREGIONAL RESEARCH IN SUB–HUMID WEST AFRICA

Jimmy Smith

Summary

There are diverse opinions as to what an ecoregional research approach should involve. Ecoregional research is meant to fill gaps in natural resources management research, rationalise overlapping mandates, provide focal points and streamline interactions between NARS (National Agricultural Research Systems) and CGIAR (Consultative Group on International Agricultural Research) centres. This paper describes the institutional structure and technical operation of the proposed ecoregional programme in sub–humid West Africa. It shows the benchmark sites, pilot areas and working groups and elucidates ILRI's research focuses within the programme.

Ecoregional Research—The Origin

Since 1992, when TAC (Technical Advisory Committee) recommended and the CGIAR adopted the ecoregional research approach, diverse opinions have emerged about what such an approach embodied. Even though TAC identified the ecoregions of primary focus and the convening centres, no details were provided on how the ecoregional research approach should be operationalised. The objectives, however, were identified as follows:

- Fill gaps in coverage of natural resources management research.
- Rationalise overlapping commodity mandates.
- Provide focal points.
- Streamline interactions between NARS and CGIAR Centres.

The international outputs of ecoregional research were also identified as follows:

- Determine effective research and development approaches for natural resources management research.
- Understand the principles of managing soil, water, biological processes and their interaction.
- Determine effective mechanisms to link decision–making and policy formulation and implementation with technological opportunities and social organisation as instruments of change, across a range of population pressure, social organisations, employment opportunities and policy conditions.
- Build human resource capacity for effective natural resources management research.

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Developing the Ecoregional Programme for the Humid and Sub–Tropics of Africa

Initial steps

One of the ecoregional programmes initially designated by TAC was the ecoregional programme for the Humid and Sub–Humid Tropics of Africa (EPHTA). IITA (International Institute of Tropical Agriculture) was designated its convenor. Among the first decisions that IITA had to make with respect to discharging this responsibility was about the orientation of IITA itself to the Ecoregional Programme it was asked to convene. Was the ecoregional programme going to be managed as a 'special programme' or was it going to be an integral part of the Institute? IITA's management took the decision to make its programmes an integral part of the ecoregional programme and that programme's modalities.

The next important decision that was necessary was how the programme should be structured and operationalised. Given the number of potential partners and inherent complexities of developing such a programme, a task force of internal and external 'experts' was appointed. The taskforce backed up by extensive consultations developed a plan which was presented to potential partners at a formal meeting for discussion and modification. The salient components of that plan (which was adopted) are presented below:

Formation of consortia

The area covered by the ecoregional programme included three distinct agro–ecologies. A consortium was formed to conduct research for each of these agro–ecologies under the umbrella of the programmes. Membership of the three consortia was as follows:

(WARDA) INLAND VALLEYS	(IITA) MOIST SAVANNAS	(IITA) HUMID FORESTS
Benin	Benin	Cameroon
Burkina Faso	Cameroon	Côte d'Ivoire
Côte d'Ivoire	Central African Republic	Gabon
Ghana	Côte d'Ivoire	Ghana
Guinea	Ghana	Nigeria
Mali	Guinea	Zaire
Nigeria	Nigeria	
Sierra Leone	Sierra Leone	
	Togo	

In order to ensure that research spanned the continuum and a satisfactory division of labour was achieved, it was decided that the research strategy be executed through benchmark areas, pilot sites and working groups.

Benchmark Areas

Designation of benchmark areas as focal points for strategic and diagnostic research is one of the most important features of the ecoregional approach. In EPHTA's ecoregional approach, benchmark areas (see Figure 1) are large enough for biophysical and socio–economic research at most relevant scales of sustainable systems research. Proliferation of benchmark areas is unnecessary, and could lead to duplication and inefficiency. Through careful consideration, EPHTA partners agreed to start with only six benchmark areas located in five countries. Designation of benchmark areas was based on three major criteria:

1. Representativeness of major features for the defined resource management domain (or agro-ecological zone).
2. Capturing the important biophysical and socio–economic variability and gradients.
3. Existence of appropriate circumstances (access, communication systems, physical infrastructure) for successful research and development.

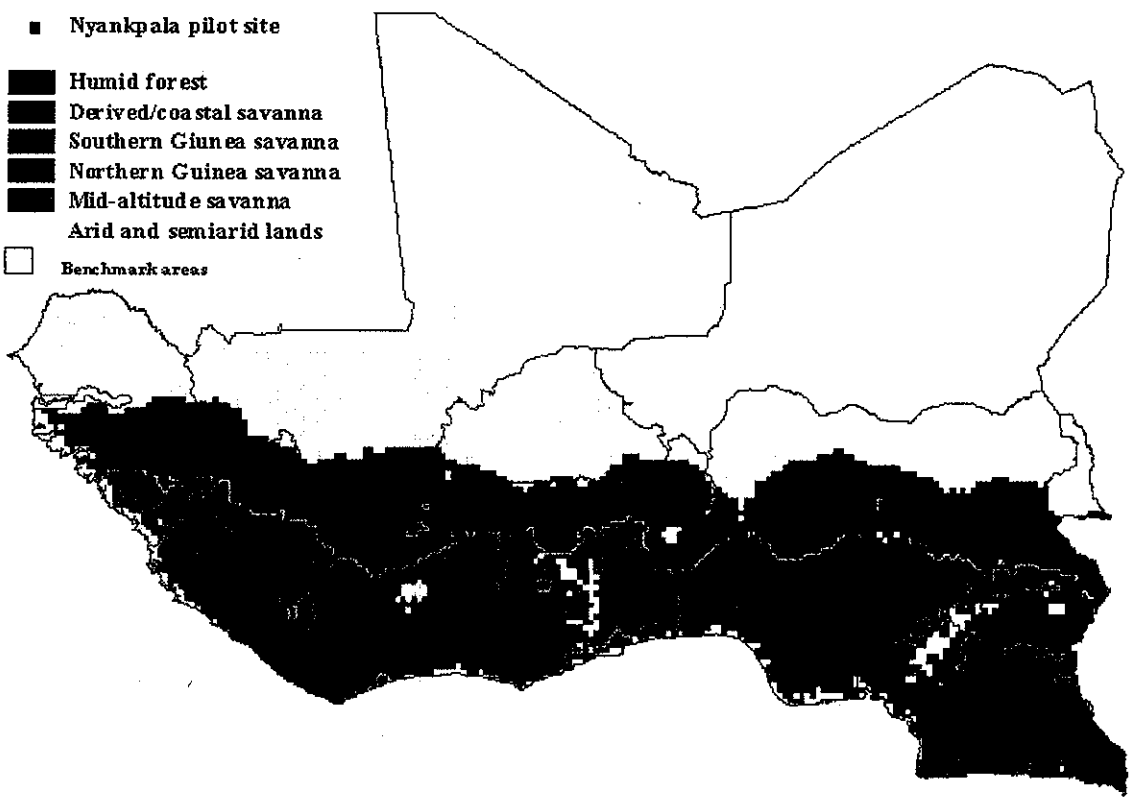

Figure 1. Benchmark areas and pilot site in West Africa.

Through the Moist Savanna Consortium, one benchmark area will be developed for each of the following domains:

- Northern Guinea savanna: an area in northwest Nigeria with the Institute of Agricultural Research, Ahmadu Bello University, Zaria, as the host institute.
- Southern Guinea savanna: an area northwest of Bouake in Côte d'Ivoire, with l'Institut des Savanes (IDESSA) as host institute.
- Derived/coastal savanna: an area north of Cotonou in Benin with l'Institut National des Recherches Agricoles du Benin (INRAB) as host institute.

Similarly, through the Humid Forest Consortium, one benchmark area will be developed for each of the following domains:

- Forest margins: an area in southern Cameroon with the Institute of Agricultural Research for Development (IRAD) as host institute.
- Forest pockets: areas in southern Ghana with the Council for Scientific and Industrial Research (CSIR) as host organisation.
- Degraded forest: area in southern Nigeria with National Root Crops Research Institute (NRCRI), Umudike, as host institute.

At present one benchmark area—for the Forest Margins in Cameroon—is fully operational. The northern Guinea savanna benchmark area in Nigeria has been operational since the end of 1996. The other benchmark areas will be phased in at a rate of two or three per year. A standardized methodology has been developed which will enable cross–cutting analysis of system dynamics and delineation domains. Application of this methodology across benchmark areas is expected to make a major contribution to priority–setting and the efficiency of research planning and targeting.

When operational, research at the benchmark areas will primarily address transitional issues but will also lead to local benefits through farmer participatory testing and institutional change. The following activities will be carried out at benchmark areas:

- Ecoregional studies to characterise domains, determine system dynamics, and assess factors affecting resource–use and farmer–welfare.
- Technology design through process studies and strategic research.
- Applied research at stations and on–farm.
- Farmer participatory technology development and transfer.
- Collaboration with developmental organisations, including farmer groups and NGOs (Non–Governmental Organizations).
- Planning and coordination to reduce overlap, create critical mass, facilitate client participation, and increase spillovers.

Pilot Sites

The primary function of pilot sites is to test, evaluate, adapt and transfer promising sustainable production technologies and post–harvest systems in appropriate farmer circumstances for target technologies. To ensure widespread benefit and participation of all programme partners, pilot sites will be spread throughout target domains and countries (at least one per member NARS).

Pilot site activities are the same as those carried out at benchmark areas with the following key distinctions:

1. Only essential (minimal) characterisation for determining representativeness.
2. Emphasis on applied research and farmer participatory technology development; process and strategic studies will be carried out only to take advantage of location–specific circumstances or expertise.

The size of pilot sites is flexible, but they will generally be much smaller than benchmark areas. Investments in diagnostic studies, planning, and coordination will also be variable, but generally much less than for benchmark areas. During the fourth task force and consortia launching meeting, member countries identified potential pilot sites for each target domain. Pilot site activities started in 1997. Activities in pilot sites will be critical in delivering practical results, and will be a necessary complement to benchmark area activities.

Working Groups

Working groups are being established to address specific themes and cross–cutting issues. Each working group, composed of scientists and developmental specialists from the partner institutes and organisations, will serve as a vehicle for focusing research and development activities of the respective consortia.

Working groups will have the following functions:

1. To provide expert advice, monitoring and evaluation.
2. To develop programme protocols for strategic and applied research which complement
3. Existing research and development activities.
4. To assist in harmonising research methods and ensuring high–quality results.
5. To maintain linkages with other systemwide programmes and existing regional networks.
6. To coordinate preparation of state–of–art papers and thematic workshops.

An important consideration in defining working groups was to limit the total number, to save costs for meetings and ensure multidisciplinarity. A goal was to have approximately the same number of working groups and target domains (and benchmark areas) as a basis for matrix planning between themes and domains.

At the fourth Task Force and launching meeting, various options were discussed and it was agreed to start with seven working groups based on the endorsed programme outputs:

1. Sustainable savanna farming systems.

2. Forest zone land–use systems.
3. Natural resource management and conservation.
4. Post–harvest systems development.
5. Enabling policies and institutions.
6. Technology transfer.
7. NARS capacity building for ecoregional research.

Separate working groups were not established for the IVC (Inland Valley Consortium) to avoid potential overlap with WARDA's (West Africa Rice Development Association) task forces and the IVC steering committee. This issue will be revisited if necessary.

What are ILRI's Research Focuses

ILRI'S emphasis is on the Moist Savanna Consortium, but ILRI also conducts some research within the Humid Forest Consortium (indigenous and exotic trees and shrubs as feed resources) and the IVC (feeding systems for smallholder dairy). The research areas presented below emphasise efforts within the Moist Savanna Consortium only.

- Developing a framework for characterising and quantifying the impact of important factors (bio–physical, socio–economic, socio–cultural) driving crop–livestock systems (Figures 2 and 3).

- Modelling feed budgets spatially and temporally in savanna agro–ecological zones (Figure 4).
- Testing technological alternatives to develop coefficients as inputs to crop–livestock simulation modelling.
- Developing a response surface to crop residues used as mulch versus feed/manure.
- Evaluating the role of livestock in continuous land–use systems.
- Testing frameworks for analysing dairy systems.
- Developing an approach to increasing feed quality and supply from food crop systems (Figure 5).
- Integration of legumes into cropping systems.
- Selecting food crop genotypes for food and feed (Table 1).

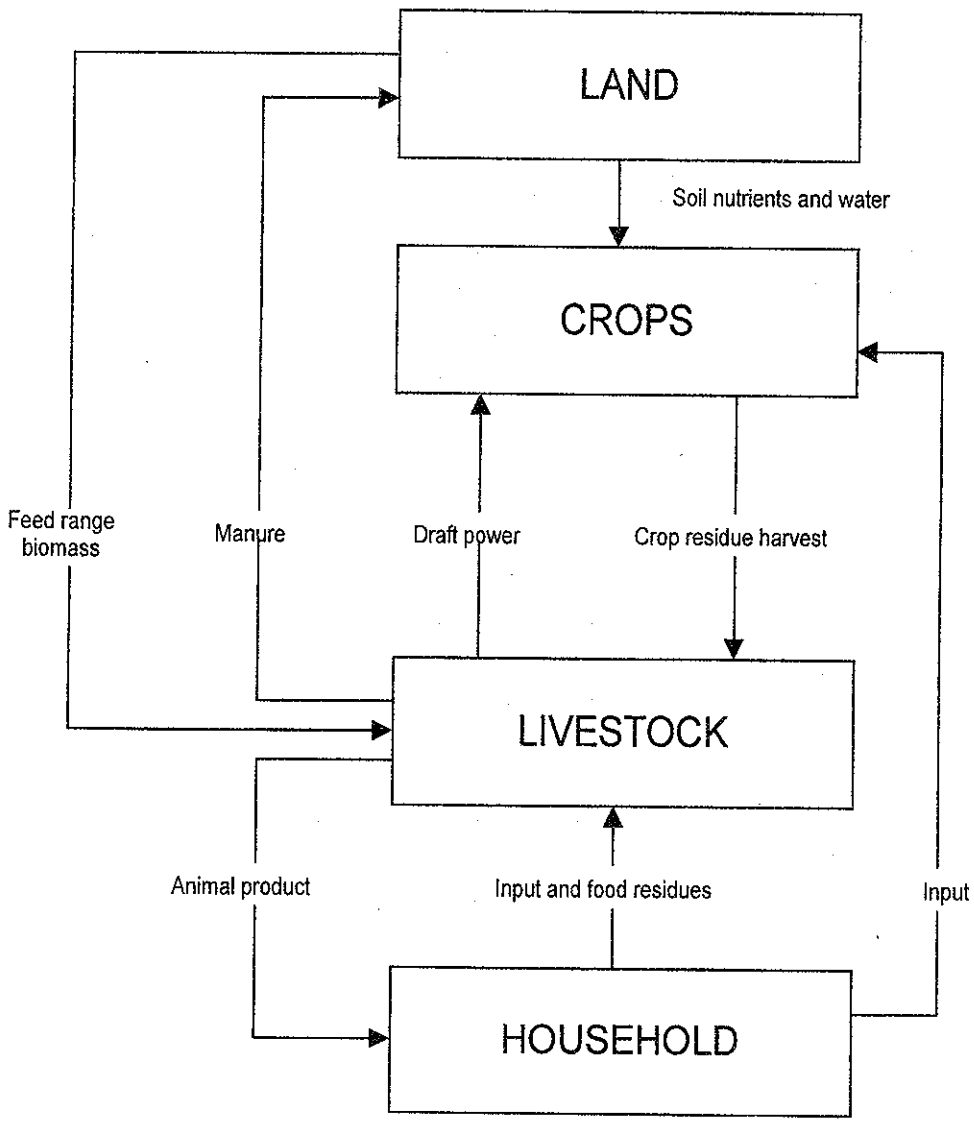

Figure 2. The interdependent elements of crop–livestock interaction.

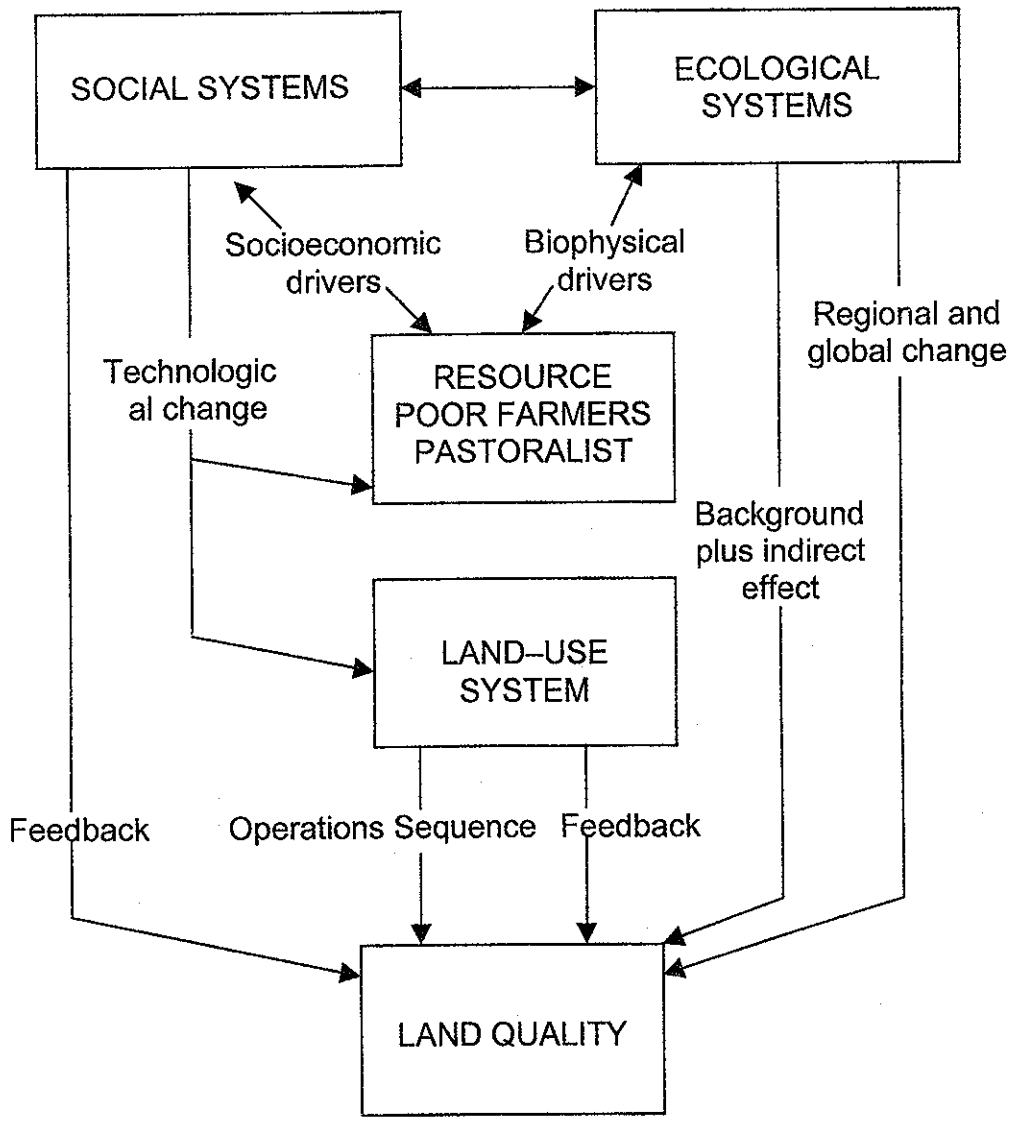

Figure 3. Framework for land–use/land–cover situations.

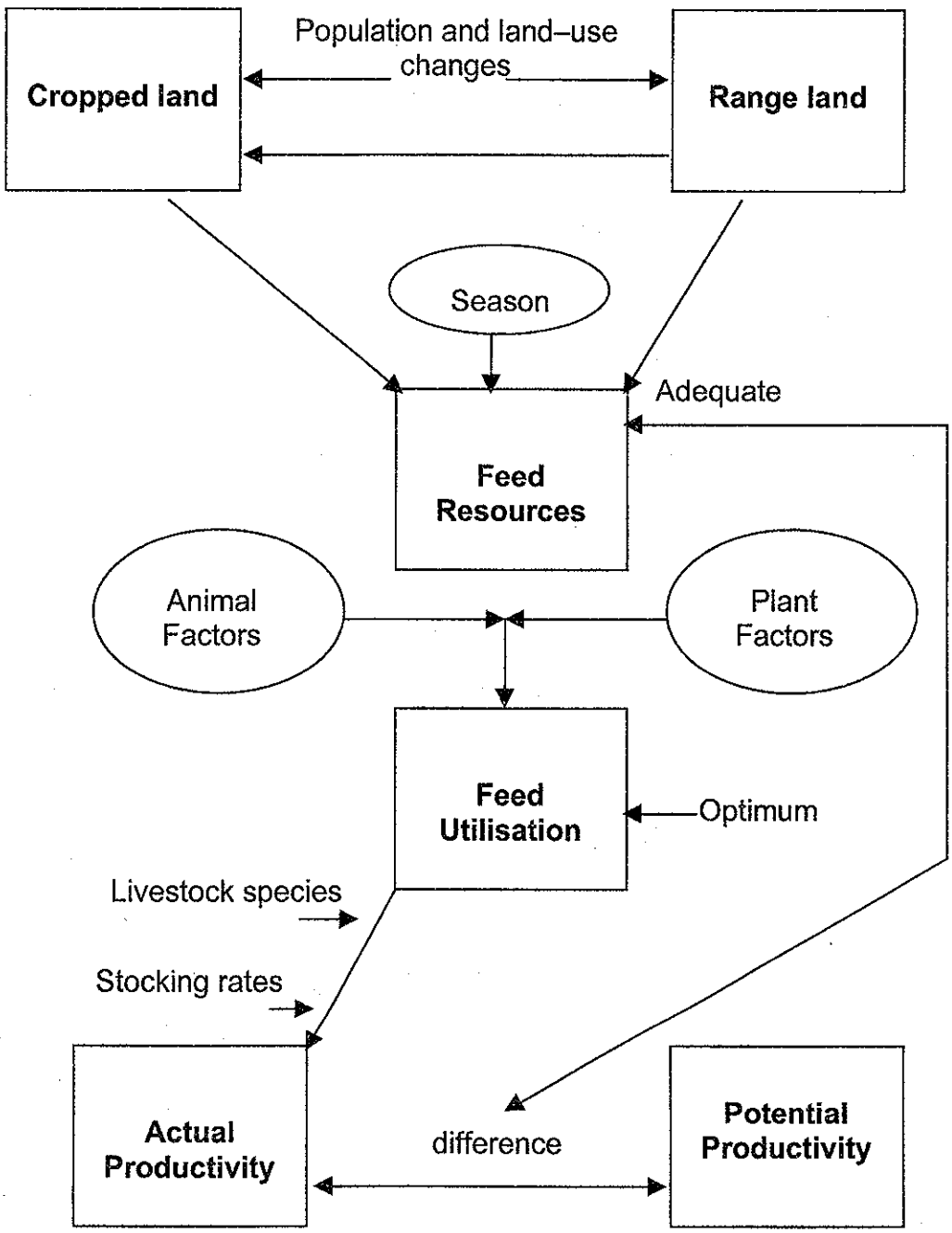

Figure 4. Main components and desired outputs of the feed budgeting model.

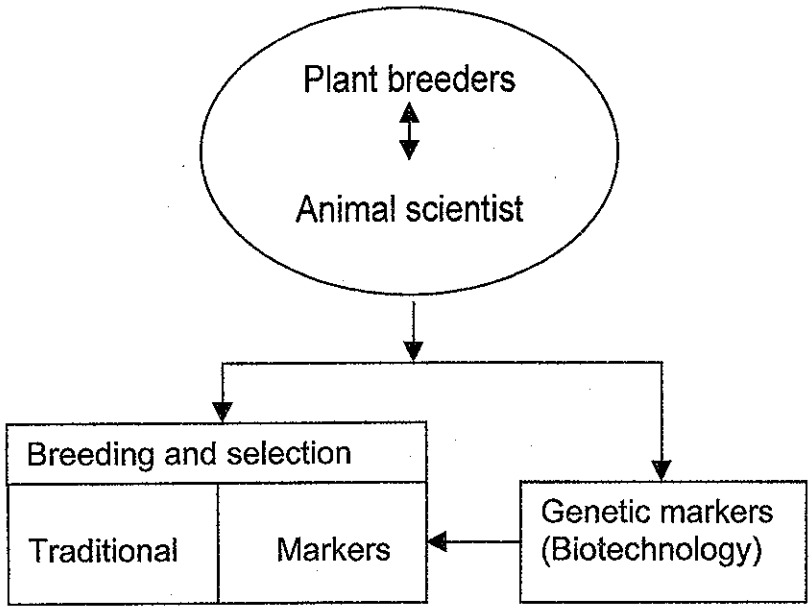

Figure 5. Genetic enhancement of crop residue yield and quality.

Table 1. Selection of food genotypes for food and feed.

Stage	Cultivar Lines	Location		Parameter
		Station	Farm	
I	>50	+++	+	• Food and fodder yield • Leaf:stem ratios • Digestibility (48 h)
II	5–40	+++	+	• Food and field yield • CP,NDF, Degradation (6-96 h) • Predictions: NIRS • Classification • Yield and quality
III	<5	++	+++	• Food and fodder yield • Fodder intake, *in vivo* DMD • Meat, milk, manure • Predictions • Farmer preference

[1] Multi–locational trials measure genotype by environment interactions.

ILRI'S SMALLHOLDER DAIRY SYSTEMS RESEARCH: EXPERIENCES AND LESSONS FROM COLLABORATIVE R&D IN EASTERN AFRICA

William Thorpe

Summary

This paper presents a conceptual framework for market–oriented dairy systems research, addressing policy, institutional and technical issues limiting the development of smallholder dairy in Eastern Africa. It outlines ILRI's collaborative research on smallholder dairy systems with experiences and lessons drawn from the region's coastal lowlands and the highlands. The importance of careful characterisation of the ecoregion, an understanding of the evolution of the agricultural systems and active participation of all major stakeholders and key–players is recognized in the identification and resolution of constraints along the dairy production–to–consumption spectrum.

Background

In most developing countries demand for dairy products exceeds domestic supply, while at the same time, recent improvements in macro–economic policy environments have reduced the attractiveness of dairy imports and increased the competitiveness of domestic milk production. As a result, the deficits in the supply of milk and dairy products, and the large projected increases in demand resulting from urbanisation and rising incomes, represent major opportunities for smallholders to enhance farm productivity and improve family well–being through adopting or increasing dairy production.

In support of smallholders' efforts to exploit these opportunities, ILRI and its R&D (Research and Development) partners are carrying out research on dairy systems using a production–to–consumption approach (Rey *et al.*, 1993). The research is required:

- To strengthen the capacity of regional, national and local R&D agencies to carry out dairy systems research through the provision of proven methodologies and tools and the training of staff, and

- To increase the production and marketing of milk from smallholder dairy systems through identifying improved policies, institutional mechanisms and technologies.

The dairy systems research is carried out at global, regional, country and milk shed levels. It follows sequential steps characterising dairy systems and sub–systems (consumption, processing–marketing and production) to identify and address constraints to, and opportunities for, smallholder dairy development.

The ecoregional approach of the CGIAR (Consultative Group on International Agricultural Research) assumes that the efficiency of use of scarce R&D resources can be improved by carrying out descriptive and diagnostic

analyses, the resulting interventions in geographic regions having a common agro–ecology and similar socio–political environments (Li Pun *et al.,* 1998). In this paper, ILRI's collaborative research on dairy systems is outlined and its approach described. Then, experiences and lessons are drawn from East Africa to illustrate for the region's coastal lowlands and for the highlands, some of the advantages and challenges for development–oriented research in an ecoregional context.

The Conceptual Framework for Development–Oriented Dairy Systems Research

A "dairy system" incorporates all areas, production systems and marketing channels (and the policy environment in which they operate) delivering dairy products to consumers (rural and urban) at the national level or within a specific geographic region (milk shed) of the country. Generally the study of the dairy system will focus on a large consumption centre, often a major urban centre, and the system's four component sub–systems—production, processing, marketing, and consumption (Figure 1).

The broad objective of the research conducted within this framework is to identify and address policy, institutional and technical issues limiting the development of the dairy sub–sector, and particularly its smallholder component (Rey *et al.*, 1993). As Figure 1 shows, the characterisation begins at the systems level, which for countries lacking a recent review of their dairy sub–sector, should ideally be carried out at the national level. This Systems (or Rapid) Appraisal examines the demand for milk and dairy products and the supply from each of the country's milk sheds, and any contribution towards meeting that demand from imports (MOAC/SUA/ILRI, 1998). Since 1996, country Rapid Appraisals have been implemented in Uganda, Tanzania and Kenya, and most recently in Sri Lanka.

For the next stage of the analysis, detailed methodologies have been developed and tested to characterise the consumption (Mullins *et al.*, 1994), marketing (Jabbar *et al.*, 1997) and production (Rey *et al.*, 1998) sub–systems (Figure 1). These sub–system characterisation methodologies have been applied in West and East Africa under a wide range of production, processing market and consumption conditions (ILRI, 1995–7). Along with the Rapid Appraisals, these studies have confirmed the major opportunities for substantial economic growth through market–oriented smallholder dairy, and have highlighted the significant constraints to smallholder dairy development resulting from low productivity, high risks, inadequate market access, and unhelpful policy environments.

In order to address these issues systematically, ILRI contends that a demand–driven production–to–consumption approach to dairy R&D is a prerequisite to success, and therefore that a partnership mode of implementation, consistent with the CGIAR's ecoregional concept, is essential. Consequently, with its partners, ILRI's global, regional and country analyses of dairy systems are:

- Seeking a better understanding of the evolution of dairy systems, and
- Applying these lessons to strengthen ecoregional R&D efforts to improve the productivity of smallholder systems.

The research outputs, therefore, tend to be applied and adaptive at the regional and country levels, but using cross–site comparisons, are strategic at the transregional and global levels. In addition, the research methodologies and tools, and the demonstration of the effectiveness of the inter–institutional and inter–disciplinary approach, are important strategic outputs applicable at all levels.

Improving Dairy Systems Productivity in the Coastal Lowlands of East Africa

Since the mid 1980s, ILRI's dairy research has focused on West and Eastern Africa, and until the mid 1990s, the research in Eastern Africa was concentrated in the Ethiopian highlands and the coastal lowlands.

In the coastal lowlands of Eastern Africa smallholder dairy development has been slow; this lack of development has been mirrored in West Africa, where disease risk for dairy cattle was also high. By contrast, the highlands of Kenya have experienced a rapid increase in smallholder dairy production during the last thirty years, such that its smallholder population represents well over half of the total dairy cattle population in Eastern and Southern Africa. In the east African coastal lowlands the absence of significant dairy development was surprising considering the large milk deficit in both of the major cities in the zone, Mombasa, Kenya's second largest city and in Dar–es–Salaam, Tanzania's largest city (Mullins, 1995).

It was against this background that in 1988 Kenya's Ministry of Livestock Development (MoLD), the Kenya Agricultural Research Institute (KARI) and the International Livestock Centre for Africa (ILCA, now absorbed into ILRI) established a project to identify and resolve biological, social and economic constraints to the development, adoption and productivity of smallholder dairy systems in the coastal lowlands. From ILCA's perspective the target group for the research products were the crop–livestock smallholders in the medium rainfall, lowland tropics of sub–Saharan Africa (and of Eastern Africa in particular), while the target group from KARI's perspective (and the test group for ILCA), were the crop–livestock smallholders in coastal lowland Kenya.

The project, which used a production–to–consumption systems approach (Rey *et al.*, 1993), was planned and carried out in close collaboration with MoLD's extension service through its National Dairy Development Project (NDDP; Maarse *et al.*, 1990), and with the participation of other research institutions.

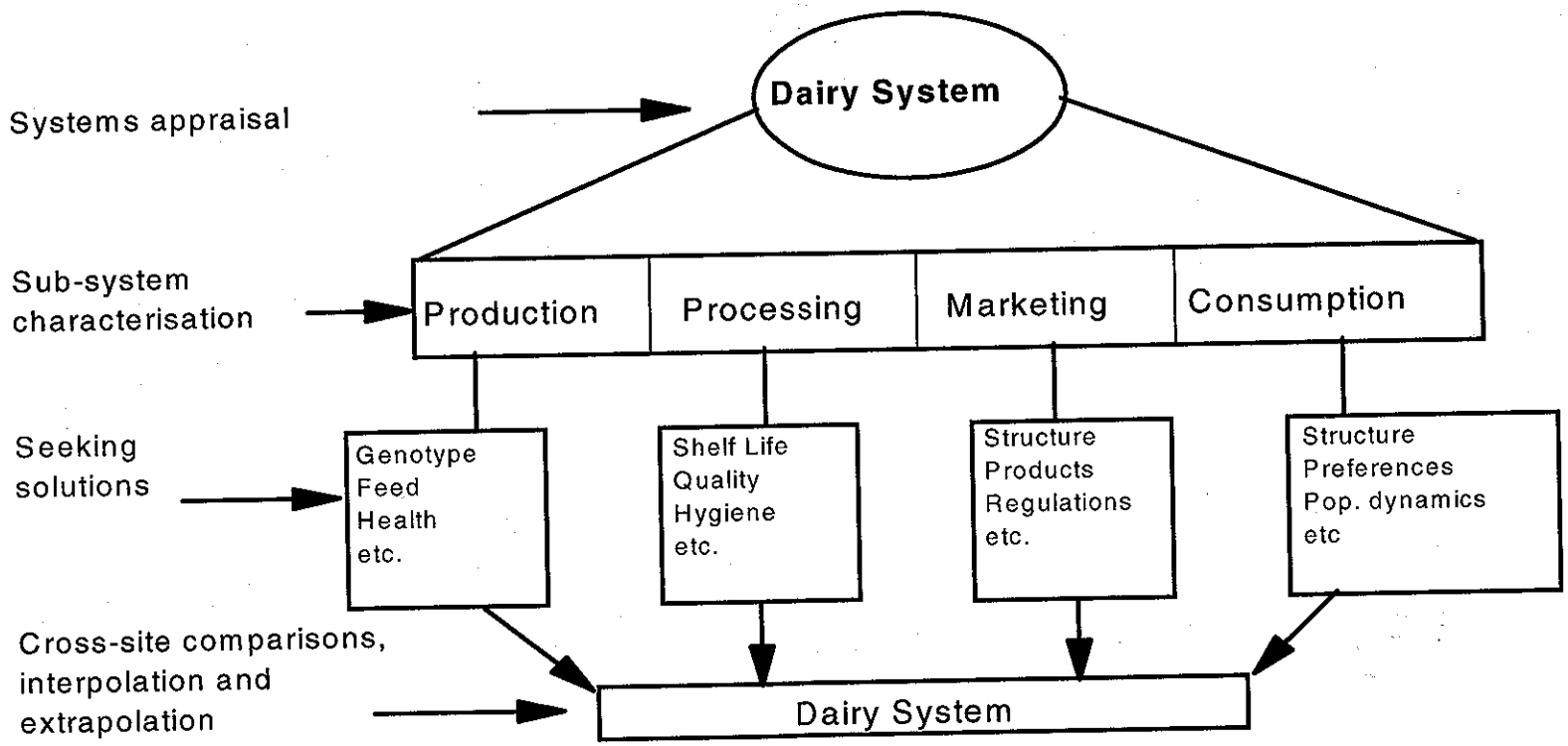

Figure 1. Schematic representation of development–oriented dairy systems research.

The integrated programme of household, on–farm and on–station research covered farming systems description and constraint identification and technology development and testing. The major research areas were studies of dairy consumption and marketing, smallholder resource management, disease risk to dairy cattle, feeding systems development and dairy cattle breeding. The results of the research confirmed:

- The large milk deficit (Mullins, 1995).

- There were seasonal feed shortages and inadequate nutrient concentrations in diets for milk production (Reynolds *et al.*, 1993), constraints which were addressed through the development of improved feeding systems based on intercropping fodder grasses and shrub and herbaceous legumes and the use of maize by–products (Muinga *et al.* 1995; Mureithi *et al.*, 1995b).
- East Coast fever (ECF) was shown to cause major losses in smallholder dairy cattle (Maloo *et al.*, 1994), losses that could be substantially reduced by immunization through infection and treatment (Nyangito *et al.*, 1994; Mukhebi *et al.*, 1995).

- Rotational crossbreeding was identified as an efficient breeding system for smallholder milk production (Mackinnon *et al.*, 1996).

Collaboration with the NDDP ensured strong research–extension–farmer linkages resulting in, for example, farmer–managed forage trials to improve year–round feed availability and, therefore, dairy cattle productivity. Proven (on–station) technologies (improved germplasm and agronomic practices) for the legumes *Leucaena leucocephala* and *Clitoria ternatea* (Mureithi *et al.*, 1995b), were tested systematically with smallholder farmers through, sequentially:

- Farmer/extension staff visits to the long–term on–station experiments.

- Research–extension managed demonstration plots on selected farms.

- Field days held on these farms and those of early adopters.

- Farmer–managed trials on some 300 farms in four districts of Coast Province.

The studies of smallholder farming systems and resource levels (Thorpe *et al.*, 1993; Mureithi *et al.*, 1995a) indicated that for the majority of households, agricultural change will be a sequential intensification through the adoption of individual technological components rather than through the adoption of a multi–component package, such as the NDDP's zero–grazing package. Subsequent research and extension has therefore been developing and testing a range of technological options adaptable to individual circumstances (Thorpe, 1996).

Underpinning these technical achievements was the effective interaction between researchers, extension staff and farmers established from the beginning of the project. The orientation of the research towards field–based problems and studies and the continuous contact with farmers built up confidence between the three groups and ensured effective and productive working relationships. Contributing to this process were monthly seminars and regular workshops for presenting research proposals and reviewing results from the field studies and the experimental programme.

Subsequently these planning and review processes were institutionalised. In 1991, it was agreed that KARI's Regional Research Centre (RRC) would host quarterly "cluster" meetings of research and senior extension staff and other invited participants to review programme activities, and to consider new proposals. Initially these meetings were held at the RRC, but after 1992 they rotated between Kilifi, Taita/Taveta and Lamu Districts. In turn, these quarterly planning and review meetings nominated research–extension working groups to organise specific interventions. For example, a working group developed the protocol for, and supervised the implementation of, the farmer–managed forage trials.

The success of this "cluster" mechanism for strengthening research–extension–user linkages was such that KARI and the Ministry of Agriculture, Livestock Development and Marketing (MoALDM; with funding from the Netherlands) replicated it nationally through KARI's regionally–mandated Research Centres (Thorpe, 1996).

In terms of impact, the development and transfer of appropriate technologies to address the productivity losses resulting from inadequate year–round feed resources and ECF have had a significant effect, particularly in the smallholder sub–sector:

- Over 95% of participating farmers subsequently surveyed had recommended the legumes to their neighbours.

- Approximately 60% adopted the recommended agronomic and feeding practices (Njunie *et al.*, 1994).

- Application of ECF immunisation in the Kaloleni study area was estimated to have reduced mortality and increased calving rates resulting in an 8.6 per cent annual internal growth of the dairy herd (Mukhebi *et al.*, 1995).

These results stimulated demand from smallholders for technologies such as the immunisation of dairy cattle. In response to this demand, private veterinarians were trained as a step towards the sustainable delivery of the immunisation technology. If the technology is delivered effectively to the estimated 24,000 smallholder dairy cattle in the high rainfall coastal lowlands, its direct impact on their survival and performance and the expected spill–over effect resulting from greater confidence to adopt dairy as an enterprise by other smallholders, will be considerable. The effectiveness of the delivery of the immunisation (or a related technology such as a vaccine) will be a major

factor determining the smallholder sub–sector's contribution towards reducing the current milk deficit and meeting the increasing demand for milk at the Coast. Nevertheless these technological impacts will be limited unless supported by more efficient output (milk) and input markets, particularly for clinical veterinary services, AI (Artificial Insemination) and concentrate feeds, and will depend on the competitiveness of dairy relative to other financial opportunities available to smallholder households (Nicholson *et al.,* 1998).

In conclusion, this "ecoregional" inter–disciplinary, inter–institutional programme at its benchmark site in Kenya built strong linkages between the research institutions, the extension services and their clients, current and potential smallholder dairy farmers. It ensured a more effective development, testing and transfer of appropriate technologies such as improved feeding systems and ECF immunisation. It increased the awareness of research and development officials of the importance of effective input and output markets for smallholder dairy development. It has also served as a model for the strengthening of research–extension–farmer linkages for smallholder dairy development and related agricultural development in the medium and high potential regions of Kenya, and elsewhere in Eastern Africa.

From this six–year programme important lessons were learnt that are applicable wherever attempts are being made to implement the ecoregional approach to R&D support to smallholder agricultural development. These lessons include the need for:

- Careful characterisation of the ecoregion, its systems and their evolution to ensure that the selected benchmark site or sites serve the future needs of a significant majority of the region's resource–poor households.
- Active participation of all major stakeholders and key players in the identification and resolution of the technical, socio–economic and policy constraints along the production–to–consumption chain.
- Effective linkages with the Ministry of Agriculture and related Ministries at policy as well as operational level.
- Effective linkages with the private sector for the provision of output and input services.
- Effective means to implement policy, institutional and technical recommendations by feeding directly into the design of pilot initiatives.

Improving Dairy Systems Productivity in the Highlands of East Africa

Having learnt these important lessons through their shared experiences in the coastal lowlands from 1988 to 1994, the three principal institutions in the collaborative dairy research, the Ministry of Agriculture, KARI and ILRI, agreed to apply an "improved" collaborative model in the Kenya highlands, the home of the majority of smallholder dairy producers in Eastern Africa. Limited funds became available in 1995 and 1996, which were complemented by a

substantial two–year bilateral grant from DFID (Department For International Development) in 1997.

While the collaborative R&D activities were originally planned for the central highlands, falling therefore within the broad benchmark area of the ecoregional African Highlands Initiative (Place, 1998), the bilateral grant allowed the team to implement the sequential steps for characterising dairy systems nationally (through a Rapid Appraisal), and then over much of the region serving the Nairobi milk shed.

The goal of the dairy systems research was to improve access by smallholder dairy farmers to efficient, demand–driven services, technologies, advice and information. As in the coastal lowlands programme, the sequential approach to problem identification was followed, with the conceptual framework shown in Figure 1 used to guide the process. First, in order to place the benchmark site activities into the national context, the inter–institutional and inter–disciplinary project team carried out a Rapid Appraisal of the dairy systems in Kenya's major milk production sheds, and compiled a national synthesis of constraints and opportunities to smallholder dairy development (Box1).

Concurrently a characterisation survey was carried out to describe the production sub–system and its market linkages at selected sites within the Nairobi milk shed. These survey sites reflected the important variation within the milk shed for agro–ecological production potential and market access (Baltenweck *et al.,* 1998). The survey applied the basic survey methodology developed by ILRI originally in Ethiopia (Rey *et al.,* 1998), with some refinements tested in a pilot survey carried out in Kiambu District, a peri–urban area adjoining Nairobi. Kiambu has some of the most intensive smallholder crop–dairy systems in the eastern African highlands (Staal *et al.,* 1998).

At the same time, the project collaborators have been carrying out in–depth longitudinal studies on selected smallholder dairy farms in Kiambu, representative of defined target groups (Staal *et al.,* 1998), to describe and analyse household decision–making, with particular emphasis on dairy production and its market linkages.

These studies are the basis for *ex–ante* analyses leading to the design of pilot interventions addressing priority policy, institutional and technical issues. In support of this process, the project has "contracted" studies to understand more about specific constraints and opportunities to smallholder dairy production and marketing. These studies include:

- Delivery of technical extension advice on dairy production.
- Strategic concentrate supplementation of dairy cows.
- Supply of concentrate feeds.

Box 1. Rapid Appraisal of Kenya's Dairy Sub–Sector.

Interdisciplinary analysis of:
- Economic and Structural aspects.
- Dairy Production Systems.
- Policy and Institutional Issues related to dairy development.

Information obtained from August – December 1997 through:
- Field visits and interviews.
- Literature review.

Focus on the following milk sheds and consumption centres:
- Lake Basin; Central and South Rift Valley; Central Province; Eastern Province; Greater Nairobi; and, Coast Province.

Highlights of findings and primary constraints:

Milk Marketing and Consumption
- Good opportunities for continued growth in smallholder dairying.
- The important interaction between market access and levels of milk sales and prices.
- Importance of informal private sector, but poorly understood structure and performance.
- Concerns over public health hazards associated with informal milk marketing.
- Limited market information on input (e.g., feed) and output markets.
- Lack of accurate estimates of demand patterns.
- Farmers' preference for reliable milk channels that pay promptly and that offer additional services.

Dairy Production Systems
- Under–nutrition and seasonal fluctuations in quantity and quality of feed resources.
- Low rate of adoption of available technologies to address feed constraints.
- The important disease challenge in extensive areas.
- Unreliable access to inputs, particularly credit, breeding (AI and suitable replacements) and veterinary services.
- Lack of accurate livestock census reports to allow accurate *ex–ante* impact assessments.

Policy and Institutional Issues
- Underdeveloped infrastructure, particularly roads in many dairy producing areas.
- The positive impacts of market liberalisation including:
- The potential for large increases in productivity and profitability.
- Increasing income generating opportunities (e.g. increase in number of hawkers).
- Low level of farmer control/active participation in dairy co–operatives.
- Slow changes in policy environment and regulations (e.g. informal milk markets).
- Concerns over unfair competition by some formal market agents.
- Poor linkages between input and output markets by farmers' organisations (excl. Kiambu).
- Low impact of government extension services.

- Maize cropping practices for food and fodder.
- Water management for dairy cattle.
- Herd dynamics and replacement strategies.
- Raw milk marketing and public health risks.
- Transactions costs of smallholder milk marketing.
- Whole–farm/household modelling.
- Spatial analysis of dairy production.
- Development and management of milk marketing groups.

The information from these cross–sectional, longitudinal and experimental studies has (or will be) used to carry out *ex–ante* analyses, the results of which are guiding (or will guide) the selection of the pilot interventions. For example, papers by Tanner *et al.* (1998), Biwott *et al.* (1998) and Owango *et al.* (1998) have justified a pilot intervention to test the feeding of strategic concentrate supplementation for newly–calved dairy cows, with the concentrate supplied on credit through dairy marketing co–operatives. The immediate challenge is to convert these plans into effective field activities.

Concurrently a survey of the dairy consumption sub–system and the related marketing aspects, particularly addressing public health risks associated with the marketing of fresh (raw) milk and dairy products, is identifying potential interventions to improve dairy processing and marketing (Omore *et al.*, 1998).

The coverage and results of these surveys, studies and experiments will better describe and address the constraints to, and opportunities for, improving the performance of the dairy systems supplying Nairobi consumers. In addition, the strategic lessons learnt from the surveys, such as through the development of research methodologies and tools, and approaches to the development of institutions and policy options, will be very valuable to the efforts of stakeholders and key players to support dairy development in the Eastern African highland ecoregion, and in similar agro–ecological, policy and institutional environments elsewhere in the world.

Conclusions

These experiences of ILRI and its R&D partners have highlighted the importance of the careful characterisation of the ecoregion and an understanding of the evolution of its agricultural systems. Putting the systems into this historical perspective and relating their dynamic nature to current and future market opportunities will improve the likelihood of selecting benchmark site or sites in which the R&D activities will serve the future needs of a significant majority of the ecoregion's resource–poor households.

Success will also depend upon the active participation of all major stakeholders and key players in the identification and resolution of the technical, socio–economic and policy constraints along the production–to–consumption chain. This process will only be possible through effective linkages with the Ministry of Agriculture and related ministries at policy as well as operational levels, and with the private sector for the provision of output

and input services. And finally, as emphasised earlier, the impact on agricultural productivity, natural resource management and household well–being of these ecoregional R&D activities will be dependent on putting in place effective means to implement policy, institutional and technical recommendations by feeding research findings directly into the design of pilot interventions.

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INTEGRATING EXPERIMENTS WITH AGRONOMIC MODELS AND GEOGRAPHIC INFORMATION SYSTEMS TO BETTER TARGET RESEARCH AND THE EXTENSION OF RESEARCH RESULTS

Arjan Gijsman and Peter Kerridge

Summary

This paper outlines the approach being taken at CIAT to integrate outputs of agronomic simulation models and socio–economic data in a GIS–based system to define recommendation domains for multiple–use forage germplasm. The process of developing a GIS based livestock inventory for about 375 states in Latin America and the Carribean is also explained.

Background

A complementary effort utilizing modelling and GIS (Geographic Information System) facilities is employed to target the extension of CIAT's (International Centre for Tropical Agriculture) research results on forage germplasm for multiple uses in Latin America and the Caribbean (LAC), and formulate future research topics. Though the activities are being developed independently, they are complementary and can be linked.

Agronomic Simulation Models

Agronomic simulation models can play an important role in analyzing a wide range of agricultural management options (e.g. crop rotations, scheduling fertilization or irrigation, livestock production) in relation to environmental conditions. This allows us to evaluate germplasm–by–environment interactions without the need to do expensive and time–consuming multi–site, multi–treatment experiments. Experimental data from one site can thus be extrapolated to other areas that have a different soil type or climate, or where farmers use other crop varieties. Such models may help in (i) Defining the boundaries and optimal environmental and management conditions for certain crops or varieties, (ii) Analyzing aspects of system sustainability, and (iii) Economic analysis of different management options. This allows designing management strategies at the plot or whole–farm level that pay attention to both the biophysical sustainability of the agricultural system and its economic viability.

The Decision Support System for Agrotechnology Transfer (DSSAT) is a widely–used agronomic modelling system, which currently contains some 16 crop models, each with a number of cultivars and ecotypes, and more are under development. For the application of DSSAT to low–input agricultural systems, some modifications are needed:

- In low–input agricultural systems, plant nutrients come mainly from soil–organic–matter (SOM) decomposition. DSSAT does have a module for the simulation of SOM dynamics, but, because the model was developed in countries with high–input agriculture where SOM is not considered of

great importance for the nutrient supply to a crop, this module cannot be considered very detailed and is not useful for low–input systems. A new SOM module, taken from the CENTURY soil–organic–matter model, has been incorporated into DSSAT.

- Many smallholder systems involve a legume green–manure or cover–crop phase. Presently, such crops are not included in DSSAT, but work is under way at CIAT and CIMMYT to include *Mucuna pruriens* and *Arachis pintoi*.
- Similarly, many crop rotational systems involve a ley pasture phase. DSSAT has an option for *Bahía* grass, which, however, is not the most common grass species used in the LAC area. A new *Brachiaria decumbens* option has been added.

There are hundreds of agricultural crop species and accessions which may be of interest for use in smallholder systems, and DSSAT contains only very few of those. An intermediate model approach may then be followed, in which DSSAT is used for an in–depth analysis of system response (e.g. soil fertility development or water competition over time) to a limited number of key species, while the suitability of a wider range of species and accessions to certain environmental and socio–economic conditions is analyzed by the application of a less detailed GIS–based tool.

GIS Mapping of Livestock Inventory for Latin America and the Caribbean (LAC)

A map of livestock inventory, linked to a GIS, is being prepared for LAC. Livestock population density is highly correlated with the level of agricultural intensification. Having information on the livestock inventory in LAC will facilitate the dissemination of improved germplasm with known adaptability. It will also facilitate analysis of policy options.

For each country, a herd inventory will be made at the state level (there are about 375 states in LAC), which will then be sub–divided by animal production system (beef, dairy, and dual–purpose). The breakdown of the cattle population figures into production system for each state will be estimated based on contacts with LAC cattle system experts. Some data from agricultural census and annual reports are already available for certain countries. Detailed activities to collect information in order to construct the GIS map for livestock population are: (i) Conduct world–wide web or library searches for the information needed; (ii) Find census volumes and other information on the spatial distribution of animal production systems in Latin America (FAO–Food and Agriculture Organization, CIAT, etc); (iii) Error checking; and (iv) Positioning of data with respect to land–cover. This will involve using the land–cover data sets to locate cattle populations within administrative units.

Targeting of Forage Germplasm with GIS

A wealth of information on the agro–ecological adaptation of forage germplasm is available in CIAT–held databases. However, the access and

hence utilization of this information needs to be improved. In previous evaluations and documentation of forage germplasm adaptation, the agro–ecological information was separated from the socio–economic factors influencing forage germplasm adaptation. The present work aims to integrate agro–ecological, economic and social information in a GIS–based system that allows targeting of forage germplasm for multiple uses. This should enhance the efficiency and client–orientation of future research, and improve the dissemination of research results. It is anticipated that this approach will allow a more accurate and client–oriented prediction of possible entry points of forage germplasm.

A step–wise procedure will be followed for the development of the system:

- Inclusion of the existing RIEPT (International Network for the Evaluation of Tropical Pastures) database into a GIS to describe agro–ecological adaptation of forage germplasm in Latin America.
- Inclusion of supplementary information on agro–ecological adaptation, as existing in CIAT–held databases.
- Inclusion of experiences of CIAT scientists and collaborators.
- Incorporation of socio–economic information based on existing results, from adoption studies and from on–going work, first at a regional level (i.e. Central America). It is assumed that in the design of future regional experiments enhanced attention will be given to the socio–economic adaptation of forage germplasm, including the utilization of farmer–participatory technologies in on–farm evaluation of forage germplasm

Indicators of forage germplasm adaptation retrieved from certain of the RIEPT regional trials have been identified and the data are currently being organized and statistically analyzed for inclusion into the GIS. During several internal consultations, it was agreed that the current system of ecosystem classification utilized in the RIEPT, is not suitable for the development of the GIS. Research has been initiated to revise the description of ecosystems based on existing database information.

INTEGRATING METHODOLOGIES FOR ANALYSING CROP–LIVESTOCK PRODUCTION SYSTEMS

Mario Herrero

Summary

To adapt to change, smallholder dairy farmers have to look at different options or alternative systems of production and better uses of their land. Local governments and policy–makers also need to be able to predict the short– and long–term effects of new policies for agriculture, on land and resource–use, and on farmers' welfare. Decision support systems as part of the systems approach have potential for speeding the transition from the technology design stage to the testing stage and beyond. Smallholder production systems are highly complex, and it is crucial that any tool developed has the ability to test the trade–offs between different uses of resources at the farm level. At Edinburgh, research has been in progress since 1992 on the construction of a generic whole crop–livestock farm decision support system for optimising on–farm use of resources. This integrated decision support system has been used to solve management problems in grazing systems in Costa Rica and in crop–livestock systems in Bolivia and Mexico.

Introduction

Substantial progress has been made in recent years in modelling biological processes. In the case of crops and livestock the nature of the processes represented has led to the construction, at different levels of aggregation, of very similar models throughout the world. This overlapping has made model–building an expensive and time–consuming activity because researchers often take on the enormous task of building new models rather than selecting and adapting existing ones for their own purpose. Efforts have usually been directed towards representing individual units or processes within a defined system (i.e. the animal, the crop, growth, lactation). These types of models by themselves are useful but usually fail to provide the decision maker with solutions to managerial problems (Dent *et al.*, 1994). As the dairy farming enterprise is a dynamic multi–component activity, integration of these 'individual models' together with herd and socio–economic data should provide a framework for a decision support system.

In activities where allocation of resources plays an important role, testing different management strategies via systems simulation may not provide ideal solutions. In such cases the output of the simulations can be used as inputs to multiple criteria decision models (MCDMs) to obtain alternatives that produce the best combinations of outputs for given levels of resources (Romero and Rehman, 1989).

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This paper very briefly describes a decision support system based on systems simulation and optimisation techniques to identify viable strategies to improve nutrition and management in crop–livestock systems.

Background

Since 1992, we have been working on generic integrated methodologies for the analysis of crop–livestock systems. The objective is to provide decision support tools for natural resource management to extension and advisory services and policy–makers. The geographical focus to date has been mainly Latin America: Bolivia, Mexico, Costa Rica, Brazil and Venezuela. The systems involved are mainly smallholder crop–dairy and dual–purpose systems, but there are also some crop–beef and sheep systems. The crops most commonly grown in these systems are maize and/or rice.

Methodology

The general characteristics of the decision support system are shown in Figure 1. The components are adapted from existing models wherever possible, in an attempt to preclude reinvention of the wheel. The components are generic and modular, and are capable of working with minimum data sets. The components are also open, in the sense that they can be modified and adapted freely. If other methodologies exist, they can be incorporated into the system accordingly.

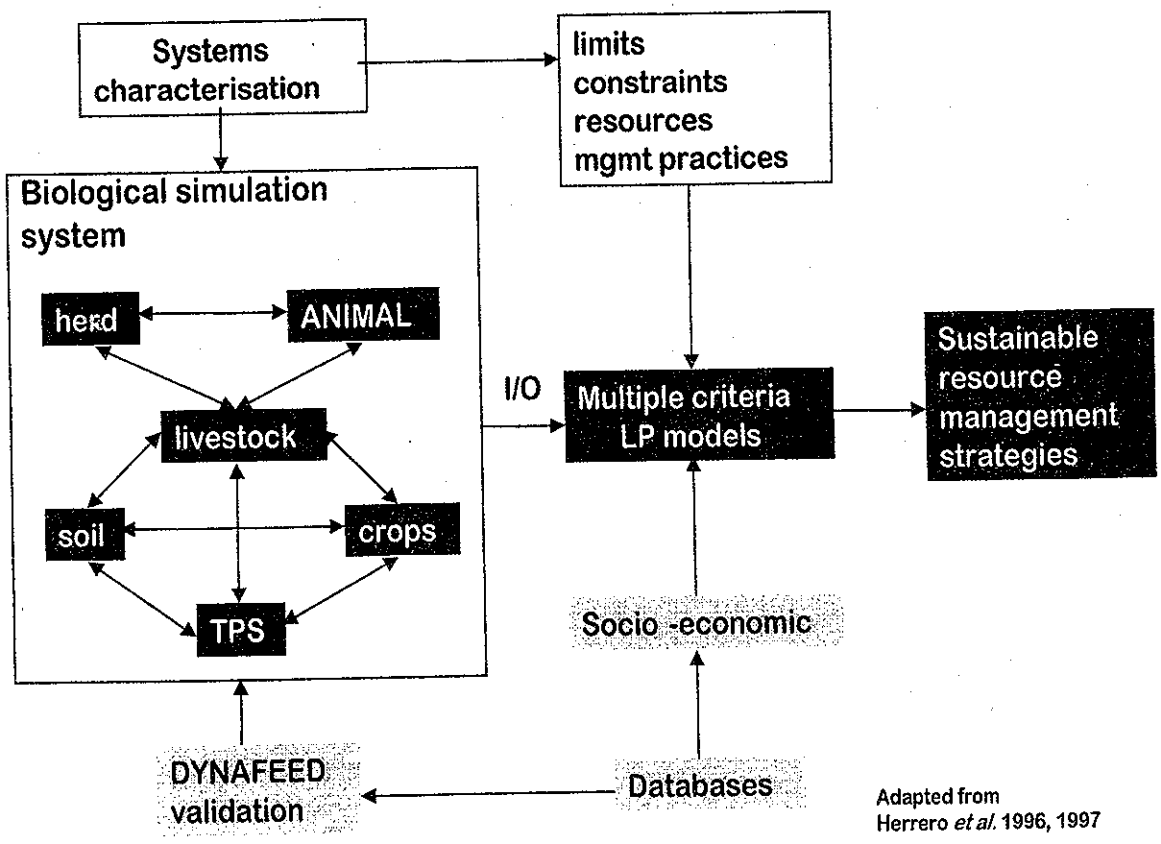

Figure 1. Structure of the decision support system.

Characterising production systems

The characterisation of production systems is the first step in systems analysis. This is required to find out about the limits of the system, its problems and its constraints (ecological, biological, economic and social). Characterisation has been done for the projects in Latin America on the basis of key management practices and farmers' perceptions about their system and its components. Outputs include information that can be used for research priority–setting. In the systems under study, we have collected data using participatory methods and dynamic and static surveys. These data have then been analysed using principal components analysis, cluster analysis and discriminant analysis. An example is shown in Figure 2, relating various social variables to

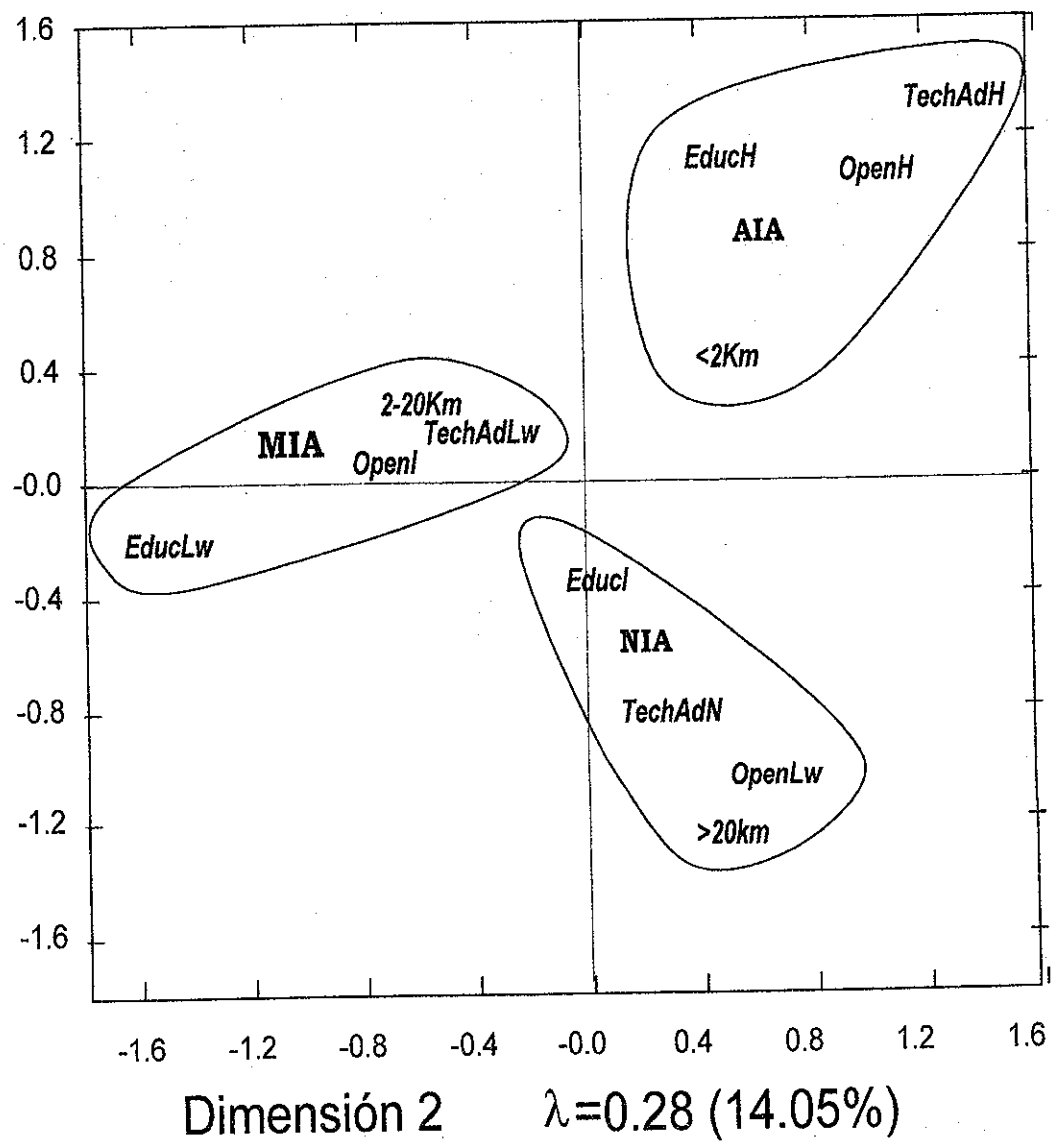

Figure 2. Spatial relationships between social variables and variables related to access to information.

variables concerned with access to information. This information is then used to define and identify farm groups based on structural, social and technological use characteristics of the farmers (Solano *et al.*, 1998).

Bio–physical simulation of crop–livestock *systems*

Livestock model

A simple model was developed to predict intake, digestion and animal performance for ruminants. This has been tested in dairy, dual–purpose, beef and sheep production systems. It consists of a dynamic model of digestion linked to a nutrient requirements system. The outputs from the model include animal intake (pastures and supplements), animal products (milk, weight gain), and excretions. The model has been validated with more than 30 tropical diets. The animal model is linked to DYNAFEED. This is a database of dynamic nutritional information of tropical feeds. Some 150 tropical feeds have been characterised, including grasses (leaves, stems and dead material), legumes and browse, cereal straws and by–products, and other supplements. The information available in the database includes crude protein, carbohydrate fractions (NDF, ADF, soluble CHO), digestibilities and rates of degradation of crude protein and carbohydrate fractions, and energy values. An example of the performance of the model is shown in Figure 3, in terms of predicted and observed intake of different forages.

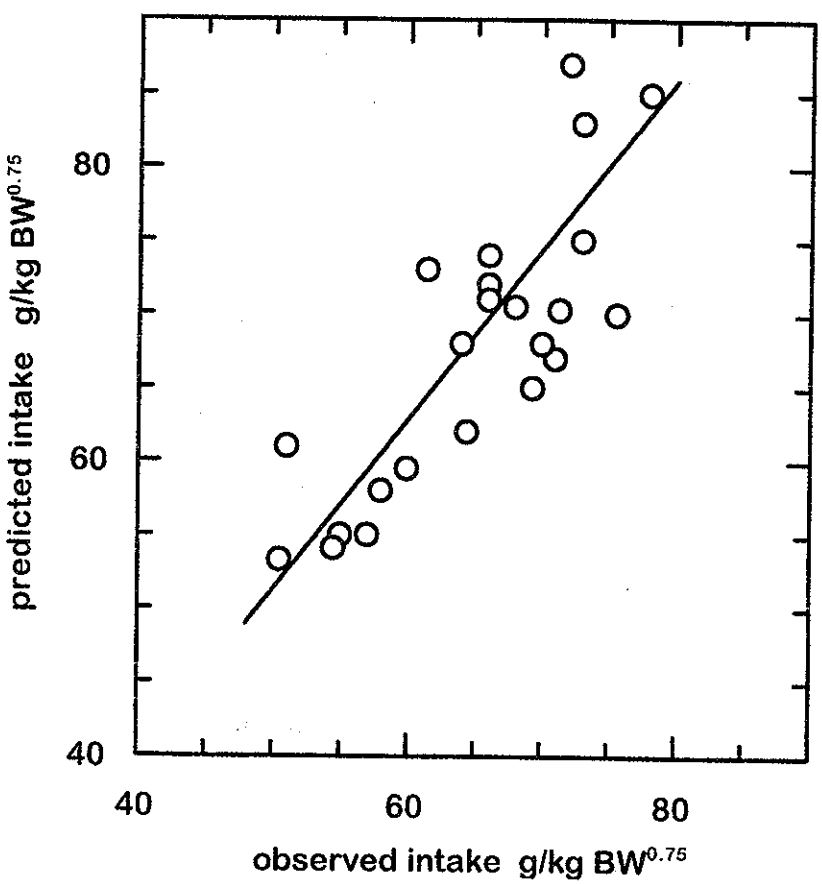

Figure 3. Observed versus predicted intake of 23 forages.

Herd model

The herd model is used to simulate herds with different characteristics (i.e. calving intervals, culling rates, mortality rates, etc). It is able to represent the effects of changes in management practices on herd dynamics, production and economic performance. It provides the required variables for driving the animal component.

Grassland model

Grasslands are modelled using the Tropical Pasture Simulator (TPS). Currently there are three versions available, for Kikuyu grass, *Brachiaria decumbens* and rangelands. The model is driven by environmental variables, and the processes are based on eco–physiological concepts. Various management practices can be investigated: stocking rates, fertiliser applications, continuous and rotational grazing, and varying rest periods. Model outputs include herbage mass and botanical composition (leaf, stem, litter) throughout the year. Extensive validations for Kikuyu grass have been carried out by measuring instantaneous green biomass in experiments carried out in Costa Rica, Hawaii and Australia.

Crop models

Crop growth and development are modelled using the simulation models in the Decision Support System for Agrotechnology Transfer (DSSAT) (Tsuji *et al.*, 1998). The CERES–Maize and CERES–Rice models have been validated using various experiments from Latin America.

Soil model

The soil model is based on CENTURY, and is linked to the animal model, the pasture simulator and the crop models. It is used to simulate the availability of N for crops and pastures, and to simulate the effects of different resource management strategies on nutrient cycling, such as the effects of plant litter quantity and quality and the incorporation of manure and crop residues.

Evaluating Production Strategies and Their Trade–offs: Beyond Simulation

In real life, farmers (and humans in general) usually want to fulfil more than one objective at the same time (multiple criteria). Trade–offs almost always have to be made between them. The example in Table 1 demonstrates the trade–offs between maximising net revenue and capital assets. This leads to very different management and land–use scenarios. Maximising net revenue might be seen in an intensive system, while maximising capital may be more important in a relatively extensive system.

The compromise between these objectives is a problem that can be explained graphically in Figure 4. In this graph the X–axis represents capital in livestock, while the Y–axis represents daily net revenue. The coordinate (0,1) represents the maximum net revenue that can be obtained, while the coordinate (1,0) represents the maximum capital that can be achieved. The scales of the graph are normalised between the values for net revenue and

capital obtained from the two solutions by maximising each objective separately (see Table 1). The coordinate (1,1) represents an ideal solution, where both objectives could be met at the same time, in this case achieving a maximum net revenue while maximising the asset values of the farm.

Table 1. Farm–level activities depending on the objective: the case of a 50 ha farm in the UK.

Objective ***Activity***	**Maximise net profits**	**Maximise capital value of livestock assets**
Total land–use (ha)	40	50
Lactating cows	44	63
Total herd size (animals)	118	168
Average concentrates use (kg lact. cow/d)	5.5	3.2
Stocking rate (lact cows/ha)	2.9	3.5
Fertilise use (kg N/ha)	100	150
Paddock rest period (days)	20	30
Net profits (£/d)	49	34
Capital value of livestock assets (£)	49907	71993

It is clear that both of these objectives cannot be achieved simultaneously. Therefore, the best compromise between them would be the point on the graph that is closest to the ideal solution (*L1*). This point is found by setting two "deviational" variables, one for each objective, and trying to minimise their values in relation to the maximisation of both objectives. For illustrative purposes, the graph also contains other points (▲) representing different calculated values for the deviational variables, but these are no closer to the ideal point, and therefore do not represent the best compromise.

Point *Linf* represents the solution of the model when only one deviational variable is used. In this case, since the solutions are integers, the surface space for searching for the optimal solution is discontinuous. Normally, the surface space would need to be sampled to find the optimal solution. However, in this case, point *L1* is the same as *Linf*, and so this point represents the overall and only optimal compromise between the two objectives.

This type of analysis has important management implications. For this farm of 50 ha and with a daily milk quota of 915 kg, the compromise generates a net revenue of £44 per day at a capital asset value in livestock of £60,507. This is obtained by having a total herd size of 138 animals, with 51 lactating cows producing on average 19.7 kg milk per day, and consuming on average 4.5 kg concentrate per day. The method of concentrate allocation used in this strategy would be a 4:1 milk–to–concentrate ratio. Cows would need to graze at stocking rates of 3.2 cows per ha on 0.6 ha paddocks that are fertilised with

100 kg N per ha per year on a 25–day rotational grazing system. Total land–use would be 44.8 ha, thus leaving 5.2 ha for alternative enterprises.

This type of analysis has the advantage that it can represent a wide variety of management styles. For example, some farmers may opt for the highest net revenue possible, irrespective of the level of risk, since they prefer to have fewer but higher yielding animals.

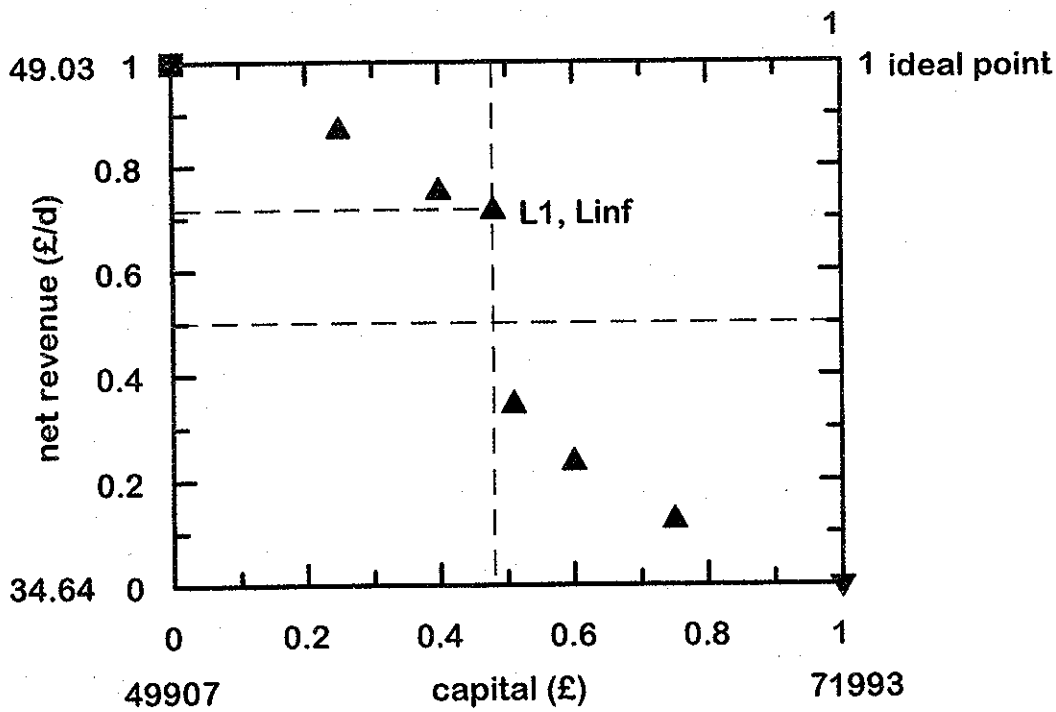

Figure 4. Optimal compromise between the maximisation of net revenue and capital in a medium–sized specialised dairy farm in the UK.

Other farmers may want to maximise the value of their herd, so that high profit is important. Such farmers may not depend directly on the farm but have income from other activities.

Precisely the same methods can be used for smallholders, to investigate feasible options that involve trade–offs between their (probably very different) objectives.

Implementing the Methodology: Logical Steps

The steps involved in implementing the methodology outlined above are shown in Figure 5.

Poverty in the rural areas of Bolivia and Mexico, where this decision support system is being tested, is increasing. Some 65 and 40%, respectively, of the total population of each country live under poverty conditions, and in both cases it has been estimated that around 75% of the poor live in the countryside. Most of the rural poor are small farm households that rely on

mixed crop–livestock systems for their subsistence. In tropical Bolivia, the system comprises a rice crop, small livestock and less than 10 lactating cows producing between 2 and 5 litres of milk per day. Dairying is the small farmer's activity of choice because, while crops provide most of the staple subsistence diet with the small livestock, milk sales provide a daily source of income and livestock represent a capital source to prevent risk or for occasional sales.

In the Mexican case, 80% of all farmers are small farmers (campesinos), and they produce most of the staple food products, particularly maize, which is the basis of the Mexican diet.

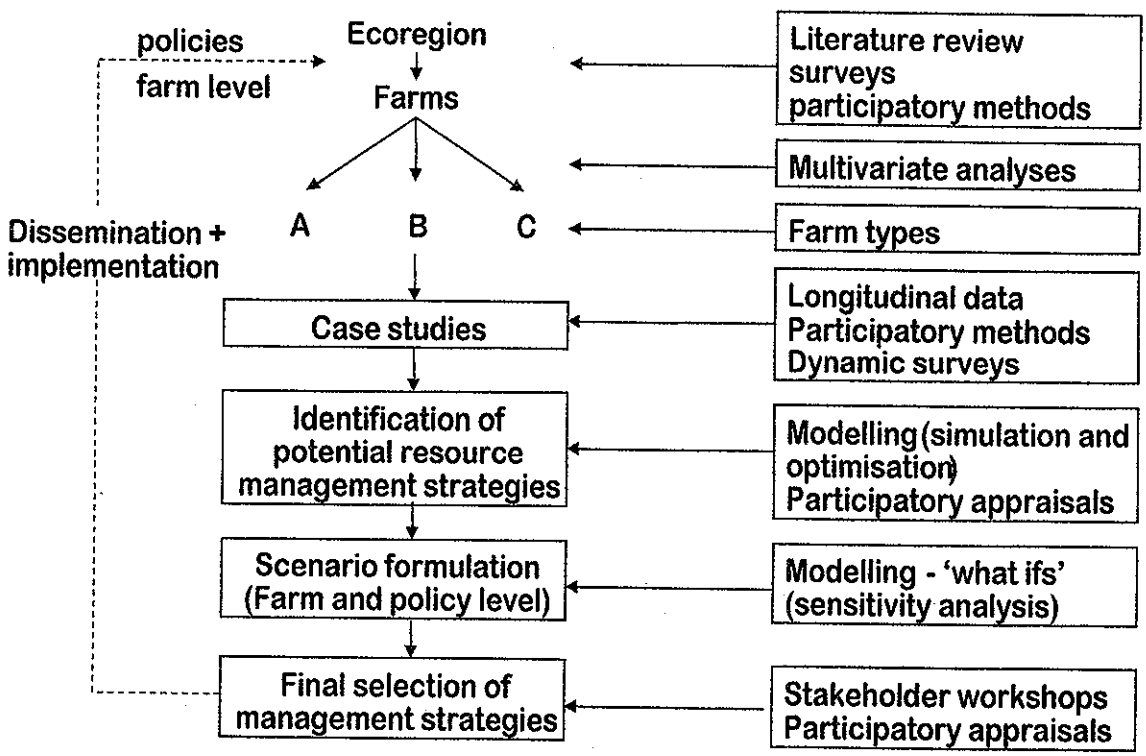

Figure 5. Implementing the crop–livestock decision support system.

Maize occupies 46% of the total arable land. The campesinos also produce 45% of all the milk produced in the country, and possess 25% of the national dairy herd. Increasing the contribution of cattle to Bolivian and Mexican smallholder farmers' livelihoods, through increased milk and beef production, is an option that has a great deal of potential to improve standards of living and reduce poverty in the region. However, in both cases, there area serious constraints in terms of feeding and management strategies, because of the seasonal availability and quality of forages and supplements (diets are based on straws, crop by–products, cut–and–carry forages and low quality grazed pastures), particularly during the dry season. In order to develop appropriate technical interventions that are likely to have impact at the farm level, it is important to understand the influence of seasonal effects on the complex interactions between supply and demand of feed resources and the use of

livestock products. The decision support system described above is one tool for helping to do this.

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INTEGRATING REMOTE SENSING AND DYNAMIC MODELS TO ASSESS PASTURE AND LIVESTOCK PRODUCTION AT THE ECOREGIONAL LEVEL: DEVELOPMENTS IN THE ALTIPLANO

Roberto Quiroz, Walter Bowen and Aldo Gutarra

Summary

This paper describes a project supported by CONDESAN (Consortium for Sustainable Development of the Andean Region) in the Altipano region. The overall objective of the project is to develop and test methodologies that will improve the predictive ability of crop, pasture and animal production models. This is expected to be achieved through integration of remote sensing, GIS and dynamic process models. The project will be useful for evaluating the current status of regional production, monitoring land–use changes, and quantifying climatic and production risks. The paper also addresses scale issues in ecoregional research as well as methodological approaches for linking crop growth, pasture and livestock models with data from NOAA–AVHRR (National Oceanic and Atmospheric Administration–Advanced Very High Resolution Radiometer).

Background

The Altiplano, a wide and mostly flat plain about 170 km across and 500 km long, is situated in the Andean region of southern Peru and western Bolivia. It is one of the largest and highest plateaus in the world, ranking second in size and elevation only to the Tibetan Plateau. With an average elevation of almost 4000 m, the Altiplano is a closed drainage basin feeding Lake Titicaca in the north and Lake Poopo in the south. Annual rainfall runs in a decreasing gradient from about 800 mm in the north to less than 100 mm in the south; these amounts generally fall in a period of 3–5 consecutive months, with the rest of the year being dry. Most agricultural activities—mixed crop and livestock systems—occur along the shore or in the plains and gentle hills near Lake Titicaca, which is the world's highest navigable freshwater lake at 3850 m above sea level.

As part of the central Andean Mountain belt, the Altiplano of Bolivia and Peru is home to more than two million people. The largest urban areas are La Paz and Oruro in Bolivia and Puno and Juliaca in Peru, although most of the inhabitants live in rural communities. Poverty maps show that the poorest communities of both Bolivia and Peru reside in the rural Altiplano, cultivating crops and raising livestock in a harsh environment that is near the upper climatic boundary for viable agriculture. Important food crops include potato, quinoa, barley, and oats. Livestock include cattle, sheep, alpaca and llama, grazed mostly on native rangeland.

In general, the Altiplano is a region characterized by low average income ($300–500 per year), extreme variability in agricultural prices, and high levels of uncertainty and risk at the farm household level. Weather–related events such as periodic droughts, frequent frosts, occasional floods and seasonal wind erosion contribute most to this uncertainty and risk. In addition, crop

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yields in some areas may be reduced by soil salinity aggravated by improper management of irrigation systems.

Project Goal and Objectives

A continuing rise in poverty levels, the inherent high risks to agriculture, and evidence that the productivity of natural resources is being degraded, all point to the need for a better understanding of the social, economic, and environmental forces at work in the Altiplano. In search of this understanding, partners in CONDESAN and others have been conducting farm– and community–level studies in the region to describe and quantify decision–making processes related to risk management (Valdivia *et al.*, 1997). Farming systems research methods have been employed in such studies, but these methods alone are not sufficient for an integrated assessment of the sustainability of agriculture in the Altiplano. Innovative methods based on remote sensing data (Moreau *et al.*, 1997) and process–based simulation models (Arce *et al.*, 1994) have been identified as additional tools for ecoregional approaches to research and development. The potential for linking remote sensing data and crop growth models to estimate production over large areas has been demonstrated elsewhere (Bouman, 1995; Thornton *et al.*, 1997), although methods for making such linkages generic and easily applicable to other ecoregions are generally lacking.

The methodology proposed in this project will build upon remote sensing and process–based simulation experience in the Altiplano, complemented by similar expertise in other regions, to provide generic procedures for linking remote sensing data, GIS and crop and livestock models. The goal of the project is to develop and test methodologies that will improve the predictive performance of crop, pasture, and animal production models through the inclusion of remote sensing data, which can be updated to provide continuous spatial coverage.

Specific objectives of the project are as follows:

1. To develop methods to link remote sensing, GIS, and dynamic models to increase the accuracy in agricultural production prediction at landscape and regional levels.

2. To test the methods developed by comparing the confidence bands of simulated agricultural production with census data, remote sensing data, and outputs from existing simulation models.

The main output of the proposed research will be an integrated assessment system, based on remotely–sensed data, GIS, and process–based models, capable of estimating crop and animal production at different scales of spatial aggregation (at least landscape and region). Such a system will be useful for evaluating the current status of regional production, monitoring land–use changes, quantifying climatic and production risks, and conducting scenario analyses of different policy options or new technological interventions.

Scale Issues in Ecoregional Research

Scale is perhaps one of the most ambiguous and overused terms in research, having different meanings in both spatial and temporal dimensions (Goodchild and Quattrochi, 1997). With regard to the spatial dimension, Cao and Lam (1997) have identified four meanings of scale:

- The cartographic or map scale, which is the ratio of distance on a map to the corresponding distance on the ground.
- The geographic or observational scale that defines the size or spatial extent of a study.
- The operational scale that refers to the scale at which certain processes operate in the environment (scale of action).
- Measurement scale or spatial resolution, which indicates the smallest distinguishable parts of an object.

In ecoregional studies, the geographical scale is determined by the boundaries delimiting the ecoregion chosen. In most cases, researchers have a limited role in the selection of the ecoregion where agricultural or natural resource management research is to be conducted. Researchers are therefore more concerned with operational and measurement scales.

The selection of the measurement scale or spatial resolution is crucial in ecoregional research. This scale defines the lower limit of observation of the research area. The linear dimension is known as the limiting spatial resolution, the size of the smallest observable object, the pixel size or the grain of the photographic emulsion (Goodchild and Quattrochi, 1997).

A decision to work at high resolution increases the amount of data required, and is impractical to implement across an ecoregion. Working at too coarse a resolution, on the other hand, can be meaningless for agricultural or natural resource management research. In this project, representative sites are selected from each defined agro–ecological zone. Intensive ground–truthing is used to validate process–based models and to define the functional relationship between remote sensing variables and the actual on–ground observations. High–resolution remote sensors such as radar (ERS–1 and –2, RADARSAT, and SIR–C), LANDSAT, and SPOT are used. The linkages between remote sensing data and the models (described below) are developed and tested for these sites and then validated elsewhere in the ecoregion.

To define the operational scale, the visualization and analysis of image pyramids are used (Richards, 1993). Successive combinations of groups of neighboring pixels build a pyramid, producing a new composite image of reduced resolution. Mean and variance are used for a quantitative characterization of the pyramids. The variance is particularly sensitive to spatial structure (Arbia, 1990). With this method, the resolution at which the feature of interest is spatially coherent might be detected and with it the type of sensor required for its interpretation (De Cola, 1997).

Ecoregional research can benefit from the use of the Advanced Very High Resolution Radiometer (AVHRR) on board the NOAA (National Oceanic and Atmospheric Administration) satellites. In spite of the coarse ground resolution of the NOAA–AVHRR of 1.1 km at nadir (Richards, 1993), the multi–spectral, multi–temporal, and regional coverage characteristics provide a unique tool for regional observation. An additional important feature is the very low cost, compared with other images. It is worth noting that ten–day composite images (dekad) for the last five years are available at no cost on the Internet. Figure 1 shows the flow diagram for cropping areas larger than the ground resolution cell of the sensor (1.1 km). This is very seldom the case in the Altiplano, with the exception of the communal cropping areas called "Aynokas". These are communal cropping areas where the same crop may be planted over 100 ha of land. The same procedure is used with higher resolution sensors such as LANDSAT and SPOT.

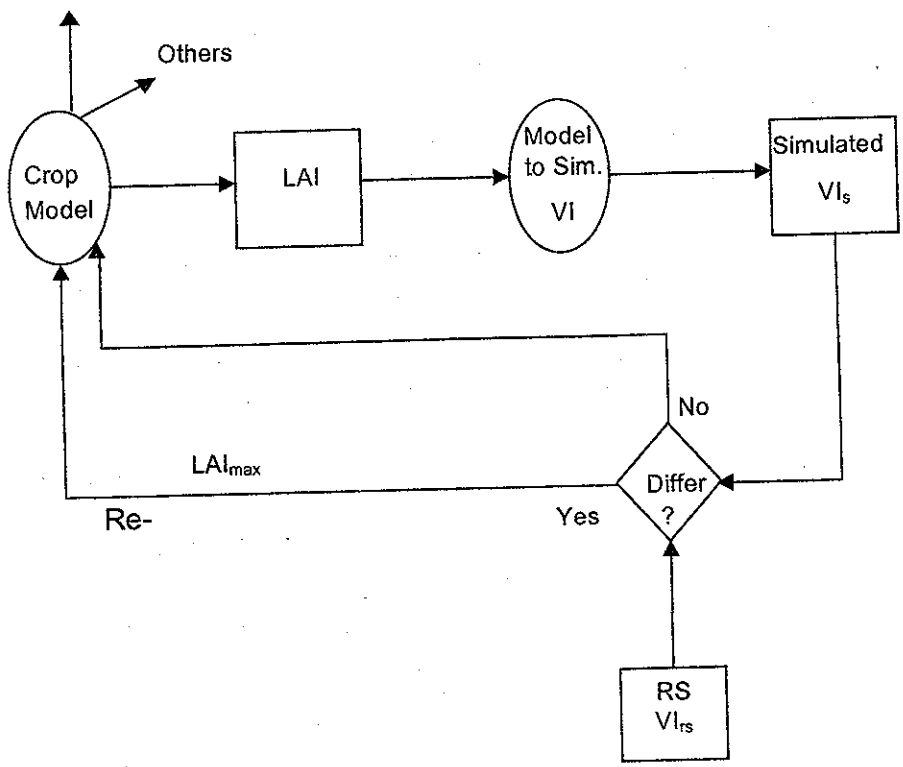

Figure 1. Flow diagram showing the linkage between crop growth models and remote sensing data.

Model Integration

The model integration activities in this project refer to the coupling of dynamic process–based models, GIS, and remote sensing. The following section summarizes, in a schematic way, how the process–based models are updated with remotely–sensed data.

Crop growth models and NOAA–AVHRR

The leaf area index (LAI) estimated by the crop growth models is inverted to estimate the simulated vegetation index (VI_s). This VI_s is then compared with the vegetation index calculated by combining the reflectance measured by the sensor in the red and near infrared portions of the electromagnetic spectrum (VI_{rs}). If the indices are different, the simulation model is re–parameterized with the maximum LAI estimated from the inversion of the VI_{rs} data. The underlying objective of this integration is to check simulation results, and to down–scale simulation results from the theoretical levels of potential and water– and nitrogen–limited to actual attainable levels.

Most of the cropped area in the Altiplano is composed of small plots of different crops. To accommodate this, an alternative procedure is being tested in the field. All the crops within an area comparable to the ground resolution cell of the sensor are simulated. A weighted LAI is determined and the VI_s estimated, and then compared with the VI_{rs}. All the crop growth models in use are then re–parameterized according to the proportion of each crop with respect to the total area.

Pasture and livestock models linked to NOAA–AVHRR

The linkage between the pasture models and AVHRR data shown in Figure 2 is similar to that of crop models described above. All livestock models are being re–programmed to fit the needs of the system being developed. Livestock models can be used with biomass and digestibility data introduced by the user, estimated with the sensor or simulated with the pasture growth model. The system is capable of estimating the reduction in the vegetation index due to grazing. However, this is difficult to validate, because most of the grasslands are continuously grazed.

Linking crop growth and pasture models with radar

The rationale for linking crop models with radar data is similar to that described for optical sensors. In the case of radar, estimation of the backscattering (σ^0) coefficient can be done based on the water content of the plant used to estimate dry matter. This simulated backscattering coefficient can then be compared with the coefficient calculated with the sensor. The model is then updated through a re–parameterization, if required (Figure 3).

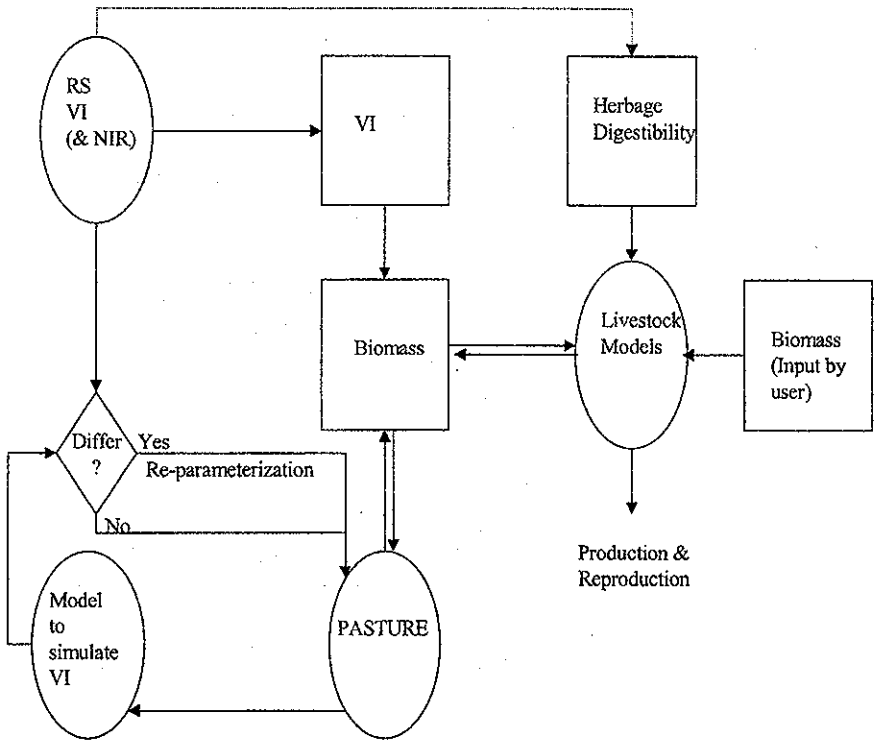

Figure 2. Flow diagram showing the linkage between pasture and livestock models with remote sensing data.

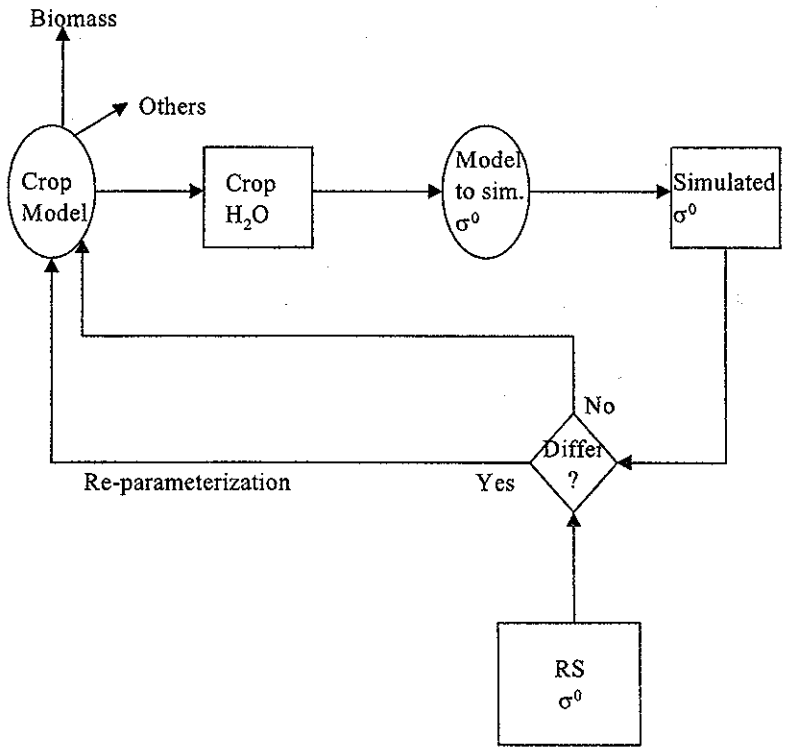

Figure 3. Flow diagram showing the linkage between crop growth models and radar data.

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DEVELOPING INTEGRATED MODELS FOR APPLICATION IN CROP LIVESTOCK SYSTEMS

Peter Thorne

Summary

Integrated modelling of crop–livestock interactions is a cost–effective approach in constraint evaluation and *ex–ante* assessment of interventions in ecoregional research. This paper presents general features of a crop–livestock model, showing the key interfaces in crop–livestock systems. A case study based on the ANORAC (Allocation of Nitrogen in Organic Resources for Animals and Crops) crop—livestock model is also discussed. The core structure, data requirements and various components of the model are explained. The paper points out the likely occurrence of inconsistencies that may hinder the applicability of such multi–component models.

Introduction

The development of integrated models of crop–livestock interactions is a challenging area of activity but one with potential pay–offs in supporting consistency of constraint evaluation and *ex–ante* assessment of intervention development for crop–livestock systems on an ecoregional scale. One of the principal difficulties in developing these kinds of models is the availability of resources allowing the development of coherent simulations of both crop and livestock components at consistent levels of resolution. For this reason, there has been considerable interest in taking existing crop and livestock models and concentrating effort on developing valid and robust interfaces between them. This paper discusses some issues that need to be considered if this approach is to be taken and presents a case study based on the ANORAC (Allocation of Nitrogen in Organic Resources for Animals and Crops) model of Thorne and Cadisch (1998).

A General Crop Livestock System

Figure 1 represents, at the most aggregated and general level, the components of an agricultural system and their linkages. The extent to which each of these components would need to be modelled in order to simulate the behaviour of a given system may vary depending on the nature of that system. Figure 1 also illustrates several aspects of agricultural systems that are relevant to their representation as models:

- There is scope for considerable structural differences amongst systems even when they are represented at this most simple level. Livestock may or may not be present. The contribution of off–farm resources such as range or forest to the farm's organic resource pool may be highly significant or minimal. Models implemented at a more disaggregated level than Figure 1 can only, therefore, hope to be as reliable as the system characterisations that underpin their design or operation.
- The farming system is essentially cyclic at its core (organic resources – livestock – land – crops). Therefore, management decisions in one

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component may produce an impact in all others. By extension, these decisions can also feedback on the component being manipulated in the first place as a result of the changes induced in other components. It is this feature of agricultural systems that makes modelling a particularly powerful tool in their analysis. Controlling variation in experimentation across multiple system components to an extent that will allow the identification of these subtle but often highly significant sources of variation is rarely likely to be feasible.

- Resource competition is a significant issue at most decision points in the system. Decisions on the optimum allocation of scarce resources are often made, by farmers and planners alike, with an incomplete knowledge of their impacts. Modelling approaches should seek to fill in at least some of the gaps.

Key Interfaces in Crop–Livestock Systems

The following key interfaces will need to be considered if livestock models, integrated with crop or soil models, are to be used successfully to simulate the operation of crop–livestock systems:

- Organic resources–livestock.
- Livestock–land.
- Livestock product utilisation.

At each interface there may be a number of processes operating and an integrated model should be able to account both for the individual effects of these processes and their interactions.

Organic resources–livestock

The interface between organic resources—of both on–farm and off–farm origin—and livestock largely represents the supply of nutrients and energy in feed. Some organic matter may also be used as bedding material for animals. However, this is generally associated with the effective trapping of voided nutrients in faeces and urine and is therefore more properly associated with the livestock–land interface.

The management of nutritional inputs at the organic resources–livestock interface may be achieved in two distinct ways which need to be treated differently when modelled:

- Indirect management in a grazing or browsing situation.
- Direct management of feed offers to stall–fed livestock.

The management of grazing usually leaves animals to exercise a considerable degree of self–determination in what they actually consume. The length of access time and the general geographical area may be controlled by the herder but, unless grazing a single–species planted pasture, it is likely that the animal will have the freedom to choose a varied diet. The prediction of quantitative intake and the mix of species consumed is a matter

that has occupied grazing ecologists for a number of years. This issue must be addressed by models wherever grazing is a major element of the system under study.

Stall–feeding is common in mixed farming systems as it allows farmers to exert a greater degree of control over the valuable manure outputs of their animals and also reduces the possibility of damage to crops that may be caused by free–ranging livestock.

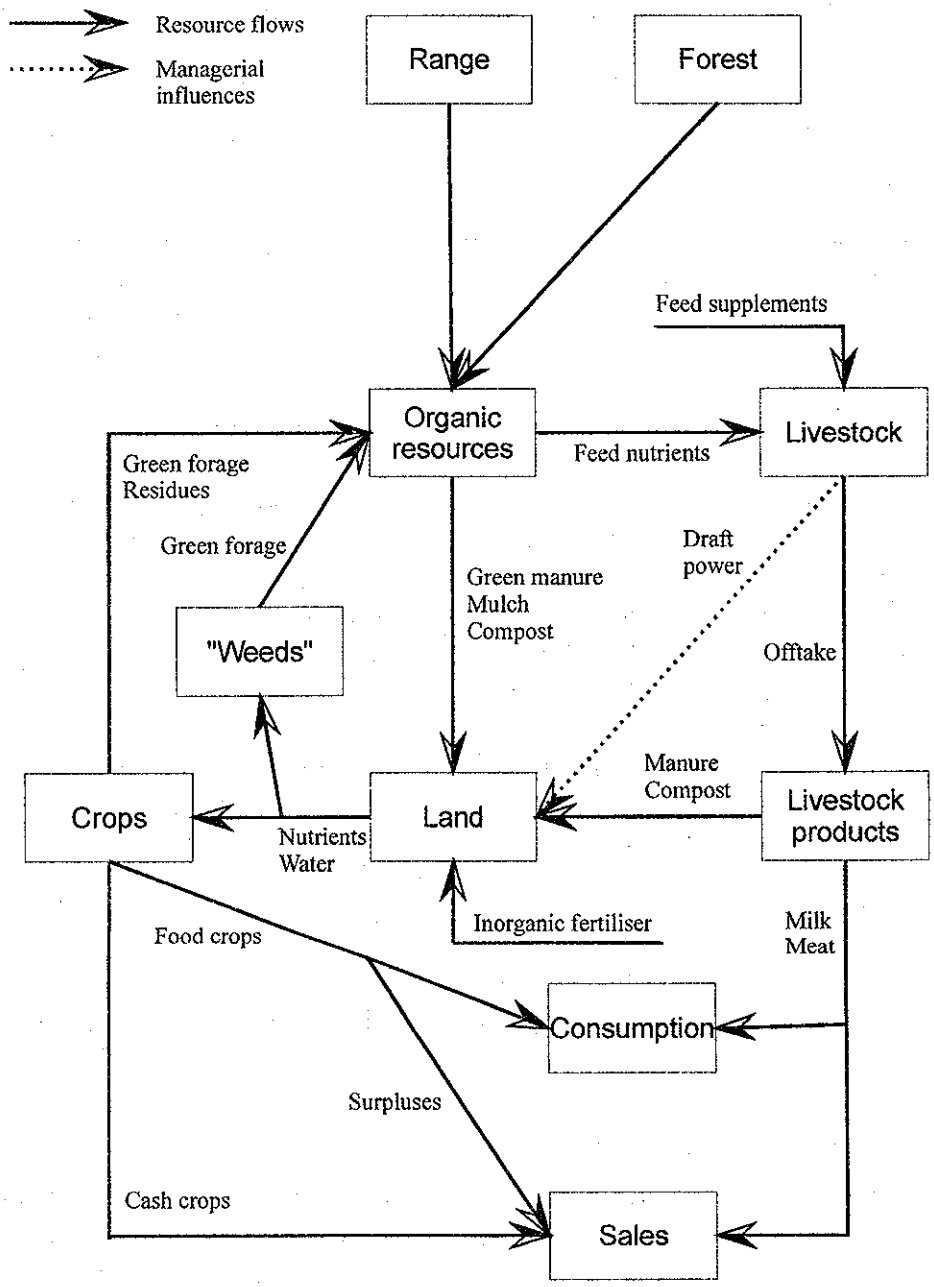

Figure 1. A general schematic representation of the components of agricultural systems and their interactions.

This managerial control makes the simulation, in modelling studies, of the quantities and types of feeds used easier than it is in the grazing situation. However, pure stall–feeding is probably relatively rare. The extra labour

required for feed collection is not always available. Furthermore, where communal grazing is available, not to use it may represent a waste of a potential resource that a farmer will not countenance. Thus, livestock in "stalled" systems will often be grazed as well, usually at a particular time of the year when seasonal factors make this the most desirable management option.

Livestock–land

The livestock–land interface includes two, quite distinct forms of interaction: The production of manure and compost; and the provision of draught animal power. Both of these may exert a considerable impact on the productivity of the cropping system.

Production of manure and compost

The pivotal role of livestock in the cycling of nutrients to crops, wherever the two are associated, has gained considerable ground in recent years as a topic of interest to both the research and the development communities. An international conference (Powell *et al.*, 1995) sponsored by ILCA (International Livestock Centre for Africa) in 1993 covered a wide range of issues relating to this aspect of the interface between livestock and soils.

It is not under dispute that livestock can exert considerable, beneficial effects on system productivity through the manure (and compost)–soil–crop pathway, improving both chemical and physical properties of the soil for plant growth. However, few attempts have been made to derive an integrated, mechanistic understanding of the ways in which dynamic processes in livestock become interlaced with dynamic processes in soils.

Many current soil models rely on superficial characterisations of manure quality (if they allow for its inclusion at all). In situations where the good husbandry of manure to preserve its quality is unknown, this may be justifiable as a large proportion of the nutrients that leave the livestock component of the system by this pathway never find their way to the soil. However, given the current interest in the development of improved composting and manure management practices to maintain quality, the considerable effects of livestock management on that quality are likely to assume greater significance.

Provision of draught animal power

Of the crop–livestock interactions that are pertinent to a consideration of the potential for modelling mixed farming systems, the provision of draught animal power must be viewed in a separate light. Other interactions represent resource flows from one system component to another. Draught animals are used, essentially, as tools in the management of another system component; mainly, in this context, the soil through tillage operations although their role in support of crop processing and marketing should not be underestimated in some situations.

Farmers' perceptions of draught animals in mixed farming systems are often somewhat ambiguous. Access to them is viewed as essential at times of the year when land preparation operations must be carried out. At other times their feeding and general care may be viewed as a largely unproductive chore. For this reason, Draught animals may often be managed on a basis of adequacy with little scope for major increases in productivity through improved feeding or management. Nevertheless, draught animals are consumers of (and therefore competitors for) farm resources. Where they are significant constituents of a mixed farming system, their impact on the management of that system cannot be ignored in attempts to simulate its operation.

Livestock product utilisation

The availability of organic resources and constraints on their utilisation generate a supply–side driving force in mixed farming systems. On the demand side, this role is generally played by an array of economic considerations related to on–farm utilisation and sales of products from both crop and livestock enterprises. These define the overarching objectives that farmers pursue in their farming activities and include the provision of a year–round food supply for the family (or an adequate income stream to substitute for this) and the generation of wealth and cash flow to cover other expenses such as schooling and medical costs.
A key question here is whether it is desirable to address these issues *within* the systems modelling framework or whether they should be regarded as external—that is, considered only during the processes of quantifying input variables and evaluating output scenarios.

Various economic models have been constructed to examine the behaviour of farmers in pursuit of household food security and income generation. These are generally, and often quite justifiably given their objectives, based on simplified coefficient–based treatments of the biological processes occurring in production systems. As this approach precludes an evaluation of the consequences of interactions between processes in different components of mixed farming systems, such models are unlikely to be well–suited to a detailed examination of the impacts of component interventions at the whole system level. This, of course, opens the way for an inverse criticism. The practical utility of deterministic, biological models (at the other end of the spectrum) may be limited by their inability to place their outputs in the context of the benefit that might actually be conferred upon the farmer (with reference to his or her objectives) who adopts the strategies being tested. A "third way" that has gained some ground in recent years is the development of bio–economic models which pursue the sound (in methodological terms) strategy of attempting to model all these aspects of the system at a similar level of detail. Some bio–economic models have already reached quite high levels of detail and sophistication and undoubtedly may make a contribution in the future. However, the suspicion must always remains that the complexity and degree of unpredictability in farmers' behaviour may not always be adequately assessed, undermining the reliability of the predictions of such models and, therefore, the acceptability of any recommendations based upon these.

It is clear from the above paragraph that this is a debate that has some way to run (and that this author is choosing to sit on the fence). However, it is an issue that has some bearing on how modelling activities of this sort might ultimately exert an impact. What should be a *sine qua non* is that future, biological modelling activities are integrated with an appreciation of farmers' objectives, at all levels, in the systems that are being targeted.

Case Study: Allocation of Nitrogen in Organic Resources for Animals and Crops (ANORAC)

ANORAC is a simulation model for evaluating the trade–offs associated with the allocation of organic resources in mixed farming systems for use as fodder or for soil amendment. It is based on revised versions of two existing models:

- APM (Thorne, 1995). This model describes the effects of different animal feeding and management strategies on outputs of Nitrogen (N) in manure and urine.
- CENTURY (soil–submodel; Parton *et al.*, 1987). CENTURY predicts the release patterns of N from organic litter incorporated into soils.

The two models have been substantially revised during the development of ANORAC and then linked using a specially designed manure application module.

ANORAC uses an assessment of the quality of single or mixed organic resources to predict the value of these resources for improving the supply of nitrogen from the soil and for optimising N mineralisation patterns in soils. A key issue that can be addressed using the model is the evaluation of the relative benefits of allocating organic resources directly to the litter pathway or in using animals to recycle N through manure and urine. Thus ANORAC may be used to examine strategies for improving the efficiency of nitrogen utilisation in mixed farming systems.

In its current incarnation, ANORAC is intended as a strategic tool for researchers, planners and extensionists. It is designed to assist its users to devise and pre–test integrated strategies for optimal organic resource–use on mixed farms.

The core structure of ANORAC

The model has five main components (Figure 2):

- An organic resource characterisation module.
- An animal module.
- A manure production and application module.
- A litter management module.
- A soil organic matter module.

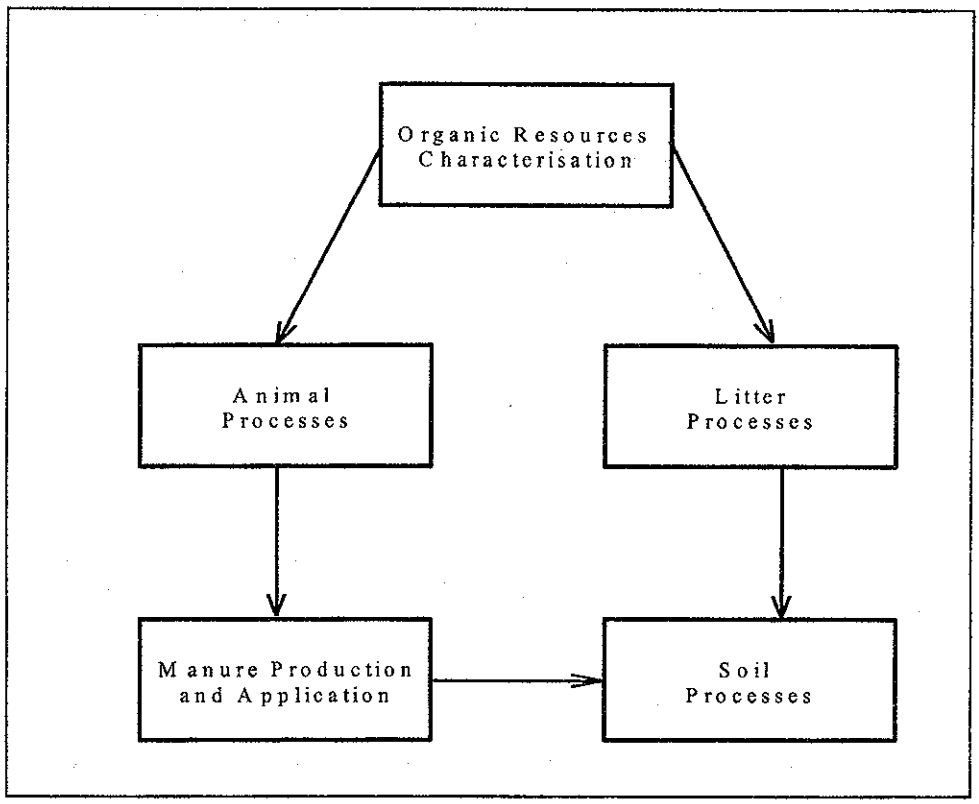

Figure 2. The core structure of the ANORAC model.

Minimum input data set

1. Organic Matter Resource Quality:

These variables are used to define the quality of the available organic resources as both feeds or for soil amendment. ANORAC simplifies the description of organic resources by allowing only two different materials to be described.

- Protein (g/kg, equals 6.25 x %N).
- Metabolisable Energy (ME, MJ/kg DM).
- Acid Detergent Insoluble Nitrogen (ADIN, g N/kg).
- Lignin content (g/kg).
- In sacco degradation constants:

  a – water soluble N (as a proportion of total N in the range 0–1).

  b – potentially degradable N (as a proportion of total N in the range 0–1).

  c – degradation rate constant (per hour).

2. Animal component:

The following variables are used to describe the livestock holding associated with the system, the amounts of feeds used and the composition of the diet.

- Number of animals.
- Mean bodyweight (kg / animal).
- Mean dry matter intake (kg / animal).
- Level of inclusion of Resource 1 (basal diet) and Resource 2 (supplement) in the diet (g/kg).

3. Organic matter handling for soil amendment:
   - Litter addition per day.
   - Excreta addition per day.
   - Urine recovery (0–100%, proportion of urine which is not lost during storage and subsequently applied to the soil at the excreta addition day).

4. Litter (soil amendment) composition:
   - Proportion of basal and supplement resources added to the field (g/kg).
   - Amount of litter added to soil (kg DM/ha).

5. Soil parameters:
   - Initial total topsoil %C and %N in the topsoil (0–0.2 m).
   - Proportion of clay and silt content (0–1).
   - Soil temperature (°C).

6. Facultative soil input parameters
   - Soil bulk density (g/dm3, default 1.3).
   - Initial active and slow soil C pools (kg C/ha/0.2 m).
   - C:N ratio of active soil organic matter pool.

The animal component of ANORAC

The animal component of ANORAC is based on the treatments of nutrient and energy absorption and utilisation outlined by Harkins *et al.* (1972) for energy supplies and by AFRC (1992) for protein. The basic input data set required has been minimised to allow the model to be operated in situations where available data are limited.

ANORAC assumes that all animals in the herd are identical in type (for example, growing animals of a fixed mean liveweight). This approach simplifies simulations for a range of herd sizes and is considered justifiable as

the model is designed principally to examine the effects of livestock, as a system component, on nutrient fluxes.

The simulation of animal performance is derived initially from the difference between the energy supplied in the feed consumed and the maintenance requirement appropriate for the type of animal in the herd. A mean daily rate of production (milk or liveweight change) and total production (or liveweight loss) during one month is calculated from the amount of energy in excess or deficit of the maintenance energy required. In the latter case, weight loss is calculated from the amount of body reserves mobilised to meet a shortfall in ME for maintenance.

The animals' ability to achieve the level of performance predicted from energy intake depends on the adequate supply of protein for turnover and production. Dietary protein supply is checked against the protein required to support the level of production by the energy component. If the former is found to be inadequate, a correction is made to the predicted production level on the basis of the rate of protein utilisation that the current protein intake will support. If protein supply is inadequate for protein turnover, a weight loss is estimated. The model's simulation of nitrogen transactions at various points in the ruminant digestive tract is used to predict the partitioning of ingested N for productive purposes (in the animal) to urine and to two faecal pools (labile and recalcitrant).

The soil component of ANORAC

Both the plant litter and soil components of ANORAC are based on the soil–submodel of CENTURY as described by Parton *et al.* (1987). The litter–soil organic matter model component incorporates multiple organic matter compartments each decomposing at different rates that vary as a function of monthly soil temperature. The model includes both nitrogen and carbon flows. Plant residues are divided into structural pools that have 1–5 year turnover times and metabolic pools that have 0.1–1 year turnover times prior to transfer into soil organic matter (SOM) pools. The lignin:N ratio of plant residues controls partitioning into structural and metabolic material. The decay rate of structural material is a function of its lignin content.

The soil submodel is composed of three organic matter fractions. These are:

- An active fraction of soil C and N consisting of live microbes and microbial products along with SOM with a short turnover time (1–5 year).
- A pool of C and N (slow SOM) that is physically protected and/or in chemical forms with more biological resitance to decomposition, with an intermediate turnover time (20–40 years.
- A fraction that is chemically recalcitrant (passive SOM) with the longest turnover time (200–1500 years).

While most new incoming materials enter the SOM model via the active soil pool the lignin fraction feeds directly into the slow SOM pool. Additionally,

stabilisation of SOM is a function of soil texture with sandy soils being less efficient than fine–textured soils.

The nitrogen model is structured in the same way as the carbon–flows (SOM). It is assumed that most N is bonded to C. The C:N ratios of structural (150), active (8), slow (11) and passive (11) fractions remain fixed, although there is an option to change the C:N ratio of the active (or soil microbial) pool. The N content of the metabolic pool is allowed to vary as a function of the N content of the incoming plant material, with the plant N not needed to create structural material passing to the metabolic–N pool. Nitrogen flows were assumed to be stoichiometrically related to C flows and were equal to the product of the C flow rate and the fixed N:C ratio of the state variables receiving the C. Either mineralization or immobilization of N may result from C flow, depending on the initial C:N ratio of material, the C:N ratio of pools receiving the C, and the fraction of the C flow lost as CO_2 respiration (30–80% of the total C flow). Both soil organic matter (soil C) and plant available soil mineral N pools are major outputs of ANORAC. Assessing changes of these main variables affords the user a rapid evaluation of the potential impact of given managerial treatments on the sustainability of and nutrient supplies within the modified system.

The current version of ANORAC does not give estimates of leaching or gaseous losses from the soil mineral N pool nor does it have a defined plant growth model. It is anticipated that these components might be easily added using appropriate modifications of existing plant growth and nitrogen leaching models.

The manure component of ANORAC

ANORAC characterises manure in a way that is analogous to its characterisation of plant litter (see above). The same turnover times and C:N ratio concepts have been used. The model assumes that ADF passes the digestive system unaltered and is the major contributor to a structural manure pool together with undigested microbial by–products. Losses from the urine pool in the manure component can be set allowing for differences in N recovery efficiency depending on the storage conditions and handling procedures. Manure can be stored for a period that may be defined by the user before being applied to the soil. At present the model does not simulate losses during this period that may arise as a result of inefficient manure/compost management and therefore predicts potential N flows under conditions of optimum management. As this is a major issue in many mixed farmer systems, further development of ANORAC to include a manure handling component would improve its utility in decision support.

An example simulation using ANORAC

The utility of a simulation model for determining the consequences of alternative strategies is dependent in the first instance on its ability to simulate the outcomes of existing scenarios. This section presents a brief overview of the consistency of ANORAC predictions with some of the observed data derived from the experiments conducted in Kenya.

Table 1 shows observed and predicted data describing the fate of ingested nitrogen in cattle. Prediction errors of between 8 and 47% were recorded for Total excreted N. The directions and magnitudes of responses to differences in dietary treatment were predicted effectively by ANORAC model for both variables.

Table 1. Experimentally observed and ANORAC (Thorne and Cadisch, 1998) predictions of values for faecal N components resulting from different feeding strategies.

	Total N		Prediction error (%)	Bound N*		Prediction error (%)
	$g\ d^{-1}$			$g\ d^{-1}$		
	O	P		O	P	
Barley straw (BS)	18.2	26.8	47	2.1	3.6	42
BS + calliandra	45.6	49.2	8	8.5	16.9	99
BS + macrotyloma	30.0	41.5	11	4.2	12.3	192
SE_d						

O = observed; P = predicted.

*–O and P are not strictly comparable. Observed values are for measured NDF whilst predicted values are derived from the partitioning of ingested N into a number of different gut pools. These values are presented for the comparison of trends only.

Figure 3 illustrates the use of ANORAC in the evaluation of alternative organic matter management strategies through the study of the time course of soil N mineralisation. Although there is a fairly strong tendency to under–predict the extent of N immobilisation on addition of the test material, this appears to be consistent amongst substrates. Furthermore, whilst quantitative accuracy of predictions is poor, the impacts of changes in diet appear to be handled well by the model.

At present, ANORAC is a unique model in that it is able to describe dynamic N transactions in animals and soils at an integrated and mechanistic level. The benefits of the approach taken lie in the potential flexibility of the model for use in a wide variety of circumstances provided that values for a set of readily accessible feed, animal and soil parameters can be specified. We believe that future versions of ANORAC will, with reduced prediction errors, provide a useful core tool for the development of a broader integrated model of mixed farming systems that could ultimately be used as a basis for practical decision support software.

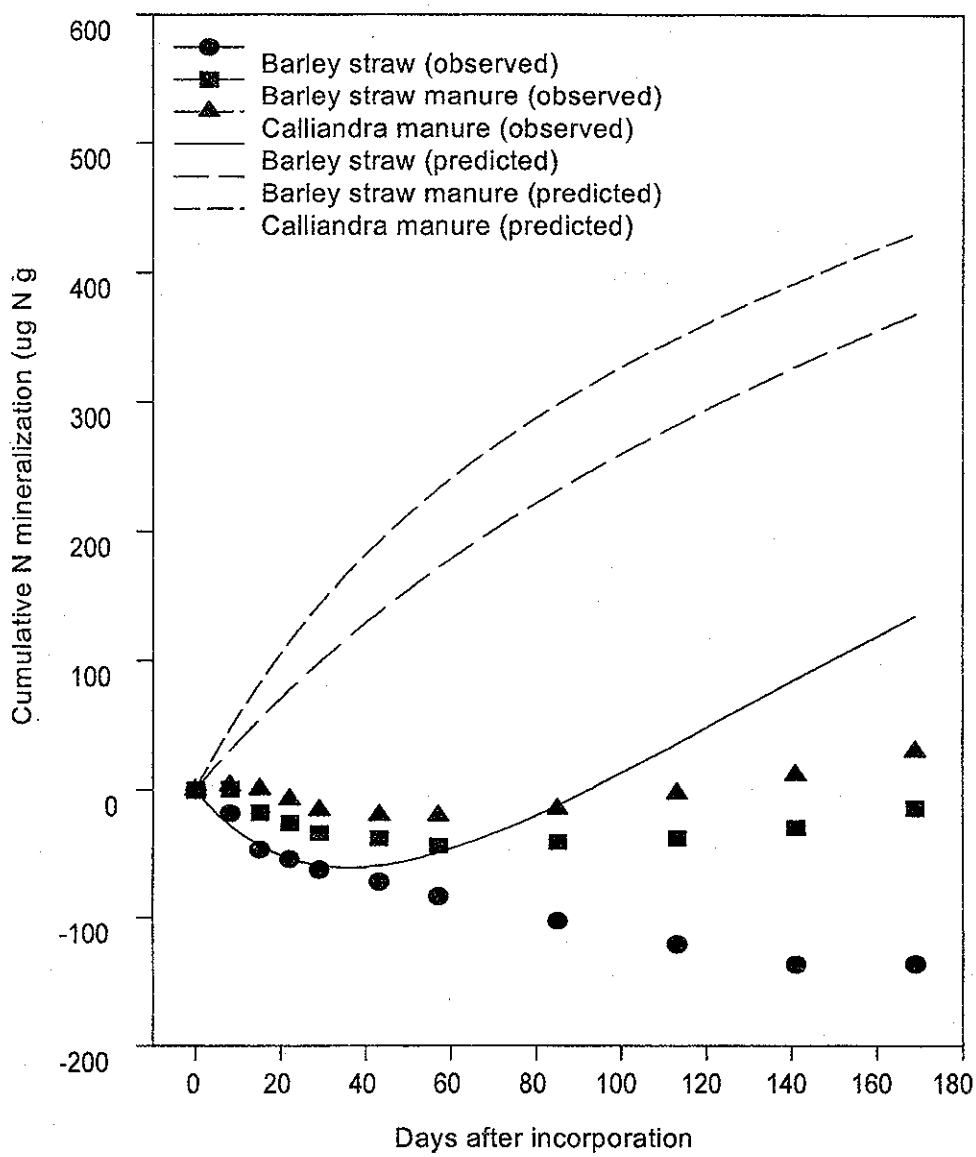

Figure 3. Nitrogen mineralisation patterns from different organic resources predicted by ANORAC (Thorne and Cadisch, 1998). Observed values are from Delve (1998).

Data Sources for Integrated Modelling

A major problem in any modelling exercise lies in the securing of comprehensive and reliable data sets for both validating and using the model. Integrated models of crop–livestock systems are likely to be particularly troublesome in this respect as their components cover a number of traditional disciplines for which data sets at a consistent level of detail need to be identified if proper approaches to validation and use are to be attempted. In practice, this is unlikely to be feasible and a more piecemeal approach based on the validation of individual components (or even the individual processes within components) tends to be adopted. The problem may be exacerbated where data sets take the form of time–series, necessary for evaluating the consequences of management changes in the longer term. Furthermore,

differences in data collection techniques and the commitment of enumerators can confound comparisons amongst sites or regions.

The scale of the data availability and reliability problem is revealed by the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project, in which the identification, collection and use of data sets in modelling was addressed systematically and rigorously and not without success. However, Hunt and Boote (1998), reviewing the development of the IBSNAT minimum data set, conclude that:

"... there is [still] a dearth of data sets for model calibration and evaluation. ... [a] lack of attention [to data management] has in some cases resulted in the loss of data sets that were aggregated for [publication of] a particular piece of work. A second impression concerns the lack of data that are essential for model operation, which in some cases reflects the inaccessibility rather than the absence of data. In some regions, required weather and soil data have not been collected, or they are archived in such a way as to be virtually inaccessible ..."

Nevertheless, the IBSNAT experience clearly illustrates the value of a considered and rigorous approach to data collection, handling and application. Future attempts to develop integrated models of crop–livestock systems will need to profit from these experiences in giving formal consideration, at this level, to the data required to support them. In particular, the minimum data set approach used in the development of the DSSAT (Decision Support System for Agrotechnology Transfer) models (Hunt and Boote, 1998) could be applied more widely.

A minimum data set for models of crop–livestock systems?

The minimum data set of crop, soil, weather and management data specified as part of the IBSNAT project was arrived at after much discussion amongst project collaborators over a period of four years in the mid 1980s. This paper will not attempt to do the same for crop–livestock systems! However, this is a fundamental issue that needs to be considered by those involved in modelling or systems–based research directed at situations in which livestock and crops interact. As a basis for debate, Table 2 summarises the main aspects of livestock that are likely to require a treatment in integrated models of mixed farming systems. Also listed are some of the variables that dynamic processes in crop–livestock systems are likely to be sensitive to and that will therefore need to be quantified in order to define these.

Data quality and availability

Where data availability is perceived as a constraint for applying modelling approaches to the evaluation of whole–system problems, two major options exist that, while perhaps leading to an increase in prediction errors, may still allow meaningful results to be achieved.

Simplify the core model. When the objectives associated with using a particular model are changed—as would be the case when existing models are integrated in the way discussed in this paper—it is likely that a different

range of sensitivity analyses will be required. For example, a model of N digestion in the animal linked to a soil N model might be used to examine mineralisation from manure. It is likely that this response will be sensitive to changes in a different set of decision variables to those used to describe N transactions in the animal allowing some simplification of the model for its new use.

Table 2. Aspects of a minimum data set for describing the impact of livestock in mixed farming systems.

Group of processes	Variables required
Feed Resources	Availability – quantities – pattern Dry matter content Nitrogen (crude protein) content Energy content (draught animals?) Utilisation potential – digestibility – kinetic parameters Production / collection costs Competitive uses
Individual (or aggregated) animals	Age Sex Genotypic variables – growth potential – reproductive potential – disease resistance
Livestock holding	Initial – size – structure
Animal Outputs	Economic value
Organic inputs to soils	Nitrogen and carbon – quantity – allocation to soil OM pools Other nutrients (depending on limiting nutrients in the soil)
Draught power	Work profiles – timing – duration – intensity

Derive relationships for quantifying required variables. Essentially, this amounts to expanding the scope of the model, although usually such extension will be based on empirical relationships. Where required input variables cannot be quantified for the situation that will be simulated, simple relationships with readily available data may sometimes be identified. For

example, Herrero's Edinburgh Cattle Production Systems Model derives this kind of relationship to generate the input data required to predict pasture productivity using the mechanistic model of Johnson and Thornley (1985). These are based on levels of N fertilisation and leaf density (Figure 4), two variables that may be readily assessed. Thorne *et al.* (1997) describe a possible approach for using the information held within the farming communities of developing countries (popularly referred to as "indigenous technical knowledge") that is often qualitative in nature. This pilot study used a fuzzy systems approach to allow information on fodder quality derived from PRA (Participatory Rural Appraisal) studies to drive a simple semi–mechanistic cattle digestion model. A similar approach has now been used in a computerised decision support tool for rationing dairy cattle (Thorne, 1998).

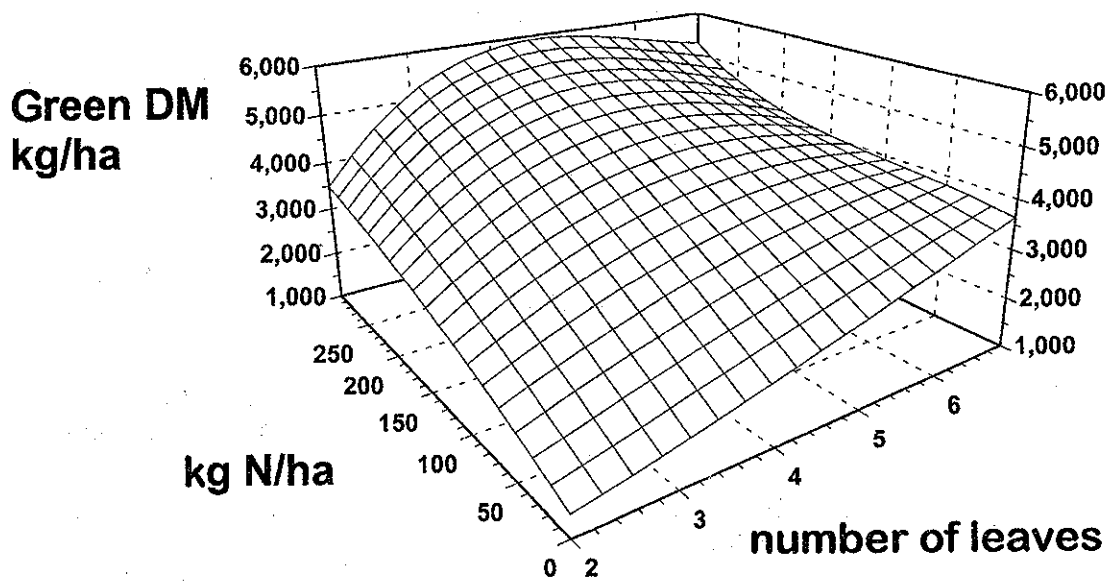

Figure 4. The relationship between number of leaves, N fertiliser level and green dry matter accumulation for Kikuyu grass grown in the highland of Costa Rica (Thorne and Herrero, 1998).

Conclusions

Combining existing models of the different components of mixed farming systems does have the potential to produce integrated models with a broad scope at a relatively low cost. There are, however, a number of potential pitfalls. Foremost amongst these are the inconsistencies that may exist amongst component models, both in terms of level of resolution and compatibility of approach. As an example of the latter, the case study presented here (ANORAC; Thorne and Cadisch, 1998) required an interface between a nitrogen–driven animal model and a carbon–driven soil model! Resolving such inconsistencies may mean that the economies derived from using an off–the–peg approach may be outweighed by practical complications that would not arise in the development of a bespoke model. Furthermore, data availability and, where this is deemed inadequate, possible alternative

sources need to be addressed at the outset of any serious attempt to derive this kind of model. If just one of the component models is judged to be unsupported by adequate data, it is highly unlikely that an integrated model that makes use of it will perform acceptably.

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A DECISION SUPPORT SYSTEM TO QUANTIFY TRADE–OFFS IN SUSTAINABLE AGRICULTURE AND THE ENVIRONMENT IN THE ANDES

Jetse Stoorvogel, Charles Crissman, John Antle and Walter Bowen

Summary

This paper presents a collaborative research project in the Andes whose main objective is to develop a decision support system for assessing trade–offs between agricultural production and the associated environmental impacts under various scenarios. The system will be developed and tested in potato/pasture production systems of the Andean region. The paper gives a conceptual account of a decision support system for Trade–off analysis and its methodological challenges. Scale issues are also discussed and one of the aspects pinpointed as a problem area is the choice of the unit of analysis. It is acknowledged that various scientific disciplines use different units of analysis and it is proposed that the disciplinary component of research intended to support the assessment of trade–offs must be planned at the beginning of the research effort to produce methods and data that can be used across disciplines to assess trade–offs. Trade–off analysis has substantial requirements for socio–economic and bio–physical data, and cost–effective means are required to generate them.

Introduction

The cumulative effects of global environmental awareness, growing populations and the need to feed them place the identification and design of sustainable agricultural systems in the centre of attention of many research and development agencies. Policies relating to trade, exchange rates, the agricultural and environmental sectors, and agricultural research all figure as a preoccupation of government policy–makers, research managers and development professionals as they engage in the search for sustainable agricultural systems. The key to designing sustainable agricultural production technologies and identifying policies that promote sustainable systems is in understanding their economic, environmental, and human health impacts. The research reported here is supporting the development of a methodology designed to quantify such impacts and to represent them as trade–offs. To this end the trade–off methodology addresses two key elements: first, the trade–off provides an organizational structure around which to design successful interdisciplinary research projects to assess sustainability of production systems; and second, the trade–off method provides a successful means to communicate research findings to policy–makers and the public.

This research project, carried out by the International Potato Centre (CIP), Montana State University (MSU), Wageningen Agricultural University (WAU), and the DLO Research Institute for Agrobiology and Soil Fertility (AB–DLO) in co–operation with several national research institutes and universities, is supported by two donors. The ISNAR (International Service for National Agricultural Research)–administered Fund to Support Ecoregional Programmes finances a project called "Regional scaling of field–level

economic–biophysical models". USAID (United States Agency for International Development), through its Soil Management Collaborative Research Programme (the SM–CRSP) finances a project called "Trade–offs in Sustainable Agriculture and the Environment in the Andes: A Decision Support System for Policy–makers". Through mutual agreement of the donors, these two projects are being managed as a single entity. The research reported here is a second application of trade–offs analysis. The initial development was in a study of the environmental and human health aspects of pesticide use in potato production in Ecuador documented in Crissman *et al.* (1998).

The principal objective of the project is to develop a decision support system for assessing trade–offs between agricultural production and the environmental impacts of agriculture, for different economic, agricultural and environmental policies, and agricultural research. The decision support system will be developed and tested in the potato/pasture production system of the Andean region. This decision support system has the following key features:

- It provides decision–makers with information on trade–offs between key sustainability indicators under alternative policy and technology scenarios.
- It links disciplinary data and models in a GIS (Geographic Information System) framework.
- It utilizes the minimum data necessary for decision support and policy analysis.
- It is generalizable: results can be extrapolated to larger geographic regions using a GIS framework.
- It is transportable: the generic structure of the system can be adapted to other geographic settings and applications.

Field research is being conducted at two sites, San Gabriel, Carchi, Ecuador and La Encañada, Cajamarca, Peru. Both are among the set of six pilot study sites of CONDESAN (Consortium for Sustainable Development of the Andean Ecoregion) of which CIP (International Potato Centre) is a partner. As pilot study sites, Carchi and Cajamarca were chosen as representative of a particular agro–ecoregion of the Andes. These sites capture a range of agro–ecological conditions typical of the northern, humid *paramo* Andes with Cajamarca considered by some as a transitional zone between the *paramo* and the dryer *puna* Andes. As consortium sites, there are selected research and development activities underway by other CONDESAN partners. The presence of other research programmes offers the opportunity for collaboration in various areas such as the IPM–CRSP (Integrated Pest Management–Collaborative Research Program) in Carchi and the CIP Late Blight program in Cajamarca. Research in this project at both sites is concentrated in the upper hillside or valley wall agricultural zone dominated by cool–weather crops, especially potatoes and grains, and pasture for milk and livestock production.

Trade–offs

Economics teaches us that in every decision and every choice there is a trade–off between benefits and costs. Along with the obvious benefit of food production, the cost of agriculture can include adverse effects on the environment and human health. Achieving a balance, based on priorities set by society, is an explicit objective in public policy making. Here, we focus on trade–off curves as a device to summarize the information produced by an integrated, multi–disciplinary analysis. Politicians implicitly use trade–off curves every day. By nature of their job, they are concerned with winners and losers resulting from policy decisions. The trade–off curve is simply a concrete expression of what is usually a mental calculation. For example, politicians or analysts can readily see if the sacrifice of a single unit of environmental quality will result in a gain of a single unit or five units of agricultural production. Politically determined weights would then guide the decision as to whether the size of sacrifice is acceptable.

The clash between agricultural and environmental goals engenders conflicting agricultural, environmental, research, and development policies directed toward agriculture and natural resources in the sierra. Agricultural and environmental policies available to governments generally fall into two categories: regulations and incentives. In general, in countries such as Ecuador and Peru, regulations have minimal effect due to the lack of monitoring and enforcement capacity in the government. This leaves policies that provide incentives to change behaviour. Compared with regulations, incentive–type policies, which include taxes and subsidies, are more difficult to target to particular areas or situations. Therefore, there is a need for an *ex–ante* analysis to determine the effect of incentive–type policies on the trade–off.

In general, a large array of different indicators and scenarios can be evaluated in a trade–off analysis. However, only a limited number is relevant for the region. It is, therefore, necessary to determine the most relevant indicators in close cooperation with stakeholders and policy–makers. Figure 1 describes the proposed procedure. Stakeholders and analysts using experience and expert knowledge identified and prioritized the indicators and scenarios. In Ecuador, project participants consulted farmers, researchers from the national agricultural research institute, professors from universities, technicians from local and international NGOs and analysts in the Ministry of Agriculture. In Peru, those consulted were farmers, representatives of local NGOs, professors from universities, and researchers from the national agricultural research institute.

The indicators selected are economic (value of production, income, risk), agricultural (attainable crop and milk yield), and environmental (water quality, soil quality, and erosion). The scenarios by which the indicators will be evaluated are divided into three groups: technological, economic and environmental. Technological changes include adoption of late blight–resistant potato varieties and other components of integrated disease

management, adoption of Andean Weevil IPM (Integrated Pest Management), genetic dairy herd improvement, improved herd management, and improved pasture management. Environmental changes include improved soil nutrient management, soil conservation, and increased mean and variance of rainfall and temperature. Economic policy changes include taxes or subsidies on inputs and outputs and changes in trade policy.

A Decision Support System for Trade–off Analysis

The trade–off research program aims at the development of a tool that provides a decision support system for assessing trade–offs between agricultural production and the environment for different economic, agricultural and environmental policies, and agricultural research. The model assesses linkages between farmers' cropping decisions, economics and natural resources and should be able to:

- Quantify the impact of existing and proposed agricultural and environmental policies on the sustainability of selected agro–ecosystems.
- Screen proposed agricultural technologies such as integrated pest management and various types of soil husbandry for their potential impact on the sustainability of selected agro–ecosystems.

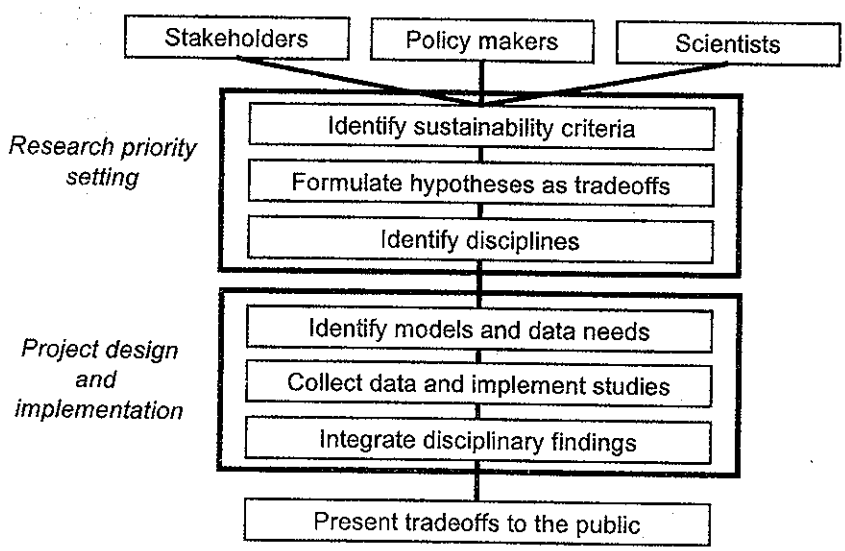

Figure 1. The process of quantifying trade–offs.

- Generate results that can be utilized to develop recommendations for research priorities for national and international research systems.
- Recognize the spatial variation of natural resources and communicate with a GIS to be able to deal with this variation.

A central theme of this approach is that quantifying trade–offs is an essential ingredient in setting research priorities and in designing and implementing the criteria of sustainable agriculture in agricultural research programmes. Trade–off assessment provides an organizing principle and conceptual model

for the design and organization of multi–disciplinary research projects to quantify and assess the sustainability of agricultural production systems.
Various challenges face researchers in implementing this type of research. Despite the widespread acceptance of the goal of sustainable agricultural systems, and the recognition of significant trade–offs associated with the regulation of technologies such as pesticides, a scientific consensus is lacking on how the economic, environmental, and public health impacts of agricultural technologies can be quantified and assessed (D'Souza and Gebremedhin, 1999). Analysis of these complex, interrelated issues raises difficult theoretical and methodological problems for researchers. Environmental, agricultural, and health characteristics of farmers, farmland, and farming technologies vary over space and time. The problems that concern the public are multi–disciplinary and thus require a multi–disciplinary approach. Overcoming disciplinary biases and establishing effective inter–disciplinary communication is a continuing challenge for a research team.

The combined economic and biophysical models and the associated GIS input and output systems are clearly not user–friendly. Thus the objective of a user–friendly system is a considerable challenge. The original conception of the DSS (Decision Support System) was a stepped analysis starting from an expert system/decision tree screening stage in which first–order conditions would be used to identify obvious problems and their potential solutions. Only in cases of uncertainty would the user then step deeper into the DSS to make use of the modelling power contained inside. Initially the perceived users ranged from skilled analysts to users interested only in end results. However, as the project progressed, our belief in the research chain described above deepened and with resources for and a commitment to training, we now perceive the DSS user as a skilled analyst with training in the use and application of the system.

The current version of the DSS (Antle *et al.*, 1997) consists of the trade–off model linked to leaching models as well as to crop growth simualation models in a Windows user interface. The interface allows the user to set scenario levels. In future versions as more biophysical models are incorporated, user selection of indicators will also be possible.

The case studies provide the empirical basis by which the DSS can be tested for *ex–ante* technology impact evaluation. An important group of clients for the DSS are research managers and administrators of IARCs (International Agricultural Research Centres) and NARS (National Agricultural Research Systems). In the current climate of reduced funding for agricultural research it is incumbent on research administrators to demonstrate to their funding sources the benefits of a given proposed line of research. With sustainability criteria, indirect costs and benefits should be considered along with the direct costs and benefits. With health and environmental linkages to agricultural changes, these benefits can be clearly demonstrated with trade–off curves.

The current application of the trade–offs model is designed to measure impacts at the field level. As mentioned above, a conscious decision was made to delimit the case study to a watershed level. A methodological

challenge being directly faced as a project objective is extrapolating results from the watershed level to regional, national or international levels. Following Bouma and Hoosbeek (1996), we are engaged in detailed K5–type modelling methods using intensive data collection to produce quantitative answers to questions relevant to the case study sites. However, the fundamental claim of the trade–off method is the ability to aggregate field–level impacts to a level meaningful for policy or technology impact analysis. Thus for example, a relevant research question is, what is the predictive value of the K5 modelling effort in the potato–pasture regions found between the two case study sites? Clearly a series of detailed efforts in the watersheds between those two points is not feasible and simplifying modifications in the trade–off model to represent a K3–type simple comprehensive method is more relevant. An obvious question is, what is the loss in predictive ability between the higher cost, more precise results of the K5 effort and the lower cost, less precise K3 effort? Thus an additional methodological objective of the project is to develop a loss function to capture this degradation in predictive ability.

Scale Issues

There is growing recognition of the critical role that aggregation and scale of analysis play in assessing the interactions between human activity and the environment. Scientific understanding of the impacts of human activity on biological and physical systems typically occurs at the level of some relatively small unit of analysis—an individual organism, or a square metre of soil. At this level the interactions between individual biological and physical units and human activity depend on characteristics of the physical environment that are temporally and spatially heterogeneous. In the inter–Andean valleys of Ecuador and Peru this heterogeneity is extreme. Consequently, the interactions between human activity and the environment are spatially and temporally variable, and aggregation of these interactions results in a loss of information about them. Yet for purposes of understanding the economic and social importance of these changes, and for analyzing policy options to manage these changes, we must work with much larger aggregate units of analysis composed of many individuals.

This research develops a methodology that directly addresses the problems of aggregation and scale of analysis. It does this by transforming the location–specific relationships between agricultural production and the environment into quantitative economic and environmental impacts of different policies and technologies. The mechanism by which this is done is a decision support system that is accessible and useful to policy–makers, development practitioners and agricultural research planners in a user–friendly form.

As noted above, one of the practical methodological challenges is the choice of the unit of analysis. Soil science, for example, typically deals with a unit of analysis—whether it is at the cellular, pedon, plant, animal, or field scale—that is different from the farm or sectoral scales relevant to policy analysis. Policy analysis typically is concerned with a large unit of analysis, usually defined in relation to a geographic or political region, that contains a population of the

units addressed by biological and physical sciences. The aggregation problem (the problem of combining heterogeneous small units into a larger unit for policy analysis) must be addressed by all researchers if their data and results are to be useful for policy analysis.

The fact that the various scientific disciplines use different units of analysis frequently means that the data and methods developed for disciplinary research are of limited value for policy research. Disciplinary research typically operates in a format dictated by disciplinary orientation and generates data intended to satisfy disciplinary objectives. This disciplinary orientation of research leads to a situation in which various pieces of the scientific puzzle are investigated without regard to the fitting together of those pieces into the larger picture that is required for policy analysis. Thus, the disciplinary component of research intended to support the assessment of trade–offs must be planned at the beginning of the research effort to produce methods and data that are required for disciplinary analysis, but that can also be utilized across disciplines to assess trade–offs. The planning, in advance, of coordinated disciplinary research is one of the key benefits of the trade–off assessment methodology that is being proposed here.

Trade–offs associated with agricultural production systems can be defined across several dimensions at any time, and can also be defined in one or more dimensions over time. In evaluating the long–term sustainability of a production system, economic and environmental indicators can be used to quantify the productivity and other attributes of a system over time. These indicators include measures of economic returns, soil erosion, chemical leaching, nitrate movement through soil profiles, and the organic content of the soil. Measuring trade–offs in these dimensions requires site–specific data and models. Because the environmental impacts of different production systems are generally site–specific, one production system may not have the same impacts in all environmental dimensions at all sites. Thus, any attempt to rank production systems according to sustainability criteria needs to account for spatial variability in economic, environmental and health outcomes.

The larger the spatial or temporal scale, the more complex becomes the process of quantifying trade–offs for analysis of agricultural sustainability. Analysis at the regional or national scale is even more difficult than analysis at smaller scales, such as a watershed. Attempts to develop quantitative indicators of the sustainability of the US farming sector, or the farming sectors of member countries of the Organization for Economic Cooperation and Development (OECD), have relied on aggregate data about production, input use, and resource degradation (US Department of Agriculture, 1994; OECD, 1994). These data do not provide a scientifically defensible foundation for policy formation because production cannot be linked to environmental and health impacts on a site–specific basis.

The research methods applied in the model make use of an alternative approach to addressing regional policy concerns in the area of sustainable agriculture and technology evaluation that is based on solid scientific

foundations. The proposed approach is to develop data and related disciplinary models which link the site–specific management decisions of producers with environmental and health impacts, and then to utilize a statistical representation of the relevant human and physical populations to statistically aggregate those impacts to a regional level for policy analysis.

Political pressure to identify a set of sustainable production technologies implies that there must be some means of ranking the importance of the various impacts. Ranking technologies according to multiple criteria requires a method of converting these criteria to a common unit of analysis. The economic approach to this problem is to convert all impacts to monetary terms and to use this information to conduct a benefit–cost analysis. However, despite decades of research on valuation of environmental and health outcomes by environmental and health economists, there is no scientific or public consensus on valuation methods or their public acceptability, and data for valuation of most environmental and health impacts are lacking. For this reason, the approach advocated here is that agricultural sustainability research should focus on establishing a sound scientific basis for quantifying trade–offs between ecological and economic objectives that exist with alternative production systems, without attempting to value impacts for benefit–cost analysis.

This study requires that important advances are made. The dynamic, site–specific economic models that provide information on a daily time step that were developed for the pesticide study represent an advance over the conventional static, representative producer models typically used by agricultural economists. Nevertheless, the stochastic simulation model that was based on the dynamic econometric production model has significant limitations for certain applications. A critical limitation is the reliance on a statistical representation of the production technology. By construction, this technology can represent only the range of behaviour observed in the data from which it is estimated. Consequently, when policy simulations are needed that go outside the range of observed behaviour, the model may not produce reliable results. For example, when policies are simulated that would reduce fungicide use, we know that beyond some point crop failures would occur. Our data do not provide for estimating this effect, however. Research planned in this project will investigate the possibility of linking the economic models with crop growth models to provide a more reliable basis for conducting simulations outside the range of observed behaviour.

Linking the economic production model to crop growth models also provides a way to utilize biophysical data available in geographic information systems to generalize the economic model beyond the case study area. As noted above, the reliability of this kind of extrapolation is one of the issues that is to be examined in this research.

An important issue addressed in the pesticide study, and related to the issue of extrapolation and generalization, is the definition of a common unit of measurement for the modelling that forms the basis of the integrated trade–off assessment. In the Carchi pesticide study, data were collected at the field

scale, and trade–offs were assessed at the watershed scale. Adaptations of conventional economic, environmental, and heath analysis models had to be made to accommodate analysis at the field scale. An important open methodological question is whether valid analysis of agricultural production systems can be conducted with data collected at larger scales. The analysis of spatial variability conducted in the Carchi study cast doubt on this proposition, as it showed that aggregation to the watershed level obscured important spatial differences in both environmental and health impacts. Nevertheless, research has not fully investigated the question of the appropriate scale of analysis needed to adequately address various policy questions. This also is an issue addressed in this project.

Another important methodological challenge is extrapolation of results over time and linkage of small–sale analyses of environmentally meaningful units such as watersheds to larger economic units such as a regional, national, or international economy. The Carchi case study examined the effects of policy and technology changes in the potato–pasture system in a partial equilibrium frame–work that is not suitable for longer–term analyses or general equilibrium analyses. The landscape ecology literature and the regional economics literature provide important insights into the added complexities that are introduced when one attempts to model long–term changes in land–use resulting from policy interventions (Fresco *et al.*, 1994; Bockstael, 1996). Linking an environmental unit to larger economic units for the analysis of environmental impacts of macroeconomic and trade policy also raises problems inherent in linking analysis conducted at different scales and levels of aggregation (Antle *et al.*, 1996).

Conclusions

The integrated model that underlies the trade–off analysis has a number of significant data requirements. First, the economics model requires data to estimate econometrically the behavioural relationships needed to simulate land–use and management decisions. While the techniques required for collection of these data can be readily replicated, the time and expense of doing so mean that such data cannot be collected to represent extensive land areas. Clearly, a key limitation of this approach is the economic data requirements. How best to overcome this limitation remains a topic for current and future research.

Second, the biophysical analysis also has substantial requirements in terms of soils and climate data. In the Carchi case study, for example, limitations in the availability of soils data have led the researchers to stratify the watersheds into four agro–ecological zones. A better approach, now being implemented, is to develop a digitized soils map that can be linked with the other data in the model in a GIS format. Weather data are available for a limited number of points in proximity to the watershed. How best to interpolate these data remains a methodological challenge in all research of this type.

The Carchi pesticide study illustrates several of the current limitations to integrated agriculture–environment–health research and directions for fruitful

work. Because of the complexity of these systems, researchers are forced to limit the scale and scope of any research project to make it financially and organizationally feasible. In the Carchi study, a conscious decision was made to limit the spatial scope of the study to a relatively small pair of watersheds and to a relatively limited set of trade–offs.

These self–imposed limitations reflect the methodological approach advocated here that focuses on quantifying the key trade–offs identified by public stakeholders, policy–makers and scientists. These limitations serve to impose much needed discipline on this type of research. Faced with a complex problem and stimulated by interdisciplinary interactions, a well functioning research team naturally tends to attempt to address more questions than are feasible given the available time and resources. Keeping the project focused on the key policy questions that need to be addressed helps the research team allocate scarce resources to the project's highest priorities. It is important for team leaders to keep in mind and to remind research team members that it is not necessary to measure all possible trade–offs.

Even with all the limitations, the pesticide project took many dollars and many years to complete. Obviously, there are trade–offs that must be considered between internal validity and generality in designing research projects. A key decision for this and other projects is the selection of the study site. Even with a limited number of impacts to be considered, the ideal site for a case study probably does not exist. The Carchi site was selected for the pesticide study based on its reputation for intensive pesticide use. A valid question for generalizing results is whether a "representative" rather than an "extreme–case" research site is more appropriate. One important area for future research is to investigate how the findings of this type of study can be generalized over space and time and across heterogeneous populations. Results of this kind of research would provide guidance on key research design questions such as site selection.

In the environmental area, various issues also need to be considered to broaden the usefulness of quantitative trade–off assessment. One critical problem (also relevant to the health area) is resolving how to deal with multiple outcomes. The trade–off analysis considers the trade–offs between agricultural production and leaching of several chemicals and neuro–behavioural risk, but generally a number of other economic, environmental, and health outcomes could be examined, such as income distribution, soil erosion, wildlife impacts, and longer–term health risks such as cancer. Although the issue of aggregation has been addressed formally in economics, there does not appear to be a comparable literature in the environmental field, and so researchers are left with the choice of dealing with a large number of dimensions or arbitrarily combining outcomes into indices that have no theoretical basis or rationale.

Future research will address the generalizability, transportability and extrapolative factors of the DSS. The generalizability will be evaluated through collaboration with the CIP–ABTEMA Ecoregional Fund project in the

arid and semi–arid Andes of Peru and Bolivia to examine the potato pasture system with the appropriate indicators and scenarios. Including this third site on the potato–pasture productivity gradient will provide a third K5 reference point for K3–type extrapolation among the sites. The transportability of the DSS will be examined by moving downhill in the Carchi site to the maize–bean–pea system. Important indicators include the quality and quantity of water delivered from the potato–pasture zone in scenarios of improved water management through the irrigation systems that serve the maize zone.

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SYSTEM PROTOTYPING AND SIMULATION MODELLING IN MIXED FARMING SYSTEMS

Harry Booltink and Philip Thornton

Summary

We describe a project proposal whose aim is to promote more appropriate resource management on smallholder crop–livestock farms in East Africa. Prototypes of mixed farming systems will be developed to characterise farming systems according to their management objectives. These prototypes will then be used to map improvements of the farming systems by combining prototyping and simulation modelling. Scenarios will be explored to assess natural resource management interventions that promote sustainability of these prototype–farming systems. If funded and implemented, the project will result in smallholder prototypes of mixed farming systems in Coastal, Central and Western Kenya, and should provide information concerning viable management options that enhance the productivity and sustainability of smallholders' farming systems.

Introduction

The human population in sub–Saharan Africa (SSA) is expected to reach 1.2 billion by the year 2025 from its current level of about 550 million (Winrock, 1992). Accompanying this increase will be a radical shift in the proportion of the population that lives in urban centres, rising to 64% from its current level of about 27%. These rapid changes will have profound implications for agriculture in all regions of the continent. Demand for cereals in SSA will treble to 150 million tonnes by 2020 (IFPRI, 1995), but supply is likely to be outstripped by this demand even under the most favourable projected response scenarios. Projections of demand and supply of livestock products show similar challenges: milk output must increase by some 4% per year, and meat output by 3.4% per year (Winrock, 1992).

This increased demand will lead to intensification of smallholder animal production systems, which will lead to greater dependency of livestock on planted crop by–products and fodder (i.e. arable production). This increased dependency will result in higher vulnerability to degradation of the arable production areas within the mixed farming systems in East Africa. Ruminant livestock are critical in nutrient cycling in crop–livestock systems (Tanner *et al.*, 1995), and increasingly integrated mixed crop–ruminant livestock systems have a crucial role to play in meeting the agricultural production challenge during the coming 25 years.

In response to market demand and high population densities, smallholder production systems in much of East Africa, as elsewhere in Africa, are thus in the process of intensifying. In smallholder dairy systems, for example, dairy producers, who represent up to 70% of households in some high–potential areas of Kenya, are grazing their animals less and depending increasingly on cut–and–carry fodders and purchased concentrates (zero grazing and semi–

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zero grazing, where system sustainability in terms of nutrient depletion may become a serious issue). In mixed systems, livestock maintain the sustainability of heavily cropped land through nutrient cycling (Shepherd and Soule, 1997).

The degree of intensification at the farm level, however, has been shown to vary widely between households even within the same agro-ecologicalzone. Throughout the region, market and policy environments are evolving at the same time as land–use intensity is increasing. The 1992 liberalisation of the Kenyan dairy market, for example, has brought about increased activity by a variety of co–operative and private marketing agents, many operating informally. The level of their activity, however, is increasingly linked to infrastructure and distance from urban consumption centres (Owango *et al.*, 1996). Some form of intensification because of policy changes is thus occurring at market levels as well.

The socio–economic and environmental conditions in the region make the implementation of options that promote increased, yet sustainable, production difficult. Given the heterogeneous nature of mixed farming systems, biophysical conditions, and smallholders' resource endowment and objectives, even within the same region, the study of farmers' ability to adopt technologies and strategies which permit more intensive or more integrated mixed production, and estimating the welfare impacts of such interventions, is very difficult. In the same way, the targeting of technology and interventions in such systems is problematic, although *ex–ante* evaluation of technology change at the household and system levels is critical if the potential impacts both of policy changes and intensification are to be quantified.

In this paper we explain the potential role of prototyping (Vereijken, 1992; Vereijken *et al.*, 1994a; Vereijken *et al.*, 1994b) to provide consistent and coherent characterisations of farming systems based on smallholders' objectives, and that can then provide information on the biophysical and economic impact of interventions and technology change at the household level for farms with particular characteristics. With a clearer understanding of how particular types of farm household can exploit the links between crop and livestock enterprises, technological and developmental interventions can be targeted more appropriately. Prototyping information combined with research chains of simulation models offers a framework for applying different types of models at different scale levels to address different problems from field to farm to ecoregional levels. As intensification occurs, increased integration of crop and livestock is required, given the comparatively low levels of inputs involved. In particular, nutrient cycling, matching feed demands of animals with available feed resources, dependence on low levels of inputs, increasing use of crop residues as animal feed, and differences in degree of market integration and differing agro-ecological endowments. Strategic research to help these smallholders must involve assessment of interventions at the systems level that can be replicated or extrapolated or interpolated over much larger regions than the study sites.

Prototyping for Systems Characterisation

Biophysical models, even if incomplete, undoubtedly have a substantial role to play in assessing likely impacts of interventions or technological changes. As the investigator moves from one scale to the other for example from field level to farm or community levels, the importance of human agency increases markedly. Smallholders and communities have different goals and objectives, and farm–level models have to consider these. One way this can be done is through classification and characterisation of farming systems.

Several studies have been executed to characterise farming systems in Eastern Africa. Staal *et al.* (1998) characterised 365 dairy systems in the Central highlands of Kenya (Kiambu). By means of a cluster analysis, patterns among dairy households in terms of level of intensification, household resources and access to services and markets were distinguished. Shepherd and Soule (1997) used participatory techniques to classify mixed farming systems in the Vihiga district in Western Kenya based on their resource endowments and constraints faced by farmers. Nicholson *et al.* (1998) characterised farm systems with respect to the adoption of livestock as a farm component.

To allow comparison of different farming systems, not only in terms of resources availability, but also in terms of farm management objectives, prototyping techniques can be used. Prototyping has been used by Vereijken (1992) to characterise ecological farming systems and to evaluate the effects of farming results in terms of well–defined management objectives. This methodology has been standardised by Vereijken *et al.* (1994a, 1994b) and tested on a wide range of ecological and integrated farming systems in Europe. The methodology of prototyping can be divided into two parts: designing prototypes, and testing prototypes.

Designing prototypes

Designing prototypes involves three methodological steps (Vereijken *et al.*, 1994a). First, the analyst makes a hierarchy of general objectives, which are rated according to their importance, based on farm management objectives. Some examples of general objectives are *"Concern for abiotic environment"*, *"Basic income"* or *"Food supply"*. Subsequently, every general objective is subdivided in one or more specific objectives. For example, specific objectives within the general objective *"Concern for abiotic environment"* would include *"Soil quality"*, *"Water quality"* and *"Air quality"*. Within a general objective these specific objectives are again ranked according to their relative importance as defined by the farm management objectives.

The second step involves the transformation of the major objectives into multi–objective parameters that can be measured and quantified. These multi–objective parameters serve as objectively measurable threshold values for one or more general or specific farm management objectives. Farming results need to be evaluated according to these threshold values. Examples of these threshold values include the following: "*Nitrogen leaching to*

groundwater should not exceed 11.2 mg per l "(EU– legislation), or, "*The net surplus of the farm should be positive*".

In the third step, methods and techniques are defined that can be used to achieve the management objectives. Methods that cover more than one objective are preferred. However, it is very likely that some methods are conflicting. This requires a fine–tuning of existing methods or the introduction of new methods and technologies that bridge the gaps between conflicting objectives.

Farm management objectives (general as well as specific) are stored together with the parameters and the methods to achieve the management objectives on so–called *"prototyping identity cards"*. These identity cards act as a log frame for ongoing farm activities and their impacts on the management objectives. The relevance of the selected method or technique to the specified objective can be derived immediately, which gives the farmer the opportunity to adjust management for the coming year(s) if necessary.

Table 1 shows an example of an identity card from the Nagele experimental farm in the Netherlands is presented (adapted from Vereijken *et al.*, 1994a). In the first column the general and specific objectives are listed according to their ranking given by the farmer. The second column represents the quantified multi–objective parameters with threshold values (abbreviations are listed in Table 2). In the third column the multi–objective methods are listed to achieve the objectives. In total, 10 objectives are listed, being evaluated through 12 parameters and achieved by six multi–objective methods.

Testing prototypes

The testing phase consists of two basic steps (Vereijken *et al.*, 1994b):

1. First, the prototypes designed above are improved until the objectives as quantified in the set of parameters have been achieved.
2. Second, the prototypes are then tested at the farm level to determine their general suitability and applicability.

Prototyping thus allows the classification of different farming systems with respect to the management goals of their operators and the sustainability of the farming system. In the first step the effect and interaction of the various methods have to be defined. In Figure 1 these interactions for the Nagele farm are presented; it clearly shows that a Multifunctional Crop Rotation (MCR) is a very important method in integrated arable farming systems and it therefore has to be the starting point of the management optimisation. This is followed by applying Farm Structure Organisation (FSO) methodology.

Once the methods and their execution order have been defined the actual designing and modification of the methods proposed can start, such as the definition of the Multifunctional Crop Rotation. Initially this will be a theoretical method that is tested and evaluated from several years of farm experiments.

Modelling Systems Interventions

Systems interventions

Ecoregional research is a holistic, systems–orientated approach that seeks:

- To integrate the contributions of different disciplines.
- To deal adequately with natural resource management issues.
- To identify meaningful recommendation domains for the application of the products of research, thus enhancing the efficiency of the research process (Rabbinge, 1995).

Rigorous methodology is required for integrating different disciplines and hierarchies, comparing research results at different sites, and carrying out multi–scale analyses.

Table 1. Quantifying and achieving objectives in the integrated arable farm in Nagele (NI) (adapted from Vereijken *et al.*, 1994a).

Major objectives ranked	Major objectives quantified in multi objective parameters	Major objectives achieved by multi objective farming methods
1. **Abiotic environ.** – Water	*1.1* EEP–water < Xw *1.2* 30 < PAR < 50 *1.3* 18 < KAR < 26 *1.4* NAR ≤ 70 kg per ha *1.5* NDW < 11.2 mg per litre	*1.1* ICP, EEPS *1.2 – 1.5* INM *1.1 – 1.5* MCR
2. **Basic income** – Farm level	*2.1* NS >0 *2.2* QPI (target per crop 1–x)	*2.1* FSO *2.2* see *1*
3. **Food supp.**– Sustainability	*3.1* EE > x (see *1.2, 1.3*)	*3.1* see *1*
4. **Abiotic env.** – Air	*4.1* EEP–air < Xa (see *1.4,3.1*)	*4.1* see *1*
5. **Basic income**–Region level	*5.1* (see *2.1, 2.2*)	*5.1* see *2*
6. **Nature/Landscape** – Flora	*6.1* EI > 5% farm area	*6.1* EIM
7. **Food supp.** – Quality	*7.1* (see *2.2)*	*7.1* (see *1*)
8. **Employment** – Farm level	*8.1* (see *2.1, 2.2*)	*8.1* (see *2*)
9. **Abiotic env.** – Soil	*9.1* EEP –soil < Xs (see *1)*	*9.1* (see *1)*
10. **Nature/Lands** Landscape	*10.1* SCI > 0.7 (see *6.1*)	10.1 (see *6* and *1* (MCR))

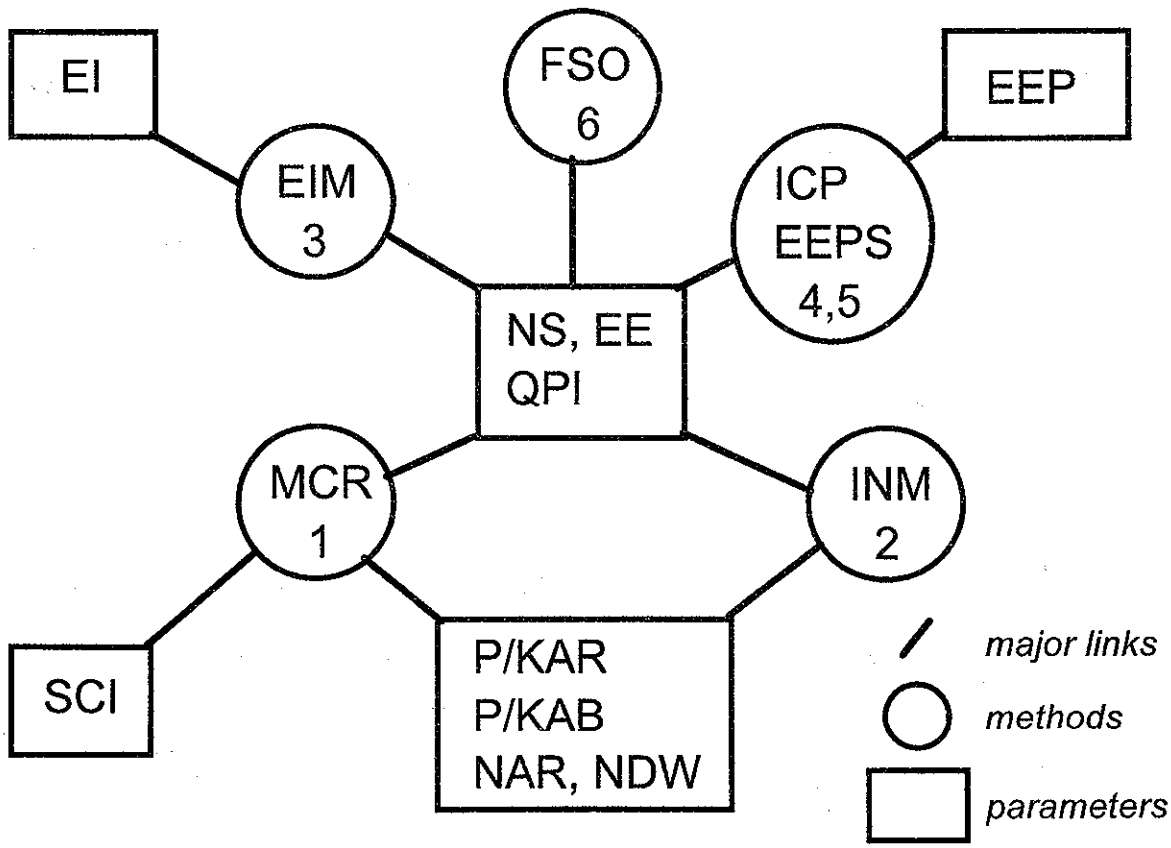

Figure 1. Example of a theoretical prototype for the Nagele experimental farm in the Netherlands(adapted from Vereijken *et al.*, 1994b).

The issues that such methodologies have to address include livestock and crop production at both field and farm levels, soil loss and degradation, changes in biodiversity, environmental pollution, inappropriate policies on pricing and resource–use, and climatic change (Teng *et al.*, 1995).

By defining problem–based systematic research chains, systems interventions can be identified and assessed. Bouma *et al.* (1998) defined seven basic steps in this process:

1. Problem definition.
2. Selection of research methodology, including spatial and temporal scales.
3. Model (in the term's broadest sense) development.
4. Data collection.
5. Model application.
6. Quality assessment (risk assessments, uncertainty analysis and error propagation).
7. Presentation of results.

Table 2. Abbreviations and acronyms in Table 1 and Figure 1.

EE	Energy Efficiency
EEP	Environmental Exposure to Pesticides
EEPS	Environmental Exposure–based Pesticides Selection
EI	Ecological Infrastructure
EIM	Ecological Infrastructure Management
FSO	Farm Structure Optimisation
ICP	Integrated Crop Mangement
INM	Integrated Nutrient Mangement
KAB	K Available Balance
KAR	K Available Reserve
NAB	N Available Balance
NAR	N Available Reserve
NDW	N leaching to Drainage Water
NS	Net Surplus
MCR	Multi–functional Crop Rotation
NAB	N Available Balance
PAR	P Available Reserve
QPI	Quality Productivity Index
SCI	Soil Cover Index

Various scales and levels of modelling have been defined in the past. Hoosbeek and Bryant (1992) and Bouma and Hoosbeek (1996) have developed a hierarchical system in which scales ranging from the world to the molecule are depicted. Such a scheme can be used to define research chains based on farmers' objectives as mapped in the prototypes. Once these research chains are developed, models and other tools can be linked together to answer research questions raised at different hierarchical levels. The benefits of an ecoregional approach using these types of research chain to address natural resource management issues are likely to be substantial, and should allow well–balanced interventions in production systems.

Modelling

For ecoregional issues dealing with nutrient management, interventions can take place at the farm, field and plot levels. Adequate characterisation, evaluation and quantification of management methods at each level are essential. Next to field experiments, well–tested and validated simulation models can play an important role in assessing options and allowing objective risk analysis to be carried out. Models that simulate crop–livestock interactions at the farm level can be used to analyse and evaluate the prototypes defined and assess farm management scenarios. Thorne (1998) studied the integration of different crop growth and livestock models in terms of their possible applications. These models operate mostly at the pedon, field or farm level. Shepherd and Soule (1998) developed a livestock–crop model that allows the integration of results from much more complex simulation models as well as the use of expert knowledge and rule–based

decisions. This model can flexibly be applied at the farm and sub–regional levels, although it is not suitable for detailed studies at the field or pedon level. The use of well–defined research chains allows complex and simple simulation models to be linked with expert knowledge and rule–based systems.

Only limited efforts have been made so far to link complex crop and livestock simulation models. Crop simulation models such as those within DSSAT (Tsuji *et al.*, 1994), the Decision Support System for Agrotechnology Transfer, are capable of simulating crop responses and biomass as a result of variable soil and weather conditions in a spatial context. The software also allows some basic economic analysis to be performed. However, modules describing the interactions between crop and livestock enterprises within a mixed farming system are not yet available. Models built at various institutes (such as the University of Florida, University of Georgia, ILRI, and Wageningen Agricultural University) concerning crop, pasture and animal growth will need to be integrated in a common framework.

The level of detail of this integration is defined by the problem studied. Smallholder mixed farming systems are generally very complex in their interactions. Intercropping with up to four crops can be observed and crop residues are generally mixed with manure and urine. Storage methods, and the length of time manure is stored, vary considerably and can have an enormous impact on quality. Simulation models need to be able to address these questions. However, it is not necessary that all these processes be modelled at every stage. Models built as a set of modules that allow the addition of relevant processes and the exclusion of less relevant processes have a great deal to offer in this regard. The basic components of a crop–livestock system involve separate but interacting *"tracks"* for the crop and the livestock enterprise simulations (Figure 2). Both tracks have requirements on a daily basis for water, labour and nutrients, and next to these a number of external and internal inputs are required. At the end of an iteration step (such as a cropping season) the farmer decides which part of the crop and livestock production will be marketed and which will be allocated for internal use (interactive feedback), which marks the beginning of the second iteration step. This iterative procedure is continued until the objectives, as defined for each prototype, are met.

By including the simulation results of scenario analysis on prototyping identity cards, three types of analyses can be performed:

1. Multiple scenarios can be tested within a selected year to evaluate the effects of interventions during a single season (seasonal analysis).
2. The evaluation of long–term effects of a single scenario over multiple years, to study farming system sustainability (sequential analysis).
3. The effects of simulation results can be expressed in probabilistic terms by using Monte Carlo techniques to carry out risk assessment.

Results of scenario analysis at field level can be scaled up and aggregated to allow impact assessments at the village, district, and ecoregional levels.

Farm types in the ecoregion would need to be classified according to the prototypes defined, and the spatial distribution of farm types stored in a Geographic Information System (GIS).

Within the framework of the Nutrient Replenishment Pilot Project (NRPP) (Shepherd and Soule, 1998; Soule and Shepherd, 1998) remote sensing, GIS and artificial intelligence techniques such as neural networks (Walsh *et al.*, 1998) have been used to extrapolate data obtained at individual farms to higher levels in the system hierarchy.

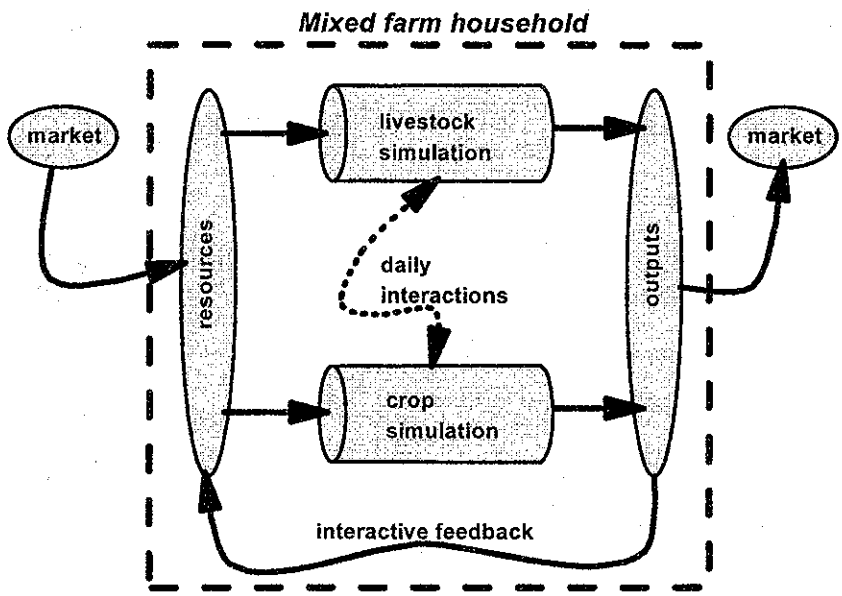

Figure 1. Crop and livestock activities and their interactions at the household level.

Conclusions

It is planned to carry out research activities utilising the methods outlined in this paper during 1999, for crop–livestock systems of varying intensities in East Africa. These activities will be aimed at promoting more efficient resource management methods on smallholders' farms, and this will be achieved by development of methods and tools for characterising crop–livestock production systems and investigating possible impacts of interventions at the household level which will in turn contribute to more effective technology uptake.

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THE AFRICAN HIGHLANDS INITIATIVE (AHI) AND ICRAF RESEARCH IN EASTERN AND CENTRAL AFRICA

Frank Place

Summary

This paper is divided into two parts; The first describes the African Highland Initiative in the context of major natural resource management issues and constraints, the benchmark location, regional natural resources management issues and themes, implementation approaches and institutional arrangements. The second part reviews methods adopted by ICRAF (International Centre for Research on Agroforestry), which are useful for ecoregional research. The flagship model and village approach to research, rapid community survey, are discussed.

African Highlands Initiative

Background of AHI

The present day and projected future scenario in the African highlands are challenging and the problems complex. In summary, the major factors contributing to the diminishing capacity of the natural resource base (soil, water and vegetation) to meet the needs of the rapidly growing population are the inadequate natural resource–management systems and their inability to respond to inappropriate national agricultural policies, internal strife and escalating costs of agricultural inputs. Thus the situation warrants attention.

Over the years NARS (Natural Agricultural Research System), in partnership with the CGIAR (Consultative Group on International Agricultural Research) and others, have made major efforts to maintain and enhance land productivity in the highlands. However, it is apparent that the expected impact has fallen short of solving the issues and several causes have been cited—lack of innovative approaches to generating and extending technologies; fewer outputs from research in the areas of soil, water and tree management; lack of diversity of options; failure to involve farmers early in the definition of problems and identification of possible solutions and impact–oriented research with a broad, cross–disciplinary perspective has been hindered by several institutional and intellectual factors.

Description of the major natural resource management issues and constraints

Population densities, already relatively high, have risen over the last 50 years within this ecoregion, resulting in changes in land–use primarily due to inheritance practices leading to subdivision of land. This has led to small, often fragmented farms reaching critically small sizes (0.25 to 1.0 ha per family of 6). Although the land area covered by population densities of >200 people/km^2 are relatively small at this time, the area covered by >100 people/km^2 and approaching higher levels is growing. Projections for the next ten years are alarming.

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Maintenance of land productivity using many of the traditional practices, such as fallowing, manuring, crop residues, and crop rotation, is no longer feasible. In many areas the reduced level of diversity of genetic resources (crop variety, crop type, forage and tree species) to solve household needs (food, feed, fuel, cash) and natural resource management issues is detrimental. Given declining access to tree products and feed sources, the growing competition for crop residues for feed, fuel and construction has led to its declining use as a soil amendment. These trends have led to decreased soil fertility through (i) Mining of nutrients given continuous export of produce and few sources of replenishment, (ii) Cultivation of more marginal areas (steep slopes) causing erosion, and (iii) Increasing pest and disease problems related to soil fertility decline. This has resulted not only in reduced fertile area to cultivate but also in declining yields. Although livestock keeping in many areas has intensified, the number of large ruminants kept per household has declined, by virtue of the fact that there is less feed available.

Farmers have employed new strategies to supplement soil fertility. For example, in the central highlands of Kenya nutrients are being imported in large quantities from the lowlands, which may eventually lead to depletion of these areas. In other areas (Southwestern Uganda and Madagascar) the short–term solution has been to 'steal' nutrients from the tops of hills through encouraging runoff and sedimentation. Manure and crop residues are now highly valued as sources of nutrients (Northern Tanzania and Western Kenya) and can bring a price higher than chemical fertilizers, which are often unavailable. Some systems have become more dependent on imported fertilizer (Areka and Ginchi in Ethiopia), despite frequent difficulties in accessing them, because of such limited quantities of nutrients available from within the system.

The problems and constraints in the highly populated parts of the highlands are amazingly similar yet the area is highly heterogeneous as shown by the different land forms, historical development, economic and social conditions, and farming enterprises. Recent survey work in selected areas of the highlands has highlighted the importance of external forces as having a major impact on land–use: population pressure, land tenure and conservation policy, and commercialization of the economy. Infrastructure including access to markets, input delivery systems, on– and off–farm income options, pricing structure and various types of services to these areas differs and has a major impact on whether or not people can address the constraints. Because of different histories and political/cultural settings (e.g. inheritance practices, livelihood traditions of ethnic groups) the situation varies from place to place.

As a cause and consequence of low productivity, increasing numbers of people have poor endowments of resources (land, labour, capital and livestock) and have other employment options outside agriculture. Once a critical minimum farm size is reached (in relation to the number of people that can be supported through agricultural activities) livelihood options outside agriculture must be made available to alleviate poverty and the trend is that wherever possible people are moving towards cash options (off–farm income

or cash crops). Thus, access to resources and resource endowment levels have a large impact on land and soil management. The greater the number of options to satisfy livelihood means, the better the chances are to solve NRM problems.

Benchmark location descriptions

The African Highlands Initiative has been working in four of the countries sharing this ecoregion: Kenya, Ethiopia, Uganda and Madagascar. Benchmark locations have been chosen on the basis of several common attributes: an altitude range of 1400–2700m, a rainfall greater than 1000mm per annum; a high population density of >100 people/km^2; evidence of decreasing soil fertility or inherently deficient soils; a risk of and/or evidence of soil erosion; steep and moderately steep slopes and/or plateaus and highland valleys; and declining number of trees and other organic sources where there is not enough to meet needs. Other desirable attributes were areas having the following: a nucleus of farmer groups and development agencies who are sufficiently interested in development and rehabilitation; the presence of committed and experienced research scientists; the presence of collaborative activities between NARS and IARCs, and available basic diagnostic information.

Seven benchmark locations have been chosen by the respective countries that fit the general criteria: Kabale, Uganda; Kakamega–Maseno area of Western Kenya; the Central Kenyan highlands; Areka and Ginchi in Ethiopia; and Fianarantsoa and Antsirabe in Madagascar. Towards the end of phase one, an eighth site was added, Lushoto in Northern Tanzania.

Aside from high altitude, abundant rainfall, and high population density, other characteristics that are similar across most of the sites include few off–farm income opportunities, poor access to input and output markets, relatively secure land tenure, small farms, some cash cropping undertaken, and relatively low nutrient inputs added to soils. There are some notable exceptions to this. Central Kenya is an area which has benefitted from relatively good market opportunities and farmers have responded by producing significant amounts of milk, tea and coffee. The cash opportunities have enabled many farmers in this region to maintain soil fertility. The Antsirabe region of Madagascar also enjoys moderate access to markets. Land is owned by the State in Ethiopia while individual titles are held with respect to land in Kenya. Farms often consist of more than one plot, but land fragmentation is considerably more severe in Kabale than in the other sites. Of course, the types of crops grown differ from site to site. Rice is the staple food grown in the valleys in Madagascar; maize is the dominant food crop in Kenya; Kabale hosts a diverse range of food crops including sorghum, wheat, and potato. Barley dominates in Ginchi while in Areka one finds ensete, maize, and sweet potatoes, among others. The importance of livestock differs considerably across the sites. There are high numbers in Ginchi, a low number but high–quality dairy cattle in Central Kenya and increasingly in Antsirabe, and mainly declining numbers elsewhere.

Priority regional Natural Resource Management (NRM) issues and themes

Given this scenario AHI has decided to highlight the central role of land productivity with the emphasis on increasing land–use efficiency and improving soil fertility in the research and development work proposed.

In 1998, the technical support group defined three general research themes under which regional and site–level research would operate. In relation to the natural resource problems of land degradation, AHI will focus its research on:

1. The impact of NRM technologies on system productivity, equity, and natural resource sustainability.

2. Sustainable intensification of agricultural systems.

3. Engaging stakeholders in long–term natural resource management.

These thematic areas are intrinsically linked and have multiple aims of improving soil fertility, reducing soil erosion, improving water management, providing feed, food and cash sources, and maintaining or enhancing biodiversity. Interactions of importance are:

- Intensifying and diversifying use of vegetation, both indigenous and introduced food and cash crops, feeds, trees in the system.
- Improving the efficiency of nutrient management.
- Enhancing the role of livestock in nutrient cycling, as a cash, transport and power source.
- Evaluating and assisting in the development and testing of soil and water conservation measures.
- Reducing losses caused by pests and diseases which are caused by or exacerbated by declining soil productivity.
- Investigating the role of policy and working with local officials and communities to solve issues.
- Improving farmer access to inputs needed and output markets.

Implementation

As an ecoregional project, AHI is proposing to strengthen research and development work at the community and regional levels and to link these two levels together to achieve impact. The comparative advantage will be in forging and strengthening linkages between numerous partners, having different orientations and who may be working in relative isolation, and enhancing coordination in NRM research and information, methodology and technology dissemination. These aspects are highlighted in the following paragraphs.

AHI has chosen to take a **participatory community–based approach** to focus research and development activities on the above areas to improve NRM within the benchmark locations. In so doing, we hope to establish

stronger linkages between the stakeholders at this level, with the aim of solving locally–raised issues related to the project purpose. By encouraging participation of different local stakeholder groups, the project anticipates an emphasis on households of low and moderate resource endowment as well as significant attention to gender aspects.

Enhancing partnerships and collaboration will continue to be a major role where AHI has an advantage as an ecoregional programme. At local levels concentration would be on strengthening traditional linkages between researchers, extensionists and farmers, as well as bringing in non–traditional partners such as district planners, policy–makers, local leaders, NGOs, the private sector, and pursuing solutions with those addressing improvement of market conditions, enhancement of local communication networks, and the like. These linkages would be sought opportunistically.

At the regional and national levels, **coordination of various interests and inputs** poses a challenge. Ideally, one would hope to enhance forms of collaboration and instil a systematic approach towards addressing issues at the regional and site levels. In addition, AHI hopes to capture more systematically knowledge from many sources, including indigenous knowledge, and organize it for various users. Given the number of partners and their global attachments, this input can be quite substantial. Mechanisms such as task forces, working groups, steering committees and others will be pursued to accomplish this objective. The premise is that working together can give greater impact than working separately—the sum being greater than the individual parts, particularly given the complex nature of the problems to be addressed.

Management structure

AHI falls under the auspices of the Association for the Strengthening of Agricultural Research in Eastern and Central Africa (ASARECA). ASARECA was formed by NARIs (National Agricultural Research Institutes) in the region and is governed by a committee of directors. ASARECA views AHI as one of two cross–cutting programmes, which try to link existing networks and institutions in addressing issues of mutual interest (a programme on policy research is the other cross–cutting programme). AHI has an overall coordinator who reports to a regional steering committee consisting of representatives from NARIs, IARCs, and donors. The coordinator also receives input from a technical support group (TSG) that is comprised of scientists of different disciplines in the region and site coordinators. In addition to providing input to planning, site coordinators are also accountable to the AHI coordinator. In Phase Two, site coordinators will be hired full time by AHI to help ensure implementation of the research agenda.

Implementation Issues

AHI has had few funds to carry out its mandate and instead has depended on collaboration with existing networks and institutions. In particular, it depends on staff time contributions from both IARCs and NARIs operating in the region. This has had varying degrees of success. It is successful in cases

where existing institutional research agendas closely resemble the objectives of AHI and in the case where sites overlap. For many other researchers in the region, the amount of time they are able to commit to AHI is limited by busy work schedules. In order to promote wide institutional participation, AHI has allocated some funds on an institutional rather than thematic basis. This has further led to some fragmentation of the research agenda and has made the development of a regional research agenda rather difficult.

At the site level, teams have been formed under the direction of a site coordinator. In the past, none of these positions had been paid for by AHI. Two types of problems have emerged. First, as in the case with IARCs, time allocation by some scientists has been insufficient and work became delayed. When time constraints are felt by site coordinators, this further implies that reporting procedures are delayed which may lead to problems of cash flow. A second problem that has arisen is the lack of a full complement of disciplines at some of the sites and, in particular, teams are lacking social scientists.

The initial choice of site may have also hindered collaboration in the beginning in that they overlapped significantly with sites where ICRAF had already established operations. With teams in place, it was relatively easy for ICRAF to engage in AHI activities, but it was clearly more difficult for other institutions, who may have been working at other sites, to shift work to the AHI sites.

Lastly, coordination for AHI in Phase One was carried out by the coordinator of the agroforestry network for East and Central Africa. Despite the enormous effort of the coordinator, there were simply too many demands from two networks for a single person.

Many of these difficulties have been reviewed and addressed in the new phase of AHI.

International Centre for Research on Agroforestry

Regional approach

ICRAF has long adopted a research approach which is regional in scope. In Africa, it developed Agroforestry Research Networks (AFRENA) that were responsible for diagnosing agricultural problems and planning research to address them. They in turn are responsible to national and regional steering committees comprised of members of national research and policy institutions. About 60 % of ICRAF's international professional research staff is outposted into regional programmes. The regional programmes themselves seek funding and the successful ones have considerable autonomy in implementing their agendas. The networks function primarily through collaborative arrangements with national research institutions. ICRAF scientists are hosted by national research centres and planning is carried out jointly between ICRAF and partner institutions. The management of network funds is sometimes done by the ICRAF scientist and sometimes by a national collaborator. ICRAF has five priority ecoregions: the humid tropics of Latin

America, the humid tropics of Southeast Asia, the highlands of East Africa, the sub–humid region of Southern Africa, and the semi–arid zone of West Africa. Full teams are located in East Africa, Southern Africa, and Southeast Asia.

Because of a lack of national capacity in agroforestry research, and indeed depth of agroforestry science, much of the early efforts of the networks was to build capacity and to generate scientifically sound agroforestry systems for use by farmers. Regional research programmes were thus focussed on the development of agroforestry systems to meet the needs of farmers near the research sites. Though implemented regionally, this work was focussed primarily on the plot level. Having generated several successes, agroforestry research is now moving beyond technologies and beyond plot scales through to global scales. The work undertaken in the humid tropics under the Alternatives to Slash and Burn programme, was conceived to operate at higher scales with significant efforts made to study ecological functions in landscapes, global environmental benefits, and national policy issues. This is truly ICRAF's best example of ecoregional research.

Useful methods and tools for ecoregional research

ICRAF has adopted several approaches that are useful, if not necessary, for successful ecoregional research. Many of them are also used in the AHI. The first is a participatory approach. Ecoregional research requires a multi–disciplinary approach to problem solving. This is best achieved by a bottom–up approach whereby researchers can jointly agree on key problems and establish a research agenda. Participation also helps to secure interest of development agents and/or policy–makers who will be critical in eventually generating impact on farms.

ICRAF is also using a flagship model of research in which regional research is conducted at several sites, with each site taking a lead role on a major research component. This avoids duplication and wasting of resources and can even expand the scope of the regional research agenda. Because national partners benefit from research in other countries, they are also more interested in undertaking research of a strategic nature.

ICRAF is also testing a village approach to research (leading to pilot dissemination projects). Rather than testing agroforestry systems with individual farmers, ICRAF is attempting to work with entire villages. This helps to engage a wide range of households in the testing and development of agroforestry practices. Working with a small number of volunteers, on the other hand, usually leads to close relationships with the relatively more wealthy farmers. Working with communities also strengthens research and development linkages because all villagers have had equal opportunity to try a new innovation and jealousies or envies do not arise. From an ecoregional research perspective the opportunity to have wide–scale testing enables an early glimpse into the externalities arising between plots or households, including emergence of pests or diseases, the hiring of labour, or the production and distribution of germplasm. Because of this, researchers are much better able to provide recommendations that are valid at wider scales.

Ecoregional research operates at multiple scales but emphasizes those above the household, such as the community and landscape. Many biophysical variables, such as soil quality and long–term climate information, are relatively easy to measure in that they are fairly static over time, but repeated measurements over wide areas are expensive. In order to obtain a better regional perspective on natural resource problems and opportunities for extrapolation from sites, ICRAF has been experimenting with techniques that combine remote sensing, ground truthing, and modelling. Remote sensing offers considerable information at relatively low cost and thus the extent to which it can replace more expensive ground surveys will lead to more effective ecoregional research programmes.

Socio–economic variables are very costly to obtain because they cannot easily be observed from remote sensing and because they can change rapidly. Hence, there is a paucity of important socio–economic data available for wide areas of developing countries. One tool for collecting some types of socio–economic data is the rapid community survey. In a single 2–3 hour interview with a group of local experts, a great deal of information can be gathered, including a sense of trends. These could be coupled with a quick survey of 10–15 households within the village to obtain more precise quantitative data for certain variables (e.g. methods of land acquisition, cropping strategies). Such a tool has been used by ICRAF initially in collaboration with IFPRI (International Food Policy Research Institute).

In order to sharpen the choice of where ICRAF works and to broaden the impact of its research, models are often employed as a research tool. Some of the models completed or currently being developed are:

- Models for delineating problem domains.
- Models to assess driving forces of land–use change.
- Models to assess system impacts of alternative land–uses.
- Models to assess farm nutrient/income impacts of agroforestry systems.
- Models to predict extrapolation domains for agroforestry systems.
- Models to assess soil and water movements under different land–uses.

In ecoregional research, there is undoubted utility from the use of models to transfer research results from a limited number of sites to an entire ecoregion. Such models may also be used to extend results to similar but distant ecoregions. To be able to multiply the applicability of results across sites is particularly important for international research centres.

GLOBAL AGRO–CLIMATIC CLASSIFICATIONS, WITH EMPHASIS ON ASIA

David White, Heping Zuo and Godfrey Lubulwa

Summary

Different methods for classifying agro–climatic zones were compared. These included methods based on estimating the length of growing period (LGP) using rainfall and temperature data, on the ratio of precipitation to potential evapotranspiration, and on more detailed agronomic models. Remote sensing data and land–use information are also being used to aid in the definition of these zones. The most appropriate classification method for the Australian Centre for International Agricultural Research (ACIAR) to use at this stage to aid research targeting and prioritisation at the country level would appear to be one based on six agro–climatic zones classified according to LGP. This is primarily because this zonation can be linked to existing livestock data. These zones are designated desert, arid, semi–arid, dry sub–humid, moist sub–humid and humid. However, within each zone it is possible for further subdivision according to the dominant livestock production system, namely grassland–based, rainfed mixed farming and irrigated mixed farming. Detailed agro–climatic analyses of mainland Asia and Sri Lanka have recently been undertaken using the GROWEST model. Using this model as the basis of agro–climatic classification appears to be significantly superior, particularly in temperate environments, to approaches based simply on the length of growing period. This technique could usefully be applied in other countries of interest, along with making digitised zone boundaries more generally available and better integrated with pasture, crop and livestock data sets.

Introduction

A review was undertaken of different ways of subdividing countries and continents into agro–climatic or agro–ecological zones. This was part of a larger study aimed at developing a global livestock commodities database and technology transfer matrices (White, 1998) for improving the allocation of research resources by ACIAR in order to aid livestock production within developing countries (Davis and Lubulwa, 1995).

The specific objectives of the task reported here were to determine the feasibility, value and limitations of different approaches that can be used, either singly or in combination, to refine agro–climatic zones for different livestock commodities, and to identify where the problems of classification and interpretation are likely to arise.

Definitions

The following definitions are used by Australia's SCARM (Standing Committee on Agriculture and Resource Management) Working Group on Sustainable Agriculture:

Agro–climatic regions

This term is used to denote regions with a characteristic inter–relationship between agronomy/farming systems and climate.

Agro–ecological regions

Similarly, agro–ecological regions are those with a characteristic inter–relationship between agronomy/farming systems and various environmental features, not just climate.

Agro–ecosystems

An agro–ecosystem has been defined as an ecosystem manipulated by frequent, marked anthropogenic modifications of its biotic and abiotic environments (Coleman and Hendrix, 1988). Four main types of modification have been recognised; these are: inputs of energy, reduction in biotic diversity so as to maximise yield of economic products, artificial selection, and external control which is goal–oriented (Odum, 1969).

Agro–Climatic and Agro–Ecological Regions

Agro–climatic and agro–ecological zonation schemes are standard tools used to target agricultural research and to set research priorities because they offer relevant and available information about target environments (Corbett, 1996). Indeed, this was the major reason for this study. A proper description of the target environment also enables research efforts to be more clearly focussed on local issues and needs.

The number of bioclimatic, agro–climatic, ecoclimatic and biogeographic classifications is very large (Le Houérou *et al.*, 1993). Some are of general use while others are focussed towards particular regions.

In choosing which classifications to evaluate and compare, attention was focussed on those that have been or are becoming in common use. It was considered appropriate to pay particular attention to the preferred systems used by the Food and Agriculture Organization of the United Nations (FAO), the Consultative Group for International Agricultural Research (CGIAR) including its Technical Advisory Committee (TAC), and the Environmental Research Group Oxford (ERGO) that has been undertaking GIS–based consultancy work for FAO, the International Livestock Research Institute (ILRI), and the Centre for Resource and Environmental Studies (CRES) at the Australian National University.

Köppen climate classification system

Until recently the most widely used system of climate classification has been that of the German climatologist Köppen (1936) – many later classifications are variants of the "Köppen (or Koeppen) system" (FAO). The classification is

based on monthly rainfall and temperatures, including the following five inputs:

- Average temperature of the warmest month.
- Average monthly temperature of the coldest month.
- Average thermal amplitude between the coldest and warmest months.
- Number of months with temperature exceeding 10ºC.
- Winter and summer rains.

The global map (Figure 1) shows the location and extent of the individual regions. This
may also be viewed or downloaded from the FAO WWW site:
http://www.fao.org/WAICENT/FAOINFO/sustdev/EIdirect/Climate/EIsp0054.htm

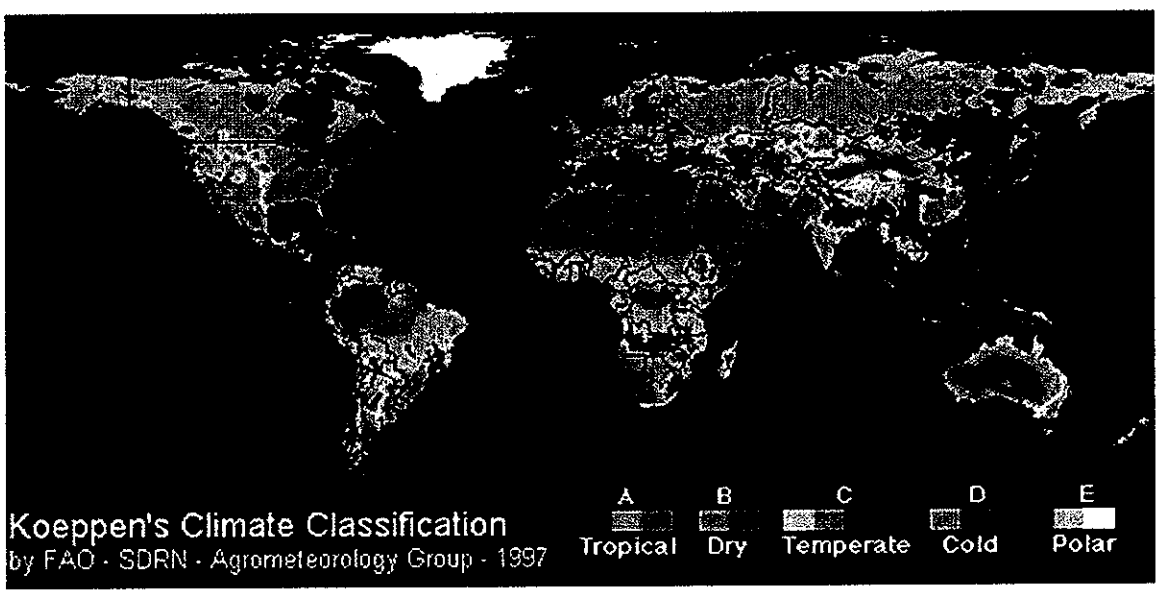

Figure 1. Köppen climate classification system.

In summary, the Köppen system is a static, empirically based descriptive system that was appropriate for the pre–computer era.

***Agro–climatic classification based on length of growing period* (FAO 1978–81)**

Probably the first serious attempt to use computers to integrate climate, soil and plant information in order to determine agro–ecological zones throughout the world reported by FAO (1978–81).

Agro–ecological zones were determined by overlaying climatic inventories for different sites on soils maps, soil characteristics in terms of slope, texture and phase being used to provide an assessment of land suitability for different crops. Crop yields were estimated on the basis of crop phenology and yield potential, reduction factors in terms of crop yield loss due to water stress,

pests, weeds and diseases, and constraints in terms of the 'workability' of the soil.

Climate data were used to estimate the length of the growing period (LGP), the time available when water and temperature permit growth, based on estimates of soil water balance. For a crop to be growing it was assumed that rainfall had to at least equal 50% of potential evapotranspiration (PET) for crop growth to be achieved, and that the mean daily temperature during the growing period had to exceed 5°C. The distinction was made between the humid and non–humid parts of the year, according to when precipitation exceeded PET.

A new approach to LGP–modelling has been proposed by Fischer *et al.* (1995) that better integrates temperature– and moisture–related constraints, and makes the concept more suitable for a global climatic resources inventory. The temperature threshold for a growing period remains, as in the standard LGP approach, a mean temperature of 5°C, but the temperature and moisture–delimited growing period is defined through both water balance and temperature thresholds.

The new approach treats moisture depletion rates as a function of moisture availability. Allowance is also made for the fact that in temperate and cold areas rainfall can be in the form of snow. A third modification of the water balance relates to dormancy periods with temperatures above 0°C but below 5°C.

***Agro–bioclimatic classification of Africa* (Le Houérou *et al.*, 1993)**

Le Houérou *et al.* (1993) rejected the Köppen (1936) and related classifications. This was because they were based on the "empirical and somewhat obsolete, albeit fairly efficient, relationship between precipitation and temperature as a criterion of water stress/water availability and on mean annual temperature as a criterion of cold or heat stress, which lacks accuracy, sensitivity and efficiency". Instead they identified simple, rational and reliable parameters to represent water and temperature requirements and constraints. The discriminating values of these parameters were selected on the basis of agronomic and ecological criteria of the distribution of native vegetation, wildlife, crops and livestock, in an attempt to make this classification realistic and utilisable for the continent as a whole, with the aim of producing a framework that could be safely used by agronomists, land managers and planners. Their classification combined a rather large number of climatic, biological, agronomic and geographic criteria. The actual number of occurring combinations is about 200. Some of these occupy very large areas, such as the hyper–humid equatorial lowlands (some 9 million km^2), or the extra–tropical, winter rainfall, cold hyper–arid lands (some 5 million km^2), whereas other combinations cover very small areas such as the afro–alpine and mediterraneo–alpine ecozones and the equatorial hyper–arid midland ecozone. The large number of classes in this classification system is clearly impractical for use in the current ACIAR project aimed at estimating the benefits within and between regions and countries from agricultural research. Furthermore, to use this classification would clearly require a digitised data set containing the boundaries and details of the wide range of agro–

ecosystems. Also, to develop an equivalent system in Asia or South America would require considerable resources.

***Zone classification based on length of growing period – Africa* (Kruska *et al.*, 1995)**

As part of a programme aimed at assembling livestock distribution coverages across Africa, Russ Kruska and Philip Thornton of ILRI kindly made available the ArcInfo data sets on Africa for length of growing period (at two levels of aggregation), and cattle density distribution.

***Agro–ecological classification of* Seré *et al.* (1996)**

This classification is also based on the length of the growing period (LGP), which is defined here as the period (in days) during the year when rainfed available soil moisture supply is greater than half potential evapotranspiration (PET). It includes the period required to evapotranspire up to 100 mm of available soil moisture stored in the soil profile. It excludes any period with daily mean temperatures less than 5°C.

A major attraction of this approach is the relatively simple formula used to estimate the length of growing period, indicating that it could be relatively easy to compute provided global climatic data sets were available. The approach started with the FAO/TAC LGP classification comprising 11 different zones. For the purpose of a livestock system classification with few clusters, these were reduced to three: arid and semi–arid (< 180 growing days); humid and sub–humid (more than 180 growing days); and temperate and highland (temperature constraint). It is therefore a rather crude aggregation of the LGP concept. Three livestock production systems were considered: grazing systems; mixed rainfed systems; mixed irrigated; which equals 3 x 3 = 9 land–based systems. Two land–detached systems for monogastrics and ruminants were also included.

Arid:	LGP less than 75 days.
Semi–arid:	LGP in the range 75 – 180 days.
Sub–humid:	LGP in the range 181 – 270 days.
Humid:	LGP greater than 270 days.

Tropical highland areas and temperate regions are defined by their mean monthly temperatures. Temperate regions have one or more months with a monthly mean temperature, corrected to sea level, of less than 5°C. Tropical highlands are tropical areas with daily mean temperature during the growing period in the range of 5–20°C.

This classification distinguishes between Solely Livestock Systems, Grassland Based Systems, Rainfed Mixed Farming Systems, Irrigated Mixed Farming Systems, Landless Monogastric and Landless Ruminant Systems. Unfortunately, data distinguishing the number of livestock in irrigated and dryland systems have not been obtained for individual countries. In any case, the area of land that is irrigated is a small proportion of that available for agriculture, and in most countries is dominated by crops (Seré *et al.*, 1996).

The study of Seré et al. (1996) contained estimates of land area, livestock numbers, livestock production and productivity indicators within each of the 11 agro–ecological systems for different regions of the world. These included sub–Saharan Africa (SSA), Asia (ASIA), Central and South America (CSA), West Asia and North Africa (WANA), Organization for Economic Cooperation and Development (OECD) member countries, excluding Turkey which was included in WANA, eastern Europe and Commonwealth of Independent States (CIS), and other developed countries—Israel and South Africa (ISA).

***Ecozones, farming systems and length of growing period* (Slingenbergh and Wint, 1997)**

Raster images for length of growing period (LGP) in 16 classes, national boundaries and human population level were available, initially for the African continent and subsequently for the world. Two primary outputs were required: vector maps of LGP zones (concatenated into six classes) within each country; and population levels for each of these zones. The original 16 LGP zones were reclassified into six; the resulting image comprised approximately 550 LGP zones by country (Figure 2).

The FAO (1996b) approach provides estimates of livestock species biomass within each of the six agro–ecological zones within each country. These have been based on using a direct ratio between animal numbers and people (animals per person) calculated from the FAO country data. It also means that the calculated national total should approximate the FAO national statistics. As an example of a product from this work, Figure 3 shows the global distribution of cattle based on FAO 1994 data.

Figure 4 depicts the distribution pattern of livestock within Asia, with the major focuses in India and China. Further query of this database in a Geographical Information System (GIS) can be used to discriminate between ruminants and monogastrics, and between individual domestic species.

There is a clear tendency in Asia towards a replacement of ruminants by monogastric livestock in wetter areas, the agro–ecological zones used by Slingenbergh and Wint (1997) being shown in Figure 5. However, some caution is required when interpreting this trend because the progressive aggregation of monogastric livestock in humid and moist sub–humid areas in Asia is not universal, and appears to be influenced not so much by the climatic conditions in which the animals are kept but rather by human preferences or anthropogenic factors.

The work of Wint and colleagues on African ecozones and farming systems is continuing (FAO 1997, 1998). Satellite data of land–surface and atmospheric characteristics are being used in the search for more ecologically based criteria for zonation, including:

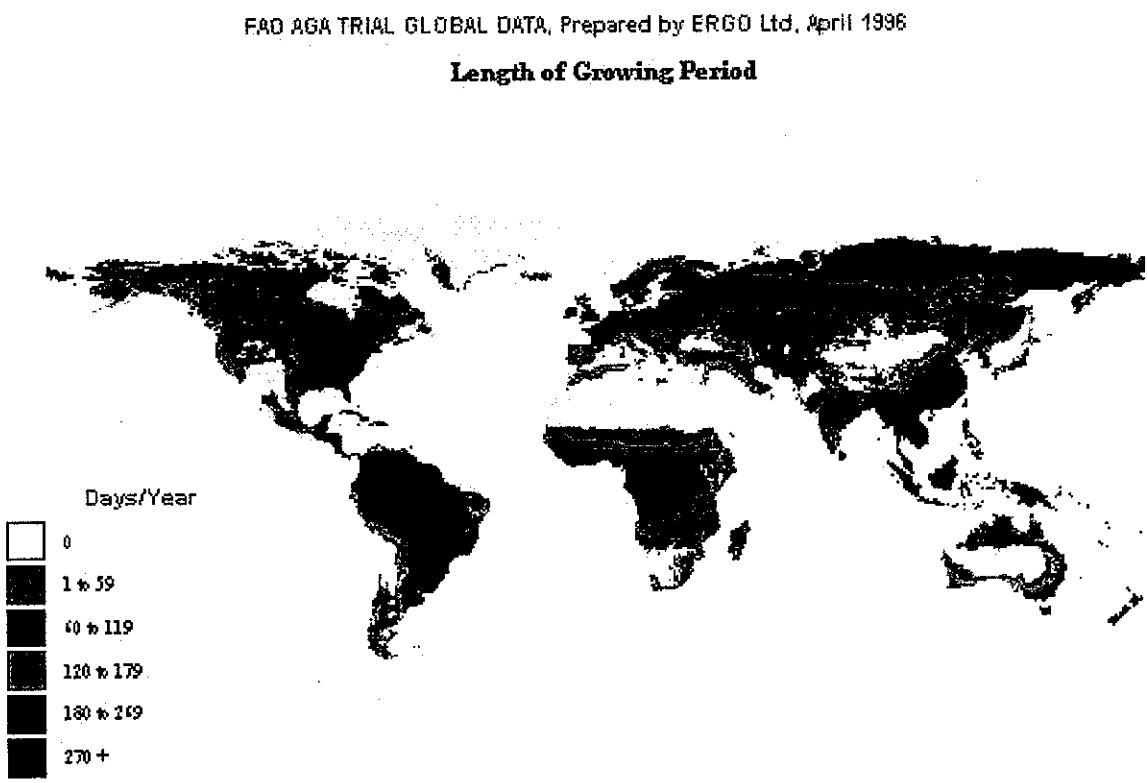

Figure 2. Length of Growing Period zones, six zones (FAO, 1996a).

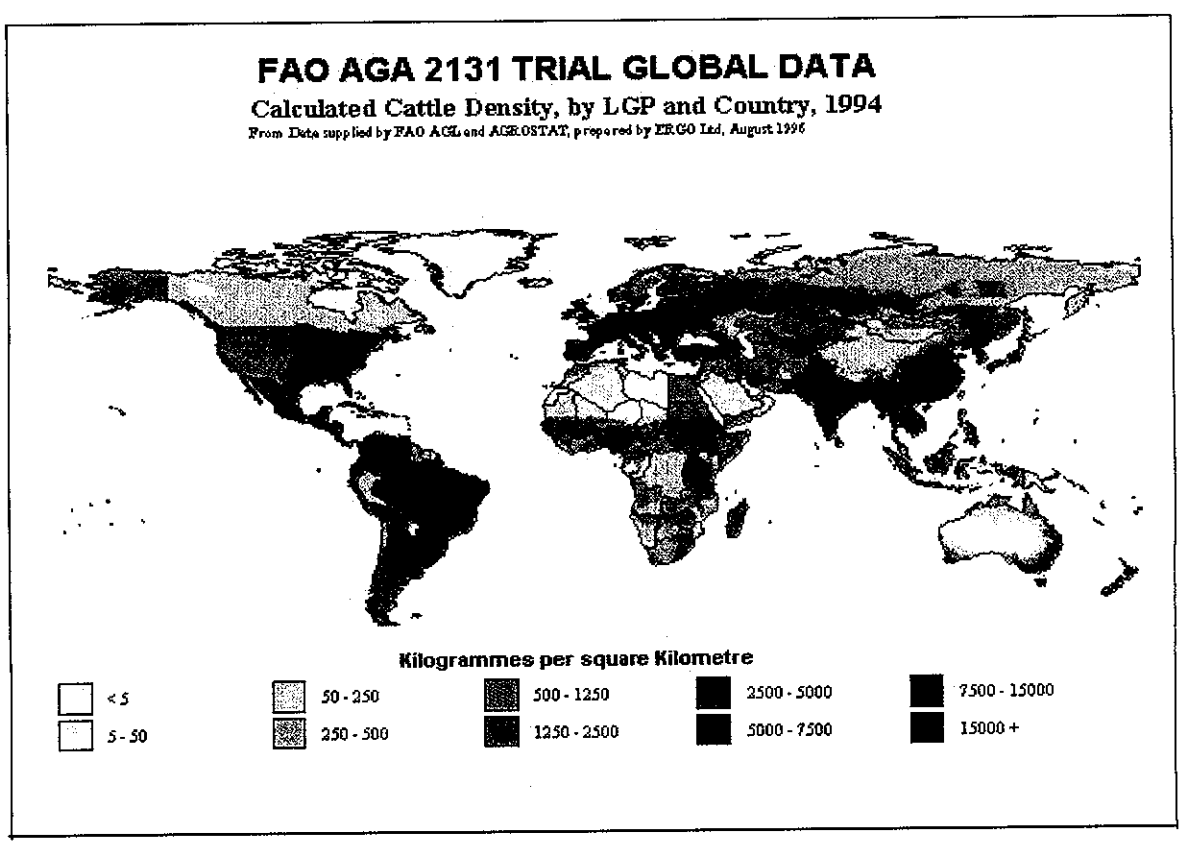

Figure 3. Calculated cattle density, by LGP and country (FAO, 1996b).

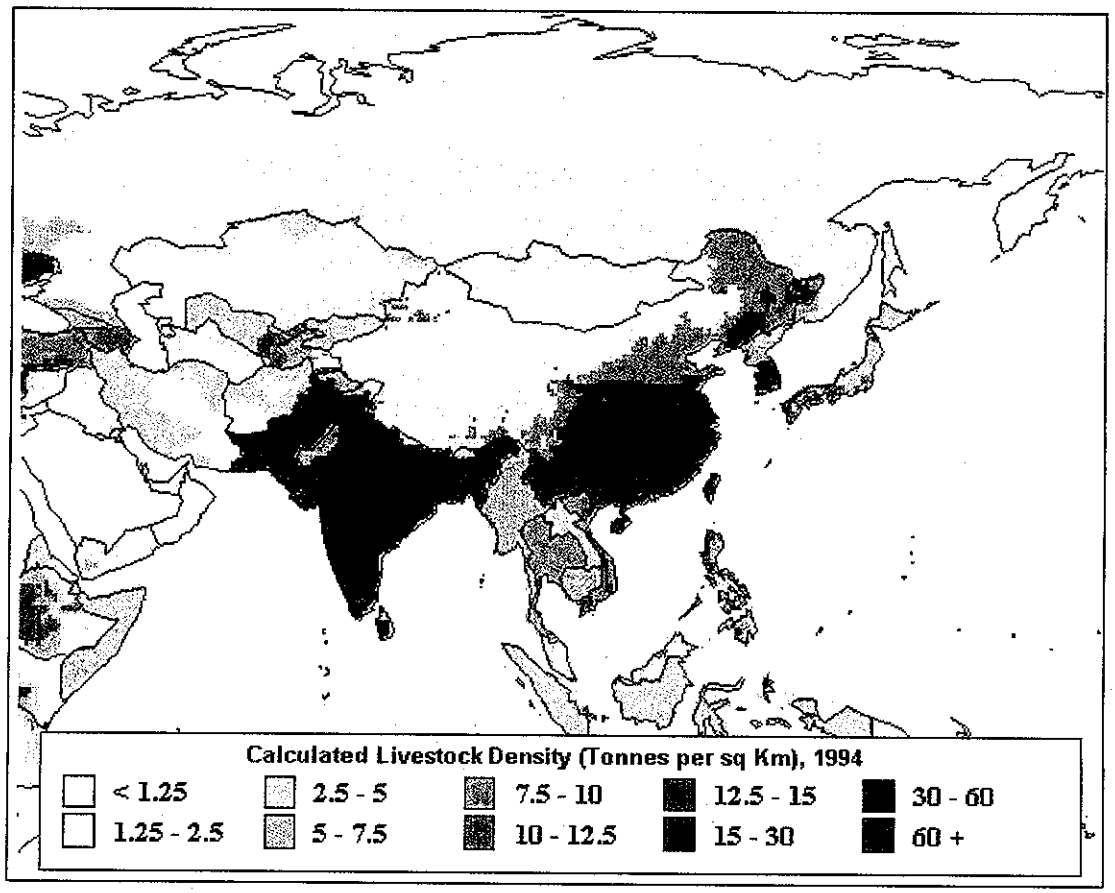

Figure 4. Livestock biomass density in Asia, 1994 (Slingenbergh and Wint, 1997).

a) The Normalised Difference Vegetation Index (NDVI), commonly used as an indicator of vegetation cover.

b) A measure of ground surface temperature, derived from one of the thermal infra–red channels (Channel 4; 10–day composite) on the satellite platform (NOAA AVHRR data; 1km x 1km resolution) by the NASA Global Inventory Monitoring and Modelling Systems (GIMMS) group.

c) A measure of surface rainfall, the Cold Cloud Duration (CCD), derived from the METEOSAT satellite (8 km x 8 km resolution).

In addition, Digital Elevation Model (DEM) data were obtained from a 0.083 degree resolution elevation surface for Africa, produced by the Global Land Information System (GLIS) of the United States Geological Survey, Earth Resources Observation Systems (USGS, EROS) data centre.

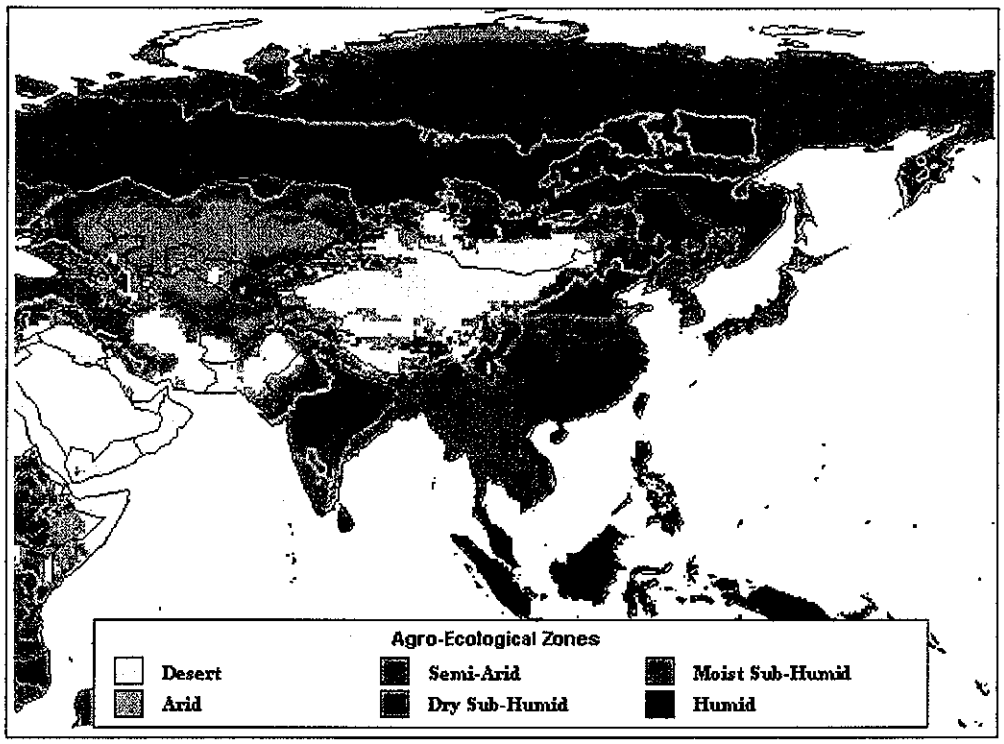

Figure 5. Agro–ecological zones in Asia (Slingenbergh and Wint 1997).

Farming systems in Kenya correspond quite closely with ecological zonations based on length of growing period (FAO 1998). Two sets of ecozones are identified, one with 11 zones and the other with 16 zones. The major effect of increasing the number of zones was to split the drier areas into more categories. MANOVA analyses showed that 11 zones encompassed 77 and 46% of the variation in cattle and crops respectively, as compared with 78 and 46% for the 16 zones.

Regression relationships were identified between remotely–sensed surrogates for climate, human population and elevation and known livestock and cropping distributions. These were used to predict livestock densities and cropping levels within a series of ecozones that were defined by unsupervised classification of the remotely–sensed data. Elevation was found to be an important determinant of the ecozones, but as Hutchinson (1989a, 1991) has shown, that would primarily be through its impact on rainfall and temperature, the influence varying with latitude. For example, the most consistent predictors of cropping percentage in Kenya and Ethiopia appear to be human population number and elevation, as befits heavily populated areas concentrated in extensive highlands (FAO, 1997). In Somalia, Sudan and Uganda, the predictors are more diverse, with rainfall and vegetation cover, to a lesser extent, being most frequent. Human population and elevation also predict cattle densities most often, in Somalia and Sudan, as well as in Kenya and Ethiopia. Rainfall is also a frequent predictor, especially in Uganda, and parts of Sudan. Cattle densities appear to be more closely related to population, especially in the more arid areas such as Mali and Chad, whilst elevation features predominantly in Niger. Elsewhere, either temperature or

rainfall are more closely related to cattle numbers than are other eco–climatic variables.

Length of growing period was closely related to the satellite–derived ecozones (FAO, 1998). The primary discriminating predictors were maximum temperature, minimum rainfall, mean NDVI and elevation, with the remainder being largely rainfall related. The AVHRR (Advanced Very High Resolution Radiometer) data were able to discern relatively slight variations within more arid areas, but were comparatively poor in discriminating between zones in the higher rainfall areas.

***Climate classification based on potential crop production* (Hutchinson *et al.*, 1992)**

This classification of the world's climates is based on the responses of plants to the climatic regimes, which were simulated using GROWEST, the generalised model of plant response to the major light, temperature and moisture regimes developed by Fitzpatrick and Nix (1970) and Nix (1981). The model was built in part on the recognition of the plant's growth responses to temperature, which were grouped as: 1) a microtherm assemblage which includes mainly conifers and cool to cold temperate climate plants; 2) a mesotherm assemblage which includes all the major temperate crop and pasture species such as wheat, barley and oats (optimum temperature for growth = 19°C); 3) a C_3 megatherm assemblage which includes tropical–broad leaved plants and rice (optimum temperature = 28°C); and 4) a C_4 megatherm assemblage for the tropical grass group which includes maize, millet, sorghum and sugarcane.

The non–linear responses of these groups to each of the light, temperature and moisture regimes were transferred to a dimensionless scale, where zero represented completely limiting conditions and unity non–limiting conditions for that factor. The resultant indices: included moisture indices (MI), thermal indices (TI), and growth indices (GI). Seasonalities of these attributes were calculated on successive 13–week accumulated values of indices as determined by the GROWEST crop growth model for each week of the year for different thermal groups of plants. Thirteen standard weeks correspond to the growing period for the earliest–maturing grain crops grown in very favourable climates, and also provide a measure of the most important period for growth of later maturing and perennial crops. The broadest groupings were based on temperature except for the warm/hot and very dry (desert) climates. This parallels the principal Köppen divisions. The next divisions were principally based on moisture, giving rise to 10 broad groups.

The separated indices together with the combinational multi–factor growth index were used first in a bioclimatic analysis of the grassland ecology of the Australian continent (Fitzpatrick and Nix, 1970). Sensitivity analysis (Fitzpatrick and Nix, 1970) indicates that for a weekly time step, the multiplicative function of the GROWEST model is marginally superior to the law of the minimum where the value of growth index is taken to be the value of the most limiting factor (Hutchinson *et al.*, 1992).

The model uses monthly climate data but interpolated the monthly values to a weekly step. The study used climatic data recorded from more than 4000 stations from around the world. The study also applied the spline interpolation technique to predict the missing values of these stations (Hutchinson, 1984; 1989a). The thin plate spline technique used in this approach is capable of spatially interpolating a variety of climatic variables from irregularly distributed station network data into climatic surfaces that are multi–dimensional functions of longitude, latitude and a third spline variable, usually elevation. Climatic variables can be calculated from these surfaces with the input of values for the appropriate independent variables (Hutchinson, 1989a). These surfaces can be used in the construction of regular grid climatic data sets or to estimate climatic variable values at sites where meteorological measurements are not available. Although this climatic classification was not GIS–based, the methodologies used in this study provided us with critical tools to develop GIS–based agro–climatic classification. This was recently achieved for Mainland East Asia by Zuo (1996) and Zuo *et al.* (1996a, 1996b). A similar classification has been done for Sri Lanka (Kannangara, 1998).

***Agro–climatic classification for mainland East Asia* (Zuo, 1996; Zuo *et al.*, 1996a; 1996b)**

Mainland East Asia, as classified by Zuo (1996), includes the countries of China, Vietnam, Laos, Thailand, Kampuchea and Peninsula Malaysia. These are some of the most densely populated areas in the world. With more than one fifth of the world's population living on less than one tenth of the world's land, in areas mostly covered by high mountains, plateaux and deserts, the resource deficiencies are obvious and very serious.

A GIS–based agro–climatic classification was developed for Mainland East Asia in this study, based on regular grid data sets at a resolution of 1/20th degree and agro–climatic indices simulated by a general plant growth model GROWEST (Nix, 1981). The climatic data sets were developed using climatic surfaces interpolated by ANUSPLIN (Hutchinson, 1984; 1991) and a digital elevation model calculated using ANUDEM (Hutchinson, 1989a; 1989b). The classification attributes were all those simulated using the GROWEST model at a weekly step for each of the grid cells across Mainland East Asia. Thirty–nine GROWEST attributes were selected as classificatory variables for each grid cell. Finally, 14 agro–climatic zones were developed using the ALOC module of the numerical taxonomy package PATN (Belbin, 1987). The ALOC module is a non–hierarchical clustering procedure, with the option of defining groups of attributes, and with each group contributing equally to the measure of association between objects. It compared the similarity of all grid cells based on the 39 agro–climatic attributes, and generated 66 groups with an association threshold value 0.20. These 66 groups were further aggregated into 14 agro–climatic zones using the FUSE module of PATN.

Growth Degree Days (GDDs) were found to be important in refining these categories (Table 1). These help to discriminate between plants that have different temperature requirements in reaching maturity. GDD values were calculated for each of the three plant groups using mean daily temperatures for the number of days that the recorded mean temperature was within the

temperature range bounded by the low and high temperature thresholds of the plant for growth. The temperature values were the mean daily temperatures simulated for each weekly time step accumulated during the growth period within the predefined temperature range. Zuo (1996) used ranges of 3°C to 35°C for mesotherm plants with an optimum temperature for growth of 19°C; 8°C to 40°C for megatherm C_3 plants with an optimum temperature of 28°C; and 10°C to 45°C for megatherm C_4 plants with an optimum temperature of 32°C.

Table 1. Selected attributes used as input for the agro–climatic classification of Mainland East Asia.

	Annual	Highest 13–week	Lowest 13–week	Highest 26–week	Lowest 26–week	Seasonality (c.v.)
GI_{19}	√	√	√	√	√	√
TI_{19} x LI	√	√	√	√	√	√
GDD_{19}	√					
GI_{28}	√	√	√	√	√	√
TI_{28} x LI	√	√	√	√	√	√
GDD_{28}	√					
GI_{32}	√	√	√	√	√	√
TI_{32} x LI	√	√	√	√	√	√
GDD_{32}	√					

GI_{19}, GI_{28}, GI_{32} = the Growth Index values for optimum temperatures for growth of 19°C, 28°C and 32°C, respectively; TI_{19}, TI_{28}, TI_{32} = the Thermal Index values for plants with optimum temperatures for growth of 19°C, 28°C and 32°C, respectively; GDD_{19}, GDD_{28}, GDD_{32} = the Growth Degree Days for plants with optimum temperatures for growth of 19°C, 28°C and 32°C, respectively.

Each agro–climatic zone represents a typical cropping system or vegetation pattern. The geographic location of these zones is shown in Figure 6:

Agro–climatic Zone 1 – The high cold plateau climate of West China.
Agro–climatic Zone 2 – The dry and hot desert areas in Northwest China.
Agro–climatic Zone 3 – The grazing grasslands of North and West China.
Agro–climatic Zone 4 – The single temperate crop area in Northeast China.
Agro–climatic Zone 5 – Wheat–dominated double cropping system of North China Plain.
Agro–climatic Zone 6 – Rice–dominated double cropping system in the south of Yangtze.
Agro–climatic Zone 7 – The sub–alpine forest area of Southern China.
Agro–climatic Zone 8 – The warm highlands of Southwest China.

Agro–climatic Zone 9 – Mountain tops of humid tropical areas of China, Southeast Asia.
Agro–climatic Zone 10 – The humid tropical highlands.
Agro–climatic Zone 11 – Triple cropping systems–Southern China, Northern Vietnam.
Agro–climatic Zone 12 – Humid tropical lowlands of Southeast Asia.
Agro–climatic Zone 13 – Wet tropical highlands of equatorial areas.
Agro–climatic Zone 14 – Wet tropical lowlands of equatorial areas.

This agro–climatic classification, using numerical taxonomic methods and based on crop growth potential attributes, has defined agro–climatic zones that have varying suitability for a range of agricultural systems and that are consistent with mapped vegetation patterns of Mainland East Asia. A major feature of the classification is that each of the 14 agro–climatic zones represents a distinct agricultural environment. All class boundaries are defined by crop growth potential regardless of geographical location. A single agro–climatic zone may include disjunct regions at widely spaced geographical positions, in which similar agro–climatic environments occur because of interactions of latitude, altitude, and marine proximity.

Although this classification agrees with the main features of previous agro–climatic classifications, differences are evident owing to the different philosophy and methodology adopted in this study. The most significant difference occurs in the areas between the Huai River and the Yangtze River. Analyses of this study indicated that the climatic environment of the area is more closely related to the northern adjacent areas than to its southern neighbouring areas as noted in previous classifications (State Meteorological Administration of China 1978; Li 1993).

Choice of Agro–Climatic Zonation Scheme

In the ACIAR study of White (1998) it was recommended that six zones be discriminated according to length of growing period (LGP), because this is consistent with ongoing work by FAO and others on LGP, complemented by satellite and other data, and estimates of total livestock biomass (Slingenbergh and Wint, 1997). There should nevertheless be an expectation and provision for these zones to be further subdivided as additional resources and data become available. These six zones are:

Zone	LGP (days)
Desert	0
Arid	1 – 59
Semi–arid	60 – 119
Dry sub–humid	120 – 179
Moist sub–humid	180 – 269
Humid	>270

It is important to appreciate that the choice of agro–climatic zones in the study of White (1998) was influenced by the fact that the FAO (1996a, 1996b) studies provided livestock data that could be linked to these zones. The use

of human population density data has been a useful step in providing initial estimates of livestock density distribution within countries, and for the most part these estimates appear to be sufficiently accurate to provide information to aid in the targeting and prioritisation of agricultural research. These estimates will be least accurate where the quality of the national data are low, where environmental regulations limit the location of livestock industries (e.g. intensively housed livestock units and feedlots), and where climatic extremes, land degradation or alternative land–uses have a greater effect on livestock densities than on those for human populations.

Definition of agro–climatic (and agro–ecological) zones will improve through applying digital elevation models, climate surfaces, plant growth models such as GROWEST (Nix 1981; Zuo 1996), field and remote sensing data, and geographic information systems (e.g. FAO 1997, 1998). The use of the GROWEST model as the basis of agro–climatic classification appears to be significantly superior, particularly in temperate environments, to approaches based simply on length of growing period.

The collection of land–use and livestock density data in Africa (Corbett *et al.*, 1995; Kruska *et al.*, 1995) and Latin America (G. Hyman, pers. comm.), complemented by local data (e.g. provincial livestock data in the yearbooks of the Peoples' Republic of China), means that before too long it will be useful to revisit the data on livestock density distribution in the light of new and more relevant zonations. International collaboration in assembling and integrating these data sets could be expected to have major benefits in improving the targeting of research and land management practices that benefit both the environment and resident human and livestock populations.

Future Directions

Opportunities for and constraints to improving the productivity, sustainability and viability of farming systems are often specific to particular agro–climatic (and agro–ecological) zones. Most of these zones traverse many countries, so that research that is relevant to a particular zone and country may well be relevant to many other countries. It is therefore important that the boundaries of the different zones, and the soil and vegetation types, livestock populations and human activities associated with each zone, are clearly defined and documented. The advent of new technologies such as remote sensing and geographic information systems are powerful tools for facilitating this process.

National and regional data are not necessarily accurate, and whilst they are the best available, some efforts should be made to gather field information to substantiate them. This is because wide–ranging decisions are likely to be based on this information, and on studies such as this one that have relied heavily on FAO and associated data. There is also an increasing need for accurate subnational data, as projects targeted to specific regions and issues become more common. This may well require more fieldwork, but the highest priority is to use technologies that can predict, interpolate and/or extrapolate resource distributions from available data.

Advantage should be taken of the considerable opportunities for collaboration with groups such as the FAO, ILRI, CIAT, and ERGO Consulting (Oxford University) to improve and make use of the international data sets on livestock numbers and productivity in different agro–ecological zones throughout the developing world. These groups have the expertise and information technology resources necessary, particularly models and GIS. There should be substantial scope for collaborative studies throughout much of Asia and the Pacific, possibly involving ILRI as well as national governments.

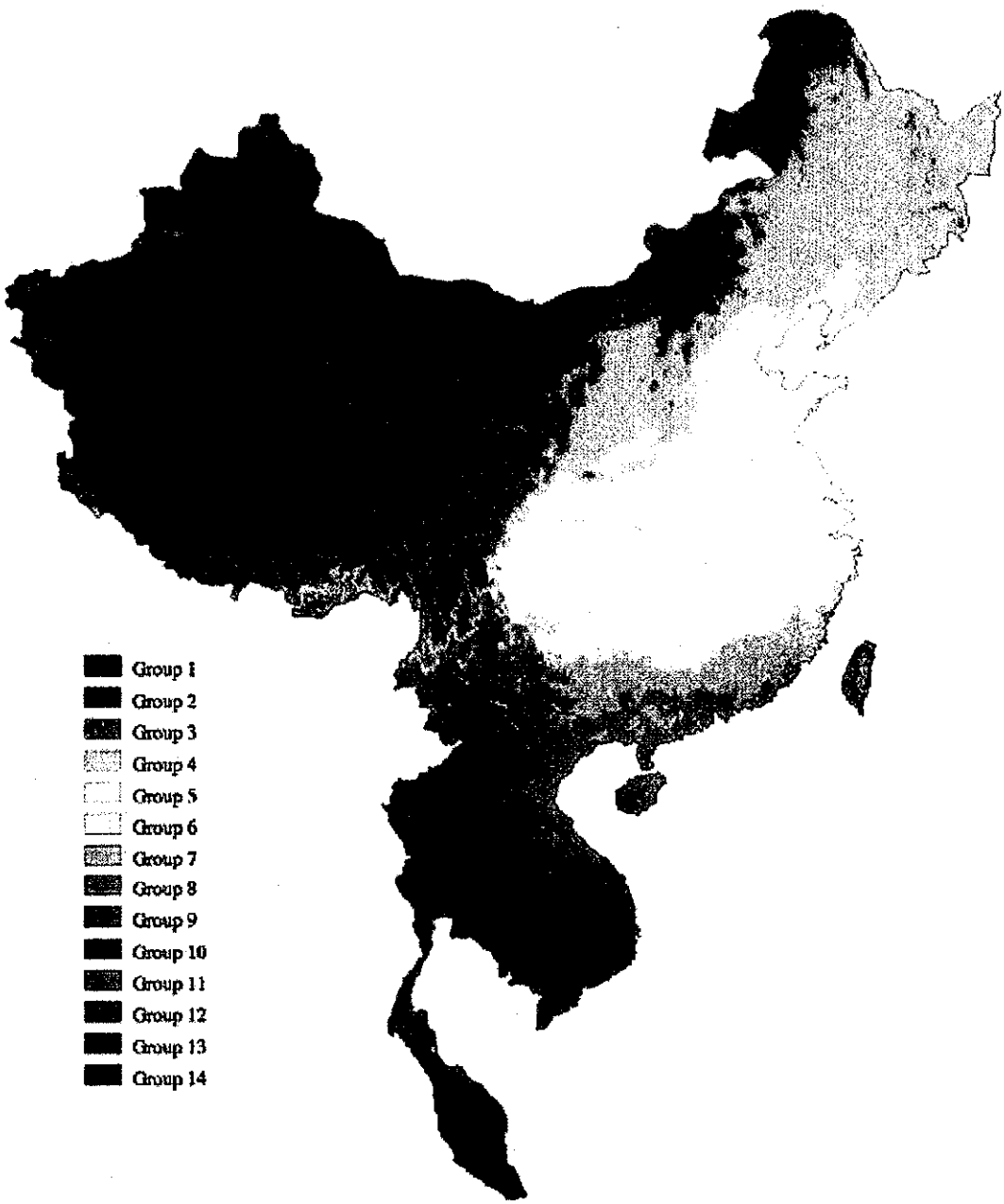

Figure 6. Agro–climatic zones of Mainland East Asia (Zuo,1996).

Definition of agro–climatic zones is likely to be determined for some time according to length of growing period, although Australia (and in particularly the Centre for Resource and Environmental Studies at the Australian National University) is at the forefront of improving that definition through the use of basic growth models. There is a need to apply model–based techniques in other countries of interest, as well as to make digitised zone boundaries more generally available and better integrated with pasture, crop and livestock data sets.

Acknowledgments

This study would not have been possible without the full support of Dr Ken Menz and Dr John Copland of ACIAR, and a number of people working for or with FAO. The latter included Dr Jan Slingenbergh, Dr Henning Steinfeld, Mr René Gommes and in particular Dr William Wint of the Environmental Research Group Oxford (ERGO) who was very generous and helpful in providing essential data, GIS products and advice.

Dr Philip Thornton and Russ Kruska (ILRI) were very helpful in making cattle distribution data available for Africa. Useful discussions were held with Professor Henry Nix and Dr Mike Hutchinson of the Centre for Resource and Environmental Studies at the Australian National University, and Dr Trevor Booth of the CSIRO (Commonwealth Scientific and Industrial Research Organisation) Division of Forestry and Forest Products, all of whom had considerable experience in agro–climatic analyses.

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DISCUSSION SUMMARIES

AND

WORKSHOP SUMMARY

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DISCUSSION SUMMARIES

Session 1. What Should the Underlying Themes be for ILRI's Ecoregional Research?

This question was discussed by three groups, and their summaries follow.

Group 1

This group started from the position that there was a need for a hierarchical order of goals and themes. At the level of the CGIAR, there is a goal (poverty alleviation, food security, and environmental protection) and associated themes: increased productivity, protecting the environment, saving or promoting biodiversity, improving policies, and strengthening NARS.

At the level of ILRI, the goal can be stated thus: to enhance the well–being of present and future generations through research that improves sustainable livestock production.

Ecoregional research themes within the Sustainable Production Systems Programme need to mesh with the overarching theme—improving productivity and sustainability of ruminant and crop–livestock systems in ways that enhance peoples' welfare. Various underlying themes were identified:

- Improving the understanding of the process of intensification to target future interventions.

- Improving nutrient management to increase production and maintain the resource base.

- Improving land–use strategies with respect to policies, common pool resources, etc.

The group felt that these themes relate to problems of increasing importance as systems intensify; they are relevant to all ecoregions; and ILRI has comparative advantages to address these problems, through the institute's multidisciplinary systems orientation and the fact that ILRI has access to many different types of production system.

Group 2

This group set out various assumptions for their discussions:

- For ecoregional research done at or with ILRI, it should have a livestock component.

- It should underpin natural resource management issues that cut across varying resource endowments.

- It should constitute a research activity that ILRI cannot do alone.

- It should be addressing constraints of a given ecoregion (globalisation was felt to be inappropriate).

The group identified the following themes:

- The impact of livestock on soil fertility and land–use systems.

- The impact of livestock on human nutrition (malnutrition being a major issue).

- Analytical methods to target crop–livestock interventions.

- Animal health management strategies that match production system constraints.

- Feeding systems.

There was some discussion as to whether the group's assumptions were reasonable, and as to whether some of the issues identified were truly ecoregional in scope.

Group 3

This group identified two themes. The first was the development of methodology and databases for assessment of the evolution of crop–livestock systems globally and in different ecoregions. It was felt that ILRI has expertise ranging from component research to integration at the systems level; it is relevant to the goal of the CGIAR; it would greatly help in making strategic choices at ILRI (and elsewhere) and to ensure focus and relevance on a global basis; such work should be attractive to donors; and that other institutions are doing some of this work, so that effort can be leveraged through appropriate partnerships.

The second theme identified was improving the contributions of livestock to nutrient management. Again, it was felt that ILRI had appropriate expertise, it is work that is highly relevant to the goal of the CGIAR, ILRI has comparative advantage to work on this theme, partially through its current emphasis on natural resource management, and prospects for leveraging effort and resources are good.

Some discussion followed on the role of policy; is it a theme in its own right, or a component of these themes? The group felt that it was the latter, and should be treated as an integral part of whatever ecoregional research ILRI does.

Discussion summary

From the three group discussions and the general discussions that followed the presentation of each group's findings, three themes were identified that most participants felt were reasonable:

1. Understanding and assessing the evolution of systems.

2. Improving the contribution of livestock to nutrient management.

3. Improving agricultural land–use strategies.

While the language of each of these could doubtless be improved, the general feeling was that the themes themselves were highly appropriate for ILRI in general. Separating the notion of what ecoregional research actually is, from the multitude of ILRI's activities, is not easy. It was pointed out that not everything that ILRI does is or should be ecoregional research—it is a subset of activities. All of ILRI's work should probably be ecoregional in applicability, but that is not the same issue. There is much difference between component research, systems research, and ecoregional research. It is clear also that ecoregional research does not have to be done in a large consortium. In addition, the separation of the notion of ecoregional research from what is going on in the various "ecoregional consortia" is not easy. ILRI is already a part of a number of these consortia, and through them is contributing to addressing the livestock agenda within the broader scope of natural resource management.

Session 2. What are the Major Activities of These Themes, and Where Should ILRI be Working on Them?

The second task for the discussion groups was to consider the themes in more detail, and to consider geographical location for the various activities. Groups were asked to get more specific about what should be done and where. To help focus discussions, the globe was divided into various zones:

Africa:	Semi–Arid Sub–Humid Humid Highlands
Latin America and the Caribbean (LAC):	Hillsides (of Central America) Forest Margins Savannahs Andes
Asia:	Semi–Arid Sub–Humid/Humid Highlands
West Asia–North Africa (WANA):	Arid/Semi–Arid

In addition, some consideration was given to the criteria that groups should use to assess relative importance of particular activities in particular places. Various criteria were suggested:

- Impact of the research on poverty alleviation.
- Impact of the research on food security.
- Size and scale of the potential impact of the research.
- Environmental protection.
- Comparative advantage.
- Ability to link with partners.
- Improved productivity.
- Fundability.
- Will the research result in international public goods?
- Standard of the science involved.

Discussion groups looked at Themes 2 and 3 (Theme 1 is a global activity and discussion of where it should be done is not really appropriate).

Group 1–Theme 2, Improving the contribution of livestock to nutrient management

Reference was made to the feed resources priority setting work done in late 1997. That was used as a basis for the discussion. Various sub–themes were identified from that document: plant genetic resources, feed utilisation, nutrient management, and feeding systems. The group felt that activities should address strategic, cross–cutting issues, and should be well within ILRI's comparative advantage.

Activities:

Plant Genetic Resources (PGR):
- Genetic enhancement of crop residues.
- Selection of forages.
- impact of livestock on biodiversity.

Feed Utilisation at the animal level (FU):
- Efficiency of nutrient utilisation (genotype, physiological state, disease etc.).

Nutrient Management issues related to the system (NM):
- Improved productivity through differential allocation of nutrient resources ("best use" options, feeding strategies).

Food/Feed Systems (FFS):
- Modification/intensification of crops and cropping systems.
- Residue hazards, pesticides/pollution.

To prioritise possible areas of research, the group assigned values on a scale of 1 to 5 (1=low, 5=high) for these areas by agro–ecological zone:

	Africa				Asia				LAC				WANA	
	SA	SH	H	HL	SA Irr	SA Rain	SH/H	HL	HS	FM	S	A	SA/A	Total
PGR	2	2	1	3	3	4	2	2	1	3	1	3	2	**30**
FU	3	3	1	4	5	3	3	4	1	2	3	2	3	**39**
NM	5	5	1	5	4	5	5	5	4	4	3	5	3	**50**
FFS	5	4	1	5	5	4	4	4	1	5	1	3	4	**46**
Total	**15**	**13**	**4**	**17**	**17**	**16**	**14**	**15**	**7**	**14**	**8**	**13**	**12**	

The group also ranked each general activity in terms of a set of criteria:

	PGR	FU	NM	FFS
Poverty Alleviation	4	4	3	3
Food Security	3	3	3	4
Environmental Protection	2	2	3	4
ILRI's Comparative Advantage	5	5	3	5
Fundability	4	4	3	5
Potential Impact	1	4	1	5
Total	**19**	**22**	**16**	**26**

Group 2–Theme 3, Improving agricultural land–use strategies

The group paid special attention to the livestock context, and defined the hierarchy in terms of the watershed and levels above, and decided on various areas of focus: degraded areas, vulnerable areas, and high potential areas.

Within this theme, an integrated approach was proposed, to identify and study complementary strategies for the use of degraded, vulnerable and high potential areas, involving assessments of the trade–offs between social, economic and environmental benefits (e.g. private versus social benefits, or equity issues versus economic growth issues and issues of environmental protection).

The group noted that the results from Theme 1 (Understanding and assessing the evolution of systems) would serve as the starting point for subsequent work under this theme (Improving agricultural land–use strategies). Their integrated approach would attempt to:

- Identify trends in land–use change.
- Identify gaps in knowledge.

Specific research activities would include:

- Identifying driving forces of land–use change.
- Adapting existing models to assess consequences of trends.

- Assessing consequences for stakeholders in terms of socio–economic and environmental impacts.

Other major activities would be:

- To design and test policy and technological options, and
- The diffusion of results.

Discussion summary

Given the themes identified, the task here was to focus more clearly on specific activities and the locations or agro–ecological zones where they might best be carried out, given ILRI's comparative advantage and partnership networks. This priority setting exercise was not completed. Clearly, there are many factors that will determine whether particular activities are seen to be within ILRI's niche (given that, even with a global mandate, focus has to be very tight). There are certainly limitations to this priority setting exercise, particularly the fact that these were done under quite tight time pressure, so that interpretation should be done cautiously. However, the exercises carried out by the groups were highly informative and form a useful basis for further refining ecoregional activities at ILRI.

Session 3. What Does ILRI Need to do to Address the Themes?

The third task for the discussion groups was to consider the activities needed to address the priority problems. The following questions were suggested to the groups to consider:

1. Which databases are needed?
2. Which methods and tools can be used?
3. What work on the ground needs to be done?
4. Which decision support elements are needed, if any?
5. What are the methodological gaps that need to be filled?

Each group addressed these issues.

Group 1–Theme 1, Understanding the evolution of systems with livestock components

The objectives of this work were defined to be as follows:

- Priority setting.
- Informing ecoregional research.
- Decision support for policy–makers.

This research activity is at the global, cross–cutting level, and should involve stakeholders, especially researchers, at the outset and throughout the activity.

1. Data requirements

The key patterns of change related to livestock were tabulated, together with relevant indicators:

Variable	Indicators
Land use	Land coverage
Consumption	Products, quantity per capita
Technology (Livestock/Crop) systems	Yields, input use, scale of operation, feed and improvement
Trade	Imports/exports
Biodiversity	Species diversity in agricultural areas
Role of livestock	
Species	% livestock in GDP
Number	% by species
Technology	households with livestock
Main outputs	livestock output

Driving or Conditioning Factors	Indicators
Technology	% Irrigation, fertiliser use
Human population	Growth, density, urbanisation
Income	GDP per capita, development indicators
Policy	Market liberalisation, tariffs
Climate/AEZ	Rain, temperature, soil types, elevation
Research scientists per capita	Expenditure as a % of GDP, number of
Animal disease	Disease incidence and severity
Infrastructure	Road density
Traditional consumption	Livestock production

Sources of data for these indicators were mainly existing secondary sources – World Bank, FAO, USGS, NASA, etc. New data acquisition could come from remote sensing sources, for example.

2. Analytical Methods

- Acquisition of data, use of GIS; models to fill gaps and rearrange spatially.
- Trend analysis—models to identify drivers.
- Projecting trends into the future.
- Identify key opportunities for intervention (e.g. problems).
- Evaluate options (policy and technological).

- Priority setting.

3. Ground work—None required.

4. Decision Support Elements

- Consultation to fill in knowledge gaps.
- Consultation in evaluation.
- Output: information products relevant to policy and researchers.
- Support institutional priority setting and structuring of research.

6. Methodological gaps—No major constraints were identified.

Group 2—Theme 2, Improving the contribution of livestock to nutrient management

IDENTIFY DATA SOURCES	Dynamic databases
↓	
DATA EVALUATION ANALYSIS	
↓	
PROBLEM IDENTIFICATION & DATA GAPS	
↓	
IDENTIFY BENCHMARK SITES	
↓	
PROTOCOLS FOR ADDITIONAL DATA COLLECTION	Methods
↓	
GROUND WORK (FUNCTIONAL MANAGEMENT UNITS)	Ground work
• FARM • COMMUNITY • REGION	
↓	
DSS USE (WITH STAKEHOLDERS)	DSS Elements
↓	
SCENARIOS (STAKEHOLDER ANALYSIS)	

The other elements of the group's discussions are tabulated below.

Dynamic Databases	Methods and Tools	Ground Work	DSS Elements	Methodology Gaps
Distribution of resources: –Livestock –Crops/Forages –Soils –Elevation –Climate Socio–economics Markets Livestock products Secondary data related to Theme 1	GIS Maps PRA Dynamic surveys Modelling	Nutrient dynamics • Farm • Village	Appropriate models Matching information with end–users • PGR • FU • NM • FFS	Scaling Spatial transfers Tools

Group 3–Theme 3, Livestock and land–use

The group focussed on processes:

Driving forces → Changes → Consequences → Solutions/Alternatives

1. Databases and driving forces at the ecoregional level.

- Demographic changes:
  Human population distribution, growth, migration.
  Livestock distribution, growth, and seasonal changes.
- Natural resources:
  Soils.
  Vegetation, productivity.
- Land cover – land use.
- Markets – Infrastructure.
- Policy.

2. Methods, tools and driving forces.

- Land–use models:
  Scale: landscape, watershed, ecoregional.
- Remote–sensing for the ecoregional scale.

3. Ground work and driving forces.

- Ground truthing.
- Inventory of existing databases, to find out if there is a need for more.
- Benchmark sites, to assess if existing sites adequate.

4. Decision support elements and outputs.

Decision support systems are needed to assess policy alternatives and technical solutions, with important links to clients and partners (NARS, community–level organisations, local authority institutions, and policy–makers).

Discussion summary

The task here was to define more clearly various activities to address the issues within the three ecoregional themes identified. For Theme 1, Evolution of Systems, activities were identified that are very specific, and indeed some of this work is currently being undertaken in various projects at ILRI, notably the Market–Oriented Smallholder Dairy and Systems Analysis and Impact Assessment projects. For Themes 2 and 3, nutrient management and land–use change, much less specificity was possible, because the priority setting in terms of what to do where is not yet complete. The importance of decision support elements was underlined for all three themes, and this represents an area of research that warrants considerable further development by ILRI and partners.

WORKSHOP SUMMARY

The workshop had three major objectives:

1. To sharpen the focus of ILRI's ecoregional research.

2. To further identify commonalities in tools and new methods that can enable ILRI to do effective transregional research.

3. To identify improvements to the way in which ILRI does ecoregional research.

This was an ambitious agenda to get through in three–and–a–half days. In terms of sharpening the focus of ILRI's ecoregional research, given that only some of ILRI's activities should be truly ecoregional, the workshop identified three major themes that it was felt were appropriate:

- Understanding and assessing the evolution of systems.

- Improving the contribution of livestock to nutrient management.

- Improving agricultural land–use strategies.

For purposes of priority setting, outputs from the first theme should feed the other two themes, primarily in terms of identifying areas or regions where rates of change in systems are particularly high ("hot spots"), where intervention might be expected to have substantial impact. In terms of focussing these themes more sharply, particularly Themes 2 and 3, some progress was made, but more remains to be done. While the priority setting activity led to useful insights, a further priority setting activity should be undertaken and completed, that leads to consensus of specific ILRI activities in specific agro–ecological zones.

The second objective, commonalities in approaches and new methods and tools that can be brought to bear on ecoregional issues, was well addressed by the participants from outside ILRI, particularly with respect to database development and modelling at various levels of detail. There are clear benefits to be gained, from ILRI's perspective, in linking in with Universities and other ecoregional consortia who are already grappling with the issues of scale and spatial variability in time and space.

Less explicit attention was able to be given to addressing the third objective, which sought to identify ways and mechanisms for improving the way that ILRI does ecoregional research. However, various strands came out of the workshop that touched on this issue. First, existing ecoregional consortia have various organisational difficulties that are not yet fully solved, and while the benefits of large consortia with many different partners may be substantial, another mode of operation is through much smaller, more tightly focussed consortia. Such a mode of operation might offer opportunities for relatively quick research impact in some of ILRI's mandate areas.

Second, there are some tensions between the two modes of operation as ILRI expands into ecoregional activities in new geographic areas, which may be termed the strategic approach and the opportunistic approach. The strategic approach is based on consultations and systems analysis, leading to identification of niches where ILRI activities are deemed to be able to have impact. The opportunistic approach is based on entrepreneurial activities, and takes advantage of opportunities as and when they come up that are deemed to offer good chances of impact. In situations where ILRI has no track record, both approaches are probably needed, but some thought has to be given to how the resultant activities that are engaged in are actually pulled together and presented as an integrated programme of research.

Third, and related to the different approaches, is the fact that ILRI has no single mode of operation in collaboration with its various partners. The appropriate mode of working varies radically depending on each situation, and new modes of operation are always required to exploit fully the strengths of the partners and to minimise their weaknesses. Ecoregional research poses particular problems in this regard, and much creativity will be needed in future to avoid stretching ILRI's resources too thinly to be effective.

At the end of the workshop, some time was spent discussing how to refine the processes engaged in at the workshop. Various activities were delineated:

1. Circulate materials from workshop, through publication of participants' presentations and short write–ups of the discussion groups.

2. Set up subgroups of interested participants, possibly commision position papers on issues that require resolution, and continue the process of prioritising where ILRI will carry out ecoregional research, and what it will consist of.

3. Set up discussions concerning the transfer and implementation of tools and methods of immediate applicability to the work of the existing ecoregional teams at ILRI, through appropriate position recruitment and consultancies.

4. In the longer term, identification of where such priority setting activity fits in institutionally, and assuming institutional adoption of the outputs of such priority setting, development of plans for implementation.

WORKSHOP PROGRAMME

AND

WORKSHOP PARTICIPANTS

ECOREGIONAL WORKSHOP
ILRI–Addis Ababa, ETHIOPIA
5–8 October 1998

Programme

Monday *5 October Part 1: "What ILRI is doing in ecoregional research"*

8.30 – 9.00	Introduction, Workshop objectives	H. Li Pun, P. Thornton
9.00 – 9.30	Highlands ecoregion	Mohamed–Saleem
9.30 –10.00	Andean ecoregion	C. León –Velarde
10.00–10.30	Semi–arid Asia	E. Zerbini
10.30–11.00	**Tea/Coffee Break**	
11.00–11.30	Semi–arid Africa	S. Fernandez–Rivera
11.30–12.00	Sub–humid Africa	J. Smith
12.00–12.30	Market–oriented smallholder dairy	W. Thorpe
1.00–2.00	**Lunch**	
2.00–3.30	Discussion Groups: *What should the underlying themes be for ILRI's ecoregional research?*	
3.30–4.00	**Tea/Coffee Break/Group Photograph**	
4.00–5.00	Report back	

Tuesday *6 October*

8:30–10.30	Discussion Groups: *Where should ILRI be working on these themes?*	
10.30–11.00	**Tea/Coffee Break**	
11:00–12.00	Discussion Groups	
12:00–1.00	Report back	
1.00–2.00	**Lunch**	
	Part 2: "What others are doing in ecoregional research"	
2:00–2.40	Modelling at CIAT	A. Gijsman
2:40–3.20	Edinburgh DFID modelling project	M. Herrero
3:20–3.50	**Tea/Coffee Break**	
3:50–4.30	Work at CIP	R. Quiroz
4:30–5.10	Modelling at NRI and beyond	P.J. Thorne

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7.00	**Reception**	

Wednesday 7 October

8:30–9.10	Land–use modelling, Wageningen	J. Stoorvogel
9:10–9.50	Nutrient modelling, Wageningen	H. Booltink
9:50–10.30	ICRAF and the AHI	F. Place
10.30–1100	**Tea/Coffee Break**	

Part 3: "What ILRI needs to do to address the themes"

2.00-3.30	Discussion Groups: *Work needs by research theme*	
1.00–2.00	**Lunch**	
2.00–3.30	Discussion Groups (continued)	
3.30–4.00	**Tea/Coffee Break**	
4.00	Discussion Groups (continued)	

Thursday 8 October

8.30–10.00	Discussion Groups (continued)	
10.30–11.00	**Tea/Coffee Break**	
11.00–11.30	Report back	
11.30–12.00	Summary and future plans	P. Thornton
12.00–12.30	Wrap–up	
12.30–1.30	**Lunch**	
1.30	Field Trip	

LIST OF WORKSHOP PARTICIPANTS

Harry BOOLTINK
Wageningen Agricultural University, PO Box 37, Diuvendaal 10
6700 AA Wageningen, THE NETHERLANDS
Tel: 31 317 482 422
Fax: 31 317 482 419
E–Mail: harry.bootlink@bodlan.beng.wau.nl

Guy D'IETEREN
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail: g.dieteren@cgiar.org

Jeroen DIJKMAN
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 61 32 15 (Ext 162)
Fax: 251 1 61 18 92
E–Mail: j.dijkman@cgiar.org

Salvador FERNANDEZ–RIVERA
ILRI–Niamey, ICRISAT, PO Box 12404
Niamey, NIGER
Tel: 227 72 25 29/72 27 25
Fax: 227 75 22 08/73 43 29
E–Mail:s.fernandez–rivera@cgiar.org

Arjan GIJSMAN
CIAT, Apartado Aereo 6713
Cali, COLOMBIA
Tel: 57 2 4450 000
Fax: 57 2 4450 073
E–Mail: a.gijsman@cgiar.org

Mario HERRERO
IERM, University of Edinburgh
West Mains Road, Edinburgh EH9 3JG, UNITED KINGDOM
Tel: 44 131 535 4384
Fax: 44 131 667 2601
E–Mail: mario.herrero@ed.ac.uk

Mohammad JABBAR
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 61 34 95 (Direct), 251 1 61 32 15 (Ext 194)
Fax: 251 1 61 18 92
E–Mail: m.jabbar@cgiar.org

Carlos LEÓN–VELARDE
ILRI/CIP, Apartado 1558
Lima 100, PERU
Tel: 51 14 36 69 20
Fax: 51 14 35 15 70
E–Mail:c.leon–velarde@cgiar.org

Hugo LI–PUN
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 61 25 05 (Direct), 251 1 61 32 15 (Ext 137)
Fax: 251 1 61 18 92
E–Mail:h.li–pun @ cgiar.org

Margaret MOREHOUSE, *Facilitator*
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail: m.morehouse@cgiar.org

Paschal OSUJI
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 33 82 90 (Direct)
Fax: 251 1 33 87 55
E–Mail: p.osuji@cgiar.org

Leticia C PADOLINA, *Administrative Coordinator*
ILRI–Addis Ababa, PO Box 5689
Addis Ababa,ETHIOPIA
Tel: 251 1 61 32 15
Fax: 251 1 61 18 92
E–Mail: l.padolina@cgiar.org

Danilo PEZO
C/O IRRI, PO Box 933
Manila 1099, PHILIPPINES
Tel: 63 2 845 0563
Fax: 63 2 891 1292
E–Mail: d.pezo@cgiar.org

Frank PLACE
ICRAF/AHI, PO Box 30677
Nairobi, KENYA
Tel: 254 2 52 14 50
Fax: 254 2 52 10 01
E–Mail: f.place@cgiar.org

Roberto QUIROZ
CIP, Apartado 1558
Lima 100, PERU
Tel: 51 14 36 69 92
Fax: 51 14 35 15 70
E–Mail: r.quiroz@cgiar.org

Robin REID
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail:r.reid@cgiar.org

Mohamed SALEEM
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 61 11 15 (Direct), 251 1 61 32 15 (Ext 123)
Fax: 251 1 61 18 92
E–Mail:m.saleem@cgiar.org

Jimmy SMITH
ILRI–Addis Ababa, PO Box 5689
Addis Ababa, ETHIOPIA
Tel: 251 1 61 58 67 (Direct), 251 1 61 32 15 (Ext 107)
Fax: 251 1 61 18 92
E–Mail:j.smith@cgiar.org

Steve STAAL
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail:s.staal@cgiar.org

Jetse STOORVOGEL
Wageningen Agricultural University, PO Box 37, Diuvendaal 10
6700 AA Wageningen, THE NETHERLANDS
Tel: 31 317 482 422
Fax: 31 317 482 419
E–Mail: jetse.stoorvogel@bodlan.beng.wau.nl

Jon TANNER
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail: j.tanner@cgiar.org

Peter THORNE
23 Tal Y Cae, Tregarth, Bangor
Gwynned, LL57 4AE, UNITED KINGDOM
Tel: 44 124 860 2921
E–Mail: peter.thorne@nri.org

Philip THORNTON, *Technical Coordinator*
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail: p.thornton@cgiar.org

William THORPE
ILRI, PO Box 30709
Nairobi, KENYA
Tel: 254 2 63 07 43
Fax: 254 2 61 14 99
E–Mail: w.thorpe@cgiar.org

Ercole ZERBINI
ILRI–ICRISAT, Patancheru 502 324
Andhra Pradesh, INDIA
Tel: 91 40 59 61 61
Fax: 91 40 24 12 39
E–Mail: e.zerbini@cgiar.org

LIST OF OTHER PRESENTATION AUTHORS

John ANTLE
Department of Agricultural Economics, Montana State University
Bozeman MT59717, USA
Tel: 1 406 994 3706
Fax: 1 406 994 4838
E–Mail: jantle@montana.edu

Walter BOWEN
IFDC/CIP, Apartado 1558
Lima 100, PERU
Tel: 51 14 36 69 92
Fax: 51 14 35 15 70
E–Mail: w.bowen@cgiar.org

Charles CRISSMAN
CIP, Apartado 17–21–1977
Quito, ECUADOR
Tel: 593 2 690 363
Fax: 593 2 692 604
E–Mail: crissman@cip.org.ec

Aldo GUTARRA
CIP, Apartado 1558
Lima 100, PERU
Tel: 51 14 36 69 92
Fax: 51 14 35 15 70
E–Mail: a.gutarra@cgiar.org

Peter KERRIDGE
CIAT, Apartado Aereo 6713
Cali, COLOMBIA
Tel: 57 2 4450 000
Fax: 57 2 4450 073
E–Mail: p.kerridge@cgiar.org

Godfrey LUBULWA
Australian Centre for International Agricultural Research, GPO Box 1571
Canberra, A.C.T., 2601 Australia
Tel: 61 2 6217 0500
Fax: 61 2 6217 0501
E–Mail: lubulwa@aciar.gov.au

David WHITE
ASIT Consulting, PO Box 328
Hawker, A.C.T., 2614 AUSTRALIA
Tel: 61 2 6254 5936
Fax: 61 2 6255 2455
E–Mail: dwhite@acslink.aone.net.au

Heping ZUO
National Land and Water Resources Audit, GPO Box 2182
Canberra, A.C.T., 2601 AUSTRALIA
E–Mail: heping.zuo@nlwra.gov.au