A Review of Bio-Economic Models

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Comments greatly appreciated.

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1. Introduction

The Cornell African Food Security and Natural Resources Management (CAFSNRM) program has recently set out to develop an integrated modelling system to facilitate the search for solutions to the food security, poverty and environmental problems faced throughout much of Africa today. Major advances have been made in the area of modelling, particularly those combining the biophysical and socio-economic aspects of these problems in a more comprehensive, integrated modelling approach. To avoid reinventing the wheel, one of CAFSNRM 's first goals has been to assess the current state of interdisciplinary integrated modelling of biological (and more specifically agroecological) and socio-economic systems. This short paper summarises the key findings of an inventory and assessment of existing approaches to interdisciplinary (agro-ecological and socio-economic) modelling. The inventory is somewhat selective in that bio-economic models representing a range of approaches and perspectives have been selected for review, rather than attempting a comprehensive analysis of all bio-economic models. A total of 21 models were reviewed, ranging from simple empirical models to complex integrated models. The key features of the models themselves are summarised in the appendices attached to this review. Appendix A contains a listing of abstracts for the documents reviewed, where available, and Appendix B contains the detailed model summaries themselves. Background documentation is on file, as noted in the listing of abstracts, and can be obtained from the author if the reader cannot readily find the material in the library or on the World Wide Web. The review reveals that existing bio-economic models fall along a continuum.

1.1 A continuum of bio-economic models

At one extreme of the continuum are those that are primarily biological process models to which an economic analysis component has been added. At the other are the economic optimisation models which include various bio-physical components as activities among the various choices for optimisation. (Note that, by economic optimisation we are not referring simply to models which seek to maximise some measure of profit or income – economic optimisation in it's pure sense refers to systematically evaluating a number of alternative activities so as to determine the one which will result in the "best" or optimum performance – however "best" is defined or measured – and hence is a relative term.) In the middle are the integrated bio-economic models. This review lays emphasis on this last category of model – revealing their strengths and weaknesses and the associated gaps.

1.1.1 Biological process models with an economics component

Biological process models designed to simulate agro-ecological processes can be quite sophisticated in their approach to modelling a particular sub-component of an ecosystem. They exist for agroforestry, crop production, grassland, savannah, soil nutrients, water dynamics and animal/livestock systems. In some cases they model single components at a very detailed level. Others model the major inter-linked components of a particular ecosystem as an integrated system.

Some are based on empirical measures of biological processes (e.g., Sustainable Stocking Rate Spreadsheet Model - Pulina et al, 1999) while the more sophisticated attempt to model the underlying processes or mechanisms at a more basic level. These are variously referred to as "mechanistic" or "theory-driven" models in the literature. Following King et al (1993), this discussion will refer to this type of biological simulation model as "biological process models" in contrast to the more general empirically-based biological models – at the same time recognising that the distinction is somewhat arbitrary since even the most finely specified theory driven biological process models are based on some empirically-determined parameters. Biological process models which mimic the actual biological process involved in animal or plant growth, nutrient cycling and competition at various scales and over various periods of time include the following: SAVANNA – Coughenour et al, 2000; Vihiga Integrated Farm Household Model – Shepherd and Soule, 1998; HILLPLAN – Maxell et al, 1999, Milne et al, 1999 and Milne and Sibbald, 1998; CDFU – Van Noordwijk, 1999 and 2000; CENTURY – Kaufman, 2000 and Metherell et al, 1996. Few of these models include the human component explicitly in the model specification beyond the part played in specifying the management regime for the scenario under simulation.

These models do, however, fall into the continuum of the bio-economic model classification as they also incorporate some socio-economic issues in their analysis. Most of these biological process models include a set of accounting equations that tabulate the benefits and costs (economic and biological) associated with a particular run of the model (i.e. scenario or management strategy) (King et al, 1993). Often this is simply an assessment of the net returns or a gross margin analysis of the scenario under consideration. In other cases it extends to a more sophisticated cost-benefit analysis (WaNuLCAS – Van Noordwijk and Lusiana, 1999 and 2000; IBIEHM – Itty, 1995, Itty et al, 1995a and 1995b). A few even include an economic optimisation sub-component, as in the case of the DAFOSYM model (Rotz et al, 1989) which optimises the use of feed resources based on the stochastic outputs of a fixed production plan for the farm. However, this doesn't classify as an economic optimisation model in the true sense of the term since the crop production decisions are not being optimised.

Several models do stand out for further mention as they exhibit potential for further development in the area of integration through the inclusion of an optimisation framework. The SAVANNA model (Coughenour et al, 2000) successfully simulates, in a spatially explicit manner, wildlife population dynamics in savannah areas and incorporates a human/livestock dimension into the model to a limited extent. There appears to be an economic simulation component to the model, but this is not described in any readily available literature. As a result, details are not clear, but it does not appear to be an optimisation model of human behaviour and livestock management. SAVANNA's strengths are in the simultaneous modelling of human-livestock-wildlife dynamics in a spatially explicit manner.

NUTMON (de Jager et al, 1998a and 1998b and Van den Bosch et al, 1998a and 1998b) models stocks and flows of nutrients (animal, plant, soil and household) and financial resources based on empirical measures for a given farm household situation. It is not a true biological process simulation model, but an exploratory empirical evaluation of the performance of a farm household. As such it serves to assess the balance of the major nutrient and financial flows in a given situation in terms of their long term sustainability.

WaNuLCAS (Water, Nutrient and Light Capture in Agroforestry Systems – Van Noordwijk and Lusiana, 1999 and 2000) successfully models the tree-crop-soil-water environment in an integrated manner (the livestock component is not explicitly modelled, though scenarios can be defined which simulate grazing or fodder harvesting), although it leaves out the household component in the evaluation of the viability of any scenarios. Likewise, it's economic component is not an optimisation submodel. On the other hand, both this model and the HyPAR model (Mobbs and Lawson, 2000 and Mobbs et al, 1999) have the potential for a recursive (dynamic) linkage to an economic optimisation component since they are designed to output results to, for example, a spreadsheet package or ASCII text file. WaNuLCAS and HyPAR give similar results for tree-soil-crop interactions, however, the HyPAR model treats the aboveground processes in more detail and gives less elaborate treatment to the belowground processes than WaNuLCAS.

1.1.2 Economic optimisation models with biophysical features

Economic optimisation models of agro-ecological systems by definition are bio-economic models since they model decisions related to biological resource use and production. The key limitation is in their ability to model the agro-ecological processes involved in such a way as to simulate the actual biological process(es) rather than simply using a fixed set of parameters for a finite set of activities derived from empirical observations.

Some economic optimisation models take a relatively simplistic approach to the incorporation of biological processes into the modelling framework. At the most basic, they optimise farm income but include a component which measures the biological or ecological sustainability of the system being modelled – usually in terms of soil loss or some other proxy variable. In essence, they are biological or accounting equations that parallel the economic accounting equations of some biological process models.

The more sophisticated economic optimisation models attempt to account for the possibility of multiple objectives held by one decision-making unit and thereby to realistically model the priorities and constraints of households (the locus of much decision-making in the African context) or the aggregate objective at a community or watershed level. In many cases they attempt to account for dynamic relationships through the use of a multi-period modelling approach.

Some models exhibit potential for further development in the area of integration through the inclusion of an agro-ecological simulation component. The Mali Bio-Economic Farm Household Model (Kuyvenhoven et al, 1995 and 1998 and Ruben et al, 2000), for example, successfully models farm households with different resource endowments in a multi-objective optimisation framework and links simulated biological processes although not in a dynamic manner. Additionally, the households with different resource endowments are successfully aggregated to the regional level to assess the supply response and the potential price effects as they interact with demand.

The SOLUS (Sustainable Options for Land USe – Bouman et al, 1998 and 1999 and Schipper et al, 2000) models incorporate endogenous output prices and wages at the regional level at the same time as allowing for heterogeneity in land use options and land unit characteristics at the local level. However, they are static models in that the biological processes are fixed for a particular period.

Finally, the BEAM model (Thomas and Willis, undated), while not a biological model, it is not an economic optimisation model either. It, however, employs a unique interface to a couple of existing biological simulation models (WaNuLCAS and HyPAR) to provide an economic performance assessment of the various activities and output.

1.2 Integrated bio-economic models

At the centre of the continuum are the integrated bio-economic models. This is the most difficult and challenging area of the bio-economic modelling field. In recent years major advances have been made in capturing the essential features of an integrated bio-economic model. Modelling efforts have advanced from both ends of the continuum towards the middle as they increase in their sophistication and ability to model both of these aspects simultaneously.

Integrated bio-economic models attempt to capture the interaction between the bio-physical/agro-ecological and socio-economic processes (Ruben et al, 2000) whether at the household or regional level of aggregation. A truly integrated bio-economic model needs to include the major characteristics of models at the two extremes. In other words, it must include the socio-economic features of the economic optimisation models on the one hand and the process simulation features of the primarily biological process models on the other.

1.2.1 Modelling decision-making

Human decision-making can be modelled in a variety of ways. Biological process models often employ rule-based search routines to model animal behaviour in response to particular environmental variables or states (for example, see SAVANNA – Coughenour et al, 2000). This approach has also been applied to the decision-making of human populations in some models. The FLORES modelling system (Vanclay, 2000 and Haggith, 1999) has used this approach to model human behaviour and this may be the approach used in the extension of the SAVANNA model which incorporates human behavioural decisions. Rule-based approaches are, however, limited to a set of predetermined responses to environmental circumstances which may or may not be optimal since the model routines do not systematically evaluate the end results of alternative courses of actions.

The principal alternative to the rule-based approaches is the employment of optimisation routines. Optimisation is at the core of most modelling of decision-making. It is based on the observation that people, including subsistence farmers in rural African households, generally want to do the best for their families. They are also reasonably rational (though this may not appear to be the case when the decision-making context and culture is incompletely understood). Wanting the best and being reasonably rational, they are therefore best modelled as optimisers, constrained optimisers, given that resources are not infinite. Hence, integrated bio-economic models typically model human behaviour as explicitly or implicitly the product of such constrained optimisation choice. This applies whether the basic unit of analysis is the farm, the household, the village or a region.

At the same time, it is important to recognise that there may be a number of objectives among which there exist trade-offs that arise due to constraints faced by decision-makers. For this reason, various forms of multiple goal modelling are frequently employed. Even so, it is fair to say that decision-makers still optimise over a set of basic needs or objectives. Identification and specification of decision-makers' objectives remains relatively ad hoc and is one of many areas of prospective significant improvement. Holden (1993) appears to have been more successful than most at capturing the essentials of the objectives of decision-makers in his work in Zambia. Kruseman (2000) has an excellent discussion of the issues related to the specification and estimation of household objective functions. What is clear is that significant efforts need to be made to understand decision-makers' objectives, the relative importance they attach to various competing and complementary goals and to the description of them in such a way that they can be incorporated appropriately into the modelling framework. In addition serious consideration needs to be given to the calibration and validation of models in an effort to determine the appropriateness of the assumptions related to the specified objectives of decision-makers. This is particularly important for models which are designed to describe and predict the collective impact of decisions made by individuals and households.

In addition to the specification of the objectives of decision-makers, there are a number of other issues that must be addressed in modelling the decision-making environment in an integrated bio-economic model. Firstly, it is important to consider the types of decisions to be incorporated into the model itself. Each has implications for model type and strategy as well as for the way in which the economic decision-making and the biological process component parts ought to be linked and integrated and will depend to a certain extent on the ultimate purpose for which the model is designed. Many models limit decisions to the allocation of inputs into the production process (labour, land, manure, cash and so on) and the choice of products to produce. However, choices can also extend to many others areas, many of which take on relevance in an integrated modelling approach. These include choices related to marketing behaviour, the allocation of resources to farm and non-farm activities, consumption choices and patterns, decisions to migrate into or out of an area, growth of population, decisions about the type of land use and the allocation of land between households as well as the heterogeneity of resource endowments and the possible implications in terms of different objectives for different households.

In an integrated modelling context the time-scale over which choices are made is of considerable importance if for no other reason than that it needs to link with key decision points in the biological process components of the model. The decision-making environment can be specified in a static or dynamic context. If choices are modelled in a dynamic framework, then the length of the time horizon (finite or infinite) and the nature of the feedback mechanisms will need to be considered (they can be modelled sequentially over time or in such a way that future decisions feedback into the present to give an overall optimum for the period of the model).

Thirdly, is the issue of the information available to decision-makers. It is important to consider whether it is reasonable to assume that decision-makers have full or complete information available to them when making decisions or if it is subject to uncertainty (either static or temporal).

Finally, there is the question as to who actually makes the decisions. The decision-making unit can be the individual, the household or some other larger collective unit (such as the village or watershed). The answer to this question will also, to a certain extent, depend upon the purpose for which the model is designed and how the objectives are specified. Descriptive and predictive models will necessarily take a different approach to the decision-making unit as well as to the specification of the optimisation criteria than those which seek to prescribe what ought to be.

1.2.2 Modelling biological processes

Biological processes are, by definition, dynamic. The values taken by variables in the process(es) and even the parameters describing variables' interaction may change over time, often interactively. Outcomes are not entirely predictable, especially if variables interact in non-linear ways not readily captured by static input-output coefficients. A truly integrated bio-economic model must capture the dynamic nature of the biological processes involved and allow for dynamic feedback effects between human decisions, biological processes, and the range of possibilities available for future decisions.

The key biological processes involved relate not only to plant and animal growth, soil physical characteristics and nutrient flows and balances as they respond to the physical environment and human activity. They also include interspecies interactions, competition and feedback effects from one subsystem component to the other – including the economic and social decision-making environment. Modelling of the soil system components typically encompasses nutrient stocks, flows and cycling as well as soil hydrology and water availability to the plant component. However, the soil biological component, and in particular the living biological cohort, plays an important role in nutrient cycling and availability, in plant growth and in soil quality and conservation.

Animal growth models can account for grazing dynamics and the energy cost of travel to find feed, the impact of the environment on animal health, production and survival. It will also be important to consider the effect of forage quality not only on animal health and production but also how it feeds back to the soil and plant communities (via the quality and quantity of nutrients available in animal excreta). In the same way, plant growth models that incorporate interspecies interactions at various levels and scales (competition for light, water and nutrients) and which include the impact of grazing and human management are essential.

At issue in the biological process modelling component of integrated bio-economic models is not only what to model, but the level of detail to include. This will clearly depend on the purpose of the modelling effort and the resources available. However, it also has implications for the range of environments over which the model can be successfully used. Although empirical models are relatively simple and require fewer state variables as inputs, they are not as easily maintained or transportable as biological process models which tend to have more stable parameters and can be more readily adapted to new environmental conditions.

The question of scale extends beyond the level of detail or basic unit of analysis to the spatial scale as well. There are issues of aggregation and interaction at the field level and beyond to the watershed and landscape level. Spatially explicit models can account for spatial variation across the landscape as well as for interaction between cells or landscape units. An important consideration is the extent to which these dynamic interactions can and should be included in the modelling framework.

Finally, the temporal scale is also relevant. Most biological process models simulate growth and development on a particular time step (day, week, month). However, human decision-making is typically modelled at a coarser scale (usually annually). How these two components interact is a major challenge for integrated modelling efforts.

1.2.3 Integration – examples

The present challenge is to bring both ends of the bio-economic modelling continuum together without losing the essential elements or compromising the strengths of either. Few models have successfully achieved this sort of integration, though there is considerable work being done in the area at the moment. Of the models reviewed/inventoried, those which stand out as having captured some of the key elements of a truly integrated bio-economic modelling approach are discussed briefly below.

The **Carchi Integrated Simulation Model** (Crissman et al, 1998) is unique among the integrated bio-economic models in that it uses an econometric optimisation model at the farm level rather than some variation of a more-common LP (Linear Programming) model. Farmers' decisions are modelled through a sequential dynamic decision model which incorporates endogenous timing of input use in response to randomly generated field and environmental characteristics. The model avoids some of the problems inherent in the "representative farm" approach by allowing for heterogeneity in production and environmental variables over the landscape by classifying it into 4 different zones in proportion to the land area of each group. The 4 groups or zones are modelled within the overall framework and in so doing the differential impact of policy changes can be considered across each of the 4 zones. Rather than define sustainability explicitly, it is used to identify the trade-offs among different economic and environmental variables over a range of parameter values for different policy and technology alternatives at the watershed level. The model, however, is limited in the number of crops analysed and does not consider livestock activities apart from the pasture component.

Crissman et al (1998) also present a discussion of concepts related to model integration and the different levels thereof (pp 245-246). Level I integration is defined as the independent simulation of economic and physical models and subsequent combination of the outputs to infer environmental impact. Their model exhibits Level I integration and they use this procedure to generate the joint distribution of output and environmental impact which is subsequently used to generate a trade-off frontier for policy analysis purposes. Level II integration occurs where the economic model is employed to simulate each policy or management scenario and the output is used as the input to the physical simulation model. There is, however, no feedback from the physical processes in one period to the economic decision-making component in subsequent periods. Level III integration occurs where an economic model is formally linked to a production model with the 2 being jointly simulated to allow for dynamic feedback from environmental conditions to production.

The **Ginchi Bio-Economic Model** (Okumu et al, 1999 and 2000) on the other hand employs a dynamic non-linear math programming model which optimises a weighted utility function wherein 3 goals are incorporated (cash income, leisure and basic food production). Similarly to the Carchi model, it can be used to identify the economic-environmental trade-offs among various possible technologies and policies. On the other hand, it goes beyond the Carchi model in that it incorporates a dynamic relationship among soil loss, productivity and community welfare. It also considers soil nutrient balances for N, P and K. At the present time, it does not incorporate a component for risk analysis nor does it model heterogeneous households, but it does endogenize the effects of land degradation.

The **Vihiga Integrated Farm Household Model** (Shepherd and Soule, 1998) is a dynamic simulation model that incorporates household needs, constraints and financial flows into the modelling framework. The model also considers households with different resource endowments and tracks their relative performance in different environmental contexts. Though it does not incorporate an economic optimisation component, it does succeed at integrating a dynamic economic simulation component alongside the biological simulation component at the household level. Within the household model there is also the possibility for off-farm employment. As a result, the model can assess both the economic and biological sustainability of households with different resource endowments under different environmental, technical and policy scenarios.

The **Burkina Bio-Economic Village Model** (Barbier, 1996 and 1998) and the **La Lima Bio-Economic Microwatershed Model** (Barbier and Bergeron, 1998 and 1999) are unique among the models in the extent to which they have been tested and calibrated. In particular, the La Lima model has been calibrated against a historical data set covering a period of 20 years. Both models employ a recursive and dynamic linear programming model together with a biological model of soil condition and plant growth. Though the biological model does not model the systems in terms of the biological processes (nor in the same detail) like some of the agro-ecological simulation models, it does dynamically link successive optimisations through the biological model in a recursive manner. The Burkina model incorporates risk aversion in the economic optimisation component (which employs expected output for decisions) and links subsequent years through the biological production model (which uses a stochastic component to determine actual output and performance as an input into the subsequent year). In neither case is the household the basic unit of decision-making nor are the effects of degradation endogenized.

The **FLORES** (Forest Land Oriented Resource Envisioning System – Vanclay, 2000 and Haggith, 1999) model has the potential to perform an integrated simulation of biological processes at the landscape scale as a result of decisions at the household level. It is still under development, but will incorporate some sort of prioritised household decision-making component – either a rule-based search routine or a form of economic optimisation model. It is unique in it's extensive simulation of agroforestry at the village level while at the same time modelling households with various resource endowments, allowing interaction among the various households according to particular rules of conduct and including forest-related land use activities. It appears that it will model the livestock, plant, soil and nutrient cycling components, but no details were found in the available literature.

The **GRAZPLAN** (Donnelly et al, 1997, Freer et al, 1997 and Moore et al, 1997) suite of models effectively simulate grazing at the farm level – incorporating actual grazing conditions into the biological process sub-models for animal production and plant growth. While soil moisture is modelled, nutrient flow dynamics are not. It also addresses issues of survival of young animals. It is lacking in a household component, but there appears to be an economic optimisation component in the works. As a result it has the potential to be a fully integrated model.

Finally, the **Zambia Household Model** (Holden, 1993) simulates household decisions and impacts for households with various resource endowments in both "traditional" and "modernised" societies. While it is based on empirical data rather than a process model for the biological component and is not dynamic in nature (in other words it is a static rather than a multiperiod model and does not have feedback between the economic and biological components), it is included under this category due to it's potential as a decision-making sub-model or component in a recursive simulation model. It successfully models what people actually do in various circumstances through a combination of lexicographic and weighted goal programming models.

2. Discussion of important features and considerations

Based on the above discussion, the following are the key features that a wholly integrated bio-economic model should have.

2.1 Dynamic and recursive process modelling

It is important that there be dynamic interaction between the economic and agro-ecological components of any model for the following reasons:

- biological processes are dynamic in their response to changes in the environment;
- the impact of decisions needs to feed back into the biological processes in a dynamic manner;
- the linkage from one period to the other involves a sequential set of decisions and outcomes which then become the initial conditions for the next period's decisions and outcomes.

Models that predict the outputs of biological processes based on a set of empirical observations of a biological process (or sequence of biological events) are limited in the range of input combinations that can be considered. Process models attempt to describe the biological processes themselves and are, as a result, more flexible and adaptable. Though the parameterisation of biological process models is far more demanding, the advantage is a model wherein the relationships are much more stable across a wide range of conditions (King et al, 1993).

2.2 Temporal and spatial scale

Given that limited resource subsistence farmers in rural Africa consume much of what they produce and that production and consumption decisions are effectively nonseparable in many cases due to market failures and limited participation in the cash economy, it is appropriate to model decision-making at the household level. It can be argued that this is the most relevant scale at which to model decision-making since it is possible to address the issue of joint production and consumption decisions at this level and it also allows for heterogeneity in the specification of various resource endowments. At the same time, an integrated model needs to incorporate some level of aggregation to the village or watershed level since many of the environmental and sustainability issues of concern reveal themselves at these levels and since many behaviours are conditioned by aggregate dynamics (e.g., general equilibrium effects, herd behaviours, etc.).

Likewise, there is need to go beyond a simple assessment of the situation at one point in time. Food security and natural resource management are, by nature, intertemporal concerns. Their spatial dimension can only be understood as the time element is incorporated into the model.

Another important feature when discussing scale is the issue of spatially explicit modelling. Whether linked to GIS data or not, spatially explicit modelling accounts for dynamic interaction between sub-areas of the area being modelled. Whether it is simply water flows between plots in a landscape or the progressive expansion of cleared forest, spatially explicit modelling is able to address these issues (the SAVANNA model offers a nice example).

2.3 Prescriptive or predictive

Swinton and Black (2000) briefly discuss 4 purposes of agricultural systems models – description, prediction, postdiction and prescription. Descriptive models are those which characterise the system being modelled. Predictive models are used to forecast system behaviour in the future. Postdictive models are used for analysis of past performance. Prescriptive models are intended to offer guidance on management of a system in light of some normatively specified goal(s).

Prescriptive models describe what ought to be done if certain objectives are to be achieved – at either the individual or societal level. They optimise some sort of measure of welfare or utility, assess the consequences of it as well as how reality diverges from it and suggest how one might move towards this optimum. Such models frequently optimise social welfare for a particular community, watershed or region whether for a single time period or in a multi-period framework. With such a basis for optimisation, they in effect prescribe what ought to be and provide an idea as to the appropriate direction one ought to proceed to improve the general level of well-being.

Descriptive models can go beyond simply describing a system as it as and serve a predictive role. Initially, they model what decision-makers and the associated agro-ecological systems will actually do in the present circumstances. Based on this they are able to project what the potential impact or consequences of this might be for the future. Additionally, they can serve as a platform to model the probable response to changes in the decision-making or biological environment. Household-based solutions optimise on some representation of household priorities and, to the extent that they describe the actual basis for household priorities in decision-making, describe what people will do either individually or collectively (depending on the level of aggregation and type of analysis) and the impact it will have individually (e.g. survival or better) and collectively (community, watershed, region). Care also needs to be taken in the specification of objective functions. With an inappropriate specification a descriptive model can change to a prescriptive one.

One may also want to consider the area of inter-generational equity. So far none of the models reviewed has done this. It could perhaps most simply be done through the definition of sustainability that is used – such that the modelling or planning used ensures that the same quantity or quality of natural and economic resources remain available to future generations.

The choice here is basically in terms if what is to be optimised and whether it is done in such a way as to model actual behaviour or to model what ought to be. One should also note that some models may not optimise as such, but may adopt an exploratory approach based on the assumption that there is no one specific optimisation condition. For example, the approach a household may take could vary depending on whether or not there is rain – with no rain they may just try to get by with enough to eat whereas if there is rain then the household may optimise around a different set of priorities.

2.4 Unit of analysis and decision-making level

Optimisation at the watershed or regional level without the explicit inclusion of households of various resource endowments will tend to mask many of the issues related to food security and natural resource management. Policies do have distributional or equity impacts and, though overall welfare may be optimised (or improved), there may be winners and losers since few places can be adequately described by representative agent models. Only by explicit modelling of the household component can these issues be addressed effectively. There is heterogeneity among economic circumstances and environmental impact for households with different initial resource endowments and it may be necessary to target policies to households with specific resource sets to ensure that they have their desired effect (Shepherd and Soule, 1998). Moreover, the efficacy of different interventions in terms of environmental or economic indicators may depend on who is directly affected. For example, more secure land rights may be more likely to induce increased investment in soil conservation and nutrient amendments among those who are not liquidity constrained. For these reasons, among others, it is important to be able to incorporate households of various resource endowments into an integrated bio-economic modelling effort as the basic unit of analysis.

This is not to say that models which extend to the watershed or regional level are not necessary. Modelling at this higher level is important in understanding and predicting the economic, social and environmental consequences of individual actions and public policy. However, it needs to use as its point of departure the explicit inclusion of households of various resource endowments within the modelling framework so as to capture the above-mentioned effects.

2.5 Integration and linkages

Some integrated models link the socio-economic and the agro-ecological components, but without effective feedback or interaction between these two parts. Such models tend to employ Technical Coefficient Generators (which can themselves be biological models) that provide technological coefficients for use in the economic optimisation component. The coefficients specify multiple (finite) biological activities representing a range of possible scenarios among which the model selects an optimal combination. This sort of integrated model, although useful, lacks the feedback mechanisms of a truly integrated dynamic model. An integrated bio-economic model with feedback among the processes holds the most promise for addressing the interrelated issues of African food security and natural resource management.

Decision-makers respond to the micro and macro-environments within which they operate – whether this is defined in terms of the local climate, resources and culture or in terms of the larger economy and society – and, in the aggregate, they have an effect on the environment itself. For this reason, as the scale of the model expands it is important to consider how an integrated bio-economic model can be dynamically related to the external agro-ecological and socio-economic environments.

2.6 Uncertainty and risk management

One of the most salient characteristics of resource poor households in Africa is the role and significance of uncertainty. One of the consequences of living at the lower margins of the range of possible livelihoods means that downside production risks have immediate and possibly irreversible (and tragic) consequences for consumption. Food security is inherently an issue of risk management. Individuals make production, consumption, and exchange decisions subject to considerable temporal and static uncertainty – both in terms of the biological environment (rainfall, adverse weather conditions, pests and diseases) and in terms of the economic environment (prices, availability of goods and services) – not to mention an uncertain political climate. Biological processes tend to have prominent, stochastic components to them. Prices fluctuate widely if and when goods are available and even when they are resources to use for purchasing are often extremely limited.

For these reasons, it is important to model decision-making based on some measure of expectations of outcomes for the decision variables and at the same time account for the stochastic element in assessing the actual outcome and performance from year to year.

Moreover, the nature of the approximations used in modelling introduces prediction error that one must acknowledge. These errors are compounded by sampling and measurement errors in the calibration and validation of models. So one needs to confront the uncertainty that exists within the system being modelled as well as uncertainty about the performance of the model. There is no unambiguously best way to handle these issues. They do, however, point to the importance of model calibration and validation. Some models are calibrated reasonably well. There are vary few which take the issue of validation seriously.

3. Concluding remarks

The term bio-economic model has, in some senses, become a catch-all term. It is variously used to describe biophysical simulation models which incorporate prices and returns in their output and economic optimisation models that model biological process using empirical observations. Few, however, model both the underlying biological or agro-ecological system and the decision-making process in an integrated manner. This review of existing bio-economic models has served to identify some common features and failings of models which, with varying degrees of success, attempt an integrated approach to bio-economic modelling. It also highlights some of the issues which are key to the CAFSNRM program’s planned integrated bio-economic modelling effort. Despite much recent and ongoing activity and notable advances, so far, to the best of my knowledge, there are no modelling efforts that consider all of these key issues in a satisfactory manner.

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Appendix A: Abstracts and notes for the models reviewed

Model Name:	**BEAM**
Reference(s):	Anonymous. 2000. Introduction to the BEAM project. www.bangor.ac.uk/~afs/beamint.htm
Abstract:	None on file.
Notes:	Printed from web.

Model Name:	**BEAM**
Reference(s):	Thomas, T.H. and R.W. Willis. undated. Putting the economics into bio-physical agroforestry models. www.bagor.ac.uk/~afs/download/paper2.zip
Abstract:	None on file.
Notes:	Saved to disk as "afmpk6.doc" and printed.

Model Name:	**Burkina bio-economic village model**
Reference(s):	Barbier, B.. 1998. Induced innovation and land degradation: Results from a bioeconomic model of a village in West Africa. Agricultural Economics 19:15-25
Abstract:	This paper introduces a modeling method which simulates a village's response to population and market pressure. The method combines a recursive and dynamic linear programming model with a biophysical model of soil condition and plant growth that predicts yields and land degradation for different type of land, land use and cropping patterns. The linear programming model simulates farmers' plans aggregated at the village level under constraints of risk aversion, food consumption, land area, soil fertility, soil depth, labour and cash availability. Detailed agroecological factors determine the main processes of land degradation. A large number of technological alternatives, representing different degrees of labour and/or land-saving techniques available in the study areas, are introduced, taking into account their respective constraints, costs and advantages. The method has been calibrated for a village located in the sub-humid region of Burkina Faso. Several simulations are carried out to the Year 2030. The results show that population pressure leads to intensification and investment in land conservation practices but not necessarily to better farm incomes. Increasing market opportunities can play a more positive role in boosting productivity, but for the next decades the best way to increase production per farmer is to let farmers migrate from the high population density areas to the low population density areas because, under the current economic conditions of most Sahelian countries, intensification per hectare is still more expensive than the fallow system.
Notes:	Article copied and saved as pdf file. Printed and on file.

Model Name:	**Burkina bio-economic village model**
Reference(s):	Barbier, B.. 1996. Impact of market and population pressure on production, incomes and natural resources in the dryland savannas of West Africa: Bioeconomic modeling at the village level. EPTD Discussion Paper No. 21, IFPRI
Abstract:	None on file.

Notes: Abstract printed. Listed on IFPRI web site, but electronic copy not available.

Model Name: **Burkina bio-economic village model**

Reference(s): Barbier, B. and M. Benoit-Cattin. 1997. Viabilite a moyen et long termes d'un systeme agraire villageois d'Afrique soudano-sahelienne. (Medium and long term viability of the agrarian system of a village in South-Sahelian Africa. The case of Bala in Burkina Faso.) Economie Rurale 239:30-39

Abstract: To contribute to the debate over whether African agrarian systems can continue to support rapidly increasing populations, a model has been built at the village level in the cotton zone of Burkina Faso and is used in a recursive way. Simulations show a crucial threshold when fallow disappear and when it is necessary to combine different techniques for better management of the soils and of the organic matter; this results in a more sustainable regime with four times as many people but with half the revenue.

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Model Name: **Carchi integrated simulation model**

Reference(s): Crissman, C. C., J. M. Antle and S. M. Capalbo eds.. 1998. Economic, Environmental, and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production. Kluwer Scientific Publishers, Dordrecht/Boston/London

Abstract: None on file.

Notes: Chapters &, 7 and 11 copied.

Model Name: **CDFU**

Reference(s): Van Noordwijk, M. 2000. Crop-down fallow-up model. http://www.icsea.or.id/models/cdfu.htm

Abstract: None on file.

Notes: Printed from web page.

Model Name: **CDFU**

Reference(s): Van Noordwijk, M. 1999. Productivity of intensified crop-fallow rotations in the Trenbath model. Agroforestry Systems 47:223-237

Abstract: None on file.

Notes: Article copied.

Model Name: **CENTURY**

Reference(s): Kaufman, C.. 2000. The CENTURY Model www.cgd.ucar.edu/vemap/abstracts/CENTURY.html

Abstract: None on file.

Notes: Page printed.

Model Name: **CENTURY**

Reference(s): Metherell, A.K., L.A. Harding, C.V. Cole and W.J. Parton. 1996. CENTURY Soil Organic Matter Model Environment: Technical Documentation, Agroecosystem Version 4.0 Great Plains System Research Unit, Technical Report No. 4, USDA-ARS, Fort Collins, Colorado

Abstract: None on file.

Notes: Manual saved to disk.
www.nrel.colostate.edu/PROGRAMS/MODELING/CENTURY/man96.html

Model Name: **DAFOSYM**

Reference(s): Rotz, C. A., D. R. Buckmaster, D. R. Mertens and J. R. Black. 1989. DAFOSYM: A dairy forage system model for evaluating alternatives in forage conservation. Journal of Dairy Science 72:3050-3063

Abstract: A simulation model called the dairy forage system model (DAFOSYM) which evaluates alternative technologies and management strategies for forage harvest and storage was used to illustrate the effects of several management strategies on the performance and economics of a 100 cow dairy farm. Hay harvest systems which used a medium or large-sized rectangular baler produced a similar return above feed costs. A small-sized baler reduced the return by $4,000/yr due to a decrease in hay yield and quality. A large round bale system provided a similar return to the conventional, rectangular bale system when hay was stored in a shed; however, when round bales were stored uncovered, the loss decreased the return by $6,000/yr. Both all hay and all silage harvest systems provided a greater return for the farm than the mixed hay and silage system. An all hay system provided the greatest return due to the lower cost of field machinery and storage structures.

Notes: I have a CAB literature search stored on ZIP disk.

Model Name: **FLORES**

Reference(s): Haggith, M. 1999. FLORES Decision Model Specification. unpublished

Abstract: None on file

Notes: Printed and saved as pdf file. This was originally on the CIFOR web site, but is no longer there.

Model Name: **FLORES**

Reference(s): Vanclay, J.K.. 2000. FLORES: for exploring land use options in forested landscapes. http://www.cgiar.org/cifor/flores

Abstract: None on file

Notes: Web pages printed.

Model Name: **Ginchi bio-economic model**

Reference(s): Okumu, B. N., M. A. Jabbar, D. Colman and N. Russell. 1999. Bio-economic modelling of watershed resources in Ethiopia Paper presented to the annual meeting of the American Agricultural Economics Association, Aug/99.

Abstract: This paper examines the theoretical and practical aspects of natural resource use in the poor tropics given limited technological and policy intervention. Results show that if farmers were to reallocate their land use activities based on land suitability, and utilise between 10-20% of their farm income to purchase and apply chemical fertiliser, their net returns could rise by over 50%. Increased specialisation and application of fertiliser, however, results in a 24% increase in soil loss in the initial year as some erosive activities with high fertiliser-yield response functions are cultivated. In subsequent years, fertiliser use lowers the level of soil loss but is unable to adequately counteract the cumulative effects of erosion and hence yields decline. The best strategy in the short run is to combine fertiliser application with crop rotation based on changing land suitability. Shortfalls in on-farm staple grains supplies caused by such rotations can then be met from market purchases. Similarly, a secure land tenure policy is likely to impact positively on land conservation by increasing the farmer’s time horizon.

Notes: Copy on file.

Model Name: **Ginchi bio-economic model**

Reference(s): Okumu, B. N., M. A. Jabbar, D. Colman, N. Russell, M. Saleem, J. Pender. 2000. Technology and policy impacts on nutrient flows, soil erosion and economic performance at watershed level: The case of Ginchi in Ethiopia. (first DRAFT: not for quotation)

Abstract: A dynamic bio-economic model is used to examine natural resource use and the resulting nutrient balances in a poor country under a range of technological and policy intervention scenarios. With limited technological intervention, incomes rise by 50% and average per ha nutrient balances stand at –58kgs for ntrogen,-32kgs for phosphorous and –114kgs for potassium. Associated soil losses are 31 tons per ha. With a set of new technologies generated by a consortium of institutions in the region involving use of new high yielding crop varieties, agro-forestry, organic (animal dung) and inorganic fertilizers, construction of a communal drain to reduce water logging and some limited land user rights, results show a tenfold increase in incomes, 20% decline in aggregate erosion levels and an increase in the dependence on livestock for dung manure, oxen draft, milk and ready cash over time. Moreover, a minimum daily calorie intake of 2000 per adult equivalent is met from on-farm outputs and per ha nutrient balances after intervention are as low as –25kgsN, -14kgsP and –68kgsK on the average. There is hence an obvious reduction in nutrient losses despite the higher reliance on the watershed for subsistence food requirements. The bias towards replenishment of nitrogen and phosphorous nutrients at the expense of potassium is, however, not resolved. Emissions (leaching, gaseous losses, and erosion) are observed to be higher than immissions (atmospheric deposition, nitrogen fixation) in both situations. From a policy perspective, these results imply an increasing need for a more secure land tenure policy than currently prevailing and provision of credit to ensure uptake of the above land management package. They also imply a shift from a general approach to land management to a site specific approach that emphasizes spatial and inter-temporal variability in input use. Such variable rate technology is known to be an efficient nutrient management strategy as it enables farmers to apply optimal rates of fertilizer for each location in the field and in each period. Moreover, residual nutrient loading is simultaneously reduced.

Notes: Copy on file.

Model Name: **GRAZPLAN**

Reference(s): Donnelly, J.R., A.D. Moore and M. Freer. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - I. Overview of the GRAZPLAN project and a description of the MetAccess and LambAlive DSS. Agricultural Systems 54(1):57-76

Abstract: Effective transfer of new information and technology to farming practice is the major goal of the GRAZPLAN project. GRAZPLAN contains a suite of complementary decision support systems (DSS) that incorporate results from research on grazing systems and are now being released through a commercial partner as aids to extension. These computer packages are designed to be used in conjunction with local weather and farm data to test the relevance of different management procedures for individual farms. The main DSS, GrazPlan, can be used to evaluate and optimize long-term management decisions in relation to profitability and sustainability. It is quite general in its application and modular in structure. The Australia-wide database of daily weather records, which drives this program, is the basis for two smaller DSS, MetAccess and LambAlive, which are described in this paper. MetAccess is designed to display and analyse daily weather records and provide users with estimates of the probability of specified weather patterns within the range of data from a specified locality. LambAlive is designed to predict the risk of lamb deaths from bad weather for specified localities and flocks and enables the user to test different procedures that may reduce these losses.

Notes: Printed and on disk as pdf file.

Model Name: **GRAZPLAN**

Reference(s): Freer, M., A.D. Moore and J.R. Donnelly. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems 54(1):77-126

Abstract: A complete specification of the animal biology module of a model for simulating grazing systems for ruminants on pasture and a description of the features of GrazFeed which enable it to be used as a discrete package, are given. The program predicts the intake of energy and protein, allowing for selective grazing and substitution by supplementary feeds, and estimates the use of the diet for maintenance and production, according to current feeding standards. Conception and death rates are predicted from the maturity and condition of the animals. The model is designed to be of general application to any type of sheep or cattle on any pasture. GrazFeed uses the same procedures for predicting feed intake and productivity within a tactical decision support system. This is designed to help graziers to assess the feeding value of specified pastures and the need for the supplementary feeding of different classes of grazing animals.

Notes: Printed and on disk as pdf file.

Model Name: **GRAZPLAN**

Reference(s): Moore, A.D., J.R. Donnelly and M. Freer. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - III. Pasture growth and soil moisture submodels and the GrassGro DSS. Agricultural Systems 55(4):535-582

Abstract: This paper specifies the pasture growth module of a model for simulating grazing systems for ruminants and the soil moisture budget that drives pasture growth. Both modules operate at a daily time step. The pasture growth module is quite general in structure but recognises four functional groups of pasture plants: annual and perennial species are distinguished, as are grasses and forbs. Shoot tissue is classified as live, senescing, standing dead, or litter, and also according to its dry matter digestibility, thus enabling integration with diet selection and feed intake models. The phenological development of pasture plants is modelled, with the transitions between each stage governed by environmental variables (day length, temperature and soil moisture). Prereproductive and postreproductive phenostages of vernalization and 'summer dormancy', respectively, are modelled in the appropriate cultivars. Functions predicting net primary production in response to light intercepted, mean daytime temperature, and available soil moisture, and also the process of maturation, are common to all functional groups. The models' treatment of the allocation of assimilate has a similarly general form. Seed and seedling dynamics are modelled for annual species only. GrassGro is a discrete computer package, developed for Microsoft Windows,TM that combines the pasture growth module with a module for predicting the intake of herbage of ruminants and their productivity. This decision support system enables users to analyse simplified grazing systems in terms of pasture and animal production, gross margins, and year-to-year variability for any specified pasture cultivar, or combination of cultivars, at any specified site. The package may also be used to simulate forward from current pasture and animal conditions, for assessing the probability distribution of production outcomes, given the historical variability of weather conditions over the specified forward period.

Notes: Printed and on disk as pdf file.

Model Name: **HILLPLAN/LADSS**

Reference(s): Maxwell, T.J., G.W. Hill and K.B. Matthews. 1999. Sustainable rural land use. Journal of the Royal Agricultural Society of England 160:28-41

Abstract: None on file.

Notes: Article copied.

Model Name: **HILLPLAN/LADSS**

Reference(s): Milne, J.A. and A. Sibbald. 1998. Modelling of grazing systems at the farm level. Ann. Zootech. 47:407-417

Abstract: None on file.

Notes: Paper copied.

Model Name: **HILLPLAN/LADSS**

Reference(s): Milne, J.A., A.R. Sibbald, K.D. Farnsworth and C.P.D. Birch. 1999. A model for predicting the impact of grazing animals on animal production and vegetation changes in temperate grasslands and rangelands. In: People and Rangelands: building the future. Proceedings of the VI International Range Congress, Townsville, Queensland, Australia, 19-23 July, 1999. Vols 1 & 2: 872-873

Abstract: None on file.

Notes: Paper copied.

Model Name: **HyPAR**

Reference(s): FRP Agroforestry Modelling Project. 1998 and 1999. Va rious articles. Agroforestry Modelling Newsletter, Numbers 6, 7 and 8

Abstract: None on file.

Notes: Numbers 6, 7 and 8 printed. Number 8 saved to disk.

Model Name: **HyPAR**

Reference(s): Mobbs, D. and G. Lawson. 2000. HyPAR Agroforestry Model www.nbu.ac.uk/hypar/

Abstract: None of file.

Notes: Pages printed.

Model Name: **HyPAR**

Reference(s): Mobbs, D.C., G.J. Lawson and T.A.W. Brown. 1999. HyPar: Model for agroforestry systems. User Guide Version 3.0. Institute of Terrestrial Ecology

Abstract: None on file.

Notes: Saved to disk as pdf file from web site. Model available for download.

Model Name: **IBIEHM**

Reference(s): Itty, P. 1995. Application of a bio-economic herd simulation model to African cattle production systems: Implications for village milk production. Quarterly Journal of International Agriculture 34(4):372-385

Abstract: None on file.

Notes: Article copied.

Model Name: **IBIEHM**

Reference(s): Itty, P., G.J. Rowlands, G. Morkramer, A. Defly and G.D.M. d'Ieteren. 1995. The economics of recently introduced village cattle production in a tetse affected area (II): Trypanotolerant cattle in southern Togo. Agricultural Systems 47:473-491

Abstract: None on file.

Notes: Article printed.

Model Name: **IBIEHM**

Reference(s): Itty, P., G.J. Rowlands, M. Minengu, S. Ngamuna, F. Van Winkel and G.D.M. d'Ieteren. 1995. The economics of recently introduced village cattle production in a tetse affected area (I): Trypanotolerant n'dama cattle in Zaire. Agricultural Systems 47:347-366

Abstract: None on file.

Notes: Article printed.

Model Name: **La Lima bio-economic microwatershed model**

Reference(s): Barbier, B. and G. Bergeron. 1999. Impact of policy interventions on land management in Honduras: results of a bioeconomic model. Agricultural Systems 60:1-16

Abstract: This study examines the effects of various State policy scenarios (such as market liberalization, road construction, and land redistribution) on farmers' incomes and natural resource conditions in central Honduras. Dynamic linear programming is combined with a biophysical model and applied to the microwatershed of La Lima, where, in recent years, farmers have turned to intensive production of vegetables. Outputs of different model scenarios are compared with historical data over the last 20 years (1975-95). The main results of the simulations are: (1) the 1990 liberalization has had a beneficial impact on the incomes of small farmers who adopted a 'vegetable pathway'; (2) the shift from extensive production to intensive vegetable production does not reduce erosion, as the greater opportunity cost of labour increased the cost of investing in land conservation; and (3) small farmers are more likely than ranchers to erode soils, because they are more likely to produce vegetables during the rainy season and usually cultivate steeper slopes. However, small farmers are more likely to invest in land conservation because soil depth becomes a limiting factor for production.

Notes: Article printed and saved as pdf file.

Model Name: **La Lima bio-economic microwatershed model**

Reference(s): Barbier, B. and G. Bergeron. 1998. Natural resource management in the hillsides of Honduras: Bioeconomic modeling at the micro-watershed level. EPTD Discussion Paper No. 32, IFPRI

Abstract: None available.

Notes: Paper printed and saved as pdf file.

Model Name: **Mali bio-economic farm household model**

Reference(s): Kuyvenhoven, A., R. Ruben and G. Kruseman. 1998. Technology, market policies and institutional reform for sustainable land use in southern Mali. Agricultural Economics 19:53-62

Abstract: None on file.

Notes: Article copied.

Model Name: **Mali bio-economic farm household model**

Reference(s): Kuyvenhoven, A., R. Ruben and G. Kruseman. 1995. Options for sustainable agricultural systems and policy instruments to reach them. In: Bouma, J., A. Kuyvenhoven, B.A.M. Bouman, J.C. Luyten and H.G. Zandstra (Eds.), Eco-Regional Approaches for Sustainable Land Use and Food Production, pp. 187-212, Kluwer, Netherlands

Abstract: Not on file

Notes: Chapter copied.

Model Name: **Mali bio-economic farm household model**

Reference(s): Ruben, R., A. Kuyvenhoven and G. Kruseman. 2000. Bio-economic models for eco-regional development: Policy instruments for sustainable intensification. Book by Lee and Barrett

Abstract: None on file

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Model Name: **NUTMON**

Reference(s): de Jager, A., I. Kariuki, F.M. Matiri, M. Odendo and J.M. Wanyam. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): IV. Linking nutrient balances and economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71:81-92

Abstract: A one year monthly monitoring activity was conducted in the 1995/1996 season in three Kenyan districts with the participation of 26 farm households covering the major existing farming systems in these districts, in which data were collected on agronomic and economic aspects of the farm management. The average N-balance at farm level was -71 kg ha-1 year-1 with large variations among farms ranging from -240 kg ha-1 year-1 to +135 kg ha-1 year-1; the average K-balance was slightly negative, the P-balance slightly positive. Net farm income showed no relation with the nutrient balance. A high market orientation on the other hand correlated with a more negative N- and K-balance. The market-oriented farms located in the highly populated areas are characterized by intensive crop and livestock activities, import nutrients through fertilizers and/or animal feeds, but insufficient to compensate the outflow through marketed products, leaching and erosion. The average annual net farm income amounts to US$ 1490 per farm, with large variations among farms. Average returns to family labour (US$ 2.2 per day) and returns to land (US$ 91 per ha) are comparable or higher than unskilled wage rates and annual land rent respectively, but 50% of the farms perform below these rates. Market oriented farms have an economic performance that is similar to subsistence oriented farms. Off-farm income, however, is essential for large groups of small-scale farm households to achieve economic viability: without additional off-farm income, 54% of the farms in the sample are estimated to be below the poverty line. The replacement costs of mined nutrients amounts to 32% of the average net farm income. At crop level the cash crops tea and coffee realise higher gross margins and considerably lower nutrient mining levels than the major food crops maize and maize-beans. It is concluded that a multi-disciplinary monitoring activity at farm level contributes to targeting and prioritization of development options aimed at optimization of soil nutrient management.

Notes: Article copied.

Model Name: **NUTMON**

Reference(s): De Jager, A., S.M. Nandwa and P.F. Okoth. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): I. Concepts and methodologies. Agriculture, Ecosystems and Environment 71:37-48

Abstract: Nutrient Monitoring (NUTMON) is a multi-disciplinary and multi-scale approach, addressing the problem of soil nutrient depletion, so far mainly in sub-Saharan Africa. It involves and aims, at the various actors influencing soil nutrient management at different levels. A quantitative and qualitative diagnostic phase, to determine nutrient management and economic performance in existing farming systems, is followed by a targeted process of participatory development of Integrated Nutrient Management technologies and formulation of facilitating policy instruments. Further development of the approach is required through inclusion of social disciplines, extrapolation of results to district and national scale, better estimations of 'difficult-to-quantify' flows and adding policy oriented activities.

Notes: Article copied.

Model Name: **NUTMON**

Reference(s): Van den Bosch, H., A. De Jager and J. Vlaming. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): II. Tool development. Agriculture, Ecosystems and Environment 71:49-62

Abstract: Farm-NUTMON is a research tool that integrates the assessment of stocks and flows of the macro-nutrients nitrogen, phosphorus and potassium on the one hand and economic farm analysis on the other. The tool is applicable at both the farm and the activity level. It includes a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and the ECCAL for calculation of economic parameters). Finally, a user interface facilitates data entry, data manipulation and extracts data from the database to produce input for both models. Farm-NUTMON allows (i) estimation of the extent to which farmers generate income from soil nutrient mining, (ii) assessment of the impact of changes in farm management techniques on nutrient balance and economic performance at activity level and farm level, and (iii) calculation of the economic impact of exogenous changes on the farm and activity level.

Notes: Article copied.

Model Name: **NUTMON**

Reference(s): Van den Bosch, H., J.N. Gitari, V.N. Ogaro, S. Maobe and J. Vlaming. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems and Environment 71:63-80

Abstract: A nutrient balance study was carried out for 26 farms in three different districts in Kenya. Balances for the major nutrients nitrogen, phosphorus and potassium were calculated for individual activities within the farms and for the entire farms, using Farm-NUTMON, a research tool that combines calculation of nutrient flows and balances with economic farm analysis. Four flows into the farm (chemical fertilizer, organic fertilizer and feeds, atmospheric deposition, nitrogen fixation), six flows out of the farm (farm products, other organic outputs, leaching, gaseous losses, erosion and human excreta) and six internal flows (consumption of external feeds, household waste, crop residues, grazing, animal manure, and home consumption of farm products) were considered. Data on fertilizer use, use of organic materials, yields, home consumption and the management of residues, manure and household waste were gathered by interviewing the farmer. Assumptions for deposition, leaching and gaseous losses were made by using empirical relationships based on literature data (transfer functions). Erosion was estimated relating the overall slopes of the farms to soil loss figures. The mean balance of all farms was -71 kg N, +3 kg P and -9 kg K ha-1 year-1, with large variations between farms and little variation between districts. Emissions (leaching, gaseous losses and erosion) were estimated to be much higher than immissions (atmospheric deposition and N-fixation). Inflows and outflows at field level were much higher for cash crops than for food crops. Soil nutrient mining under napier grass (Pennisetum purpureum) was severe from high estimated losses in the napier-livestock-manure cycle. Based on an evaluation of the results of this case study, recommendations were made for improvement to the approach. Developing a sustainability indicator for soil fertility requires the nutrient balance to be linked to the actual soil nutrient stocks and other soil quality indicators.

Notes: Article copied.

Model Name: **SAVANNA**

Reference(s): Coughenour, M., R. Reid and P. Thornton. 2000. The SAVANNA model: Providing solutions for wildlife preservation and human development in East Africa and the Western United States. http://www.futureharvest.org/ne.pdf

Abstract: None on file.

Notes: Article from Futureharvest web site saved to disk and printed.

Model Name: **SOLUS**

Reference(s): Bouman, B.A.M., H.G.P. Jansen, R.A. Schipper, A. Nieuwenhuyse, H. Hengsdijk and J. Bouma. 1999. A framework for integrated biophysical and economic land use analysis at different scales. Agriculture, Ecosystems and Environment 75:55-73

Abstract: A framework for (sub-) regional land use analysis is presented that quantifies biophysical and economic sustainability trade-offs. The framework, called sustainable options for land use (SOLUS), was developed over a 10-year period of investigation in the Northern Atlantic Zone of Costa Rica and encompasses scale levels that range from field to region. SOLUS consists of technical coefficient generators to quantify inputs and outputs of production systems, a linear programming model that selects production systems by optimizing regional economic surplus, and a geographic information system. Biophysical and economic disciplines are integrated and various types of knowledge, ranging from empirical expert judgement to deterministic process models are synthesized in a systems-analytical manner. Economic sustainability indicators include economic surplus and labour employment, and biophysical ones include soil N, P and K balances, biocide use and its environmental impact, greenhouse gas emission and nitrogen leaching loss and volatilization. Land use scenarios can be implemented by varying properties of production inputs (e.g. prices), imposing sustainability restrictions in the optimization, and incorporating alternative production systems based on different technologies. Examples of application of SOLUS in the Northern Atlantic Zone of Costa Rica show that introduction of alternative technologies may result in situations that satisfy both economic as well as biophysical sustainability. On the other hand, negative trade-offs were found among different dimensions of biophysical sustainability themselves.

Notes: Printed and on disk as pdf file.

Model Name: **SOLUS**

Reference(s): Bouman, B.A.M., R.A. Schipper, A. Nieuwenhuyse, H. Hengsdijk and H.G.P. Jansen. 1998. Quantifying economic and biophysical sustainability trade-offs in land use exploration at the regional level: A case study for the Northern Atlantic Zone of Costa Rica. Ecological Modelling 114:95-109

Abstract: None on file.

Notes: Printed.

Model Name: **SOLUS**

Reference(s): Schipper, R.A., H.G.P. Jansen, B.A.M. Bouman, H. Hengsdijk, A. Nieuwenhuyse and F. Saenz. 2000 ?. Integrated bio-economic land use models: An analysis of policy issues in the Atlantic Zone of Costa Rica. see Barrett for reference

Abstract: None on file.

Notes: Copy obtained from Chris.

Model Name: **Sustainable stocking rate spreadsheet model**

Reference(s): Pulina, G., E. Salimei, G. Masala and J. L. N. Sikosana. 1999. A spreadsheet model for the assessment of sustainable stocking density rate in semi-arid and sub-humid regions of Southern Africa. Livestock Production Science 61:287-299

Abstract: None on file

Notes: Article copied.

Model Name: **Vihiga, Kenya integrated farm household model for different resource endowments**

Reference(s): Shepherd, K. D., and M. J. Soule. 1998. Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems and Environment 71:131-145

Abstract: A farm simulation model was designed to assess the long-term impact of existing soil management strategies, on farm productivity, profitability and sustainability. The model, which runs in time units of 1 year, links soil management practices, nutrient availability, plant and livestock productivity, and farm economics. A case study is presented of the application of the model to existing, mixed farm systems in Vihiga district, in the highlands of western Kenya. Three representative farm types were developed using participatory techniques to reflect differences in resource endowments and constraints faced by farmers. The model was used to assess the sustainability of the existing systems for the three farm types as a basis for recommending improved practices for each. A summary model for calculating new sustainability indicators of soil productivity is presented. The low (LRE) and medium (MRE) resource endowment farms, which comprise approx equal to 90% of the farms in the area, have declining soil organic matter and low productivity and profitability. In contrast, the high resource endowment category of farms (HRE) have increasing soil organic matter, low soil nutrient losses and are productive and profitable. Crop nutrient yields were 17, 19 and 86 kg N ha-1 year-1 on LRE, MRE and HRE farms, respectively. Soil C, N and P budgets were negative in LRE and MRE but positive in HRE. Farm revenue in LRE and MRE was 2-13% of farm revenue in HRE. It comprised 7% of household income in LRE compared with 25% in MRE and 63% in HRE. It is concluded that low land and capital resources constrain the adoption of ecologically and economically sustainable soil management practices on the majority of farms in the area. Strategies are needed to (i) increase the value of farm output (ii) increase high quality nutrient inputs at low cash and labour costs to the farmer, and (iii) increase off-farm income.

Notes: Article copied.

Model Name: **WaNuLCAS**

Reference(s): Van Noordwijk, M. and Lusiana, B.. 2000. WaNuLCAS 2.0 Background on a model of Water, Nutrient and Light Capture in Agroforestry Systems. Downloaded from www.icsea.or.id/wanulcas/index.htm

Abstract: No abstract on file.

Notes: Printed and on disk.

Model Name: WaNuLCAS

Reference(s): Van Noordwijk, M. and Lusiana, B.. 1999. WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. Agroforestry Systems 43: 217-242

Abstract: Models of tree-soil-crop interactions in agroforestry should maintain a balance between dynamic processes and spatial patterns of interactions for common resources. An outline is given of, and major assumptions discussed, underlying the WaNuLCAS [Water, Nutrient and Light Capture in Agroforestry Systems] model of water, nitrogen and light interactions in agroforestry systems; this is a prototype model now at the testing stage. It uses the Stella Research modelling shell linked to Excel spreadsheets for data input and output, and represents a 4-layer (vertical) soil profile, and water and nutrient (at this stage only N) balance and uptake by a crop and a tree. The model was developed to deal with a wide range of agroforestry systems - hedgerow intercropping on flat or sloping land, fallow-crop mosaics, or isolated trees in parklands - with a minimum of parameter adjustments. Examples are presented for simulation runs of hedgerow intercropping systems at different hedgerow spacings and pruning regimes, a test of the safety-net function of deep tree roots, lateral interactions in crop-fallow mosaics and a first exploration for parkland systems with a circular geometry.

Notes: Article requested via Inter-Library Loan since volumes missing from library. Not received as of this date.

Model Name: Zambia Household Model

Reference(s): Holden, S. T. 1993. Peasant household modelling: Farming systems evolution and sustainability in northern Zambia. Agricultural Economics 9(3):241-267

Abstract: Chitemene slash-and-burn cultivation continues to be a dominating cropping system in northern Zambia even after the introduction of modern technologies such as hybrid maize and fertilizer. The rationale of farming systems evolution in northern Zambia where labour markets have been absent or highly imperfect, has been analysed by goal programming based on the theories of Chayanov (1966) and Nakajima (1986). Carrying capacity estimation is incorporated in the models and discussed in relation to the sustainability of land use systems in the area. The major changes in agricultural technologies in northern Zambia during this century have been the introduction of cassava, maize and fertilizer technologies. Cassava has had the most significant impact since the land could support much higher population densities when the dependence on the chitemene system no longer was critical for the survival of peasants. By switching from finger-millet to cassava as the main staple the peasants could reduce their total labour requirement to meet their basic food needs by as much as 40%. The results also show that the maize-fertilizer technology has been unable to replace the chitemene system because economic incentives to continue the system exist as long as there is suitable woodland available. Nevertheless, the introduction of the maize-fertilizer technology may have resulted in reduced chitemene cultivation. The rapid expansion of maize production in northern Zambia from the late 1970s to the late 1980s depended critically on the government policy of equity pricing and input subsidization. The models predicted that the removal of fertilizer subsidies would result in a dramatic reduction in maize production.

Notes: Article copied.

Appendix B: Summaries of models reviewed

The following model summaries are included in this review:

1. **BEAM**
2. **Burkina bio-economic village model**
3. **Carchi integrated simulation model**
4. **CDFU**
5. **CENTURY**
6. **DAFOSYM**
7. **FLORES**
8. **Ginchi bio-economic model**
9. **GRAZPLAN**
10. **HILLPLAN/LADSS**
11. **HyPAR**
12. **IBIEHM**
13. **La Lima bio-economic microwatershed model**
14. **Mali bio-economic farm household model**
15. **NUTMON**
16. **SAVANNA**
17. **SOLUS**
18. **Sustainable stocking rate spreadsheet model**
19. **Vihiga, Kenya integrated farm household model for different resource endowments**
20. **WaNuLCAS**
21. **Zambia Household Model**

BEAM

1. Basic reference information

1.1 Model name BEAM (Bio-Economic Agroforestry Modelling Project)

1.2 Reference and source

1.2.1 Title

Putting the economics into bio-physical agroforestry models. www.bagor.ac.uk/ afs/download/paper2.zip.

Related material:

Anonymous. 2000. Introduction to the BEAM project. www.bangor.ac.uk/ afs/beamint.htm.

FRP Agroforestry Modelling Project. 1998 and 1999. Various articles. Agroforestry Modelling Newsletter, Numbers 6, 7 and 8.

1.2.2 Author(s) Thomas, T.H. and R.W. Willis.

1.2.3 Institution School of Agriculture and Forest Sciences, University of Wales.

1.2.4 Date Undated.

1.2.5 Key words Bio-economic modelling.

1.3 Location World-wide application of the techniques involved.

2. Nature of model

2.1 Study and model type

Predictive.

Partial budgeting and discounted cash flow analysis to evaluate the results of biophysical models.

2.2 Component(s) modelled

Output from particular agroforestry intercropping systems is used as input into the spreadsheet model.

Has the facility to analyse the performance of a system with a tree component (one main product and up to 8 additional end products), two perennial crops and two annual crops (under different rotation schemes) as well as on-farm processing of the end products.

2.3 Unit(s) of analysis

Plot level.

2.4 Optimisation criteria

Not an optimisation model.

2.5 Optimisation alternatives available

Simulates outcome (economic performance) of alternative agroforestry intercropping production scenarios over time.

Not a farm or household model.

2.6 Model output(s)

Financial performance in terms of discounted annual cash flow or cumulative cash flow, for example, for various scenarios.

Can be used to perform sensitivity analysis to determine the effect of changes in both biological and financial parameters on the system as a whole.

2.7 Data inputs

Uses output from biophysical simulation models such as HyPAR and WaNuLCAS as input into the economic analysis model. Additionally, there is need for financial and workrate data to be provided separately for the systems under consideration.

2.8 Uses

Has been used in analysis of rubber/rice systems in Thailand, a modified taungya system in Tanzania, poplar/cereal/livestock system in the UK and a leucena/maize system in Kenya.

3. Computational issues

3.1 Solution method(s)

Sequential.

One EXCEL template file receives biophysical information from a biophysical simulation model and another template is used for input of the financial and workrate data. The contents of the templates then are used as inputs into the third template which evaluates the system's performance.

3.2 Computer language(s)

EXCEL.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty and risk are not addressed directly. Some assessments can be made through appropriate sensitivity analysis.

4.2 Inclusion of conditioning or environmental variables

Linked to external market (supply and demand) through price data. Not directly conditioned by biological or environmental conditions except through the biophysical models themselves.

4.3 Integration and linkages

See above.

4.4 Social Science issues

Does not use a representative agent since it is based on a plot-level analysis.

Heterogeneity technologies, prices, endowments, or constraints could conceivably be modelled through different scenarios reflecting changes in the relative factors.

The analysis is of a dynamic (multi-period) nature.

4.5 Biological production issues

Livestock:
– not included.

Plants:
– not modelled within the BEAM analysis framework.

Soils:
– not modelled within the BEAM analysis framework.

Nutrient cycling:
- not modelled within the BEAM analysis framework.

4.6 Ecological systems and sustainability issues

Not discussed.

5. Overall Assessment

5.1 Strengths

5.2 Weaknesses

Not an optimisation model.

Does not deal with household as the locus of decision-making.

Includes no component to assess environmental sustainability. Economic sustainability at the plot level is the only output of this nature. Presumably, though, the same biophysical model which provided the inputs into this one can provide appropriate outputs to assess biological sustainability issues.

5.3 Caveats and limitations

5.4 Lessons learned

Uses a unique spreadsheet approach to the interface between a biophysical model and an economic model to evaluate the performance of agroforestry intercropping systems in tropical and temperate zones..

Burkina bio-economic village model

1. Basic reference information

1.1 Model name Burkina bio-economic village model

1.2 Reference and source

1.2.1 Title

Induced innovation and land degradation: Results from a bioeconomic model of a village in West Africa.

Related material:

Barbier, B. and M. Benoit-Cattin. 1997. Viabilite a moyen et long termes d'un systeme agraire villageois d'Afrique soudano-sahelienne. (Medium and long term viability of the agrarian system of a village in South-Sahelian Africa. The case of Bala in Burkina Faso.) Economie Rurale 239:30-39.

Barbier, B. 1996. Impact of market and population pressure on production, incomes and natural resources in the dryland savannas of West Africa: Bioeconomic modeling at the village level. EPTD Discussion Paper No. 21, IFPRI.

1.2.2 Author(s)

Barbier, B.

1.2.3 Institution

IFPRI, CARDI

1.2.4 Date

1998

1.2.5 Key words

linear-programming. farming-systems. agricultural-policy. environmental-management. environmental-impact. land-management. villages. case-studies. environmental-degradation. innovation-adoption. simulation-models. conservation. costs. investment.

1.3 Location

Africa, Burkina Faso, semi-arid and sub-humid savannah regions.

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

Recursive and dynamic LP model of economic behaviour linked to a biophysical model of plant growth and soil condition.

2.2 Component(s) modelled

Village economics, plant and animal production, soil health (depth and SOM) and interaction with local markets.

2.3 Unit(s) of analysis

Village.

Assumes resources are managed at the community level and several farm-level constraints are not strictly binding at the farm level.

2.4 Optimisation criteria

Maximise aggregate community welfare – discounted monetary value of future income and opportunity cost of leisure (resource allocation and production decisions are made over a 3-year planning horizon).

Subject to constraints on level, quality and distribution of key production factors (land area, soil fertility, labour and cash availability, risk aversion) as well as food consumption and market demand for foods.

2.5 Optimisation alternatives available

Allows for migration (in and out), selection of crop and animal production methods, allocation of output (consumption, storage and/or sale).

2.6 Model output(s)

Population, income (village, per person and per hectare), shadow prices of production factors, crop and animal production (area and yield) seasonally and annually.

Calibrated for two villages in Burkina Faso in the base year and used to simulate trends over 40 years. (Note: a subsequent model using this methodology for a micro-watershed in Honduras was validated over a 20-year period)

2.7 Data inputs

Population birth and death rates, market demand for surplus food and prices of inputs and outputs.

Production function parameters are generated using EPIC (Erosion Productivity Impact Calculator) which was calibrated for the region.

EPIC is also used to simulate random weather outcomes and generate “actual” outcomes for each year based on the expected outcomes generated by the LP model.

2.8 Uses

Simulation of development pathways under different scenarios for population, prices and market demand. Assessment of medium and long-term viability of agrarian systems at the village level.

3. Computational issues

3.1 Solution method(s)

Simultaneous and sequential. The multiperiod LP model (limited to the 3-year planning horizon) is simultaneously solved for the optimal solution. The first-year results are used recursively as the initial resources of a new multiperiod model for the following planning period (of which the first-year’s results are used) and so on. The recursive nature of the model allows adjustments from year-to-year for stochastic weather events using EPIC to generate actual outcomes which are used to adjust the closing stocks. These then become the initial constraint set for the multiperiod beginning in the subsequent year.

3.2 Computer language(s)

GAMS

4. Key features captured and issues addressed

4.1 Uncertainty and risk

The Target MOTAD method is used to simulate farmers’ aversion to risk by maximising utility subject to a satisfactory level of compliance with the target income.

EPIC is used to make adjustments between expected outcomes and “actual” outcomes in response to stochastic weather events from year-to-year.

4.2 Inclusion of conditioning or environmental variables

Population growth, possibilities of in/out-migration, prices of inputs and outputs and stochastic weather events.

4.3 Integration and linkages

Plant and animal production systems are inter-linked and linked to the natural resource base through stocks and measures of condition. Also linked to consumption and sales to the external markets and the use/export of labour. Cash also serves as a linking factor within and between years.

4.4 Social Science issues

Uses the village as a single representative agent. Allows for heterogeneity in terms of the natural resources available (5 different landscape units) to be managed.

The village makes dynamic decisions within the planning period (3 years). The outcome of the first year then affects the subsequent 3-year planning period (t + 1).

4.5 Biological production issues

Livestock:

- four types of livestock allowed
- herd growth determined by weight gain, calf numbers and mortality as well as sales and purchases
- production decisions depend on labour, vet. expenses and feed energy from forages and purchased grain
- environmental variables are not explicitly included
- genetic variations accounted for as different livestock production activities

Plants:

- parameters for simplified production functions generated using EPIC calibrated for the region
- yields depend on type and fertility of soil, past management (input use, SOM, soil depth), use of animal traction (increase labour productivity but increase SOM mineralization), conservation methods.
-

Soils and Nutrient cycling:

- use 5 different landscape units
- track soil depth and SOM and resultant impact on yields, etc.

4.6 Ecological systems and sustainability issues

Sustainability assessed through impact on income, soil status and population movements.

5. Overall Assessment

5.1 Strengths

Effectively balances the issue of a short planning horizon for decision-making (in this case a 3-year multiperiod LP model) and the need for a long-run simulation of the impact of sequential decisions over time (recursive adjustments for stochastic environmental conditions and the fact that each year is the start of a new planning period from the point of view of decision-makers who respond to their environment and the consequences of their previous decisions).

5.2 Weaknesses

Does not deal with heterogeneity of resource endowments within the village – i.e. differences among households.

Not thoroughly calibrated (compare this the Honduras model by the same author).

5.3 Caveats and limitations

Modelling at the village level is one way to deal with the fact that land degradation issues are only addressed to a limited extent by farm-level (or household-level) analysis – especially when land is not privately held (as is the case in much of Africa). On the other hand, there are limitations in this approach since it cannot deal with issues of differences in resource endowments and how they affect individual decisions within a community.

Use of the EPIC model for generation of coefficients for the production functions facilitates construction of the model. It also allows simulation of alternative cropping patterns untested in the region.

Could 2 or 3 household types be included within a village-level LP model to allow for this consideration – i.e. differing priorities and/or resource endowments?

5.4 Lessons learned

The recursive use of a multiperiod LP model in combination with a biophysical model of plant growth and soil condition.

Carchi integrated simulation model

1. Basic reference information

1.1 Model name

Carchi Integrated Simulation Model

1.2 Reference and source

1.2.1 Title Economic, Environmental, and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production

1.2.2 Author(s) Crissman, C. C., J. M. Antle and S. M. Capalbo

1.2.3 Institution International Potato Center (CIP) and Rockefeller Foundation

1.2.4 Date 1998

1.2.5 Key words sustainability, modelling, Andes

1.3 Location

South America, Ecuador, Andean highland region, Carchi Province

Highland, tropical, about 1° N of equator

Case study site: 2 micro-watersheds and 2 communities with a physically heterogeneous landscape

2. Nature of model

2.1 Study and model type

Explanatory and predictive model

Econometric optimisation model at firm level linked to functions estimating environmental and health impacts at firm and aggregate level.

Quantifies the economic, environmental and health impacts and is used to explain and simulate tradeoffs between value of agricultural output (from potato production) and environmental/health impacts of pesticide use.

2.2 Component(s) modelled

1. Economic – stochastic simulation of the potato production system.
2. Environmental – probabilistic model of pesticide leaching into the root zone.
3. Human health – risks of negative health effects on individuals from pesticide use.
4. Integrated simulation model – combines the results from the 3 components to generate trade-off curves.

2.3 Unit(s) of analysis

Field level data for inputs, outputs and environmental variables.

Results aggregated to the watershed level using a statistical representation of the relevant human and physical populations.

2.4 Optimisation criteria

The economic component (stochastic simulation model of the potato production system) – individual farmers allocate land and other inputs to maximise expected economic returns.

Results (economic, environmental and human health) are aggregated to the watershed level.

2.5 Optimisation alternatives available

Farmer maximises expected economic return by:
1. allocation of land to crop (potato) and noncrop (pasture) use (extensive margin decisions) and
2. optimisation of input use (pesticides - quantity and timing) in crop production (intensive margin decision)
in a sequential decision model.

2.6 Model output(s)

Individual components generated value of production, predicted amount of leaching and effects on human health at the watershed level.

Integrated simulation model generated tradeoffs among economic, environmental and health outcomes by using 7 price settings and then simulating and aggregating the results (output value, chemical leaching and health outcomes) for 30 randomly drawn fields over 5 production cycles.

A set of elasticity estimates for input use and timing

2.7 Data inputs

Survey data for field-level variables related to soil, topography, input use and timing, output, pesticide exposure from over 300 parcels was used.

Simulations are based on data drawn from empirical distributions estimated for the sample data.

2.8 Integration of components

Definition of the same unit of analysis for the production, leaching and pesticide exposure levels ensures that causal relationships can be identified.

2.9 Uses

Used to simulate policy (domestic and trade) and technology alternatives at the watershed level.

3. Computational issues

3.1 Solution method(s)

Sequential solution method based on stochastic inputs and expected outputs.

3.2 Computer language(s)

Not specified.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Random selection of field and environmental characteristics, timing of production processes, prices and yields as inputs into the economic optimisation component.

4.2 Inclusion of conditioning or environmental variables

Linked to the macroeconomic and policy environment through price variables.

There is no provision for feedback of aggregate price effects on the decision variables in the model.

Linked to biological/production variables at the field level.

4.3 Integration and linkages

Forward linkages exist from the economic optimisation model to the environmental and human health components. Backward linkages from human health and environmental variables to productivity are not included.

This is defined as Level I model integration (p245).

There is an interesting discussion of the 3 levels of model integration – Level III being an economic model that is formally linked to a production model with the 2 being jointly simulated to allow for dynamic feedback from environmental conditions to production.

4.4 Social Science issues

Avoids the problems inherent in using the “representative farm” approach by allowing for heterogeneity in environmental and production variables over the area under consideration – in this case there were 4 separate zones modelled within the watershed proportionately to their land area. Differential impact of policy changes could therefore be assessed across the different zones. This would be masked using a representative farm approach.

While it allows for heterogeneity at the landscape level, it does not allow for heterogeneity in individual preferences, endowments, constraints or off-farm income earning opportunities. It is not a household decision-making model but an agricultural decision-making model. Nor does it include nonmaterial concerns.

The potato production model took the form of a dynamic production model with endogenous timing of production decisions, which maximised expected net returns. The module was specified as a system of log-linear factor demand and timing equations estimated by OLS. Since the reduced-form equations for each factor type had the same RHS variables a SURM was not used. The model included lagged dependent variables for input use and timing of previous input use.

Individuals make decisions in a dynamic framework on one field during a season so as to provide information on timing and use of and exposure to pesticides during the cropping season that is required by the other model components. It is not a multiperiod dynamic optimisation model.

The potato production model was incorporated into the stochastic simulation model for farm production decisions which simulates crop choice and pesticide use decisions at a field scale. Field characteristics were randomly selected and then the land use allocation decision was made between crop and noncrop uses so as to maximise expected economic returns. Then the potato production model was used to model the potato production decisions. This provided 3 outputs on a field basis:

1. value of agricultural output;
2. pesticide use as an input into the leaching model;
3. pesticide applications and amounts as input into the health model.

4.5 Biological production issues

Given the variety of pesticides used and the number of types and prices of potatoes the input and output data were converted to standardised units. The quality adjustment for the pesticide input data used a log-linear model. The quality adjustment for the potato output data used a linear model.

The pesticide-leaching model uses the Heckman 2-stage econometric procedure whereby (1) the probability of a positive leaching event is estimated using a probit model and then, for those cases where leaching occurs, (2) the fraction leached is estimated.

The human health component predicts both mean exposure and probability of exposure beyond a certain level.

4.6 Ecological systems and sustainability issues

Sustainability is not defined per se.

Rather, the value of production vs. environment (pesticide leaching potential) and value of production vs. human health tradeoffs are quantified and compared under the base (actual) scenario and alternative price (pesticide and potato) and technology (IPM, disease resistance, pesticide management) policy/program scenarios.

The output from the leaching model, the human health risk model and the value of agricultural output on a field basis is used as the input to assess the trade-offs through the integrated simulation component.

5. Overall Assessment

5.1 Strengths

Representative of the potato-pasture based farming systems in the upper ecological floors of the Andes.

Permits the linkage of environmental and health impacts to the choice of production systems/activities on a site-specific basis thereby providing sound scientific basis for analysis of cause-and-effect relationships (p2).

Accounts for spatial variability in economic, environmental and health outcomes. Models production system and environmental impact at small scale and assesses their effect at larger scales.

5.2 Weaknesses

No attempt is made to attach a value to the environmental and human health effects and optimise among them (since “there is no scientific or public consensus on valuation methods or their public acceptability” p. 7) nor are alternative objective functions specified (such as minimisation of human health impact).

5.3 Caveats and limitations

Does not model the biological component of production. Nor does it address the long-term maintenance of soil productivity and externalities associated with soil erosion.

The “stochastic simulation model based on the dynamic econometric production model is limited due to it’s reliance on the statistical representation of the production technology” since it cannot be used outside the range of the observed data. Linking the economic model to crop growth models would help in this.

There was insufficient information to estimate environmental damage.

There was no feedback linkage made from health effects to labour productivity although there is evidence that such a link exists.

The study was limited to quantifying the key trade-offs identified by stakeholders.

5.4 Lessons learned

Spatial variability needs to be accounted for in environmental impact assessment since there is spatial variability in the economic, environmental and health trade-offs, which has implications for policy design (a fact that would have been masked had a “representative farm model” been sued). This means that policies to improve pesticide use efficiency and safety have the potential from significant health and environmental benefits without high economic costs unlike the imposition of broad restrictions on pesticide use.

CDFU

1. Basic reference information

1.1 Model name Crop-Down Fallow-Up Model

1.2 Reference and source

1.2.1 Title

Crop-down fallow-up model. http://www.icsea.or.id/models/cdfu.htm

Related material:

Van Noordwijk, M. 1999. Productivity of intensified crop-fallow rotations in the Trenbath model. Agroforestry Systems 47:223-237.

1.2.2 Author(s)

Van Noordwijk, M.

1.2.3 Institution

ICRAF-S.E. Asia, ASB Program

1.2.4 Date

2000

1.2.5 Key words

Shifting cultivation. Crop-fallow rotations. Models. Food self-sufficiency. Sustainability. Fallow period. Intensification.

1.3 Location

Humid tropics, Asia in particular.

2. Nature of model

2.1 Study and model type

Predictive.

Dynamic simulation model.

2.2 Component(s) modelled

Simulation of the results of a crop-fallow sequence for a 100-grid cell landscape over a period of years. Components include crop production, fallow management, soil fertility and food production.

2.3 Unit(s) of analysis

A spatially distributed set of 100 fields managed by a single entity.

2.4 Optimisation criteria

Not an optimisation model. Simulates outcome of a particular set of ecosystem parameters and management conditions. Primary goal is to assess sustainability of a particular system.

2.5 Optimisation alternatives available

Can explore the results of various combinations of biophysical and management parameters:

- human population density;
- half-recovery time of fallow;
- use of farmer knowledge for field selection
- initial soil fertility;
- recovery time;
- decision criteria for rice stock to induce intensification.

2.6 Model output(s)

Rice production, food self-sufficiency, carbon stocks (above and below ground) and plant species richness.

This is an initial test version.

2.7 Data inputs

2.8 Uses

Exploration of the sustainability of food crop production through the prediction of food self-sufficiency, soil fertility, carbon stocks and plant species richness of shifting cultivation systems.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

Stella.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

No information.

4.2 Inclusion of conditioning or environmental variables

Not linked to market environment since it assesses food production for household use.

Primary conditioning variable is population density and fallow recovery time.

4.3 Integration and linkages

Well integrated and linked.

4.4 Social Science issues

Does not model the decision-making process.

The model on which it is based assesses food production in terms of output per unit labour as well as per hectare.

4.5 Biological production issues

Livestock:
- not included.

Plants:
- no details.

Soils:
- no details.

Nutrient cycling:
- no details.

4.6 Ecological systems and sustainability issues

Sustainability of crop production is assessed in terms of the change in yields between subsequent crop-fallow cycles.

5. Overall Assessment

5.1 Strengths

An extension of the Trenbath model, which describes the build-up and decline of soil fertility during the fallow-cropping cycle (see “related material” above), from a single field to a spatially distributed set of fields.

5.2 Weaknesses

5.3 Caveats and limitations

A useful tool for certain situations – in particular for assessment of the sustainability of a particular management system over time.

5.4 Lessons learned

CENTURY

1. Basic reference information

1.1 Model name CENTURY

1.2 Reference and source

1.2.1 Title CENTURY Soil Organic Matter Model Environment: Technical Documentation, Agroecosystem Version 4.0 Great Plains System Research Unit, Technical Report No. 4, USDA-ARS, Fort Collins, Colorado.

Related materials:

Kaufman, C.. 2000. The CENTURY Model www.cgd.ucar.edu/vemap/abstracts/CENTURY.html.

1.2.2 Author(s) Metherell, A.K., L.A. Harding, C.V. Cole and W.J. Parton

1.2.3 Institution Natural Resource Ecology Laboratory.

1.2.4 Date 1996

1.2.5 Key words CENTURY soil organic matter model.

1.3 Location World-wide application. Has biome-specific fixed parameters files.

2. Nature of model

2.1 Study and model type

Predictive.

Simulates the long-term dynamics of Carbon (C), Nitrogen (N), Phosphorus (P), and Sulphur (S) for different Plant-Soil systems. In particular, the model can simulate the dynamics of grassland, agricultural crop, forest and savannah ecosystems.

2.2 Component(s) modelled

Includes submodels for soil organic matter and decomposition, water budget, grassland/crop and forest production as well as management events and scheduling functions.

2.3 Unit(s) of analysis

Regional, with resolution at 1m2.

2.4 Optimisation criteria

Not an optimisation model.

2.5 Optimisation alternatives available

Simulates, on a monthly time step, for periods of 100s to thousands of years, the flows of C, N, P and S for a particular ecosystem and management scenario.

2.6 Model output(s)

Computes flow of carbon, nitrogen, phosphorous and sulphur through the model’s compartments.

Output contains information on carbon, nitrogen, phosphorous and sulphur fluxes, net primary production and soil organic matter.

Has been used in 22 different regions for global change research.

2.7 Data inputs

The driving variables required for input are:

- monthly average max. and min air temperature;
- monthly precipitation;
- soil texture;
- plant N, P, S and lignin content;
- atmospheric and soil N inputs;
- initial soil carbon and nitrogen (P and S are optional).

These input variables are available for most natural and agricultural ecosystems or can be estimated from existing literature.

There is the option of stochastically generating the precipitation data for the period of the simulation.

Additionally, there is the sequence of management activites which are input via an “Event file”.

2.8 Uses

Used for analysing the effects of management and global change on the productivity and sustainability of agroecosystems. It integrates the effects of climate and soil driving variables and agricultural management to simulate C, N, P, S and water dynamics in soil plant systems.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

FORTRAN for PC or UNIX. Can view output via the TIME-ZERO modelling environment or direct it to an ASCII file for import into other software.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty is only addressed in terms of the generation of stochastic precipitation events for a model run.

4.2 Inclusion of conditioning or environmental variables

No market linkages since there is no economic component to the model.

4.3 Integration and linkages

The grassland/crop and forest systems, have different plant production submodels which are linked to a common soil organic matter submodel. The savannah model uses the grassland/crop and forest subsystems and allows for the two subsystems to interact through shading effects and nitrogen competition. The soil organic matter submodel simulates the flow of C, N, P, and S through plant litter and the different inorganic and organic pools in the soil. The water budget submodel is likewise linked to the SOM and plant production submodels.

4.4 Social Science issues

The model represents the dynamics of an ecosystem on a regional basis, simulating the results of the driving variables (soil and climate) and a sequence of user-defined management events over a period of time for a particular scenario.

Management activities that can be modelled include:

- crop rotations;
- tillage practices;
- fertilisation and irrigation;
- grazing;
- harvest methods.

4.5 Biological production issues

Livestock:
- not modelled except as a management activity.

Plants:
- monthly maximum plant production is assumed to be a function of moisture and temperature and is reduced if nutrients are limiting;
- the forest model simulates the growth of deciduous or evergreen forests in the mature and juvenile phases;
- the grasslands/crops model uses pre-defined parameters for existing management options (harvest, grazing, fire and cultivation directly effect aboveground biomass, while grazing and fire also impact root to shoot ratios and nutrient content);
- the savannah system is simulated as a tree-grass system, essentially using the existing forest and grassland/crop submodels where the two subsystems interact through shading effects and nitrogen competition. The maximum grass production is affected by a shade modifier that is a function of tree leaf biomass and canopy cover. Additional nutrient constraints on plant production due to nutrient allocation between trees and grasses decrease maximum production rates for the grasses as well.

Soils and nutrient cycling:
- SOM is modelled via 3 organic matter pools (active, slow and passive) with different potential decomposition rates as well as above and belowground litter pools and a surface microbial pool which is associated with decomposing surface litter;
- the model has N, P, and S pools analogous to all of the C pools;
- the model includes a simplified water budget model which calculates monthly evaporation and transpiration water loss, water content of the soil layers, snow water content, and saturated flow of water between soil layers.

4.6 Ecological systems and sustainability issues

Sustainability is assessed through changes in carbon and nutrient flows and stocks as well as primary production.

5. Overall Assessment

5.1 Strengths

Modelling of soil carbon and nutrient flows over long periods of time.

Global change research.

5.2 Weaknesses

No component for analysis of economic impacts.

Limited possibilities for simulation of animal production systems.

5.3 Caveats and limitations

SOM simulation is limited to the top 20 cm of the soil profile.

5.4 Lessons learned

DAFOSYM

1. Basic reference information

1.1 Model name DAFOSYM: Dairy Forage System Model

1.2 Reference and source

1.2.1 Title DAFOSYM: A dairy forage system model for evaluating alternatives in forage conservation. Journal of Dairy Science 72:3050-3063

1.2.2 Author(s) Rotz, C. A., D. R. Buckmaster, D. R. Mertens and J. R. Black

1.2.3 Institution Pennsylvania State University and Pasture Systems and Management Research lab, Agricultural Research Service, USDA

1.2.4 Date 1989

1.2.5 Key words representative farm model, economics, simulation-models

1.3 Location North America, USA, Northeast

Temperate

2. Nature of model

2.1 Study and model type An exploratory and predictive static simulation model for analysing resource use and economics of representative forage-based dairy farms in the NE USA.

2.2 Component(s) modelled Components include crop growth, harvest, storage, feeding, animal utilisation and economic analysis accounting for feed quantity and quality variations throughout the production and use cycle.

Modelled on a daily time-step following historical weather data over a sequence of years based on the growing season.

2.3 Unit(s) of analysis Representative farm.

2.4 Optimisation criteria Forecasting input usage, output and costs under alternative management scenarios.

The model is optimised around the needs of the animal. The only specific optimisation subcomponent is in the feed ration formulation for each of the 6 categories of livestock wherein the objective is to maximise use of home-grown forage while minimising the use of purchased protein and energy supplements. No assessment or measure of utility, welfare or sustainability is conducted.

2.5 Optimisation alternatives available Optimise efficiency of use of available feed resources and evaluate the return over feed costs of the specified farm for each year simulated.

2.6 Model output(s) Can simulate operation of a representative farm over many years and evaluate the long term benefit and risk (through simulation of weather conditions from year-to-year) of a technology or strategy on the farm.

By running the model under various management and resource scenarios the model can be used to identify the best choice among the alternatives evaluated. Not an economic optimisation model per se.

Performance has been validated by comparison to actual farms in the area.

2.7 Data inputs

Historical weather data - soil water availability, degree days.

Farm characteristics, machinery data, storage options and characteristics, corn production data.

Animal requirements.

Prices based on average values for a specified time period.

2.8 Integration of components

2.9 Uses

Analysis of the relative economic viability of various options.

3. Computational issues

3.1 Solution method(s)

Sequential solution.

3.2 Computer language(s)

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Can assess the impact of risk due to weather conditions through the distribution of annual values for return over feed costs. The mean return as well as the probability of attaining it can be compared for various alternatives.

4.2 Inclusion of conditioning or environmental variables

The model can be used to evaluate the impact of different economic and environmental policy and pricing scenarios on different representative farms.

4.3 Integration and linkages

Forward linkages exist through both the quantity and quality of feeds.

4.4 Social Science issues

Uses a single representative farm. Heterogeneity of technologies, prices, endowments, or constraints is allowed for only through re-running the model under a different set of conditions.

Feed and resource allocation decisions are static (single-period) though the cumulative effect over a period of years is assessed.

4.5 Biological production issues

Livestock component:

– accounts for impact of changes in feed quality and quality through adjusting ration formulation and purchase of supplemental inputs such that it falls within constraints specified in an LP model. Where available feed falls short, production is reduced to that which can be supported with given feeds.

– productivity is measure through milk production

– does not account for water requirements or climate variables in the livestock component

– genetic variations are not accounted for

Crop growth component:

– ALSIM1, level 2 for alfalfa growth

– CERES-maize corn growth model

Crop harvest component:

– a static model estimates harvest rates, speeds and costs for 6 yields and these are linked back to crop growth so that harvest characteristics are a function of yield

– assesses impact of harvest conditions on quality of corn and alfalfa

Feed storage component:

– evaluates impact of storage options on quantity and quality of feed

Nutrient cycling is not modelled.

4.6 Ecological systems and sustainability issues

Sustainability issues are not directly addressed.

5. Overall Assessment

5.1 Strengths

Incorporates climate and timing of field operations.

Provides a clear modelling of the annual production cycle over time and accounts for the impact of production and storage conditions on feed quality and quantity as well as on subsequent production by the dairy herd based on the nutrient content of the feed and the nutrient needs of the herd as specified in the NRC Nutrient Requirements of Dairy Cattle.

Incorporates very detailed production cost and resource use information in terms of fixed and variable costs of plant and equipment, in terms of labour constraints/needs, in terms of storage space and equipment capacity and the impact of the timing of field operations on feed quality and quantity

5.2 Weaknesses

Does not include feedback on crop growth due to soil erosion, etc.

Assumes a uniform resource input base (soil type and so on).

5.3 Caveats and limitations

Does the model accommodate a sufficient range of inputs to account for crop growth and animal production under African conditions? The range of feed sources and the measure of animal productivity are limited.

It does not appear to be able to accommodate heterogeneity of objectives or environmental conditions within the model itself.

Could components of the model be used as a basis for simulation of individual farm output for different field/resource endowments which are then aggregated on a landscape basis?

Does not allow for alternative uses of farm labour or crop production.

5.4 Lessons learned

The model has since been expanded to include submodels for manure production, storage, handling and use on crop land. It accounts for the scheduling choice and timing of tillage and manure handling operations. Predicts suitable days for the various operations based on soil and crop residue conditions.

FLORES

1. Basic reference information

1.1 Model name

FLORES (Forest Land Oriented Resource Envisioning System)

1.2 Reference and source

1.2.1	**Title**	FLORES: for exploring land use options in forested landscapes. http://www.cgiar.org/cifor/flores.
1.2.2	**Author(s)**	Vanclay, J.K.
1.2.3	**Institution**	CIFOR
1.2.4	**Date**	2000
1.2.5	**Key words**	

1.3 Location

Tropical forest regions.

2. Nature of model

2.1 Study and model type

Predictive.

FLORES is intended to be a dynamic simulation model within which the various actors make independent optimisation decisions.

2.2 Component(s) modelled

Forested lands, agricultural lands (crop, trees and livestock), village/community.

Will include sub-models for:
- decision-making by actors;
- prediction of growth of trees;
- prediction of growth of crops;
- changes in soil and water balance;
- interactions between key plant and animal species;
- other key ecosystem processes.

Will integrate existing models for some of these components into the FLORES framework where they exist and are amenable to doing so.

2.3 Unit(s) of analysis

Intended to operate at the landscape scale, spanning forest and agricultural lands as well as villages. Land use decisions are made at the level of individual actors. Undecided as to whether to model individual actors or classes of actors.

2.4 Optimisation criteria

Actors undertake activities which maximise their expected benefits or minimise anticipated risks to themselves and their beneficiaries. May consider modelling both benefit-seeking and risk-avoiding by considering risk-adjusted benefits.

2.5 Optimisation alternatives available

Assumes that land use patterns are created by **actors** who make **rational** decisions based on their **perceptions** of reality, that they decide among all available options within the constraints imposed on them by resources, knowledge and comfort zone.

Actors compile a menu of possible activities from which they choose the most appealing under the prevailing circumstances. Innovators may have a more extensive menu from which to choose than others, for example.

Activities will include clearing land, planting crops, hunting, making things, working for wages, etc.

2.6 Model output(s)

There will be a range of outputs for different user requirements. One is intended to be a SimCity-type output called “SimForest” which allows one to observe the spatial changes in the forest over time. Another would be a dynamic map responsive to changes in input parameters – allowing one to analyse visually changes in policies or other instruments.

Specific environmental, social, biological, economic indicators are not spelled out.

Model is in development.

2.7 Data inputs

Not specifically defined, though they will be demanding. It will need, among other things, date on anticipated yields and prices on all possible crops under a range of situations, detailed tenure and demographic data and a good understanding of the community’s socio-economic culture. Some will come from sub-models, but others will come from survey work.

2.8 Uses

Simulation of changes in patterns of use of forest landscapes. Intended as a tool to synthesise existing knowledge and present in a clear, concise manner, to provide a basis for testing land use policy hypotheses and to serve as a planning tool for planners.

3. Computational issues

3.1 Solution method(s)

Simultaneous and sequential equilibrium.

3.2 Computer language(s)

Will likely implement it in AME (Agroforestry Modelling Environment) which has a graphical interface.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty will be addressed, but unsure as to what extent.

4.2 Inclusion of conditioning or environmental variables

Will likely be linked to macroeconomic, policy, ecological environment variables.

4.3 Integration and linkages

All internal components will likely be linked forward and backwards as well as to external environment.

4.4 Social Science issues

Intended to allow for heterogeneity of preferences, technologies, prices, endowments and or constraints.

Intended to consider non-material concerns.

4.5 Biological production issues

Livestock:
– details not specified.

Plants:
– details not specified.

Soils:
– details not specified.

Nutrient cycling:
– details not specified.

4.6 Ecological systems and sustainability issues

Details not specified.

5. Overall Assessment

5.1 Strengths

5.2 Weaknesses

5.3 Caveats and limitations

Some of the challenges of model development will be:

– quantification of a social profile of the actors in a community in a way that meaningful predictions can be made from a simple utility function;

– ability to quantify risks and attitudes to risk;

– modelling selected species interactions (both plant and animal) – this is more than modelling the energy relationships in a food web since symbiotic relationships, modification of micro-climate and so on may need to be included as well;

– scaling up beyond the village level since, due to limitations on model size, it may be necessary to extrapolate from a sample of actors;

– development of methods for sensitivity and benchmark testing.

5.4 Lessons learned

This was the general level of specification of the model prior to a workshop in Sumatra in January 1999 where a prototype decision model was built. Subsequent to that, further work on specification of an improved decision model is now underway – see “FLORES-decision.pdf” for details of the specification.

Key specifications:

– models of village, household and individual decision-making will be integrated with the bio-physical model of the system;

– there are 2 types of decisions which will be modelled – long-term strategic and short-term operational;

– the different classes of decisions will be modelled on different time steps (i.e. land allocation on an annual basis decided at village level and livelihood activities at household level on a weekly time step to co-ordinate with the weekly time step of the bio-physical model);

– will allow for population growth (births, deaths, formation and dissolution of households) and migration;

– model will define and track in various registers relations between individuals, households and villages, tenure relations and decision conclusions;

– the **annual model** will incorporate population dynamics, land tenure and inheritance, strategic thinking, resource negotiations and land use planning;

– strategic thinking decisions at the household level could use any of three approaches: goal-driven, value-driven, means-driven – the model will initially use a means-driven approach;

– “norm tables” are defined for different land use strategies and guide the allocation of labour by a household once it has decided on the strategy to adopt;

– the **weekly cycle** incorporates decisions on labour allocation to activities based on strategic plan of a household as well as consumption yields from the land and conversion of products;

– extensions to the model will allow for intensification of production, for a labour market for those who wish to hire or seek paid employment and for share-cropping and a refined land market.

Ginchi bio-economic model

1. Basic reference information

1.1 Model name

Ginchi Bio-Economic Model

1.2 Reference and source

1.2.1 Title

Bio-economic modelling of watershed resources in Ethiopia

Related material:

Okumu, B. N., M. A. Jabbar, D. Colman, N. Russell, M. Saleem, J. Pender. 2000. Technology and policy impacts on nutrient flows, soil erosion and economic performance at watershed level: The case of Ginchi in Ethiopia. (first DRAFT: not for quotation).

1.2.2 Author(s)

Okumu, B. N., M. A. Jabbar, D. Colman and N. Russell

1.2.3 Institution

ILRI

1.2.4 Date

1999

1.2.5 Key words

bio-economic models, watershed, resource degradation, nutrient mining, nutrient balances, erosion, dynamic programming, Ethiopia

1.3 Location

Africa, Ethiopia, central highlands, Ginchi watershed

Semi-arid tropics above 1500 metres elevation

Severely denuded, steeply sloping landscape with low and declining crop and animal productivity levels and high rates of soil erosion

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

Determination of the most cost-effective strategy for raising productivity in the watershed given the static traditional technology available (fertiliser is the only viable external input).

Two versions of the Ginchi model are generated:

1. static goal programming model which simultaneously optimises environmental and economic goals;

2. dynamic non-linear math programming model which optimises an aggregate watershed utility function.

2.2 Component(s) modelled

Animal and plant production systems through a generalised Cobb-Douglas production function.

Watershed level optimisation of land and labour use.

Feedback to productivity through use of modified USLE to change yield potential.

Estimation of nutrient balances for N, P and K.

2.3 Unit(s) of analysis

Watershed-level analysis wherein household decision-making is aggregated to the watershed level. A single decision-maker at the watershed level is justified on the basis of homogeneity at the community level – in terms of resource endowments and the nature of intra-household interactions.

Household-level analysis is limited since it ignores the spatial variation in the landscape and is unable to account for the resource multi-functionality, multi-dimensioned trade-offs and the importance of community participation in the solving of externalities.

2.4 Optimisation criteria

1. Static model: minimise deviations from a set of target objectives using a weighted goal programming model. Farmers are assumed to explicitly or implicitly set income and soil loss targets and to maximise income while causing as little erosion as possible so as to maintain yields in subsequent years.

2. Dynamic model: maximise watershed aggregate utility, which consists of cash income, leisure and basic food requirements. Incorporates the intertemporal effects of land use decisions. There is a constraint which restricts the stock of natural resources from falling below a certain level (the sustainability constraint).

2.5 Optimisation alternatives available

Available choices for production on the 4 different zones (land types) of the watershed are teff, wheat, other field crops, hay and grazing. Choice was constrained by static tradiational technologies on one hand and a set of new technologies on the other.

The multiple intervention scenario included the following additional technology options: drainage in low areas, HYV wheat, use of dung for fertilizer rather than fuel, eucalyptus plantings for fuel and wood, optimization of livesock numbers and improved marketing infrastructure.

Non-agricultural income is included as an option in the model.

2.6 Model output(s)

Cash income, land allocation to the various uses, total soil erosion, estimates of N, P and K balance and purchases of teff and wheat on a watershed basis as well as broken down by soil zone.

The static model was validated against observed data by specifying minimum teff and wheat areas to reflect consumption habits and a desire for self-sufficiency in grains and pulses. This was then used to develop the dynamic model. Additional validation of the dynamic model was done using crop budgets from other areas with similar environmental characteristics.

2.7 Data inputs

Soil erosion potential of land zones based on USLE modified for Ethiopia and it’s effect on yield in subsequent years. Requires inputs regarding land cover, management, rainfall and soil erodibility.

Data for input and output coefficients was collected by strucutured questionaire.

Accounts for seasonality of land and labour use as well as labour type (male, female and children).

Risk factors were not included due to data limitations and the size of the model which would be required.

The discount rate used is the bank rate for borrowed capital. There is no need to consider the discount rate for future generations since the sustainability constraint takes this into consideration.

2.8 Integration of components

Soil erosion is linked back to yields in subsequent years in the dynamic model.

2.9 Uses

Explore the impact of various institutional and policy scenarios on economic and environmental indicators - in particular income, soil loss and food self-sufficiency within the watershed.

3. Computational issues

3.1 Solution method(s)

Simultaneous solution.

3.2 Computer language(s)

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Risk and uncertainty is not addressed due to limitations on model size and due to inadequate time series data on most of the relevant variables.

4.2 Inclusion of conditioning or environmental variables

macroeconomic, policy, ecological environment variables?

linked to external market (supply and demand) or biological environment conditions?

4.3 Integration and linkages

The dynamic model adjusts yields every year based on the cumulative soil loss in prior years. Likewise, inputs are related to outputs through a Cobb-Douglas production function.

4.4 Social Science issues

The model uses a single representative decision-maker at the watershed level. It does allow for heterogeneity of natural resources by incorporating trade-offs among 4 land types within the watershed.

In the dynamic utility function the model assigns weights to the various possible activities. Farmers prefer those activities which are less risky but within culturally acceptable norms.

4.5 Biological production issues

The biological processes are empirically specified using a Cobb-Douglas production function which is adjusted in the dynamic model for the cumulative effects of soil erosion from one year to the next.

The modified USLE is used to determine annual soil loss which in turn is used to calculate cumulative losses with a weighted adjustment for loss of top soil vs. subsequent layers.

Used data from Nigeria to calculate percentage impact of soil loss on yields for different soils and slopes (due to lack of data for Ethiopia) but made adjustments for Ethiopian conditions based on expert judgement and intuition.

The division of the watershed into 4 zones (based on slope and soil type) allows for differential effects of the same amount of soil loss on crop yields across field types.

4.6 Ecological systems and sustainability issues

Sustainability is assessed in terms of accumulated soil loss.

The dynamic model addresses the issue of the long term effects of soil erosion on income and food self-sufficiency. By optimising over a short (4 years) and a long (12 years) time horizon one is able to demonstrate the impact of security of tenure on the natural resource base.

5. Overall Assessment

5.1 Strengths

Effectively linked the natural resources environment and its ecological characteristics to the community of human users and its socio-economic characteristics by defining the unit of analysis at the watershed level given that the human community is sufficiently homogeneous in decision-making at that level.

Able to assess ability of the watershed to supply sufficient food crops to meet minimum dietary intake needs of the population while evaluating the impact of such an objective on land use practices, soil erosion, nutrient balances and income.

5.2 Weaknesses

Assumes certainty in knowledge of prices and yields.

Assumes homogeneity on the part of decision-makers at the watershed level.

5.3 Caveats and limitations

The model could be adjusted to allow for heterogeneity in household resource endowments and other unique characteristics.

Limited by lack of linkages to the external market environment?

Would be worthwhile to run the model(s) specifying alternative goals and/or weightings to allow for reduced risk through diversified production and subsistence needs.

Sensitivity analysis of the discount rate on income and soil erosion was done. It was not done for the full dynamic model with all interventions included. Likewise, the various technology options were not assessed individually but rather incorporated into the model all at once and allowed to compete with existing activities and each other.

5.4 Lessons learned

The static model results (when the goal was assumed to be income maximisation) show that the community could increase income by a more specialised land use pattern, but with higher soil erosion. By so doing they could be self-sufficient in teff production and need to purchase less wheat. When optimising across 2 goals (income increase and soil erosion decrease) the model indicates further specialisation and more dependency on purchased food staples. However, people prefer more livestock than the model indicates and so don’t make these decisions based on optimisation behaviour. They also prefer a more diversified which results in a lower cash income, reduced soil erosion and reduced risk. They appear to be producing more for subsistence needs.

The short-run dynamic model produced cropping activities for the early years very close to the actual values. This may indicate that the farmers have a high time preference and want short-term gains. This may be a result of existing land tenure policy. Soil losses with the short time horizon were much higher than for the long time horizon – as one might expect. What one didn’t expect was that the projected income in the short time horizon model was only marginally higher than in the long time horizon model. Insecure land policy “creates an income illusion that promotes land degradation”.

There appears to be a strong trade-off between food self-sufficiency and soil erosion reduction with existing production technology.

GRAZPLAN

1. Basic reference information

1.1 Model name

GRAZPLAN

1.2 Reference and source

1.2.1 Title

GRAZPLAN: Decision support systems for Australian grazing enterprises - I. Overview of the GRAZPLAN project and a description of the MetAccess and LambAlive DSS. Agricultural Systems 54(1):57-76.

Related materials:

Freer, M., A.D. Moore and J.R. Donnelly. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems 54(1):77-126.

Moore, A.D., J.R. Donnelly and M. Freer. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - III. Pasture growth and soil moisture submodels and the GrassGro DSS. Agricultural Systems 55(4):535-582.

1.2.2 Author(s)

Donnelly, J.R., A.D. Moore and M. Freer

1.2.3 Institution

CSIRO, Australia.

1.2.4 Date

1997

1.2.5 Key words

computer-software. grazing-systems. weather. farm-planning. sheep-farming. animal-production. farm-management. decision-making. information-services. economics. lambs. mortality. climatic-factors.

1.3 Location

Australia, temperate grassland ecosystems.

2. Nature of model

2.1 Study and model type

Predictive.

Dynamic simulation model.

2.2 Component(s) modelled

Animal biology (any type of sheep or cattle), plant growth (any type of pasture), soil moisture, weather patterns, lamb survival and gross margin.

2.3 Unit(s) of analysis

Livestock enterprise (and whole farm).

2.4 Optimisation criteria

Not an optimisation model as described in the documents examined, although it appears that the intent is to integrate it into a whole farm model where the complete biological model is directed by a flexible management structure that has an optimisation facility.

2.5 Optimisation alternatives available

Simulation of various management and climate scenarios for sheep and cattle.

2.6 Model output(s)	Estimate the diet of animals and the production that will result from a particular management scenario. Can also estimate the need for feed supplements to either improve the situation or to ensure a specified level of output – weight gain, milk production or wool production. Sensitivity analysis is possible.
2.7 Data inputs	Based on a simple, but quantitative, description of the current state of the pasture and the animals which graze it. The model is driven by weather data, based on historical data or data provided by the user. Additional plant species can be added by defining new parameter sets containing the coefficients used in the equations. Using historical weather data, it can determine the probability of a particular set of circumstances.
2.8 Uses	To evaluate and compare the consumption and assimilation of herbage by various classes of cattle and sheep and thereby to predict their subsequent production of liveweight, milk, wool and offspring for particular management scenarios. Effects of year-to-year climate variability on farm profitability, feed availability and production.

3. Computational issues

3.1 Solution method(s)	Sequential.
3.2 Computer language(s)	Pascal for use in a DOS or Windows environment.

4. Key features captured and issues addressed

4.1 Uncertainty and risk	Can make probabilistic forecasts of particular climate and production events based on the range of historical climate data for the region in question.
4.2 Inclusion of conditioning or environmental variables	Linked to external biological environment through climate data and to economic environment through the prices used in the gross margin analysis.
4.3 Integration and linkages	The various sub-models are closely integrated and function on a daily time step.
4.4 Social Science issues	The model represents a single herd of cattle or flock of sheep, grazing up to five fields (paddocks). The characteristics of the pasture and flock/herd can be specified by the user according to the scenario being modelled. The model dynamically simulates the results of a specific management plan and weather scenario.

4.5 Biological production issues

Livestock:

– predicts intake of energy and protein, allows for selective grazing and substitution with supplements and estimates the use of the diet for maintenance and production;

– survival of young is modelled as a function of chill factor (rain, wind and temperature);

– the model accounts for seasonality in feed availability (quantity and quality) through the pasture growth module;

– distance to feed is not explicitly accounted for, but energy requirements for grazing are included and vary with slope and temperature;

– productivity is measured in terms of milk, meat and offspring (as well as fleece production in the case of sheep);

– does not model the water needs of livestock;

– genetic variations accounted for in the model parameters for breed of livestock;

Plants:

– the pasture growth module recognises four groups (annual and perennial grasses and forbs) in up to 5 fields/pastures/paddocks;

– phenological development is modelled and the transitions from one stage to the next are governed by the environmental variables (day length, soil moisture and temperature);

– shoot tissue is classified in terms of it's growth state (live, senescing, standing dead or litter) and digestibility and is thereby integrated into the diet selection and feed intake components of the animal biology module;

– net primary production is predicted in relation to light intercepted, temperature, available soil moisture and the stage of maturation;

– calculates the herbage available for grazing.

Soils:

– modelled as a soil moisture budget only (charging, evaporation from surface and subsoil layers);

– the soil moisture budget drives pasture growth.

Nutrient cycling:

– not modelled.

4.6 Ecological systems and sustainability issues

Not discussed.

5. Overall Assessment

5.1 Strengths

Constructed in a modular form with all the information necessary for a simulation run contained in "simulation files". These files contain the data required to initialise the soil, pasture and animal models as well as to access the weather data that drive the models. Similarly, the results are stored in a simulation file.

Can conduct 2 types of simulations:

– evaluation of the results of the model through time using climate data from several years;

– comparison of the results from an initial starting point over a short period of time using climate data from different years – derive a probability distribution of the outcome for an initial starting point.

5.2 Weaknesses

Lack of facility to handle grazing of shrub vegetation.

5.3 Caveats and limitations

Focuses on the above-ground processes – soil biological processes and nutrient flows are not included. Live underground tissue is modelled as a single pool. Neither is soil erosion or degradation modelled.

Interspecific interaction in the model is limited to interference competition only (radiation interception and use of soil moisture).

Lacking in details about the optimisation component of the model. Based on some information from the web, it looks like this component may not be fully developed and operational at the present time.

Is the model specified in such a way that it is valid for the tropics? Could parameter sets for tropical forages and pasture species be developed?

5.4 Lessons learned

The integration of the animal biology model with the pasture growth model appears well done.

The animal biology model appears to have potential for adaptation to African conditions since it incorporates grazing conditions and milk production into the model.

HILLPLAN/LADSS

1. Basic reference information

1.1 Model name HILLPLAN/LADSS

1.2 Reference and source

1.2.1 Title Modelling of grazing systems at the farm level. Ann. Zootech. 47:407-417.

Related materials:

Milne, J.A., A.R. Sibbald, K.D. Farnsworth and C.P.D. Birch. 1999. A model for predicting the impact of grazing animals on animal production and vegetation changes in temperate grasslands and rangelands. In: People and Rangelands: building the future. Proceedings of the VI International Range Congress, Townsville, Queensland, Australia, 19-23 July, 1999. Vols 1 & 2: 872-873.

Maxwell, T.J., G.W. Hill and K.B. Matthews. 1999. Sustainable rural land use. Journal of the Royal Agricultural Society of England 160:28-41.

1.2.2 Author(s) Milne, J.A. and A. Sibbald

1.2.3 Institution Macaulay Land research Institute, Scotland

1.2.4 Date 1998

1.2.5 Key words Decision support tools. Animal production. Vegetation dynamics. Grassland ecosystems.

1.3 Location

Europe, Scotland

Temperate.

2. Nature of model

2.1 Study and model type

Predictive.

HILLPLAN is a static model and predicts changes in vegetation, animal production and economic consequences of management plans.

LADSS dynamically allocates land to various uses so as to most closely match the criteria set by management – in terms of economic, environmental and social impacts.

2.2 Component(s) modelled

HILLPLAN models grazing dynamics for any number of fields and flocks on a farm. Within each field it can model any number of patches of vegetation and any number of species in each patch. Incorporates a model by Birch of vegetation dynamics under grazing to predict the proportion of species in a vegetation patch.

LADSS consists of a GIS (Smallworld) and a knowledge-based system (Gensym G2), is spatially explicit and contains land use modules for sheep and cattle grazing, barley cropping and deciduous or coniferous woodland systems.

2.3 Unit(s) of analysis

Both model the farm level.

2.4 Optimisation criteria	HILLPLAN: Not an optimisation model. LADSS: The land use plan which most closely meets the economic, environmental or social impact criteria set by the manager. Uses a “genetic algorithm” to “breed” solutions.
2.5 Optimisation alternatives available	HILLPLAN: Not applicable. LADSS: Allocates land among various uses (grazing, barley, woodland) based on land suitability criteria.
2.6 Model output(s)	HILLPLAN: prediction of changes in proportion of different vegetation communities due to grazing, prediction of animal production from flocks of sheep and herds of cattle, prediction of economic consequences of the plan as well as impact on bio-diversity. LADSS: Impact on farm finances, bio-diversity and landscape of the resultant pattern of land use. Outputs displayed visually in map form or in tabulated form and user can work with them interactively.
2.7 Data inputs	HILLPLAN: climate, soils and fertiliser levels. LADSS: the data requirements for the land use models and impact assessment models are not specified.
2.8 Uses	HILLPLAN: decision support. LADSS: strategic farm planning.

3. Computational issues

3.1 Solution method(s)	HILLPLAN: sequential. LADSS: simultaneous equilibrium
3.2 Computer language(s)	HILLPLAN: C+. LADSS: Smallworld (GIS) and Gensym G2

4. Key features captured and issues addressed

4.1 Uncertainty and risk	Not discussed.
4.2 Inclusion of conditioning or environmental variables	Not discussed, but presumably they are specified as input parameters.
4.3 Integration and linkages	Highly integrated within the models.
4.4 Social Science issues	Farm-level tools – not for households. Can specify resource endowments for the farm.

4.5 Biological production issues

Livestock:
- Not discussed.

Plants:
- Not discussed.

Soils:
- Not discussed.

Nutrient cycling:
- Not discussed.

4.6 Ecological systems and sustainability issues

Sustainability is assessed in terms of impact on bio-diversity.

5. Overall Assessment

5.1 Strengths

Comprehensive and interactive. Models change in species composition of grasslands at the field and patch levels.

5.2 Weaknesses

Does not deal with the household or landscape level.

5.3 Caveats and limitations

Not adapted to tropical systems?

5.4 Lessons learned

HILLPLAN uses the Australian grazing model GRAZPLAN which may be of relevance since it is based on the Australian feed system – a system designed for grazing conditions.

HyPAR

1. Basic reference information

1.1 Model name HyPAR

1.2 Reference and source

1.2.1 Title	HyPar: Model for agroforestry systems. User Guide Version 3.0. Institute of Terrestrial Ecology. Related materials: Mobbs, D. and G. Lawson. 2000. HyPAR Agroforestry Model www.nbu.ac.uk/hypar/. FRP Agroforestry Modelling Project. 1998 and 1999. Various articles. Agroforestry Modelling Newsletter, Numbers 6, 7 and 8.
1.2.2 Author(s)	Mobbs, D.C., G.J. Lawson and T.A.W. Brown
1.2.3 Institution	Centre for Ecology and Hydrology, Edinburgh, Scotland.
1.2.4 Date	1999.
1.2.5 Key words	HyPAR. Agroforestry. Modelling.
1.3 Location	Tropics. Semi-arid.

2. Nature of model

2.1 Study and model type	Predictive. Dynamic simulation model of resource capture and growth of tropical agroforestry systems. The HyPAR model is based on ‘Hybrid’, a model of forest canopies developed by the Institute of Terrestrial Ecology, and ‘PARCH’, a crop growth model developed by the University of Notting-ham, particularly for application in the dry tropics. Hybrid is a ‘hybrid’ of a detailed ‘big-leaf’ photosynthesis model, and a gap model that represents competition between individuals of different plant types. PARCH is an acronym of the ‘Predicting Arable Resource Capture in Hostile environments’.
2.2 Component(s) modelled	Models tree and crop growth, soil nutrient and water flows and light capture.
2.3 Unit(s) of analysis	Based on a field-level analysis (results on a per hectare basis), with fields sub-divided into plots for spatial representation.
2.4 Optimisation criteria	Not an optimisation model.
2.5 Optimisation alternatives available	Can simulate crop growth for maize and sorghum under agroforestry systems with different options for tree canopy management.

2.6 Model output(s)

Crop and tree growth, yield as well as nutrient, soil water and other variables over time – daily and yearly.

Tested for an agroforestry system in Kenya.

2.7 Data inputs

Based on soil, crop and tree-specific parameters and climate data. Also required is input about specific management options over the duration of the model scenario.

Can use daily weather from input files or generate it from monthly data based on latitude and longitude.

2.8 Uses

Whole system modelling of crop-tree interactions. Similar to WaNuLCAS.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

FORTRAN with a Windows interface for editing the ASCII parameter input files and linkages to EXCEL for data output and graphical analysis.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty is only addressed when the daily weather generator is used.

4.2 Inclusion of conditioning or environmental variables

Includes no economic analysis component. Designed as part of a modular system – e.g. can provide input to the BEAM economic analysis model.

Linked to external biological environment through specification of input parameters describing the particular conditions.

4.3 Integration and linkages

The soil water flow, nutrient flow, light capture and resource competition components are tightly linked.

4.4 Social Science issues

Does not use a representative agent. Based on a field level simulation of the results of a pre-specified set of management decisions and climate data for the period of the simulation.

It is a dynamic (multi-period) model.

4.5 Biological production issues

Livestock:
– not modelled though manure can be added to the field and plant material can be "removed" by grazing.

Plants:
– the crop model considers the effects of solar radiation, atmospheric humidity, temperature, soil water availability and nutrition, on crop growth and development;
– the crop model uses a daily time step for the simulation of crop growth. On each day, the available light, water and nutrients are 'intercepted' or 'extracted' and converted into assimilated dry matter. Depending upon the availability of these resources and the crop's ability to intercept them, its growth is considered as either light, water or nutrient 'limited';
– the tree model describes the daily cycling of carbon, nitrogen and water

within a unit of vegetation and combines a mass-balance approach to these growth resources with the capacity to predict the relative dominance of different plant types. Individual trees and the grass/crop layer compete with each other for light, water and nitrogen within a ‘plot’ of any size;

– crop model is presently limited to 3 sorghum and 1 maize cultivar though one can specify parameters for other crops and cultivars;

– tree canopy can be modelled as homogeneous or disaggregated;

Soils:

– modelled as several layers (up to 15);

– can choose one of 4 soil hydrology models.

Water and nutrient cycling:

– a multi-layer water balance simulates vertical redistribution of soil water, infiltration, drainage and soil evaporation;

– nutrients are cycled through various pools in the soil and into the plant systems.

4.6 Ecological systems and sustainability issues

Sustainability is assessed through changes in the key variables over time – production and soil carbon and nutrient levels.

5. Overall Assessment

5.1 Strengths

Ease of use for parameter entry and/or modification. Ability to output data to existing analysis software (e.g. Excel).

5.2 Weaknesses

Relatively few crop and tree options can be simulated at the present time.

No direct modelling of the livestock component.

5.3 Caveats and limitations

5.4 Lessons learned

Method of data input and output is useful.

IBIEHM

1. Basic reference information

1.1 Model name

IBIEHM (ILCA Bio-Economic Herd Model for Microcomputer)

1.2 Reference and source

1.2.1 Title

Application of a bio-economic herd simulation model to African cattle production systems: Implications for village milk production. Quarterly Journal of International Agriculture 34(4):372-385.

1.2.2 Author(s)

Itty, P.

1.2.3 Institution

ILRI

1.2.4 Date

1995

1.2.5 Key words

1.3 Location

Sub-Saharan Africa, any ecological environment.

2. Nature of model

2.1 Study and model type

Predictive.

Simulation model.

2.2 Component(s) modelled

Herd production, feed resource utilisation and economic performance.

2.3 Unit(s) of analysis

A herd of livestock.

2.4 Optimisation criteria

Not an optimisation model.

2.5 Optimisation alternatives available

Simulates herd growth and performance (physical and economic) over a 10-year period for a specified initial herd composition and management strategy.

2.6 Model output(s)

Can compare the biological (milk, meat and cattle offtake) and economic performance of alternative management strategies.

Accounts for milk production as one of the outputs in modelling the dynamics of cattle systems.

Can be used to perform sensitivity analysis.

2.7 Data inputs

Based on data readily attainable for traditional systems found in Africa.

Livestock data required relate to herd structure, live weights, offtake (slaughter, breeding and milk) and rates of calving and mortality.

Feed data requirements relate to rainfall, DM production of pastures, land areas, forage production, feed supplements and the nutritional content of the various feedstuffs (DM and crude protein).

Economic data required are input costs, output prices and exchange rates.

2.8 Uses

Simulation of the effect of changes in management and inputs on the biophysical and economic output of herd-based enterprises over a 10-year planning horizon.

Used for planning, determination of feed requirements, cost-benefit analysis and as a training tool for livestock management.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

LOTUS 1-2-3

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Deterministic – relies on mean values of variables rather than stochastic data.

4.2 Inclusion of conditioning or environmental variables

Linked to external environment through specification of input parameters such as rainfall, prices, mortality and calving rates, forage production in response to rainfall and feed quality.

4.3 Integration and linkages

The feed resources section is not linked to the animal production component.

4.4 Social Science issues

Models a specific herd as the representative agent. Herd composition and characteristics are specified for each scenario of the model.

4.5 Biological production issues

Livestock:

– model accounts for seasonality in feed availability and quality in the specification of feed resources available;

– productivity is measured in terms of milk, meat and offspring;

– variations in water quality, distance to water and other environmental variables which impact disease, insect and production variables are not explicitly included – accounted for through calving and mortality rates;

– genetic variations are accounted for in specification of herd composition.

Plants:

– not a biological model of plant production;

– calculates feed (from pastures, cultivated forage and purchased feed) availability in terms of DM and crude protein in relation to feed requirements of the herd at a point in time based on data specified in the feed resources section of the model.

Soils:
- not modelled.

Nutrient cycling:
- not modelled.

4.6 Ecological systems and sustainability issues

Not discussed. The main sustainability term relates to the NPV of the simulated outcome over the 10-year period.

5. Overall Assessment

5.1 Strengths

Relatively straightforward to use in terms of data requirements.

Explicitly incorporates milk production as a key output of the model, unlike many other livestock simulation models.

5.2 Weaknesses

Based on feed resources, the model determines whether feed requirements are met, whether or not there is overstocking and the amount of additional feedstuffs required, but does not link the feed and animal production variables.

5.3 Caveats and limitations

Were unable to include a stochastic simulation component due to the greater data requirements of such a model.

The study in question did not include crop-livestock interactions (such as manure production and animal traction) since they were not quantitatively accounted for in the productivity survey and there was insufficient secondary data.

5.4 Lessons learned

Milk production needs to be a component of animal production models for African village systems since it plays a key role in the profitability and productivity assessment of these systems.

La Lima bio-economic microwatershed model

1. Basic reference information

1.1 Model name La Lima bio-economic microwatershed model

1.2 Reference and source

1.2.1 Title

Impact of policy interventions on land management in Honduras: results of a bioeconomic model. Agricultural Systems 60:1-16

Related material:

Barbier, B. and G. Bergeron. 1998. Natural resource management in the hillsides of Honduras: Bioeconomic modeling at the micro-watershed level. EPTD Discussion Paper No. 32, IFPRI.

1.2.2 Author(s)

Barbier, B. and G. Bergeron

1.2.3 Institution

IFPRI

1.2.4 Date

1999

1.2.5 Key words

watersheds. land-use. vegetable-growing. erosion. farm-income. economic-impact. small-farms. environmental-impact. soil-conservation. land-management. ranching. agricultural-development. intensification. economic-policy. rural-development.

1.3 Location

Central America, Honduras.

Mixed hillside farming (1000-1800 metres), bimodal rainfall (1200 mm).

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

Recursive and dynamic LP model of economic behaviour linked to a biophysical model of plant growth and soil condition.

NB: This model is basically a further development of the **Burkina bio-economic village model** (see Barbier1.doc). For this reason, I will highlight the differences between the two model variations.

2.2 Component(s) modelled

Microwatershed labour market (interaction of two social groups – small farmers and ranchers), economics, plant, animal and forest production, soil erosion and interaction with local markets.

2.3 Unit(s) of analysis

Microwatershed.

Accounts for the entire microwatershed and allows the two social groups to interact at the level of the local labour market.

2.4 Optimisation criteria

Maximise aggregate utility of the whole microwatershed – discounted monetary value of future net income plus the closing value of livestock and the value of leisure (resource allocation and production decisions are made over a 5-year planning horizon).

2.5 Optimisation alternatives available

Allows for migration (in and out), selection of crop, animal and perennial (pine groves, coffee) production methods, allocation of output (consumption, storage and/or sale).

2.6 Model output(s)

Land use, income by group (farmer and rancher) and sector, income by source, soil erosion and use of conservation measures, shadow prices of production factors (esp. land and labour). Can simulate per capita income and soil erosion under various policy scenarios as compared to the baseline policy.

Validated for the microwatershed of La Lima for the 20-year period from 1975-95.

2.7 Data inputs

Population birth and death rates, market demand for surplus food and prices of inputs and outputs.

Production function parameters are generated using EPIC (Erosion Productivity Impact Calculator) to calculate average expected yield over a 12-year period. Epic was calibrated for the region.

2.8 Uses

Simulation of development pathways under different policy scenarios. Assessment of medium and long-term viability of agrarian systems at the microwatershed level as well as the differential impact on different social groups within the watershed..

3. Computational issues

3.1 Solution method(s)

Simultaneous and sequential. The multiperiod LP model (limited to the 5-year planning horizon) is simultaneously solved for the optimal solution. The first-year results are used recursively as the initial resources of a new multiperiod model for the following planning period (of which the first-year's results are used) and so on. The recursive nature of the model allows adjustments from year-to-year using real historical prices which are introduced into the model between simulations. The resources carried over from year-to-year in the simulation are population, livestock, tree volume, soil depth, soil conservation structures and plows.

3.2 Computer language(s)

GAMS.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Risk aversion is not addressed in the optimisation problem.

It appears that, unlike the Burkina Faso model, stochastic weather events were not incorporated into the model except, possibly, in the initial derivation of the production coefficients using EPIC.

4.2 Inclusion of conditioning or environmental variables

Population growth, possibilities of in/out-migration, prices of inputs and outputs.

4.3 Integration and linkages

Plant and animal production systems are inter-linked and linked to the natural resource base through stocks and measures of condition. Also linked to consumption and sales to the external markets and the use/export of labour. Between-year linkages include population, livestock, tree volume at different ages, soil depth, soil conservation structures and plows.

4.4 Social Science issues

Heterogeneity of resource endowment (differential access to water as determined by altitude and soil type) as well as farmer type (small farmer and rancher) is incorporated into the model. As a result it is possible to track income and other effects for the 2 farmer types in each of the 3 different sectors (determined by altitude).

The watershed makes dynamic decisions within the planning period (5 years). The outcome of the first year then affects the subsequent 5-year planning period (t + 1). It is unclear whether the 2 groups of farmers are optimised independently within the model – since the exact feedback effects are not clearly spelled out.

4.5 Biological production issues

Livestock:
– simulates the size and management of cattle, oxen and mules;
– herd growth determined by weight gain, births and mortality as well as sales and purchases;
– production decisions depend on labour, vet. expenses and feed energy from forages and purchased grain;
– environmental variables are not explicitly included.

Plants - annuals:
– parameters for simplified production functions generated using EPIC calibrated for the region – based on the average expected response to the different factors of production over a 12-year period;
– yields depend on type and fertility of soil, past management (input use, SOM, soil depth), use of animal traction (increase labour productivity but increase SOM mineralization), conservation methods;
– production is divided into 4 seasons.

Plants - perennials:
– pine groves, coffee (traditional and intensive) can be planted and cleared;
– abandoned crop or pasture land returns to forest;
– dead wood from perennials and wood from forest clearing can be used for fuel wood.

Soils and Nutrient cycling:
– uses 3 different soil types;
– erosion affects yields through both loss of nutrients in runoff and through change in soil depth;
– can adopt conservation measures to control erosion if profitable within the 5-year planning horizon;
– tracks soil depth and resultant impact on yields, etc.

4.6 Ecological systems and sustainability issues

Sustainability assessed through impact on income, soil status and population movements.

5. Overall Assessment

5.1 Strengths

Similar to the Burkina model with the added advantage of overcoming the limitation it had of assuming all households were the same – this model allows for household heterogeneity within the watershed by specifying 2 different types of farmers.

Very thoroughly calibrated – using 20 years of historical data for comparison.

Able to compare the actual events with what might have occurred under different policy scenarios.

5.2 Weaknesses

Does not incorporate risk aversion into decision-making and links the years only through price changes. Eliminates the linkage through stochastic environmental conditions.

5.3 Caveats and limitations

The year-to-year linkage is not so clearly defined.

5.4 Lessons learned

The long-term comparison with actual events/trends is unique. As a result, one would have considerable confidence that the model effectively incorporates the key factors and can be effectively used to simulate future events/trends.

Mali bio-economic farm household model

1. Basic reference information

1.1 Model name

Mali bio-economic farm household model

1.2 Reference and source

1.2.1 Title

Technology, market policies and institutional reform for sustainable land use in southern Mali. Agricultural Economics 19:53-62.

Related material:

Ruben, R., A. Kuyvenhoven and G. Kruseman. 2000. Bio-economic models for eco-regional development: Policy instruments for sustainable intensification. In book by Lee and Barrett.

Kuyvenhoven, A., R. Ruben and G. Kruseman. 1995. Options for sustainable agricultural systems and policy instruments to reach them. In: Bouma, J., A. Kuyvenhoven, B.A.M. Bouman, J.C. Luyten and H.G. Zandstra (Eds.), Eco-Regional Approaches for Sustainable Land Use and Food Production, pp. 187-212, Kluwer, Netherlands.

1.2.2 Author(s)

Kuyvenhoven, A., R. Ruben and G. Kruseman

1.2.3 Institution

Wageningen

1.2.4 Date

1998

1.2.5 Key words

farm household modelling, sustainable land use, intensification, policy interventions, Mali

1.3 Location

Africa, Mali, Cercle de Koutiala in southern Mali.

Semi-arid tropics, 800 mm rainfall.

2. Nature of model

2.1 Study and model type

Recursive LP and farm household bio-economic model for analysis of short and medium term reactions of farm households to changes in production conditions.

Explanatory and predictive.

Crop and technology choice is made on the production side through a multiple goal LP model (MGLP). Farm household modelling component is used to assess impact of price modifications on farm profits, factor allocation and land use. A recursive modelling framework wherein econometrically specified relations are used to guide the procedures for an LP optimisation of the production structure.

2.2 Component(s) modelled

Includes modules for price determination, household expenditures, production activities, farm household resources, savings and investments, goal weights and nutrient/carbon balances at the household level.

2.3 Unit(s) of analysis

Household.

2.4 Optimisation criteria

Multi-objective optimisation – consumption utility and adjusted net income (difference between net revenue and replacement value of nutrient losses – to account for sustainability).

2.5 Optimisation alternatives available

A combination of current and potential practices in crop and livestock production. Includes the possibility of off-farm income sources.

2.6 Model output(s)

Results are in the for of response multipliers – adjustment of factor allocation to parametric changes in market prices and institutional features.

Calibrated in the base year by comparison of land use pattern and activities under current prices against those determined by field survey data.

2.7 Data inputs

Farm household types based on survey data. Production coefficients based on crop simulation procedures (not specified precisely).

2.8 Uses

Used to measure the effect on sustainable land use and household welfare of adoption of alternative technologies, changes in transaction costs, access to credit and land taxes.

3. Computational issues

3.1 Solution method(s)

Simultaneous solution of LP model.

3.2 Computer language(s)

Not specified.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Limited. Weather risks are accounted for in the development of the production coefficients by weighting them according to the percentage of years which are dry, normal or wet. Price variation is accounted for by using a weighted average of the past 3 years prices to derive expected prices.

4.2 Inclusion of conditioning or environmental variables

Allows for changes in policy and price environment.

4.3 Integration and linkages

Consumption and production activities linked through the various modules.

Linked to external markets through prices and demand. Addition of a market-clearing module makes prices endogenous.

Incorporates dynamic properties through the savings and investment module which allows adjustment of the resource base in subsequent years.

4.4 Social Science issues

Identifies three farm types according to initial resource endowment of land, labour force, livestock and equipment. Typification based on survey data of resources, savings coefficients and time discount rates.

Are individuals making static decisions.

4.5 Biological production issues

Livestock:
– allows for use of crop residues for feed as well as rangelands in the area; – no indication is given about productivity measures
– nine different livestock activities are defined in the LP model – livestock component is not modelled separately.

Plants:
– crop simulation procedures and expert knowledge are used to define production input and output coefficients for existing and potential management practices;
–

Soils and nutrient cycling:
– impact of activities is measured in terms of soil loss as well as carbon and nutrient balances

Details of the crop, livestock and soils simulation modules are not given. It appears that they are used to derive the coefficients for the model, but it is not clear that there is feedback from one to the other.

4.6 Ecological systems and sustainability issues

Income, soil loss and nutrient/carbon balances are measures of sustainability.

5. Overall Assessment

5.1 Strengths

Clearly accounts for the different resource endowments of households and the different possibilities permitted by the different land resources in the area.

Incorporation of multiple goals into the optimisation procedure.

Response multipliers can be used to determine an aggregate supply response and, through estimates of demand, the impact on market prices of locally traded commodities.

5.2 Weaknesses

Appears to be limited to one year of analysis.

5.3 Caveats and limitations

Gives no indication of the changes which might occur over time.

5.4 Lessons learned

Structural policies appear to be more effective at reducing soil degradation than price policies – though their effectiveness is reduced when prices are determined endogenously.

The response multiplier appoach is unique.

A similar approach has been used by the author in work in Costa Rica.

NUTMON

1. Basic reference information

1.1 Model name

NUTMON

1.2 Reference and source

1.2.1 Title

Monitoring nutrient flows and economic performance in African farming systems (NUTMON): I. Concepts and methodologies. Agriculture, Ecosystems and Environment 71:37-48.

Related Material:

Van den Bosch, H., A. De Jager and J. Vlaming. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): II. Tool development. Agriculture, Ecosystems and Environment 71:49-62.

Van den Bosch, H., J.N. Gitari, V.N. Ogaro, S. Maobe and J. Vlaming. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems and Environment 71:63-80.

de Jager, A., I. Kariuki, F.M. Matiri, M. Odendo and J.M. Wanyam. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): IV. Linking nutrient balances and economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71:81-92.

1.2.2 Author(s)

De Jager, A., S.M. Nandwa and P.F. Okoth

1.2.3 Institution

LEI-DLO, Netherlands; KARI, Kenya

1.2.4 Date

1998

1.2.5 Key words

economics. nutrients. soil. monitoring. farming-systems. methodology. integrated-systems. soil-management.

1.3 Location

Africa, Kenya, three high and medium-potential districts (Kisii, Kakamega and Embu)

2. Nature of model

2.1 Study and model type

Explanatory.

Static research tool for assessing stocks and flows of nutrient and economic analysis of existing farm systems.

2.2 Component(s) modelled

Models nutrient and monetary flows at the farm and plot level for a farm household - accounts for annual production and use of animal, plant and human systems in determining net nutrient and financial inflows and outflows.

Consists of 2 components:

- NUTCAL for the quantification of nutrient flows;
- ECCAL(or ECMON) for the determination of economic performance.

2.3 Unit(s) of analysis

Farm household and individual plots.

2.4 Optimisation criteria

Not an optimisation tool, but assess potential for sustainability in terms of nutrient balance and economic health.

2.5 Optimisation alternatives available

Each run of the model is designed to describe the nutrient balance and economic status of an existing farm household. Presumably the model could also be extended to examine hypothetical situations.

Incorporates the hiring of outside labour and the income from off-farm activities as well as the import and export of nutrient resources.

2.6 Model output(s)

Measures of nutrient balance (N, P and K) and economic well-being for the period of analysis (one year). No sensitivity analysis.

Results have been tabulated for 26 farms in the 3 districts and comparisons made to country-wide nutrient balances estimates.

2.7 Data inputs

A mixture of primary data, estimates and assumptions.

Main data source is questionnaire administered to farms being analysed. Additional data come from market surveys, laboratory measurements, expert opinion and the scientific literature.

2.8 Uses

The quantification of nutrient flows at a farm level as well as economic parameters.

Not a predictive model.

3. Computational issues

3.1 Solution method(s)

Simultaneous.

3.2 Computer language(s)

Not specified.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Not addressed.

4.2 Inclusion of conditioning or environmental variables

Linked to external market through prices. No explicit linkage to biological environment conditions except through their effect on the yields provided by farmers and the particular transfer functions which incorporate precipitation, erosion and other average climate variables into the nutrient balance flows.

4.3 Integration and linkages

Model components are very closely linked and integrated.

4.4 Social Science issues

The model analyses the situation for a single representative agent. However, it allows for heterogeneity of technologies, prices, endowments and other circumstances/constraints in the specification of the individual characteristics which apply to each farm household.

It is limited to a static modelling of the results of a farm household’s management decisions over a year (data collected monthly by questionnaire).

Includes farm and household cash inflows and outflows as well as flows of labour and products (produce, fodder, manure) within the farm.

4.5 Biological production issues

Livestock:
- this is modelled as the Secondary Production Compartment;
- N, P and K flows as well as financial and other flows are monitored between it and the Primary Production Compartment and the Homestead as well as to/from the external environment;
- through the monthly collection of data, the model accounts for seasonality in feeding patterns;
- productivity per se is not measured since the primary purpose is monitoring of nutrient flows though this data is likely collected in the questionnaire;
- quantification of grazing and use of feed was based solely on the daily feed requirements of the animals;
- published data for N, P and K content of livestock outputs is used;
- genetic variations are only accounted for in the measurement of output.

Plants:
- crop growth is not modelled as such;
- data is based on actual analysis of samples of the crop products, manure and residues for N, P and K content and published data for the external inputs.

Soils:
- N, P and K content determined for most of the farms by soil analysis;
- erosion losses are determined by USLE adjusted by an enrichment factor;
- only the top 30 cm of the soil profile is modelled.

Nutrient cycling:
- modelled at the plot level;
- variations in manure quality and quantity are accounted for through analysis of samples;
- inflows: mineral fertilisers, atmospheric deposition, sedimentation, manure (grazing and spreading), organic fertiliser;
- outflows: leaching, gaseous losses, erosion (in addition to harvest losses).

4.6 Ecological systems and sustainability issues

Economic sustainability – in terms of the following measures:
- Income Minimum-Expenditure Quotient;
- Farmers Income Sustainability Quotient;
- Gross Margin Sustainability Quotient.

Biological sustainability:
- nutrient balances of N, P and K
- measured in terms of Partial Balance (those going through the farm gate under the direct control of the farmer) and Full Balance (includes immissions and emissions from and to the environment).

5. Overall Assessment

5.1 Strengths

Integrative and holistic study of the farm household – employing the results of biophysical and economic research.

Able to estimate the extent to which the farm household generates its income from nutrient mining.

Able to compare the situations of different farm household situations/types – i.e. different resource endowments.

Able to assess the economic and labour-related possibilities and constraints to adoption of alternative INM strategies (though the research reported in the 4 papers doesn't show this).

Applicable in low-data environments since it uses data from previous scientific work to estimate flows.

5.2 Weaknesses

Unreliability of the data for off-farm activities – in particular off-farm income.

Difficulty of interpreting the balances since they are not directly related to soil stocks and they are not broken down into proportions in the soil solution, organic matter, etc.

Transfer functions are not site-specifically validated.

5.3 Caveats and limitations

Does not appear to incorporate the benefits of crop rotation on nutrient balances. In some cases the study did not monitor complete production cycles of a crop.

Using nutrient balances as an indicator of sustainability has it's limitations since the method does not account for the stock of nutrients in the soil profile (Shepherd and Soule, 1998 discuss this issue – see Shephrd2.doc).

Since it is a static model, it cannot be used for predictions. Evaluation requires a dynamic model able to extrapolate over time.

Need to incorporate nutrient flows in subsoil as well as quantify feed consumption and manure excretion.

Need to develop alternative ways to measure off-farm income and imputed values for non-traded goods.

The questionnaire method is too long for ease of use.

5.4 Lessons learned

SAVANNA

1. Basic reference information

1.1 Model name SAVANNA

1.2 Reference and source

1.2.1 Title	The SAVANNA model: Providing solutions for wildlife preservation and human development in East Africa and the Western United States. http://www.futureharvest.org/ne.pdf also: Coughenour, M. B. 1994. Savanna - Landscape and Regional Ecosystem Model: Model Description. Register of Ecological Models, http://dino.wiz.uni-kassel.de/model_db/mdb/savanna.html
1.2.2 Author(s)	Coughenour, M., R. Reid and P. Thornton
1.2.3 Institution	Colorado State University, ILRI, Future Harvest
1.2.4 Date	2000
1.2.5 Key words	wildlife, dynamic and spatial models, East Africa
1.3 Location	Africa and North America, in particular East Africa and western USA. Grassland, shrubland, savanna and forested ecosystems.

2. Nature of model

2.1 Study and model type	Dynamic, spatially explicit simulation model for prediction of ecological change over time and space.
2.2 Component(s) modelled	Simulates effects of natural change, land use practices and management strategies. Represents the processes which give rise to ecosystem change – including plant growth, animal population growth and nutrient cycling. Includes components for human activity and welfare. Can model situations where people initiate and respond to change in the environment.
2.3 Unit(s) of analysis	Simulates landscapes composed of grid cells on a weekly time step over periods ranging from 5 to 100 years. Models activity of 100 to 1000 grid cells spatially across the landscape as well as proportions of grid-cell area and the vertical spatial structure above (vegetation canopy) and below ground (soil).
2.4 Optimisation criteria	Not an optimisation model. Simulates natural ecological processes.
2.5 Optimisation alternatives available	–

2.6 Model output(s)

Temporal and spatial-temporal output showing the average number of animals and plant biomass across the landscape and forward/backward in time.

2.7 Data inputs

The driving force is the climate data (precipitation, temperature, wind speed and relative humidity). Calculates solar radiation based on latitude, time and cloud cover data.

GIS data on vegetation, soils, elevation and slope – includes description of tree cover and height, herbaceous root biomass, plant species composition, soil water holding capacity, soil depth, soil nutrient content.

Can accommodate stochastic weather data.

2.8 Uses

Simulation of ecosystems dynamics, including changes in plant and animal populations as well as human component.

For example, has been used to predict outcomes of various scenarios on the plant, animal and human populations of the Ngorongoro ecosystem in Tanzania – more land under cultivation, more drought, more livestock, more water resources used by tourist lodges, more people.

Also used in Maasai Mara and Amboseli, Kenya.

3. Computational issues

3.1 Solution method(s)

Sequential over time.

3.2 Computer language(s)

Runs on DOS systems.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Can accommodate uncertainty in terms of the rainfall input data.

4.2 Inclusion of conditioning or environmental variables

External environment effects it through rainfall/weather variables. Can also specify policy/management restrictions which condition the simulation.

4.3 Integration and linkages

Links primary production to soil water budgets, nutrient cycles and pools, rainfall distribution, solar radiation and other climate data. Also links plant production and population processes as well as ungulate energy balance and their population processes.

There are links to human and livestock populations, but they are not defined in the information I have at this point.

Linked to GIS for data input and output.

4.4 Social Science issues

Human submodel focuses on economics of Maasai ranching using three household endowment levels – measured in terms of dietary energy flow, cash flow, sale, cropping decisions and livestock herding. Accounts for household location, roads, water wells and other aspects of community infrastructure.

Runs based on rules which are specified to model actual human behaviour.

4.5 Biological production issues

Driving force is monthly weather data which, in combination with the GIS data, is used to simulate rainfall events spatially throughout the area being modelled.

Submodels included are:

– **water budget** – simulates soil moisture dynamics including precipitation, interception, runoff, run-on, infiltration, deep drainage, bare soil evaporation, transpiration;

– **light** – simulates shading within and among plant canopies accounting for light extinction as a function of LAI;

– **net primary production (NPP)** – simulates plant biomass flows and dynamics, plant nitrogen uptake and losses due to herbivory and tissue mortality;

– **plant population** – simulate plant establishment, size and mortality – includes herb shrub and tree (6 size classes) components;

– **fire response** – simulates changes in biomass, plant size and numbers – uses fire severity maps to specify the spatial distribution;

– **herbivory** – simulates foraging as a function of diet selection, forage abundance, forage quality, accounting for temporal distribution – based on preference indices and relative forage abundance;

– **ungulate energy balance** – simulates weight and condition based on energy balance – intake is a function of biomass intake and digestibility – expenditure is a function of body weight and travel patterns;

– **ungulate spatial distribution** – simulates dynamic distribution among grid cells on a monthly basis according to habitat suitability (forage distribution, topography, water, vegetation structure, management);

– **ungulate population dynamics** – five sex/age classes wherein birth and death rates are affected by animal condition indices. Animals can be culled in a rule-based manner;

– **wolf (predation)** – simulates predation and wolf population dynamics – predation is a function of prey density and wolf population responds to prey intake.

Forward and backward linkages exist throughout the submodels.

Ungulates:

– accounts for seasonality in feed availability, quantity, quality and distance to feed – intake and diet composition depend on distribution and abundance of available forage;

– accounts for variations in water quality, quantity and distance through their impact on the Habitat Suitability Index which is used to redistribute the ungulate population on a monthly basis;

– there does not appear to be a specific disease submodel – the linkage to condition (and mortality) is primarily through forage intake;

– genetic variations can be accounted for by modelling different species or breeds separately;

Plants:

– includes components for nitrogen uptake, leaf growth initiation, biomass allocation, phenology and senescence and mortality.

Soils:

– simulates soil water budgets – determines available water in each layer and what is used by the 3 types of vegetation.

4.6 Ecological systems and sustainability issues

Sustainability is addressed through simulating how the population and ecosystem changes over time – does it improve or not? – is it in balance in the long term or not?

5. Overall Assessment

5.1 Strengths

Can simulate seasonal dynamics and seasonal bottlenecks.

Can simulate externally forced distributions (e.g. fencing or responses to a perceived threat of predation) through the Habitat Suitability Index.

5.2 Weaknesses

Data requirements are very large.

There is no data in the documentation I have which explains how predation is dealt with in the African context.

5.3 Caveats and limitations

This is not an optimisation model which looks for the best use given certain constraints. It simulates an ecosystem over time and how it changes in terms of the plant, animal and human population. The data requirements are very large and would therefore limit applications to areas where there is already an existing biophysical database in plant, animal and soil systems.

On the other hand it appears to be able to deal with micro and landscape-level issues and allow for extensive feedback from one component to the other.

Details of the household and economic components are lacking in the data I have found and so it is not possible to specify the behavioural, price/market and other assumptions incorporated into this component.

I have not been able to find published results of this model's use in the African context.

5.4 Lessons learned

SOLUS

1. Basic reference information

1.1 Model name SOLUS

1.2 Reference and source

1.2.1 Title

Integrated bio-economic land use models: An analysis of policy issues in the Atlantic Zone of Costa Rica. see Barrett for reference.

Related material:

Bouman, B.A.M., H.G.P. Jansen, R.A. Schipper, A. Nieuwenhuyse, H. Hengsdijk and J. Bouma. 1999. A framework for integrated biophysical and economic land use analysis at different scales. Agriculture, Ecosystems and Environment 75:55-73.

Bouman, B.A.M., R.A. Schipper, A. Nieuwenhuyse, H. Hengsdijk and H.G.P. Jansen. 1998. Quantifying economic and biophysical sustainability trade-offs in land use exploration at the regional level: A case study for the Northern Atlantic Zone of Costa Rica. Ecological Modelling 114:95-109.

1.2.2 Author(s)

Schipper, R.A., H.G.P. Jansen, B.A.M. Bouman, H. Hengsdijk, A. Nieuwenhuyse and F. Saenz.

1.2.3 Institution

Wageningen, CATIE, Costa Rica Ministry of Agr.

1.2.4 Date

2000?

1.2.5 Key words

Land use analysis. Sustainability. Policy decision support. SOLUS.

1.3 Location

Central America, Costa Rica, Northern Agricultural Zone, Caribbean Lowlands

Humid tropics (3500-5500 mm rainfall, 0-400 metre elevation).

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

Static LP optimisation integrated with GIS and Technical Coefficient Generators.

2.2 Component(s) modelled

Land use choices for sub-regions and land units within a region incorporating animal and plant production alternatives, nutrient balance and environmental externalities, labour supply and variable product prices.

2.3 Unit(s) of analysis

Regional level for optimisation.

Based on land use choices within sub-regions and land units.

2.4 Optimisation criteria

Selects optimal combination of land use per sub-region and per land unit so as to maximize the regional economic surplus (sum of producer and consumer surpluses).

Since output price and labour wage are variables too, the model selects the optimal P-Q combination of all products together that maximises economic surplus.

Subject to resource constraints (e.g. land and labour) and normative constraints (e.g. upper limits on sustainability indicators or lower limits on production levels).

2.5 Optimisation alternatives available

Selection among actual and alternative crop, forestry and pasture/animal production systems. Choice is made among production alternatives on particular land units (unique combination of soil, landscape and weather) within sub-regions defined according to transportation costs.

Can import labour from outside the region.

2.6 Model output(s)

Economic surplus, labour use, land use, and sustainability indicators (N, P and K balance, N losses (denitrification, leaching, volatilisation), pesticide active ingredients and biocide index.

Evaluated by solving with existing land use options without normative constraints and comparing to actual land use.

2.7 Data inputs

Biophysical: crop, forest, pasture and herd characteristics, management characteristics, weather data, land characteristics, soil properties, attribute data.

GIS: soils, roads, district boundaries, labour force distribution and protected areas.

Economic: input prices, base quantities of products and labour, elasticities of demand and labour supply, transport costs to markets, labour mobility costs, total labour size and discount rate.

2.8 Uses

Used to analyse different scenarios by varying:

– input parameters (e.g. input prices) via the technical coefficient generators;
– normative constraints w.r.t. sustainability parameters;
– land use options available within the model.

Quantification of trade-offs between scenarios.

3. Computational issues

3.1 Solution method(s)

Simultaneous equilibrium.

3.2 Computer language(s)

GAMS for the LP model.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty is not addressed.

4.2 Inclusion of conditioning or environmental variables

Product prices are endogenous as is labour wage.

Linked to external market (supply and demand) through elasticities of product and labour supply and demand.

Other linkages are not explicit, but through the technical coefficient generators used to build the LP model.

4.3 Integration and linkages

See above.

SOLUS (Sustainable Options for Land Use) consists of three integrated components:

- -- REALM LP model (Regional Economic and Agricultural Land use Model);
- -- 2 Technical Coefficient Generators or TCGs (LUCTOR and PASTOR)
- -- GIS data integration.

4.4 Social Science issues

Incorporates heterogeneity of technologies, resource endowments and constraints in terms of land use options and land unit characteristics. The REALM LP model incorporates endogenous prices and selects the optimal P-Q combination for all products taken together to maximize the sum of producer and consumer surplus.

Static (single-period) decisions optimised for the entire region.

NPV of production activities involving several years is calculated and incorporated into the model as the value of an annuity over the lifetime of the system.

The model evaluates several thousand actual and alternative land use systems for which the technical, economic and environmental sustainability coefficients are generated by the TCGs.

REALM simulates geographic variation in product prices by dividing the region into 12 sub-regions (according to transport costs – based on a regression model) and uses endogenous product prices based on econometrically estimated demand elasticities linearised around an observed base Q and P.

Incorporates both the sectoral (sub-regions) pool of labour and the possibility of hiring labour from outside a sector and from outside the region.

4.5 Biological production issues

Livestock:

– incorporates various possibilities for feed (5 pasture types, 5 feed supplements) and livestock (breeding and fattening) through alternative activities for which the TCGs generate the coefficients;

– the TCG for the pasture/livestock activities is PASTOR (Pasture and Livestock Systems Technical Coefficient Generator);

– genetic variations are not accounted for.

Crops:

– the TCG is LUCTOR (Land Use Crop Technical Coefficient Generator)

– coefficients account for nutrient requirements during growth and nutrient content of product harvested.

Soils:

– soil erosion is not modelled as the area is not considered to have serious problems in this dimension.

Nutrient cycling:

– modelled in terms of nutrient balance (N, P and K);

– values derived from the TCGs for each activity.

4.6 Ecological systems and sustainability issues

Sustainability is addressed in terms of **economics**:

- – labour use;
- – economic surplus;

and in terms of **environmental** indicators:

- – N, P and K balance;
- – N losses through (de)nitrification, volatilisation and leaching;
- – use of pesticide active ingredients;
- – biocide index.

5. Overall Assessment

5.1 Strengths

Able to assess the different impacts of taxation (e.g. a flat tax on biocides vs. a progressive tax) on economic surplus and environmental indicators.

Can be used to analyse land use change at the margin – e.g. impact of an increase or decrease in protected areas.

5.2 Weaknesses

Does not directly account for the farm level where actual land use decisions are made.

5.3 Caveats and limitations

There are limitations to the type of policy issues that can be explored – not suited to those related to improvements in extension or market operation for example.

It can explore the scope and possibilities of policy incentives at the aggregate level of the region – such as environmental taxes/subsidies and there effect on income, sustainability and environmental issues, consequences of policies prohibiting use of chemicals or creating buffer zones or other land use restrictions and the impact of changes in certain parameters such as wages and interest rates.

Not equipped to analyse the distributional aspects of changes in the economic surplus from scenario to scenario.

The gains (to the economic surplus and the environmental indicators) from use of alternative technologies are difficult to realize in reality due to the frictions that exist in real life.

The model optimises a measure of societal economic welfare rather than modelling what individuals will decide based on their individual priorities and constraints.

5.4 Lessons learned

The SOLUS modelling system has also been implemented at smaller scales (settlement and county levels) focusing on the decisions of small and medium farmers with respect to cropping options and using different technical coefficient generators and NUTMON for calculating the soil nutrient balances. The farm level served as the intermediate step between the land unit and the larger landscape unit since this is where land use decisions are made.

The SOLUS modelling system is such that the data flow between the GIS, the TCGs and the LP model is highly automated.

Sustainable stocking rate spreadsheet model

1. Basic reference information

1.1 Model name

Sustainable Stocking Rate Spreadsheet Model

1.2 Reference and source

1.2.1 Title	A spreadsheet model for the assessment of sustainable stocking density rate in semi-arid and sub-humid regions of Southern Africa. Livestock Production Science 61:287-299.
1.2.2 Author(s)	Pulina, G., E. Salimei, G. Masala and J. L. N. Sikosana
1.2.3 Institution	Field research: Matopos, Zimbabwe
1.2.4 Date	1999
1.2.5 Key words	multispecies herding, stocking rate, mixed grazing, model, arid and sub-humid regions

1.3 Location

Africa, Zimbabwe, Matopos Research Station.

Tropics, 1340 meter elevation, 570 mm average rainfall with one rainy season, highly variable (250-1400 mm/year).

2. Nature of model

2.1 Study and model type

Exploratory.

Assessment of grazing pressure and it’s compatibility with rangeland conservation.

2.2 Component(s) modelled

Forage production, animal nutrition and stocking rate of mixed species herds.

2.3 Unit(s) of analysis

Regional scale over a 12-month period. The region is divided into homogeneous units for the purpose of analysis (based on topography, soils and vegetation cover).

2.4 Optimisation criteria

Based on a nutritional approach – nutrients available from feed and nutrient needs of livestock being grazed. Assesses the numbers which can be grazed under three different definitions of optimal stocking density/rate – defined as minimum, intermediate and maximum.

2.5 Optimisation alternatives available

Not an optimisation model. Determines stocking rate (for multispecies herding) as well as Intake, DM and energy balance based on forage availability.

2.6 Model output(s)

Stocking rate and DM and energy balance of the ecosystem.

Performance tested on a 2500 ha area of the Matopos research station where goats, sheep and cattle were grazing together. Calculated stocking rates were within the range of those from other Matopos studies.

2.7 *Data inputs*

Information related to forage availability, surface area covered by each vegetation type, animal characteristics and livestock numbers, diet selected.

In this example data came from research station reports on plant production and average annual livestock data.

In practice, the forage availability (area/distribution of forage types, forage production on a DM/ha basis and forage availability coefficients) and livestock data (body weight, milk production, body weight gain) would be provided by the users.

2.8 Uses

A technical tool to balance livestock numbers to forage availability in large grazing areas.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

Excel spreadsheet.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty is not addressed.

4.2 Inclusion of conditioning or environmental variables

No direct linkages to the external environment. Only indirectly through forage yields and area of each type of forage.

4.3 Integration and linkages

Forage production and availability is linked to the amount available for use by the livestock.

4.4 Social Science issues

Not addressed.

4.5 Biological production issues

Animal nutrition module:

– calculates animal feed and intake requirements in terms of energy and DM based on NRC figures plus additional energy requirements for grazing on rangelands, lactation and gain

– user provides metabolisable energy content of fruit, flowers, tree foliage, shrubs and grasses;

– seasonality in feed availability, quantity and quality is not accounted for explicitly – only through the overall estimates of forage availability;

– productivity is not measured but used as an input into the nutritional requirements module;

– water is only accounted for in the calculation of energy requirements for travel;

Forage module:

– determines percentage of surface area covered by grass shrubs and trees (based on aerial photography);

– calculates the total DM available to the animals in practice based on estimates of forage production and availability coefficients for each forage source.

Soils and nutrient cycling:
– not included in the model.

4.6 Ecological systems and sustainability issues

Optimal stocking rate (SR) is defined in three different ways:
(a) **minimum**: based on the forage resource of the lowest availability (most limiting feeding resource), assuming it will be completely used;
(b) **intermediate**: based on forage resource of intermediate availability (intermediate feeding resource) – the minimum forage resource will be overgrazed;
(c) **maximum**: based on forage resource of highest availability – the other 2 resources will be overgrazed.

Dry matter balance is calculated and used to analyse impact on vegetation types of these different SR definitions.

5. Overall Assessment

5.1 Strengths

Simple to use.

5.2 Weaknesses

Not adapted to farm or household level scales of management. Cannot accommodate variations in vegetation types/mixtures within a management area. On the other hand, given the data, the model could be easily adapted/expanded to add this capability.

See above for notes about seasonality in feed and water.

5.3 Caveats and limitations

Critical points in the model are the estimates of forage availability and the selective behaviour of animals in mixed grazing situations.

Estimates are the responsibility of the user and therefore subjective. There is the potential for further work to develop objective estimates based on easily-measured parameters such as soil type, rainfall, temperature, type of vegetation and indicators of biomass yield.

5.4 Lessons learned

Vihiga, Kenya integrated farm household model for different resource endowments

1. Basic reference information

1.1 Model name

Vihiga, Kenya integrated farm household model for different resources endowments.

1.2 Reference and source

1.2.1 Title

Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems and Environment 71:131-145

1.2.2 Author(s)

Shepherd, K. D. and M. J. Soule

1.2.3 Institution

ICRAF

1.2.4 Date

1998

1.2.5 Key words

systems analysis. ecological economics. nutrient balance. sustainability indicators. farm systems. Kenya.

1.3 Location

Africa, Kenya, western highlands, Vihiga District.

High agricultural potential with severe nutrient depletion, bimodal rainfall of 1500-1800 mm per year, high population density.

2. Nature of model

2.1 Study and model type

Explanatory and predictive economic-ecological farm simulation model.

Dynamic, running in units of 1 year for a 20 year period. Economic component is not an optimisation model.

Designed to evaluate the sustainability and profitability over time of various farm sizes – categorised as low, medium and high resource endowment (LRE, MRE, HRE) – but can also be sued to evaluate alternative production systems.

Land use options are maize, beans, fodder grass, pasture and woodlot. Dairy cattle are Zebu or Fresian.

2.2 Component(s) modelled

An economic-ecological simulation which links the biophysical and economic processes at the farm household scale.

Ecological and economic sub-models are divided into 7 principal compartments (fields, hedges, woodlot, natural pasture, livestock, compost and homestead) and flows between them are measured in terms of C, N, P and monetary value.

2.3 Unit(s) of analysis

Farm scale – the unit of decision for the household.

2.4 Optimisation criteria

Not an optimisation model. Designed to analyse improved soil management practices over time whereby changes in available nutrient supply indicate on-farm sustainability and changes in farm income indicate the potential adoptability of the system being modelled.

2.5 *Optimisation alternatives available*

Allows specification of farm size, household characteristics, land use and management practices as well as opportunities for work off the farm for each run of the simulation model.

2.6 Model output(s)

Simulates farm production, soil sustainability indicators and economic returns to farming and to household labour for farms with different resource endowment levels.

No sensitivity analysis reported.

The model was validated for crop and milk yields against local survey data. It was also validated for self-sufficiency in maize and wood production.

2.7 Data inputs

Data inputs include:
– farm areas (proportions of area in different uses);
– climate (precipitation and soil temperature);
– plant growth variables, plant parts, plant nutrients and plant management;
– soil characteristics;
– livestock (numbers, weights, time grazing off-farm, calving, etc.);
– compost (composition and fraction returned to field);
– economic (family size, input quantities and prices, output prices, labour wage and labour requirements, self-sufficiency requirements for grain and wood;
– fixed parameters related to related to composition of milk, soil pools and flows of C, N and P, moisture content of plant products, fodder intake limits and decomposition rates.

2.8 Integration of components

Linked through flows of C, N, P and money between the 7 compartments.

2.9 Uses

Assessment of the biological and economic sustainability of different farming systems with different initial resource endowments.

3. Computational issues

3.1 Solution method(s)

Sequential.

3.2 Computer language(s)

Stella II model building software.

See Shepherd and Soule (1998) for full description and computer code.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Not incorporated into the model.

4.2 Inclusion of conditioning or environmental variables

Macroeconomic, policy, ecological environment variables are provided as input factors, but there is no dynamic linkage.

4.3 Integration and linkages

Ecological sub-model is inter-linked through soil management practices, soil nutrient availability and plant productivity. External linkages are primarily through climate variables.

Economic sub-model is linked to the ecological sub-model through the various outputs from production, to the external environment through input/output prices, opportunities for off-farm work and back to the ecological sub-model through the impact of farm production and management decisions on the level of nutrients available for the following year.

Considers annual material flows between the various compartments of the farm system as well as across the farm system boundary.

4.4 Social Science issues

The model permits specification of resource endowment levels, management options/technologies, prices and other constraints.

Self-sufficiency fractions can be specified and it can be determined if the system can meet them.

The model is a multi-period dynamic model.

4.5 Biological production issues

Livestock:
– simulates milk and calf production separately for herds of local and imported breeds based on herd numbers entered directly;
– C, N and P are partitioned into milk and excreta by the model;
– proportion of year that local cows graze off-farm and the quality/quantity available is specified by the user;
– fodder sources on and off-farm are available for use;
– model does not account for variations in water quality, quantity, and distance
– other environmental variables are not included.

Hedge and tree compartments:
– above-ground productivity entered directly.

Field compartment:
– effective areas occupied over the course of the year by the various plant types are entered directly;
– model calculates N and P demand and availability based on input values and calculates growth.

Soils and nutrient cycling:
– simulates soil C, N and P dynamics for the topsoil and mineral N for the subsoil as well;
– soil pools are adjusted for erosion using the USLE with feedback on plant cover from annual biomass production.

Compost:
– plant residues can be allocated to compost and the proportion returned to the field is specified by the user.

4.6 Ecological systems and sustainability issues

Short-to-medium term (20 years) sustainability is measured in terms of soil erosion and nutrient balances as well as in terms of time trends in soil carbon and nutrient supplying capacity. Economic sustainability is measured in terms of net farm income and household income.

5. Overall Assessment

5.1 Strengths

Provides details of the long-term trends in soil nutrient supply capacity and in soil carbon levels for different farm systems.

Is able to disaggregate nutrient balances and flows by farm type and so demonstrate the different status of LRE, MRE and HRE farm households.

Incorporates the concept of the farm household and the potential for outside sources of income.

Incorporates the idea of subsistence production through the use of self-sufficiency ratios for food grains and firewood.

5.2 Weaknesses

Lack of an optimisation/decision-making component.

5.3 Caveats and limitations

Does not consider competition for growth resources between compartments (field, hedge, tree areas) although within the field compartment nutrient resources are shared. Does not consider sedimentation of eroded soil within the farm.

Annual time period for analysis limits the detail in nutrient trends and economic budgets. Seasonality in rainfall, nutrient availability, fodder quality, prices and labour demand is not directly accounted for although aggregate is used from both seasons. Variations in annual rainfall could be accounted for, but weren’t since nutrients are always the limiting factor in production.

Production inputs are from physical data rather than from an optimisation problem.

Understates value of total farm production since the homestead area is not modelled.

5.4 Lessons learned

Provides valuable confirmation of the importance of accounting for (1) the farm household as an entity rather than looking simply at the farm firm, (2) heterogeneity in resource endowments and (3) the use of production for subsistence needs.

Could this basic model be expanded to allow for seasonal variations?

Could it be linked to additional sub-model components which model markets, climate variables and the decisions of other farmers in the area on a spatial basis?

WaNuLCAS

1. Basic reference information

1.1 Model name WaNuLCAS (Water, Nutrient and Light Capture in Agroforestry Systems)

1.2 Reference and source

1.2.1 Title

WaNuLCAS 2.0 Background on a model of Water, Nutrient and Light Capture in Agroforestry Systems. Downloaded from www.icsea.or.id/wanulcas/index.htm

Related material (based on version 1):

Van Noordwijk, M. and Lusiana, B., 1999 WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. Agroforestry Systems 43: 217-242

1.2.2 Author(s)

Van Noordwijk, M. and Lusiana, B.

1.2.3 Institution

ICRAF Southeast Asia

1.2.4 Date

2000

1.2.5 Key words

agroforestry-systems. alley-cropping. intercropping. trees. soil. crops. interactions. soil-water. mathematical-models. plant-water-relations. plant-nutrition. nitrogen. soil-water-balance. nutrient-uptake. sloping-land. fallow. simulation. spacing. pruning. roots. soil-depth. light. plant-competition.

1.3 Location

Humid and semi-arid tropics (as far as I can tell). Unclear from the documentation as to the range of climate zones it is intended to cover.

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

Dynamic simulation model of tree-crop-soil interactions at the field/plot level.

Based on the above and below ground architecture of tree and crop, basic tree and crop physiology and soil science.

2.2 Component(s) modelled

Models the tree, crop, nutrient (N and P), water and light interactions and flows at the field/plot level. Includes a cost-benefit calculation component.

2.3 Unit(s) of analysis

Field level (with 4 zones or patches within the field).

2.4 Optimisation criteria

Not an optimisation model.

2.5 Optimisation alternatives available

Simulates the performance of specific agroforestry systems alternatives (up to 3 tree species and 1 crop/weed species) over a period of years (specified by the user) under a specified management regime and ecosystem (soil type, slope, nutrient content, rainfall and light).

2.6 Model output(s)

Biomass production of components, nutrient balance, water balance, NPV over a production cycle. Can perform sensitivity analysis to changes in particular parameters.

Results have not yet been tested against specific data sets, nor has parameter fitting been done. To date most of the work has been to demonstrate that it can be applied to a variety of agroforestry research questions.

2.7 Data inputs

Key data is input from spreadsheet tables that are part of the WaNuLCAS model – e.g. climate, calendar of events,

Designed to be used with independently measured parameters.

2.8 Uses

Exploring positive (complementarity) and negative (competition) interactions for different combinations of trees, crops, soil, climate and management.

3. Computational issues

3.1 Solution method(s)

Sequential solution.

3.2 Computer language(s)

Stella Research modelling software linked to Excel spreadsheets.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Uncertainty is only addressed in terms of the probability of particular rainfall events that goes into the daily time-step of the model.

4.2 Inclusion of conditioning or environmental variables

Primarily a biological model with a cost-benefit component. This provides a linkage to the economic environment through prices and interest rates. To the extent possible, the model is based on parameters that can be independently measured rather than empirical data sets.

4.3 Integration and linkages

The model is directly linked to the particular ecosystem (through the environmental variables related to weather and soils) and to the management regime.

4.4 Social Science issues

Is not a decision-making model. It can, however, simulate the results of decisions made based in a particular set of preferences, technologies, prices, endowments and constraints.

4.5 Biological production issues

Zonation:
– the agroforestry system is divided into 4 zones with Zone 1 for the trees and Zones 2-4 for the crops with the intensity of the above and below ground interaction between the trees and crops decreasing from Zone 2 to 4.

Calendar of Events:
– tree management (start, pruning, cutting), crop planting, fertilisation, slashing, plowing and climatic data (from daily event tables, random event generator or monthly averages) are specified prior to simulation;
– harvest, burning, etc. are determined by the model.

Livestock:
– a livestock component is not included, but the model can be used to predict fodder production – the tree pruning rules can be used to describe

fodder harvesting or grazing. In such a case external inputs of manure may have to be included.

Crops and trees:
– a sequence of up to 5 crop types can be specified for the duration of a simulation for each zone;
– accounts for canopy interception of rainfall in modelling soil water flows;
– models tree and crop root growth by using root length density formulas;
– models light capture by trees in terms of BAI (Branch Area Index) and LAI and by crops in terms of LAI, but accounting for shading of trees;
– calculates crop and tree growth through the use of existing crop and tree growth models.

Soils:
– soil biota are accounted for in the parameters of the decomposition component;
– soil field capacity, water retention and flows are calculated by the model from soil texture, organic matter and bulk density measurements using 'pedotransfer' functions;
– temperature data modify the soil organic matter transformations;
– accounts for soil redistribution on slopes.

Nutrient cycling:
– models N and P balance by tracking stocks and flows of organic and inorganic N and P at the patch scale;
– accounts for external inputs of fertiliser and organic N and P, atmospheric N fixation, lateral in and out-flows of N and P and biomass inputs and outputs of N and P;
– includes components for N and P uptake (potential, nutrient deficit and actual) as well as leaching losses.

Water balance:
– incorporates components for infiltration, storage, evaporation and uptake;
– models hydraulic lift and sink;
– calculates lateral flows, run-off and run-on.

4.6 Ecological systems and sustainability issues

Sustainability is evaluated over time through the trends in biomass accumulation as well as C, N and P balances.

5. Overall Assessment

5.1 Strengths

So as to capture the inter-species effects which are a problem in single-species resource capture models, WaNuLCAS calculates total resources capture and shares it out over the components in proportion to their root length density or leaf area.

Built on well-established models of soil, water and nutrient balance as well as models of tree and crop growth and development.

Can be used to model either simultaneous or sequential agroforestry systems.

Based on an open modelling frame which allows users to add other relationships when and where they wish.

5.2 Weaknesses

Unable to simulate crop-weed interactions within a zone at the present time.

5.3 Caveats and limitations

At present it is a prototype model.

5.4 Lessons learned

WaNuLCAS gives similar results to the HyPAR model (www.nbu.ac.uk/hypar) for tree-soil-crop interactions, however, the HyPAR model treats the aboveground processes in more detail and gives less elaborate treatment to the belowground processes than WaNuLCAS.

Designed to generate output that can be used directly by existing spreadsheet and graphical software.

Zambia Household Model

1. Basic reference information

1.1 Model name

Zambia Household Model

1.2 Reference and source

1.2.1 Title	Peasant household modelling: Farming systems evolution and sustainability in northern Zambia. Agricultural Economics 9(3):241-267.
1.2.2 Author(s)	Holden, S. T.
1.2.3 Institution	Norwegian Agricultural University, NORAGRIC.
1.2.4 Date	1993
1.2.5 Key words	maize. fertilizers. technical-progress. cassava. peasant-farming. crops. substitution. farming-systems. sustainability. models. land-use. shifting-cultivation.

1.3 Location

Africa, Zambia, Northern Province.

Sub-humid tropics, 1200-1500 metres, 1000-1600 mm rain per year, unimodal.

2. Nature of model

2.1 Study and model type

Explanatory and predictive.

LP optimisation model – a combination of lexicographic and weighted goal programming models.

2.2 Component(s) modelled

Household decision-making behaviour, incorporating household goals and constraints.

2.3 Unit(s) of analysis

Households of various resource endowments, different goal sets and with different land use options.

2.4 Optimisation criteria

Optimise on two different sets of goals:

1. **Traditional society:** Minimisation of labour required based on a “limited material wants” hypothesis (a variable income constraint – initially set to zero for 100% subsistence production);

2. **Modernised society:** Weighted income and leisure goal.

Optimise by trading off the expected utility of the expected marginal production against the marginal disutility of labour (marginal utility of leisure).

Income and leisure goals were weighted and combined into one objective function and other goals were treated as constraints.

2.5 Optimisation alternatives available

1. **Traditional society:** limited access to markets and only traditional technologies for food production and income generation and a standard household composition – used to analyse interrelationship between traditional cropping systems, population density and market access w.r.t. past historical development and the introduction of cassava in northern Zambia;

2. **Modernised society:** more market integration along with additional food production technologies and households of varying resource endowment and access to off-farm income opportunities – incorporated risk and soft seasonal labour constraints.

Modelled production, consumption and trading activities.

2.6 Model output(s)

Net income, income in a bad year (modernised society only), labour requirement, consumption and production and selling activities, area cropped by crop type, carrying capacity (traditional society) and land required per household (modernised society).

Evaluated by comparing results with observed land use patterns.

2.7 Data inputs

Household composition, types of production technology available, labour available, income preferences, etc.

Primary data based on surveys of 60 households from 3 villages with a range of population densities from 1986-89 (land use, yields, income and expenditures) as well as detailed time and cash-flow studies on a subset over an entire year. Additional, less formal, data came from an area of lower population density and secondary data sources.

2.8 Uses

Explain and predict farm household behaviour in terms of choice of cropping systems, input and output D and S, seasonal labour allocation and off-farm income as well as to analyse the ability of households to meet their needs under different conditions (e.g. population density, consumer-producer ratios in household, household preferences, technology options, market access, prices).

3. Computational issues

3.1 Solution method(s)

Simultaneous equilibrium.

3.2 Computer language(s)

Not specified.

4. Key features captured and issues addressed

4.1 Uncertainty and risk

Incorporated into production activities as safety-first constraints – ensuring that basic needs are met (energy, protein and minimum cash). Uses a minimum income constraint for the lowest acceptable income in a bad year.

Used expected production rather than production.

4.2 Inclusion of conditioning or environmental variables

Linked to external market through prices and possibilities for trade and off-farm income.

4.3 Integration and linkages

Production, consumption, labour/leisure and buy/sell activities are integrated.

Linked to the external environment by various price and land parameters.

4.4 Social Science issues

Models the farm household based on Chayanov's and Nakajima's subjective equilibrium theory of the farm household, but extended to include risk/uncertainty and seasonality.

Model a representative household, but allows for heterogeneity of preferences, technologies, prices, endowments, and constraints depending on the scenario under consideration.

Simulated the increasing marginal value of time by including constraints similar to the standard soft constraints of goal programming.

Households make static decisions.

4.5 Biological production issues

Livestock:
– not considered as an activity.

Plants:
– not modelled per se. Parameters in the model based on primary and secondary data on productivity, input requirements and labour;
– accounts for seasonality in production activities;
– simulates typical cropping systems and rotations, intercropping patterns and staggered planting.

Soils:
– not modelled.

Nutrient cycling:
– not modelled.

4.6 Ecological systems and sustainability issues

Sustainability is assessed in terms of the carrying capacity for the traditional systems and in terms of land area required per capita for the modernized systems.

5. Overall Assessment

5.1 Strengths

Clearly spells out the hypotheses to be tested and the results of the tests – i.e. that peasants are rational and adapt to changing conditions to maximize their utility.

Accounts for annual distribution of labour and possibilities for off-farm sources of income in the model.

Incorporates risk constraints into the model.

A useful tool to analyse the response of farming households to changing circumstances and the impact on carrying capacity (and sustainability).

Aids in understanding the persistence of traditional production systems.

5.2 Weaknesses

The biophysical elements of the food production system are not modelled.

5.3 Caveats and limitations

Limited to analysis over one period. However, it could possibly be modified to model sequential decisions over a period of years using biophysical sub-models to link the years by determining the "actual" production and outcome of decisions (which were based on expected production) and the resources to be transferred from year to year.

5.4 Lessons learned

Constructed indifference curves for the labour-income trade-off for the two different programming models.

A very useful layout to model the decision-making of the farm household. Seems to capture the essential components better than many. Potentially adaptable as a sub-model in other circumstances.