Low External Input Strategies for Sustainable Small-Scale Farming in Kenya: A Systems Dynamic Approach

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ABSTRACT

This study sets out to assess the significance of the implementation of low external input strategies on small-scale farming households in rural Kenya. Data collected on two surveys was used to develop a conceptual model of the system and establish links between different internal components within it. This enabled relationships to be made between changes in soil nitrogen (a limiting physical factor to agriculture) and household incomes (a socio-economic attribute). A system dynamic model was developed and used to test the influence of low external input strategies on small-scale farming under different scenarios. It is found that adopting low external input strategies or optimizing its practice could create several positive reinforcing feedback effects on small-scale Kenyan agriculture. It is also found that food crop cultivation is more sustainable in terms of net annual soil nitrogen balance than cash crop cultivation.

INTRODUCTION

It has been recognized that agricultural production in Kenya East Africa is characterized by a negative nutrient balance (Roy *et al*, 2003; De Jager *et al*, 1998). The situation in Kenya is only a microcosm of what is happening in Africa as a whole. According to Sanchez (2002) Africa's food insecurity is directly related to insufficient food production (not a crisis of distribution or lack of purchasing power as is the case in other parts of the developing world). Insufficiency of food production can be associated to two main causes: declining soil fertility and the problems of crop pests, weeds and diseases.

With regard to the problem of declining soil fertility, it has been estimated that the average annual rate of depletion of essential soil nutrients in Africa stands at 22kg of nitrogen, 2.5kg of phosphorus, and 15kg of potassium per hectare of cultivated land (Sanchez, 2002). The most common way of addressing this problem is through the use of mineral fertilizers. However as Sanchez (2002) and Ruben and Lee (2000) point out, small scale African farming households lack the financial resources to procure these fertilizers which are much more expensive in Africa than in North America, Europe or Asia. The second cause relates to problems associated with pests, weeds and diseases. Weed infestation, disease outbreaks and attack of food crops by pests have become more frequent (Oswald *et al*., 1996) with a fall in agro diversity and climate change. As is the case with chemical fertilizers, farmers lack the financial and technical resources needed to cope with this problem.

Given the limited financial resources farmers have for meeting the above challenges, government agencies, international and national non-governmental organizations have been looking into ways of overcoming these hurdles to agricultural productivity using local resources and technologies that demand minimum financial investments (Manyong *et al*., 1997; Giller and Cadisch, 1995; Reinjtjes *et al*., 1992). To be successful, such strategies must meet two objectives: i) ameliorate the extent to which farmers can improve food production and raise income with low-cost, locally-available technologies and inputs, and ii) obtain this in an environmentally sustainable manner (Ruben and Lee, 2000). A number of strategies have been developed and have undergone different levels of trials and tests with varying degrees of success. Some of these have been applied at varying scales in tropical agriculture with varying results: Young (1998), Palm (1995), and Cooper *et al*. (1996) present some results of agroforestry trials; Kwesiga and Coe (1994) present outcomes of short-term rotation with sesbania (*Sesbania sesban)*; Gan *et al.* (2003) and Sullivan (2003) present the outcomes of intercropping.

Many studies have explored the place and role of different input optimization strategies in tropical agriculture. Some have focused on the role these strategies can play in improving particular aspects of soil processes like nutrient cycling (Kapkiyai, 1996; Brouwer and Powell, 1995; Giller and Cadisch, 1995). Others have investigated the impact of these technologies on soil fertility generally and hence the potential for increasing yields through them (Woomer and Swift., 1997; Probert *et al.*, 1995; Reinjtjes *et al*., 1992; Bationo and Mokwunye, 1991). Some still, have looked at the impact of the adoption of these technologies on the economics of rural farming livelihoods (Molua, 2005; Shepherd, and Soule, 1998); It has been found that it is possible and practicable to optimize the use of nutrients in tropical agriculture through the use of affordable agronomic technologies like agro-forestry, intercropping and crop rotation (Reinjtjes *et al.* (1992). Most of these studies have limited the scope of their analysis on the adoption and use of only one out of the many agronomic technological options available. While this brings simplicity to the understanding of how individual technologies can help (or in the case of field trials, have helped) in improving agriculture, it is quite limiting in its representation of reality in tropical agriculture. One of the main features of agriculture in sub-Saharan Africa is the fact that there is a mixture of techniques and cultivated crops principally to serve as a bet-hedging strategy (Binswanger and McIntire, 1987). Hence one will likely find the practice of intercropping being associated with crop rotation, fallowing, some form of agro-forestry, and some livestock rearing or other practices.

There is therefore, need to examine the entire process of incorporation of agronomic technologies into tropical agriculture as a system with a much more holistic picture. For this reason, the agronomic technologies under consideration in this study will be agroforestry, crop rotation and intercropping. They will otherwise be collectively called low external input strategies (below called LEIS). Furthermore, while giving priority to soil fertility, the research agenda has given limited attention to human and sociological aspects of the adoption of innovative agronomic technologies (Nair, 1997). Hence aspects such as the costs and benefits of adopting different technologies, issues of access to and up-scaling innovations, and the role of adopting innovations on the socioeconomic situation of households has received limited attention. A few studies have made attempts at understanding the processes of decision-making that lead to the adoption of innovative agronomic technologies (Franzel *et al*., 2003; Manyong *et al*., 1997)

OBJECTIVES

This study set out to use a model of Kenya’s small-scale farming household in assessing the significance low external input strategies could play in small-scale farming systems in rural Kenya. This goal can be broken down to two objectives:

1. Examine the feasibility of incorporating and or optimizing the benefits of LEIS in small-scale farming systems in rural Kenya.
2. Assess the extent to which the incorporation of such practices could affect the soil nitrogen and socioeconomic situation of farming households and thus the sustainability of small-scale farms.

SCOPE AND LIMITATIONS

The socioeconomic context of farming households involves complex processes of income acquisition and expenditure (Ellis, 1998a; 1998b; and 1991; Dose, 1997). This study will limit its analysis to household income as an indicator of the socioeconomic situation of farming households. Within this context, inputs to household income and expenditures from it will be limited to income from, and expenditures to the agricultural activities. In the same light, farming practices involve complex interactions with the physical landscape. The outcome is a complex modification of the physical environment (Houghton, 1994). The study will limit its analysis to the effects of different agronomic practices on soil nitrogen (an indicator of the physical environment) and household income (an indicator of the socioeconomic situation of farming households). The unit of focus will be the individual small-scale farming household because it is the level at which land use and management decisions are taken (Tschakert, 2003; Golan, 1990). There is a short-term time limitation to the data collected and the analysis made of it. However, the model developed in this study could be used to forecast long-term trends.

MATERIALS AND METHODS

Data Collection in Case Study

Mumias is a district in the Western Province of Kenya with a size of 3606km^2; average annual precipitation of 960mm; and annual average temperature of 20^{o}C. According to Dose (1997), the population pressure on land resources in this district is high with as much as 76% of its land area under cultivation by small-scale farmers. Nyandarua on the other hand is located in the central province of Kenya. With a size of 3260km^2, this district in the Kenyan Highlands has generally cooler temperatures 15^{o}C; and lower precipitation 960mm (IWMI, 2008). The choice of Mumias and Nyandarua as case study sites for this study was made principally because they have been well established as research sites. It follows that, significant social networks have been created which could assist in gathering data. The socioeconomic contexts of most of its residents also provide most of the data desired by this study.

Data for this study was collected in a two-phase cross-sectional survey carried out in 2006 and 2007. To get an objective and representative survey, the services of agricultural field extension workers were used. Backed by a knowledge of farmers’ land holding status; cropping patterns; attitude towards information sharing; willingness to participate in surveys; and other such attributes, field extension workers identified farmers who would be interviewed. Questionnaires used for the collection of data in the 2007 survey were designed using among other things, the experience of the 2006 fieldwork. Through deep, semi-structured interviews information on farm household types, farm operations, financial flows, investments, as well as nutrient management was collected. Some data was gathered through farm walks and group interaction with farmers and farmers’ groups (Yin, 2003).

Tools and Approaches

Data obtained through the two surveys was complemented by published secondary data at district, regional and national level on Kenya. Tools of systems analysis were also used for the study. They include causal loop diagramming, feedback loop analysis and model simulation using STELLA software Version 9.0.1. The choice of systems analysis as an approach for this study is grounded in the justification given by Tschakert (2003, pp. 19). This author holds that systems analysis is a method that has proven to be "helpful in proceeding from a conceptual systems understanding of household resource allocation to a dynamic systems model". This view is supported by Shepherd and Soule (1998) who see the importance of systems analysis as a tool for *ex-ante* assessments of complex natural resource management practices over long time scales.

Model Description

To benefit from the whole perspective offered by the systems approach, four crops and four livestock types were combined into a model. This method of integration is partly inspired by Ellis, (1998a; 1998b), who saw the mean household income portfolio of most small-scale tropical farmers to be made up of resources from livestock, food crops, off-farm income and cash crops. The four crops include two food crops (potatoes and maize) and two cash crops (sugarcane and sugar beet). The food crops were chosen on the basis of their being widely cultivated in the study area (Table 1 shows the different crop parameters used in the model). While sugarcane is the main cash crop in Mumias, sugar beets are chosen because they are the main competing cash crop to sugarcane, though yet not well established. Their cultivation is presently under trial in both study areas.

Table 1 Parameter Table for Crop Sub-Model

Parameter	Description,	Value and Units
Crop yields per hectare [a; d]	Maize	1.6 tons/ha
	Potatoes	15.4 tons/ha
	Sugar beets	55 tons/ha
	Sugarcane	75 tons/ha
Economic costs of production [a]	Labour costs Fertilizer costs Seed costs Pesticide/Herbicide costs	Kenyan Shillings/hectare
Biophysical factors of production [a]	Rainfall	
	Soil type	5-class fertility scale
Crop residues [b]	Residues	tons residues/ton yield
Nutrient (nitrogen) content of harvested crops and residues [c]	Maize grains	16.8 kg/ton
	Maize residues	9.7 kg/ton
	Potatoes	4.4 kg/ton
	Potato residues	2.3 kg/ton
	Sugarcane	0.6 kg/ton
	Sugarcane residues	0.3 kg/ton
	Sugar beets	4 kg/ton
	Beet residues	1.5 kg/ton

Source: [a] = and b Ministry of Agriculture Kenya (2003; 2004; 2005); [b] = Acland (1986); [c] = FAO (2004); [d] = Questionnaires

Four dominant livestock types kept by Kenyan small-scale farmers (cattle, goats, sheep and chicken) are used. Parameters used in the livestock sub-model are listed in Table 2. The reason for integrating four livestock types to food crops is because it is the minimum for achieving a balance between complexity and simplicity while still capturing the reality in rural Kenya's small-scale farming households. To complete the model, two other sub-systems are added - the nutrients and household economy sub-systems (Figure 1 and Figure 3 respectively).

Table 2 Parameter Table for Livestock Sub-Model

Parameter	Description, Value and Units	Value and Units
Livestock production [a] and [b]	Milk production Cost prices Birth & death rates	Liters/animal/year Kenyan Shillings/animal Varies
Economic costs of production [a]	Labour costs Feeding costs Medical costs	Kenyan Shillings/animal
Manure production [a]	Manure per animal	tons/animal/year
Nutrient content of manure [c]	Cattle dung Goat/sheep dung Chicken manure	0.30% 0.65% 2.8%

Source: [a] Ministry of Agriculture Kenya (2003; 2004; 2005); [b] = Questionnaires; [c] = Roy et al 2006

The main characteristics of small-scale rural farming households in Kenya that the model design intends to include: the production of several crops at a time; the rearing of small numbers of animals alongside crop production; carrying out farm operations on generally small holdings with relatively poor but varying levels of fertility; the limited use of chemical fertilizers and other agricultural inputs; heavy reliance on family labour with the employment of outside labour only if household labour is insufficient; and where household consumption needs overrides cash profit maximization (Shepherd and Soule,1998; De Jager *et al*, 1998; Dose, 1997; Oswald *et al* 1996; Probert *et al*., 1995; Binswanger, and McIntire, 1987).

To decide the timescale over which the model would be run, a compromise had to be made between: the length of time small-scale farmers may need to justify their economic decisions; and the time it could take to observe meaningful biophysical changes on farms after the implementation of a change in an agricultural practice. From deep interviews, on the field, it was evident that small-scale farmers generally make plans for no longer than five years ahead. The physical environment on the other hand responds much more slowly to subtle stimuli like changes in agricultural patterns. Response times could range from a few decades to hundreds of years. A length of simulation of 30 years was therefore chosen as a rough compromise between these two extremes.

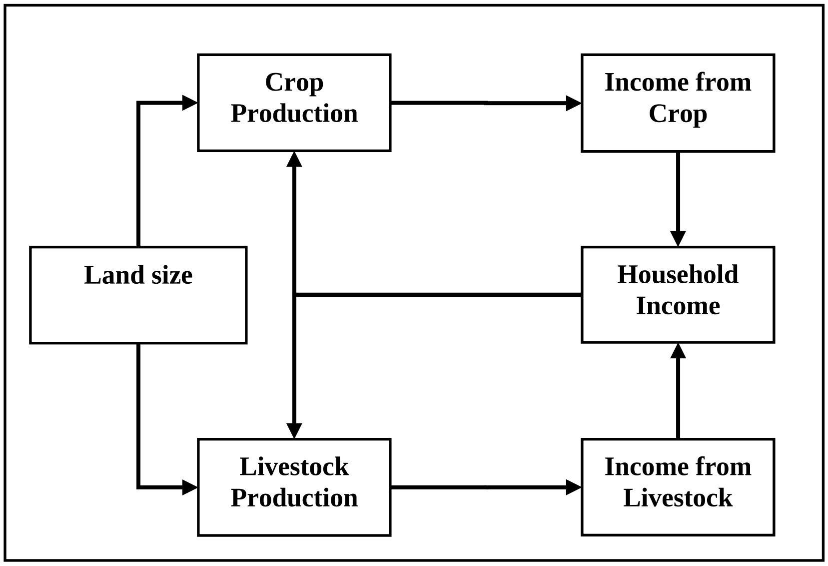


Figure 1 Stock-and-Flow Diagram of the Household Income Sub-System

Plant sub-systems consist of biophysical crop growth determinants (soil type and rainfall); economic inputs in crop production (cost of fertilizers, seeds, labour, pesticides, etc); a computation of crop losses that may be incurred during harvesting, transportation and storage; income from crop sales; and the accumulation of residues from crop harvest (see Table 1). Soils have been divided into five classes – very clay; clay; loam; sandy; and very sandy. The response of crops to precipitation was based on rainfall data from IWMI (2008) and crop response factors to water stress based on Acland (1986).

Livestock sub-systems consists of three main sectors (Table 2): animal production (young animals, eggs, milk, etc); economic costs of production (expenditures incurred in labour, supplementary feed, medical care and others); and livestock income (from the sales of animals and associated products). In livestock sub-systems (as with plant sub-systems), income from these activities is the main driver of the household decision to engage in production (Figure 1).

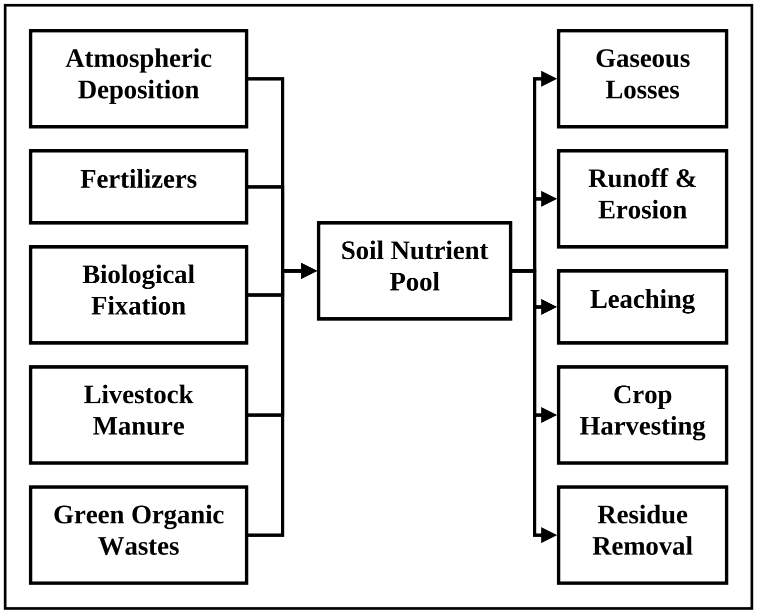


Figure 2 Structure of the Nitrogen Sub-System

The *nutrients sub-system* computes nutrient (nitrogen) balances in the system at farm scale. The main reason for using nitrogen as a proxy for the soil fertility is because nitrogen has been identified as being the most limiting nutrient in small-scale agricultural productivity in Kenya (Shepherd, and Soule, 1998; Smaling *et al*, 1997; Stoorvogel, and Smaling, 1990). In this sub-system, inputs and outputs of nutrients are balanced from natural and anthropogenic processes as shown in Figure 2.

RESULTS

The Small-Scale Farming System in Kenya (Business as Usual Scenario)

Limited household income constitutes a hindrance to increased crop and livestock production in small-scale farming households in rural Kenya. The fact that low external input practices are not optimized means that farmers have to depend on chemical fertilizers to increase crop yields. They also have to depend on herding or the purchase of forage to increase livestock production. The fact that this category of farmers has small incomes limits growth of agricultural productivity which in turn limits growth in household income. This is the scenario presented in Figure 3.

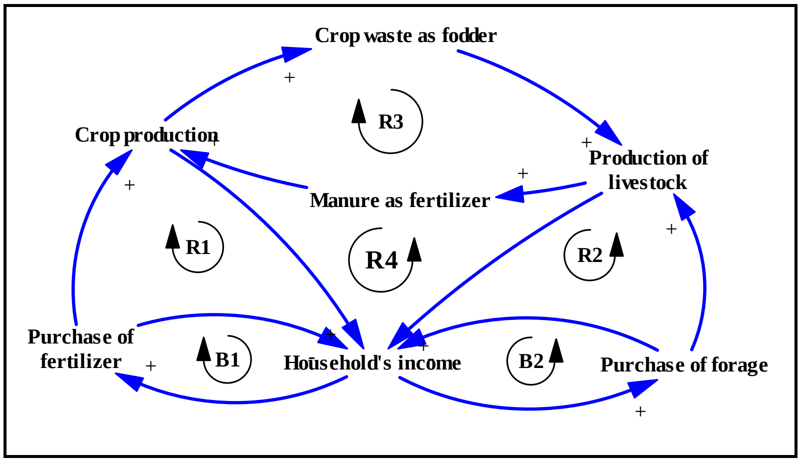


Figure 3 Constraints of Fertilizer and Purchased Forage on the Growth of Household Income

In Figure 3 R1 represents increases in crop production that should be expected if access to chemical fertilizers was not a constraint; B1 represents constraints imposed by limited household income on the use of chemical fertilizers. R2 represents increase in livestock production that could be obtained if access to fodder were not limited by household income; B2 represents the constraint imposed by limited household income on access to fodder. R3 represents the mutual relationships between the two sub-systems of agricultural productivity in rural Kenya. This relationship is built on the fact that in the face of limited household income, farmers tend to depend on manure for soil fertilization and on crop wastes for animal feed. Since increases in crop production and access to bought fodder are limited by household income, animal feed is limited and livestock production cannot grow. A stagnation in livestock production means manure for fertilizing the soil is limited and so crop production cannot be ameliorated. The challenge of sustainable agriculture is among other things to, strike a balance between soil conservation (environmental protection) and economic profitability (Buresh and Tian, 1997; Cooper *et al.*, 1996; Young, 1989; Carsky *et al*, 1999; Kwesiga and Coe, 1994).

Minimizing the Fertilizer-Dependent Cycle

The need to face up to the challenge of limited economic resources to ameliorate the conditions of low soil fertility in tropical regions has called for much attention in recent soil management research Ruben and Heerink (1995).

Rotational Intercropping

Crop rotation moves agriculture from a simple monoculture to a complex system of diversification, and in the process, breaks cycles of weed and pest infestations while providing supplementary fertilization to crops (Dima and Odero, 1997; Sullivan, 2003). Recent research on crop rotation has laid emphasis on estimating the amount of inorganic nitrogen that may be "*required following a non-legume crop to produce another non-legume crop with an equivalent yield to that obtained following a legume*" (Wani *et al.* 1995). This gives a quantitative estimate of the contribution of a leguminous crop to the nitrogen requirements of a non-leguminous crop that precedes it and is termed differently by different authors as "fertilizer N replacement value" (Carsky *et al.*, 1999), and "N residual effect" (Gan *et al.*, 2003). These values have been computed for certain crops and stands as evidence to the fact that soil nitrogen conditions can be enhanced by undertaking rotations of leguminous and non-leguminous crops. Table 3 shows the fertilizer nitrogen replacement values derived from preceding legumes on maize yield.

A well planned rotation will besides increasing soil nitrogen also reduce the build-up of crop diseases pests, improve soil texture, ameliorate soil biodiversity, enable crops benefit from residual herbicide carryover, and reduce soil erosion (Carsky *et al*, 1999; Kwesiga and Coe, 1994; Reinjtjes, *et al*., 1992). Experimental data on trials with different crops including maize, sugar beets and wheat has proven that when a crop precedes itself, yields are usually lower than when it precedes another crop even in mono-cropping systems (Wani *et al*, 1995; Kwesiga and Coe, 1994).

Table 3 Residual Effect of Preceding Legume on Maize Yields in Terms of Fertilizer N Equivalents

Preceding Legume	Following Cereal	Fertilizer N Equivalent (kg ha-1)
Chickpea	Maize	60-70
Cowpea	Maize	60
Lablab bean	Maize	33
Pigeon pea	Maize	20-67
Peas	Maize	20-32
Groundnuts	Maize	9-60
Soybean	Maize	7

Wani et al. (1995), (a compilation of results from different studies).

Small-scale farmers in rural Kenya (as in most parts of sub-Saharan Africa) do not commonly practice crop rotation by rotating individual food crops over a specific area under cultivation. Instead, they cultivate a number of food crops at the same time (intercropping) on the same piece of land. They may however rotate this set of intercrops over different fields if they have enough land, or over the same field as dictated by seasons. This form of *rotational intercropping* is driven by the need to secure diversity in household food supply as well as diversify risks of crop failure over a wide number of crops. The practice of farming purely cash crops however imposes rotational mono-cropping on farmers and is practiced mainly but not exclusively by large-scale farmers.

Green Manure

Single tropical species like leucaena and sesbania can significantly change the level of deficiency suffered by small-scale agricultural systems in Kenya. Table 4 shows the contributions to soil nitrogen that can be added through the complete incorporation of four common plant species into the soil from hedgerow prunnings.

Table 4 Some Green Manure Crops and Their Nitrogen Contribution to the Soil Under Optimal Conditions

Crop	N Contribution (kg/ha)
Sesbania (*Sesbania rostrata)*	100
Sesbania (*Sesbania bispinosa)*	80
Ipil-ipil (*Leucaena leucocephala)*	125
Gliricidia (*Gliricidia sepium)*	80-100

Source: Roy et al., 2006

It is possible to estimate the effects that such levels of nitrogen contribution would have on the small-scale farmer in terms of contribution to crop yield increases. By estimating that as much as 30% of nitrogen from prunnings reaches the crop, Young (1989) was able to ball-park an estimate of 30-80 kg N/ha/year as being the likely contribution to crops from hedgerow prunnings of leucaena. Young (1989) argued that by multiplying this amount by 10-15, hedgerow prunnings alone could raise cereal yields by as much as 300-1200 kg/ha.

Prospects for Sustainable Small-Scale Farming (Best Case Scenario)

By introducing low external input strategies (LEIS) into Figure 3, the outcome is a system as shown in Figure 4. Here one sees that through the use of different strategies of low external input soil erosion can be controlled and nutrient runoff associated with it will then be checked. Other benefits include: the accumulation of green fertilizers will ameliorate the soil organic nutrient content which will improve crop yields; the biological fixation of nitrogen would ameliorate the soil's nitrogen content; and biological weed control which leaves farmers with more time that could be used for other non-farm income generating activities. Benefits from biological weed control mean fewer plant pests and need for spending on pesticides. There is greater availability of forage which saves household income that would have been spent on buying fodder. It also saves time, labour and financial resources that would have been spent on herding.

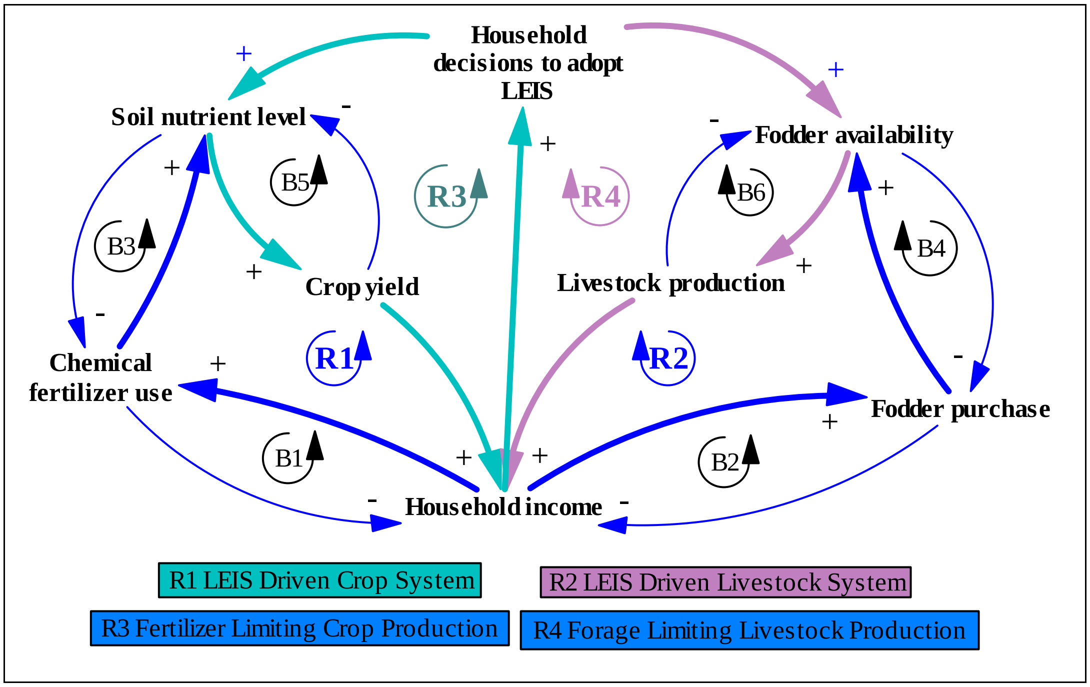


Figure 4 The Role of Low External Inputs on Household Income

By upgrading Figure 3 with low external input strategies, two important new reinforcing loops emerge. R3, the low external input driven crop system represents the system in which dependence on chemical fertilizers for increased crop production is off-set by the provision of soil nutrients through low external input practices. R4 represents the low external input driven fodder system in which low external input practices off-set the dependence on purchased forage for expanding livestock productivity. Figure 5 shows the different levels of benefits that can be made from the adoption of low external input practices.

Scopes for the Optimization of Low External Input Strategies

Figure 6 shows that intercropping is the most widespread low external input practice in Nyandarua (practiced by 85% of farmers: N = 35) and Mumias (practiced by 100% of farmers: N = 26). At least 95% of farmer associate intercropping to one or more other low external input practices. Together with crop rotation and agroforestry, these three form the most widespread practices of low external input strategies in the study areas.

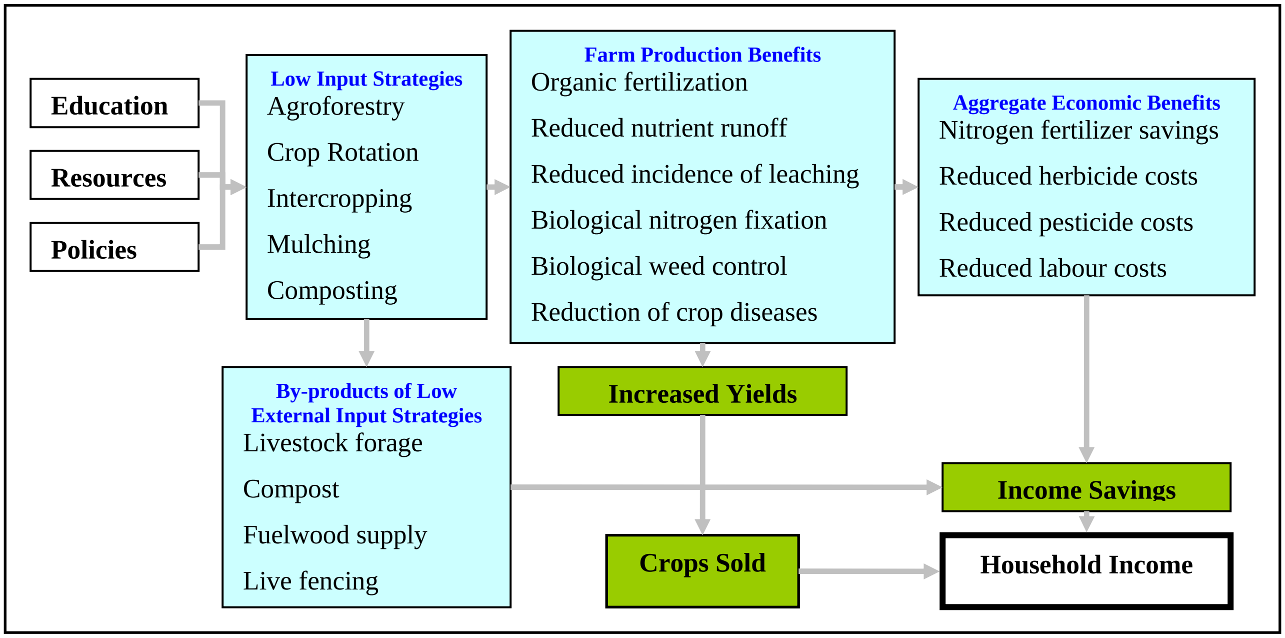


Figure 5 Direct and Indirect Benefits of Introducing and/or optimizing Low Input Practices

To understand why there should be a negative nutrient balance when a majority of the farming population is practicing at least one or more forms of soil improvement practices, one may tend to question the seriousness with which these practices are undertaken. The acquisition of basic skills to undertake crop rotation, intercropping and agroforestry may be needed to ensure that the right resources and the right methods are used in the implementation of these practices. It is found that most farmers have had little exposure to these skills. In Mumias for example, only 9 out of 28 (approximately 32%) of farmers have had any exposure to a forum in which basic skills of low external input practices was discussed. In Figure 7 which shows the number of days spent in training on low external input strategies for farmers in the study areas, one finds that the bulk of farmers have had no training at all.

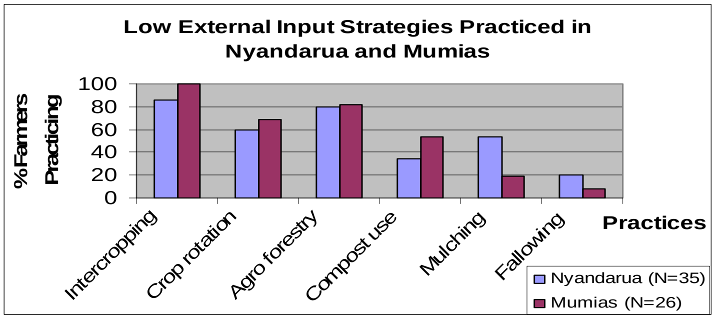


Figure 6 Percentage of Farmers Practicing Low External Input Strategies
Source: Questionnaire 2007

It follows that the low external input practices that are being undertaken may not be based on formally researched principles. If the right materials and methods are not used, the output of such practices may be quite minimal. A combination of the right materials, methods and informed consent could optimize benefits from these practices.

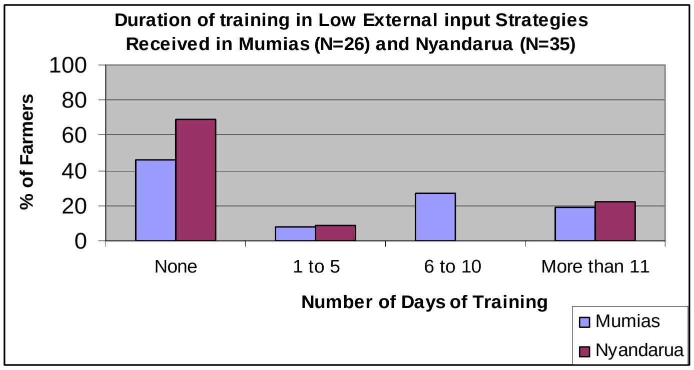


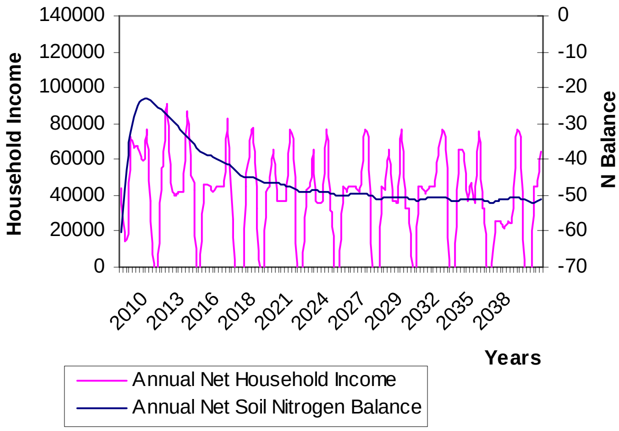
Figure 7 Duration of Training on Low External Input Strategies in Nyandarua and Mumias
Source: Questionnaire 2007

More insights into the problems associated with optimizing benefits from low input strategies are presented in Figure 10 The fact that the lack of technical know-how is ranked the most important factor influencing the practice of low external input strategies goes to support the fact that the limited exposure to training on these practices is a problem. Other factors which rank high are lack of resources, limited labour, limited land and information.

Exploring Scenarios in Small-Scale Kenyan Farming Systems

Fluctuating prices have been described as one of the main problems affecting the incomes of small-scale farmers in developing countries (Naiman and Watkins, 1999). For small-scale farmers, the impacts of price fluctuations are much more severe given that their small agricultural capital cannot easily absorb the shock of negative price fluctuations. They are then forced to make choices on the allocation of production resources in order to minimize the impact of such fluctuations either when they occur or are expected.

8a: Without LEIS



8b: With LEIS

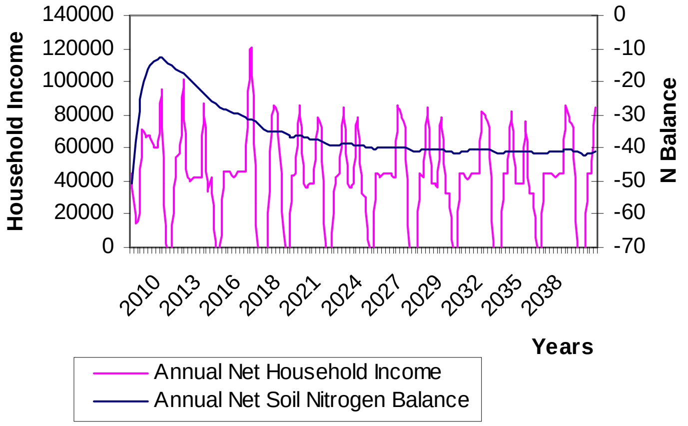
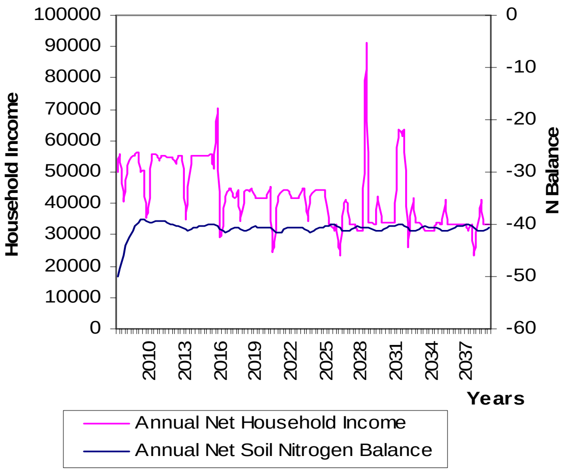


Figure 8 Effects of LEIS on Cash Crop Income and Net Nitrogen Balance

However, in the face of uncertainty, farmers will choose to invest in food crops – the surpluses of which can be stored for consumption in times of poor harvests if they cannot be sold. Prices and the profitability of production tend to be the most outstanding factors that determine the allocation of land between different uses even for small-scale farmers (Fieldwork, 2007). Figure 8a and 8b show the effects of LEIS (represented by an addition of 60kg nitrogen per hectare per year) on household income if only cash crops are cultivated. Low external inputs are seen to have very little effects on net household income from cash crops. While the net nitrogen balance seems to be a little improved, in real terms the deficit is still high (Figure 8a and 8b). On food crops, low external input practices lead to modest increases in net annual household income. They also lead to significant gains in the net soil nitrogen balance of farms (Figure 9a and 9b). Even though the balance remains negative, it stabilizes at a smaller deficit. This could partly be explained by the fact that cash crop yields are transported out of the farm system (together with the nutrients contained in them) while most food crops (and the nutrients they contain) are recycled within the farm system. By comparing the curves of net soil nitrogen balance for the two cropping systems (8a;b and 9a;b), one finds that cash crops will lead to a more rapid depletion of soil nitrogen than food crops. Cash crops tend to show signs of not being sustainable even with the same level of intensity of low external input strategies.

9a: Without LEIS



9b: With LEIS

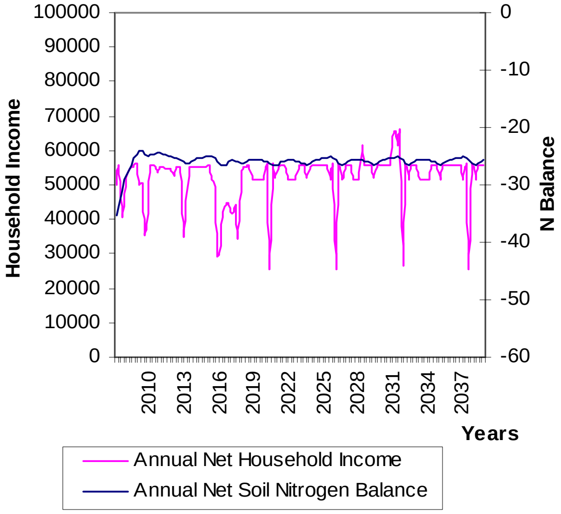


Figure 9 Effects of LEIS on Food Crop Income and Net Nitrogen Balance

When land for cash crops (sugar beets and sugarcane) is converted to food crops (maize and potatoes), there is a significant fall in household income. This should be due to the fact that food crops generally fetch a lower market price per unit area cultivated than cash crops. This is because the system under study had sugarcane which is a "semi-permanent cash crop" with a four-year cycle.

DISCUSSIONS

The practice of low external input agriculture is a common feature in the Kenyan rural landscape (see Figure 6). With over 95% of farmers associating intercropping with one or many other low external input practices, one tends to wonder why the soil nitrogen balance in Kenya is still negative (De Jager *et al*., 1998; Stoorvogel and Smaling 1990; FAO, 2004). Data on the level of exposure to information and/or training on low input strategies reveal that very few farmers have had education of any kind on these practices. Where people have had some level of exposure to such information, it has been for very limited periods of time (see Figure 7). Undertaking these practices is therefore more an issue of custom than a conscious and educated effort to reap the full benefits that the practices stand to offer. To optimize the benefits offered by low external input strategies, the acquisition of some level of technical know-how seems to be indispensable. According to De Costa and Sangakkara (2006) access to the right technical know-how, planting resources and related materials to undertake low external input practices is not accessible to smallholder farmers of the tropics today. The need to strengthen farmers' knowledge base on some of the basic information and skills in the practice of agriculture had been emphasized by Tschakert, (2003). While noting that farmers did understand that practices like crop rotation and fallowing would increase production, she noted that there was a significant lack of knowledge on how these practices could be effectively practiced to optimize benefits from them.

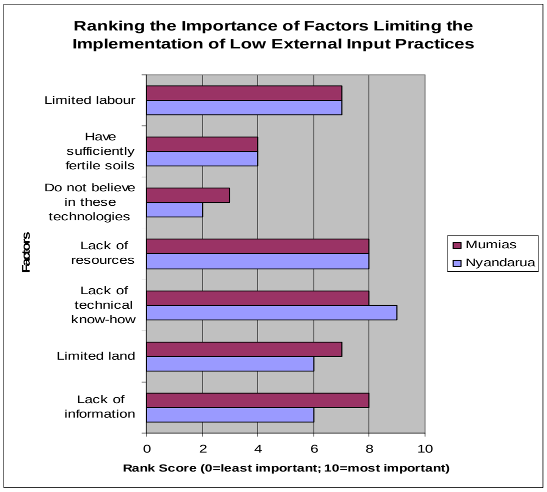


Figure 10 Limits to the Practice of Low External Input Strategies
Source: Fieldwork 2007

The best case scenario of a full-scale adoption of a low external input system could be criticized too for being over-ambitious. However, as argued by Altieri *et al* (1999), the lack of access to chemical fertilizers in Cuba has led to an agricultural revolution in which the entire system is almost reliant on organic agriculture. Even though this may not be immediately translated into significantly high increases in income for the small-scale farmer, a net positive soil nitrogen balance supports the view that a carefully planned set of low external input practices could be used to address some of the problems of low soil nitrogen in small-scale tropical agriculture. Given that LEIS offers opportunities for increasing household income beyond crop and livestock production (such as providing fuelwood, building and other materials which could be converted to money), one may remind that in the long-term, LEIS may have a positive impact on household income. Figure 9a and 9b also show that low external input strategies may stabilize incomes for the small-scale farmer. Stable incomes could be a useful tool for decision making in many aspects of agricultural production.

Previous studies have identified some benchmarks that have to be used to assessed the sustainability of low external input strategies: De Jager *et al.* (2001) concluded after a study of a conventional farm and one under low external input practices in Machakos, Kenya that besides improving soil nutrient conditions, the positive impact of LEIS can only be felt if it reduces nutrient losses through leaching and gaseous losses as well; Shepherd and Soule (1998) in a study in the Vihiga District of Kenya came to the conclusion that LEIS must be able to increase the quality of farm outputs while opening up opportunities for non-farm income as well as raise nutrient inputs at low labour and financial costs. Some of these benchmarks have been tested on individual crops (Wani *et al*, 1995; and Kwesiga and Coe, 1994) and on individual practices (Peel, 1998; and Oswald *et al.* 1996). The present study has given an opportunity of testing two of the benchmarks (soil nitrogen/fertility and household income) in a more holistic perspective.

Other studies have questioned in which areas tropical agriculture should be optimized (De Costa and Sangakkara, 2006). This study identifies practices of sustainable agriculture that are already common in the Kenyan rural landscape, outlines scientific arguments for their choice as viable low external input practices and identifies constraints to their optimal application.

CONCLUSION

Crop rotation, agroforestry, and intercropping are the most widely practiced of the low external input practices in the rural Kenyan districts of Nyandarua and Mumias. However, minimal benefits are being reaped from their practice. Low education on the proper implementation of these practices is one of the main hindrances to reaping optimal benefits from these practices. An analysis of the system confirms that it is possible to increase the level of soil nitrogen using low external input practices. However, improving soil nitrogen may not necessarily mean an increase in household income. Within a thirty year period of simulation, the adoption of low external input practices is less sustainable as an option in cash crop production. In food crop cultivation on the other hand, low external input strategies can lead to modest increases in household income and an amelioration of the net balance of soil nitrogen. It is however argued that in the long-run, household income could eventually increase as the low external input system gets mature and begins providing alternative sources of income through sources like fuel wood production.

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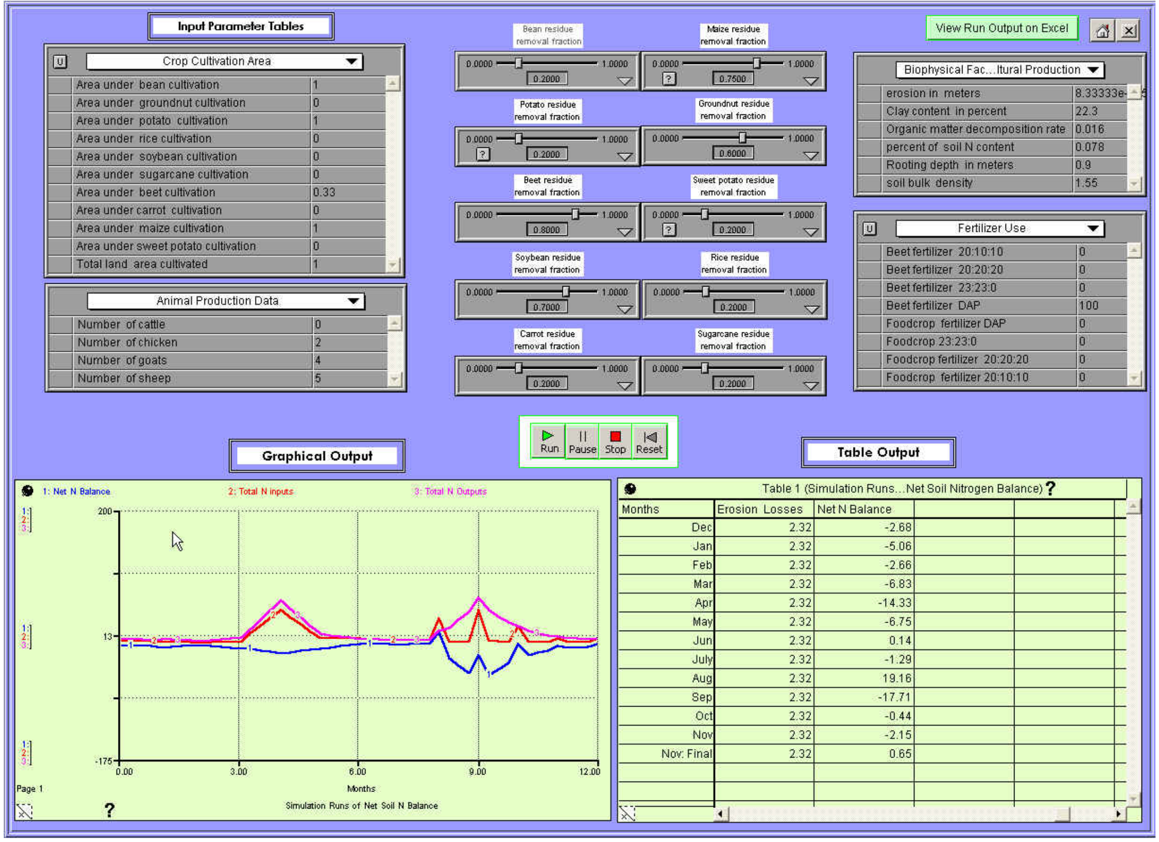
APPENDIX

A: Process window of the Nitrogen Subsystem



Crop Cultivation Area

Area under bean cultivation	1
Area under groundnut cultivation	0
Area under potato cultivation	1
Area under rice cultivation	0
Area under soybean cultivation	0
Area under sugarcane cultivation	0
Area under beet cultivation	0.33
Area under carrot cultivation	0
Area under maize cultivation	1
Area under sweet potato cultivation	0
Total land area cultivated	1

Animal Production Data

Number of cattle	0
Number of chicken	2
Number of goats	4
Number of sheep	5

Bean residue removal fraction (0.0000–1.0000)	0.2000
Maize residue removal fraction (0.0000–1.0000)	0.7500
Potato residue removal fraction (0.0000–1.0000)	0.2000
Groundnut residue removal fraction (0.0000–1.0000)	0.6000
Beet residue removal fraction (0.0000–1.0000)	0.8000
Sweet potato residue removal fraction (0.0000–1.0000)	0.2000
Soybean residue removal fraction (0.0000–1.0000)	0.7000
Rice residue removal fraction (0.0000–1.0000)	0.2000
Carrot residue removal fraction (0.0000–1.0000)	0.2000
Sugarcane residue removal fraction (0.0000–1.0000)	0.2000

Biophysical Fac...ltural Production

erosion in meters	8.33333e-
Clay content in percent	22.3
Organic matter decomposition rate	0.016
percent of soil N content	0.078
Rooting depth in meters	0.9
soil bulk density	1.55

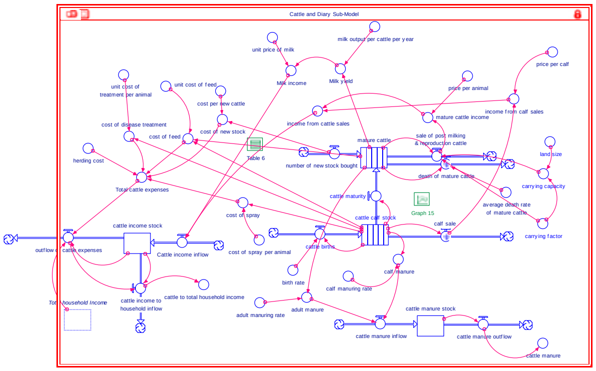
Fertilizer Use

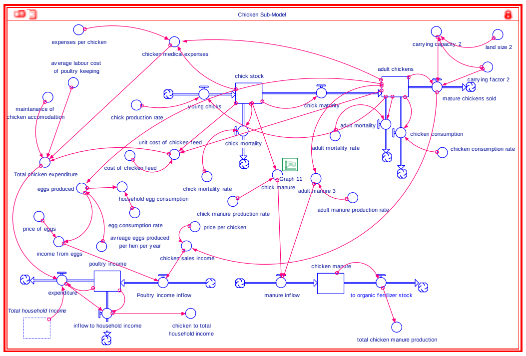
Beet fertilizer 20:10:10	0
Beet fertilizer 20:20:20	0
Beet fertilizer 23:23:0	0
Beet fertilizer DAP	100
Foodcrop fertilizer DAP	0
Foodcrop 23:23:0	0
Foodcrop fertilizer 20:20:20	0
Foodcrop fertilizer 20:10:10	0

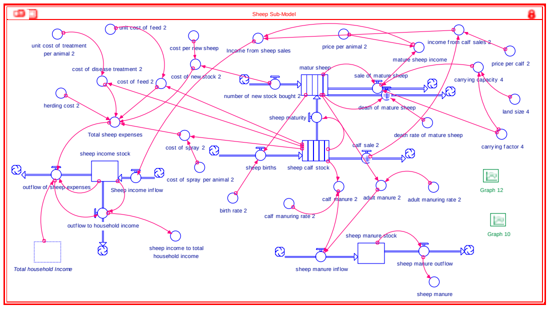
Table 1 (Simulation Runs...Net Soil Nitrogen Balance)

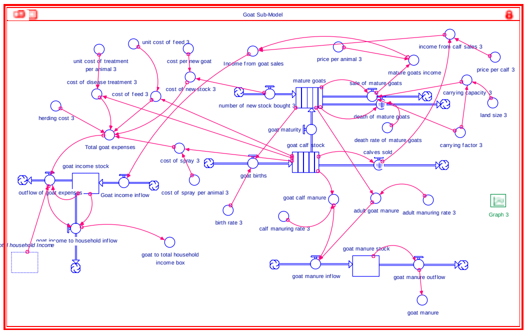
Months	Erosion Losses	Net N Balance
Dec	2.32	-2.68
Jan	2.32	-5.06
Feb	2.32	-2.66
Mar	2.32	-6.83
Apr	2.32	-14.33
May	2.32	-6.75
Jun	2.32	0.14
July	2.32	-1.29
Aug	2.32	19.16
Sep	2.32	-17.71
Oct	2.32	-0.44
Nov	2.32	-2.15
Nov: Final	2.32	0.65

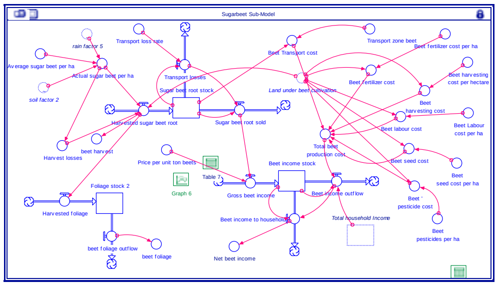
B: Model View

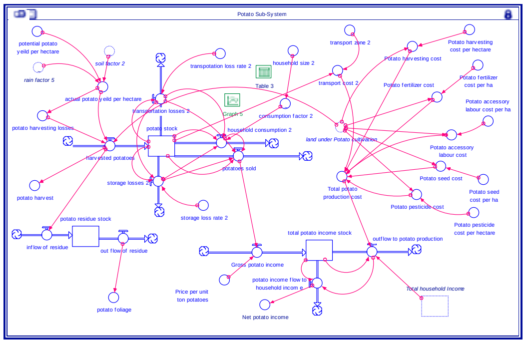

Cattle and Diary Sub-Model
unit price of milk
milk output per cattle per year
Milk income
Milk yield
price per calf
unit cost of treatment per animal
unit cost of feed
cost per new cattle
price per animal
mature cattle income
income from calf sales
income from cattle sales
cost of disease treatment
cost of feed
cost of new stock
mature cattle
sale of post milking & reproduction cattle
herding cost
Table 6
number of new stock bought
death of mature cattle
land size
carrying capacity
Total cattle expenses
cattle maturity
Graph 15
average death rate of mature cattle
cost of spray
cattle calf stock
calf sale
carrying factor
cattle income stock
outflow of cattle expenses
Cattle income inflow
cost of spray per animal
cattle births
calf manure
birth rate
calf manuring rate
Total household Income
cattle income to household inflow
cattle to total household income
adult manure
adult manuring rate
cattle manure stock
cattle manure inflow
cattle manure outflow
cattle manure

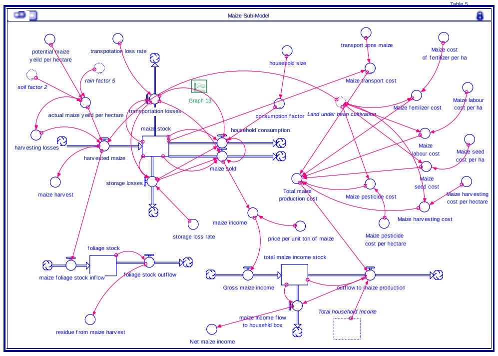

Chicken Sub-Model
expenses per chicken
chicken medical expenses
carrying capacity 2
land size 2
average labour cost of poultry keeping
adult chickens
chick stock
carrying factor 2
mature chickens sold
maintanance of chicken accomodattion
young chicks
chick maturity
chick production rate
adult mortality
chicken consumption
unit cost of chicken feed
chick mortality
adult mortality rate
chicken consumption rate
cost of chicken feed
Total chicken expenditure
Graph 11
chick manure
adult manure 3
chick mortality rate
eggs produced
household egg consumption
chick manure production rate
adult manure production rate
egg consumption rate
price per chicken
price of eggs
avreage eggs produced per hen per year
chicken sales income
income from eggs
poultry income
chicken manure
expenditure
Poultry income inflow
manure inflow
to organic fertilizer stock
Total household Income
inflow to household income
chicken to total household income
total chicken manure production

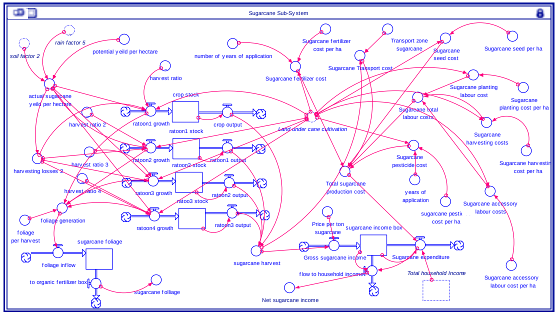

Sheep Sub-Model
unit cost of feed 2
unit cost of treatment per animal 2
cost per new sheep
Income from sheep sales
price per animal 2
income from calf sales 2
mature sheep income
price per calf 2
cost of disease treatment 2
cost of feed 2
cost of new stock 2
matur sheep
sale of mature sheep
carrying capacity 4
herding cost 2
number of new stock bought 2
death of mature sheep
land size 4
sheep maturity
Total sheep expenses
death rate of mature sheep
cost of spray 2
calf sale 2
carrying factor 4
sheep income stock
sheep births
sheep calf stock
outflow of sheep expenses
Sheep income inflow
cost of spray per animal 2
Graph 12
calf manure 2
adult manure 2
adult manuring rate 2
birth rate 2
calf manuring rate 2
outflow to household income
Graph 10
sheep manure stock
sheep income to total household income
sheep manure inflow
sheep manure outflow
Total household Income
sheep manure

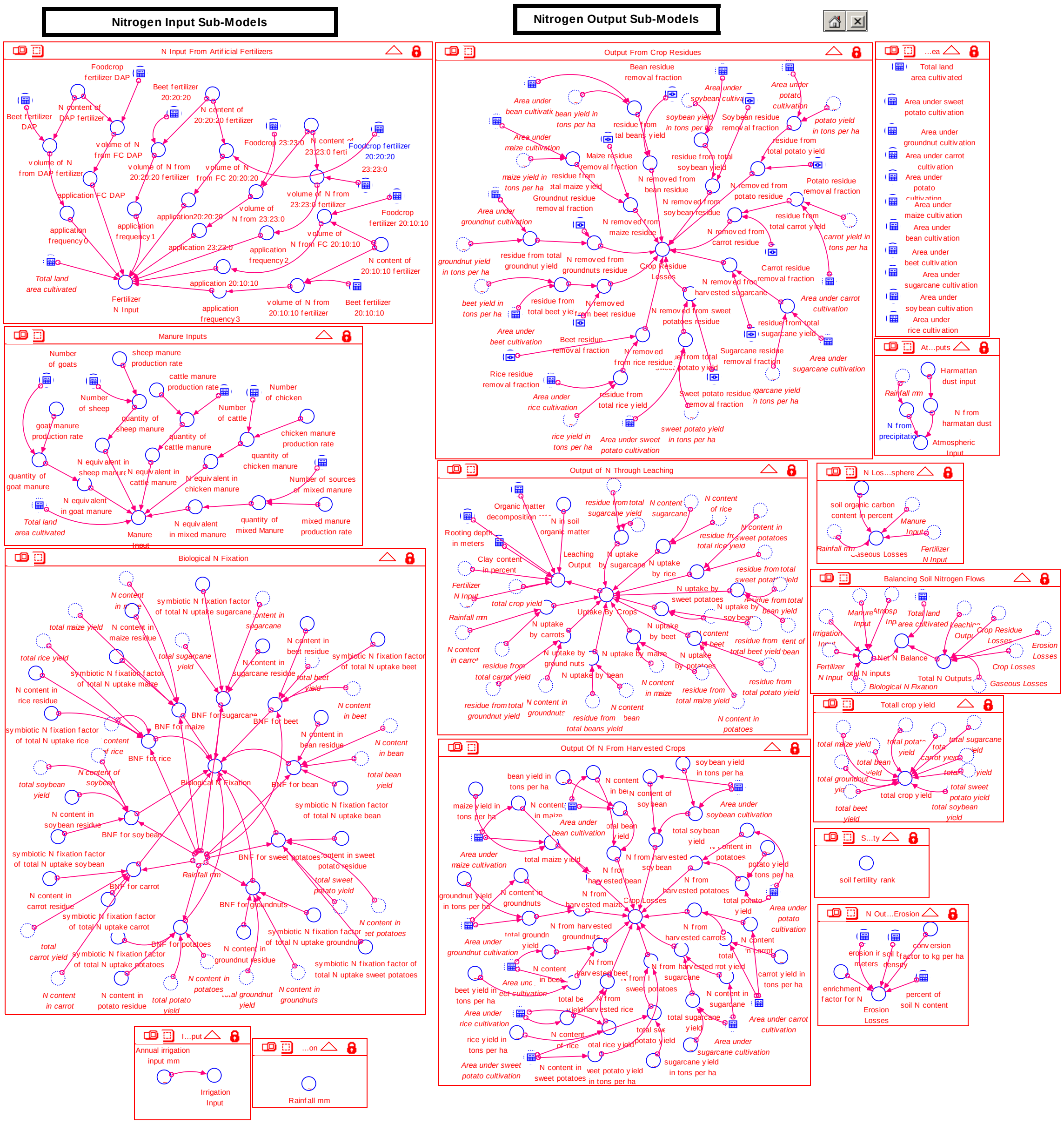

Goat Sub-Model
unit cost of feed 3
income from calf sales 3
unit cost of treatment per animal 3
cost per new goat
Income from goat sales
price per animal 3
price per calf 3
mature goats income
cost of disease treatment 3
cost of feed 3
cost of new stock 3
mature goats
sale of mature goats
carrying capacity 3
number of new stock bought 3
death of mature goats
land size 3
herding cost 3
goat maturity
Total goat expenses
death rate of mature goats
carrying factor 3
goat calf stock
calves sold
cost of spray 3
goat income stock
goat births
outflow of goat expenses
Goat income inflow
cost of spray per animal 3
goat calf manure
adult goat manure
adult manuring rate 3
Graph 3
birth rate 3
calf manuring rate 3
goat income to household inflow
Total household Income
goat to total household income box
goat manure stock
goat manure inflow
goat manure outflow
goat manure


Sugarbeet Sub-Model
rain factor 5
Transport loss rate
Transport zone beet
Beet fertilizer cost per ha
Average sugar beet per ha
Actual sugar beet per ha
Beet Transport cost
Transport losses
Beet harvesting cost per hectare
soil factor 2
Sugar beet root stock
Land under beet cultivation
Beet fertilizer cost
Beet harvesting cost
Harvested sugar beet root
Sugar beet root sold
Beet labour cost
Beet Labour cost per ha
beet harvest
Harvest losses
Total beet production cost
Price per unit ton beets
Table 7
Beet income stock
Beet seed cost
Graph 6
Beet seed cost per ha
Foliage stock 2
Gross beet income
Beet income outflow
Beet ' pesticide cost
Harvested foliage
Beet income to household
Total household Income
Beet pesticides per ha
beet foliage outflow
beet foliage
Net beet income
Table 5


Potato Sub-System
potential potato yeild per hectare
transport zone 2
Potato harvesting cost per hectare
soil factor 2
Potato harvesting cost
rain factor 5
transpotation loss rate 2
household size 2
Table 3
transport cost 2
Potato fertilizer cost
Potato fertilizer cost per ha
actual potato yeild per hectare
transportation losses 2
Graph 5
consumption factor 2
Potato accessory labour cost per ha
potato harvesting losses
potato stock
household consumption 2
land under Potato cultivation
harvested potatoes
potatoes sold
Potato accessory labour cost
potato harvest
storage losses 2
Potato seed cost
Total potato production cost
Potato seed cost per ha
Potato pesticide cost
storage loss rate 2
potato residue stock
total potato income stock
Potato pesticide cost per hectare
outflow to potato production
inflow of residue
out flow of residue
Gross potato income
potato income flow to household incom e
Price per unit ton potatoes
Total household Income
potato foliage
Net potato income


Maize Sub-Model
potential maize yeild per hectare
transpotation loss rate
transport zone maize
Maize cost of fertilizer per ha
household size
soil factor 2
rain factor 5
Maize transport cost
Graph 13
Maize labour cost per ha
actual maize yeild per hectare
transportation losses
consumption factor
Land under bean cultivation
Maize fertilizer cost
maize stock
household consumption
harvesting losses
harvested maize
Maize labour cost
Maize seed cost per ha
maize sold
storage losses
Maize seed cost
maize harvest
Total maize production cost
Maize pesticide cost
Maize harvesting cost per hectare
maize income
Maize harvesting cost
storage loss rate
price per unit ton of maize
Maize pesticide cost per hectare
foliage stock
total maize income stock
maize foliage stock inflow
foliage stock outflow
Gross maize income
outflow to maize production
maize income flow to househld box
Total household Income
residue from maize harvest
Net maize income


Sugarcane Sub-System
rain factor 5
soil factor 2
potential yeild per hectare
number of years of application
Sugarcane fertilizer cost per ha
Transport zone sugarcane
Sugarcane seed cost
Sugarcane seed per ha
harvest ratio
Sugarcane Transport cost
Sugarcane fertilizer cost
crop stock
Sugarcane planting labour cost
actual sugarcane yeild per hectare
Sugarcane planting cost per ha
harvest ratio 2
ratoon1 growth
crop output
Sugarcane total labour costs
ratoon1 stock
Land under cane cultivation
Sugarcane harvesting costs
ratoon2 growth
ratoon1 output
harvest ratio 3
ratoon2 stock
Sugarcane pesticide cost
harvesting losses 2
Sugarcane harvesting cost per ha
ratoon3 growth
Total sugarcane production cost
harvest ratio 4
ratoon2 output
ratoo3 stock
years of application
Sugarcane accessory labour costs
sugarcane pestic cost per ha
foliage generation
ratoon4 growth
ratoon3 output
Price per ton sugarcane
sugarcane income box
foliage per harvest
sugarcane foliage
Gross sugarcane income
Sugarcane expenditure
foliage inflow
sugarcane harvest
flow to household income
Total household Income
to organic fertilizer box
sugarcane folliage
Net sugarcane income
Sugarcane accessory labour cost per ha


Nitrogen Input Sub-Models
Nitrogen Output Sub-Models
N Input From Artificial Fertilizers
Fertilizer N Input
Manure Inputs
Manure Input
Biological N Fixation
I...put
Annual irrigation input mm
Irrigation Input
...on
Rainfall mm
Output From Crop Residues
Crop Residue Losses
...ea
Total land area cultivated
At...puts
Harmattan dust input
Rainfall mm
N from precipitation
N from harmattan dust
Atmospheric Input
Output of N Through Leaching
Leaching Output
Uptake By Crops
N Los...sphere
Gaseous Losses
Balancing Soil Nitrogen Flows
Net N Balance
Total N inputs
Total N Outputs
Totall crop yield
total crop yield
Output Of N From Harvested Crops
Crop Losses
S...ty
soil fertility rank
N Out...Erosion
Erosion Losses