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ASSESSING THE SIGNIFICANCE OF LOW EXTERNAL NUTRIENT INPUT STRATEGIES FOR SMALL-SCALE CROP PRODUCTION IN KENYA

(A SYSTEMS ANALYSIS APPROACH)

**By:
Yengoh Genesis Tambang
Sunnanvagen 6k, Room 1401
SE 222 26 Lund, Sweden
Tel: +46 (0) 70 48 18 486
E-mail: yengoh.genesis@gmail.com**

**Supervisor:
Mats G. E. Svensson (PhD)
PO Box 170
SE-221 00 Lund, Sweden
Phone: +46 46 222 0513
Fax: +46 46 222 0475
E-mail: mats.svensson@lucsus.lu.se
Website: www.lumes.lu.se**

Dedication

To: **Kefeyin Wiyngoh Yengoh**

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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 (in 2006 and 2007) 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 simulation model was developed and used to test the influence of low external input strategies on small-scale farming under different scenarios. These scenarios include: the influence of uncertain weather; a fall in the price of cash crops; and a positive shift in government policy and farmers' attitudes that lead to a large scale adoption and optimization of benefits reaped from such strategies. It is found that the effects of uncertain weather may be severe for an individual crop but less on overall income and nitrogen balance when the farmer is engaged in the cultivation of many different crops. A fall in the price of cash crops drives land to be converted to food crops which leads to a fall in total household income and an increase in the rates of cycling of soil nitrogen given that the cultivation cycles of food crops are shorter. In the third scenario of a large-scale adoption of low external input strategies, the result is an annual net positive balance in soil nitrogen with little effect on household income.

Key Words: small-scale agriculture, low input strategies, nitrogen, income.

1. INTRODUCTION

It has been recognized that agricultural production in Kenya 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). According to Ruben and Lee (2000), 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. 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.

1.1 Background

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 conditions 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. According to Binswanger and McIntire, (1987), 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. 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) assessed the feasibility, profitability, and acceptability of improved tree fallows in three study sites in Africa (Southern Cameroon, Eastern Zambia and Western Kenya); Manyong *et al*., (1997) studied potentials for the adoption of new agricultural technologies in Benin. Both studies identified main factors associated with the acceptability of technological innovations in an agricultural system to include: perception of soil fertility problems, previous use of soil fertility improvement measures, current fallowing, wealth level, and the economic importance of annual cropping.

1.2 Objectives

This study set out to assess the significance low external input strategies could make in small-scale farming systems in rural Kenya.

To achieve this goal, the study has to attain two objectives:

Examine the feasibility of incorporating and or optimizing the benefits of LEIS in small-scale farming systems in rural Kenya.

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.

1.3 Scope and Limitations

While acknowledging the existence and importance of numerous other agronomic practices in limiting the constraint imposed by nutrient depletion in tropical agriculture, this study will however focus on three of them: agroforestry; crop rotation; and intercropping. This focus will be limited to the extent to which these practices affect or interplay with the objectives of this study.

The socioeconomic context of farming households involves complex processes of income acquisition and expenditure, some of which have benefited from detailed documentation (Ellis, 1998a; 1998b; and 1991; Dose, 1997). Notwithstanding this, 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 under investigation.

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). This complexity will not be covered within this study. The study will, within the time and resources available 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[1] because it is the level at which land use and management decisions are taken (Tschakert, 2003; Golan, 1990). The large-scale farmers will be eliminated partly because they are too few, but also because they tend to practice purely mono-cropping destined for commercialization. Their system of farming therefore does not offer the dynamism that this study is seeking. The very small-scale farmers have also eliminated for being very few. One other problem with them was that they tend to be over-inclined to subsistence agricultural practices.

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.

1.4 Materials and Methods

1.4.1 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 (Mandere, 2003). According to Dose (1997), the population pressure on land resources in this district is high with as much as 76% of its land area is 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 with generally cooler temperatures 15^{o}C; and lower precipitation 960mm (Mandere, 2003).

The choice of Mumias and Nyandarua as case study sites for this study was made principally for two reasons: (1) These are areas where the cultivation of sugar beet is being experimented and do offer established contacts with farmers and interesting opportunities of observing the forces that come into play in governing issues like land allocation for new crops as well as decisions that determine the acceptance or not of innovative farming activities. (2) These two areas have been well established as research sites for projects within the department. It follows that, significant social networks have been created which could assist in gathering data.

1.4.2 Data Collection in Case Study

Data for this study was collected in a two-phase cross-sectional survey carried out between March and April 2006 and between March and April 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. Semi-finished copies of these questionnaires were then pre-tested on a number of individuals with known experience of working with farming in the tropical rural world before final corrections were made. In designing and pre-testing the questionnaires, attention was given on classifying, rating and in some cases ranking the expected (and even unexpected) responses so as to facilitate its compilation and analysis on spreadsheets.

Through deep, semi-structured interviews and some open ended questions, 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).

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[1] The term small-scale used here refers to farming households with land under cultivation of less than 4ha. This definition is borrowed from Kenyan agricultural extension workers. Those with land holdings between 4ha and 7ha are described as medium-scale farmers and those with holdings above 6ha are large-scale farmers.

1.4.3 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 simulation modeling 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.

Hence within the context of this study, the choice of systems analysis is dictated by the desire to achieve two goals: treat the small-scale farming household system as a cocktail of different agricultural activities (some major and some minor), interacting and influencing one another; and test the effects of different household decisions and land use scenarios which may affect different production types within the system and to different levels. These goals were achieved with the simulation model (used to simulate different scenarios within the system) causal loop diagrams (used to understand cause-effect relations within the system), and the feedback loop analysis (used to analyze the balancing and reinforcing effects of dominant feedback loops within the system).

1.4.4 Model Description

To benefit from the holistic perspective offered by the systems approach, four crops were integrated with four livestock types in the model. This method of integration was also partly inspired by Ellis, (1998a; 1998b), who saw the mean household income portfolio of most small-scale tropical farming households 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. 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.

These crops are integrated with four livestock types. Field studies revealed that the dominant livestock kept by farmers were cattle, goats, sheep and chicken. Cattle is kept mainly for milk production and eventual conversion for income in the long run; goats and sheep which are more widely possessed by small-scale farmers and more readily sold than cattle; chicken is most widely possessed and whose meat and eggs are much commonly consumed by small-scale farming households.

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. The livestock and food crop production sub-systems are integrated to three other sub-systems: nutrients; biophysical; and household decision sub-systems.

In general, the design of the model is intended to capture the most outstanding characteristics of small-scale rural farming households in Kenya. Some of these characteristics include: the production of several crops at a time; carrying out farm operations on a generally small farm holding in a single plot or number of scattered small plots with 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). The working definition of a small-scale farming household used for this study is: a household whose dominant economic activity is agriculture, cultivating at least one food and cash crop, and with less than six hectares of land under crop cultivation and animal rearing.

To decide the timescale over which the model would be run, a compromise had to be made between the lengths of time economic decisions are based on and the time it could take to observe meaningful changes on the biophysical landscape 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.

Plant Sub-Models

Certain general features can be found between all crop sub-models used in this paper. They each have five sectors:

1. A sector for biophysical plant growth determinants. Here, these determinants have been limited to soil type and rainfall.
2. The sector of economic inputs sums up total production cost by putting together costs of fertilizers, seeds, labour, pesticides and transport. The total cost for each factor is a function of the unit cost of that factor per hectare and the total number of hectares cultivated.
3. Harvested crops are stored and accumulated in one sector. They may be affected by losses during the harvesting process; transportation; and storage. It is from the accumulated stock that outflows to consumption and sales are registered.
4. The income sector registers income from sold crops and expenditures to crop production. Crop income inflow into the main income box for each crop production is a function of the total quantity of crops sold and the unit price of the crop. Outflow from an individual crop income stock goes to the production of the crop in subsequent seasons and as a contribution to the general household income box[2].
5. The crop residue accumulation sector calculates crop residue emanating from the harvest of each crop. Its outputs eventually become inputs into the nutrients sub-model.

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[2] The model has been designed such that each crop or livestock sub-system is independent in its income production and expenditure pattern. Where income from crop sales is more than expenditure for production, the surplus is reserved in the general household income box. Since in reality small-scale farmers in the study area do not make the difference between income from individual farming activities, a function has been built in the outflow of expenditure to individual crop production sub-systems which allows them to borrow from the general household income stock to make up for deficits in financing the production of any particular crop.

Table 1 Parameter Table for Crop Sub-Models

Parameter	Description, Value and Units	Source
Crop yields per hectare	a Maize = 1.6 tons/ha b Potatoes = 15.4 tons/ha c Sugar beets = 55 tons/ha d Sugarcane = 75:35:20:60 tons/ha (for crop and succeeding ratoons)	a and b Ministry of Agriculture Kenya (2003; 2004; 2005) c Fieldwork d Acland (1986)
Economic costs of production	a Labour costs = Kshs/ha b Fertilizer costs = Kshs/ha c Seed costs = Kshs/ha d Pesticide/Herbicide costs = Kshs/ha	Ministry of Agriculture Kenya (2003; 2004; 2005). NB: Values are variable for different crops.
Biophysical factors of production	a Rainfall = mm b Rainfall variation factor = random function generator c Soil type = 5-class fertility scale	a and c Ministry of Agriculture Kenya (2000; 2003; and 2005) b Estimate
Crop residues	a Residues generated = tons/ton crop yield b Residue taken from/left in the field = tons/ton of residue generated	a Estimate b Fieldwork
Nutrient (nitrogen) content of harvested crops and residues	a Maize grains = 16.8 kg/ton b Maize residues = 9.7 kg/ton c Potatoes = 4.4 kg/ton d Potato residues = 2.3 kg/ton e Sugarcane = 0.6 kg/ton f Sugarcane residues = 0.3 kg/ton g Sugar beets = 4 kg/ton h Beet residues = 1.5 kg/ton	FAO (2004)

"Kshs" refers to Kenyan Shillings. 100Kshs = 1.5USD (May, 2007).

In Figure 1 showing the general structure of crop sub-models below, inputs into crop production are biophysical and economic costs of production. Two biophysical factors have been considered in the model. One of them is soils, which have been divided into five classes – very clay; clay; loam; sandy; and very sandy[3]. A range of rainfall of between 0mm – 3000mm/yr has been used to represent the role of precipitation in crop production[4].

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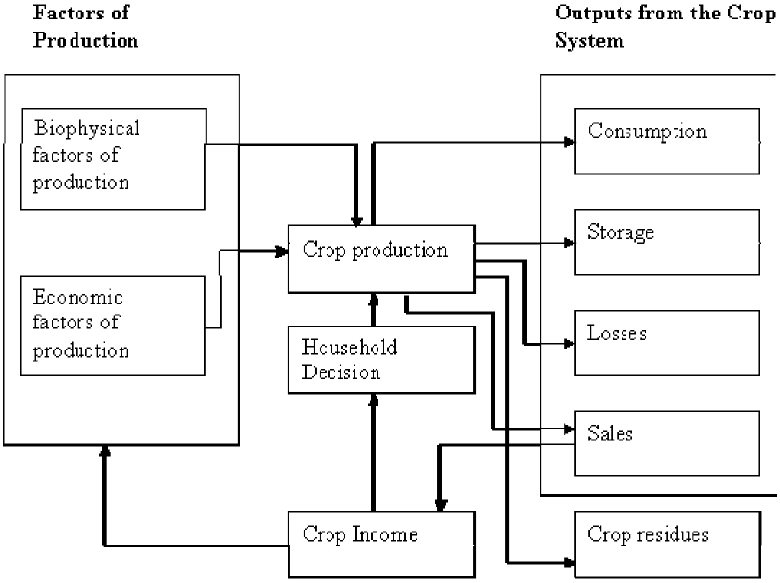
[3] This division is based on the classification of Kenyan agricultural soils made by the Kenyan Ministry of Agriculture and Rural Development (Interview with Agricultural Field Extension Officers).

[4] In the model, rainfall, like soils has been associated with a factor (rainfall and soil factor respectively) which is a reflection of the crop output that should be expected for a particular rainfall or soil type. Such expected yields are based on predictions made by the Kenyan Ministry of Agriculture and Rural Development (Ministry of Agriculture Kenya, 2000; 2001; 2003; 2004)

Figure 1 General Structure of Crop Sub-Models



Economic costs of production here refer to a combination of the costs for seeds, labour, pesticides (which also include herbicides), fertilizers, and transport.
Storage refers to that part of crop harvests which is preserved for household consumption and/or to serve as seeds for the next planting season[5]. As already explained above, losses bring together that fraction of crops that do not make it to be sold or consumed owing to their being left in the farm during the harvesting process; their dropping out and not making it to the house or market during the transportation process; and/or their being lost to rot, weevil attack or other form of degradation or loss that may be suffered after harvest which renders it not available for sale or consumption. In as much as this is an ever-existing problem with farmers, data is not readily available to determine its severity[6]. Residues refer to those parts of plants are not directly consumed as food or sold for that purpose. Examples are the maize plant after the grains have been removed; the bean plant after the seeds have been removed; or the remains of the sugar beet after the root has been taken.

The Sugar Beet Sub-Model: The main feature of the sugar beet sub-model is the noticeable absence of storage and consumption. It is assumed that sugar beets will be harvested only when the market is available. This is because in moist warm tropical environments the sugar content of the beets will very easily degrade once they have been up-rooted from the ground[7]. It is suggested that these beets can remain in relatively good conditions in the ground for significant periods of time without suffering from degradation after maturity.

The Potato Sub-Model: Potatoes are both consumed and sold. Also, they are stored and do suffer losses owing to their being stored. Outflow from consumption is a function of household size. While the relationship between household size and the amount of potatoes consumed is linear, the total amount consumed also depends on the number of alternative food crops available.

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[5] Data from the 2005 survey revealed that all farmers interviewed (N=60) who grow beans and potatoes, did not buy seeds for these crops in that farming year. They depended on the reserves they had stored as seeds. This is an indication of the importance of storage in plant sub-systems. It must however be noted that not all seeds are stored to the same extent. In the same survey, it was found that all farmers who took part did spend money on the purchase of maize seeds.

[6] In the survey, farmers were asked to give what they consider to be the most probable estimate of this loss. While this particular data may not be based on accurate scientific measurements, including it in the computation of the flow of harvested crops is an important reflection on the fact that not all that comes in as actual yield per hectare ends up as income to the farmer or as food for consumption.

[7] These are fears expressed by an agricultural field technician participating in the sugar beet trials on the study areas. Being a crop still being experimented for tropical conditions, data was not readily available to confirm or discard his assertion.

The Maize Sub-Model: It is structurally similar to the potato sub-model.

Sugarcane Sub-Model: The cycle of sugarcane cultivation lasts six years. After each planting, there are four harvests (the crop, 1st ratoon, 2nd ratoon, and 3rd ratoon). It therefore follows that certain expenditures such as on seeds and planting costs are incurred only at the beginning of the six year cycle. Each harvest within the cycle has been expressed as a ratio of the potential yield per hectare of cultivated area as follows: crop cane, 150tons/ha; first ratoon, 90tons/ha; second ratoon, 50tons/ha; and third ratoon, 65tons/ha (Acland, 1986).

Livestock Sub-Models

All livestock sub-models in this paper are similar by virtue of the number of sectors they are made of. These sectors include:

1. The reproduction and growth sector within which animals are born, develop from young to adults, and eventually leave the system through death, being consumed, or being sold. Some animals do enter this system not through births, but when through being bought and brought in.
2. The sector for livestock inputs sums up all inputs that go into the production system of each sub-system. These include costs of disease treatment, disease prevention, feeding supplements, and herding. It also includes the cost of rejuvenating of the stock through buying and introducing new animals into the system.
3. In the income-expenditure sector, the costs of inputs are accumulated as expenditures. Income is derived from the sale of livestock and livestock products within the system. Like in the crop sub-system, a surplus of income over expenditure is reserved in the general household income box from where individual sub-systems can rely when expenditures cannot be met by income.
4. The manure sector registers wastes generated by livestock. This waste production is a function of the production rate of manure by each livestock type and the number of livestock in the system.

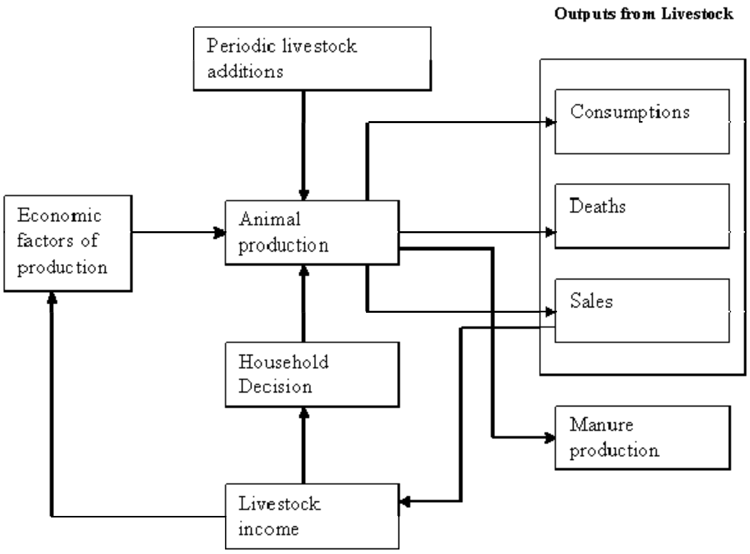
Table 2 Parameter Table for Livestock Sub-Models

Parameter	Description, Value and Units	Source
Livestock production	a Milk production = liters/animal/year b Cost prices = Kshs/animal c Birth and death rates	a and b Ministry of Agriculture Kenya (2000; 2004; 2005) c Fieldwork NB: Values are variable for different animals.
Economic costs of production	a Labour costs = Kshs/ha b Feeding costs = Kshs/ha c Medical costs = Kshs/ha	Ministry of Agriculture Kenya (2002; 2004; 2005). NB: Values are variable for different animals.
Manure production	Manure produced per animal = tons/animal/year	Fieldwork
Nutrient content of manure	a Cattle dung = 0.30% b Goat/sheep dung = 0.65% c Chicken manure = 2.8%	Roy et al 2006 *NB: The percentages are converted to tons/animal/year*

"Kshs" refers to Kenyan Shillings. 100Kshs = 1.5USD (May, 2007).

The inputs and output within the livestock sub-systems is captured in Figure 2 below. It is seen that consumption, deaths and sales take away animals from the sub-systems while manure comes out as a "by-product" of livestock production. Animal production here refers to the growth and reproduction within the sub-system.

Figure 2 General Structure of Livestock Sub-Models



It is also taken to involve the purchase of new stock to improve the genetic breed of existing stock which is a rare but nonetheless existent practice[8]. Economic costs include expenditures incurred in herding, the treatment of diseases, spraying of animals, buying of feed and all other expenses that go into production. Consumption is taken to refer to the number of animals slaughtered by households for home use as well as that given out as gifts and used in different ceremonies.

The Cattle and Diary Sub-Model: In this sub-model, the life-span of cattle has been set to eight years: two years in the calving stage and six years in the milking and reproductive stages (Ministry of Agriculture Kenya, 2000). This separation is done to capture the fate of cattle at different stages of their lives as they evolve within the farming system. While most beef cattle will be sold after two years of raising, basically only reproductive and milking cattle is allowed to go through the next stage of life in the farm. They leave the system as sales in their post-reproductive and post-milking lives or through deaths which is negligible. The number of lactation days per year was set to 300 (Ministry of Agriculture Kenya, 2000). There is the noticeable absence of household consumption from this sub-system since cattle is raised mainly for economic purposed. It is found too that milk contributes to the growth of income here (a situation that is not found in other livestock sub-systems in the model).

Chicken Sub-Model: In this sub-model, the separation between chick and adult stock is made on the basis of the high difference in mortality rate that exists between these two sub-groups (very high for chicks and very low for adults). However, their relatively short lifespan does not warrant the use of conveyors in depicting their growth process within the system. This chicken sub-system corresponds to the free-ranging extensive poultry keeping practice that is common among small-scale farming households in rural Kenya. It is therefore different from the intensive, large-scale poultry production by its limited use of purchased fowl feed, no confinement of animals (except briefly during planting periods), low rate of egg production per chicken per year, and low maturity rate of the birds.

Sheep Sub-Model: On the basis of this model, sheep production differs from cattle production mainly because of the absence of milking. Notwithstanding the generally short lifespan of sheep (compared to cattle) there is need for a functional differentiation between the calves of sheep and

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[8] Fieldwork reveals that the process of periodically acquiring new animals to add to an existing stock is not uncommon. The aim is to introduce new traits such as disease resistance, higher rate of reproduction, a greater body weight, etc into an existing animal stock.

the mature stock. This is because the consumption of lamb drives the young of sheep to the same fate as those of cattle. Unlike cattle, there is an outflow of sheep through consumption by households.

Goat Sub-Model: The goat sub-model is structurally similar to the sheep sub-model. The reason for including both sub-models however is because while goat rearing in more common in the lowland regions (represented in the study by Nyandarua), sheep rearing is a more common feature in highland regions (represented in the study by Mumias).

Nutrients Sub-Model

The term nutrient is used in this study to refer generally to the three common macro-nutrients (nitrogen (N); phosphorus (P) and potassium (K)). A further limitation will be made however to focus more specifically on nitrogen for a number of reasons: (1) nitrogen has been identified as being the most limiting of these three in small-scale agricultural productivity in Kenya (Shepherd, and Soule, 1998; Smaling et al, 1997; Stoorvogel, and Smaling, 1990); (2) given the limited time and resources available, the focus had to be limited to nitrogen only; (3) a significant amount of literature already exists on nitrogen use and balance in small-scale tropical farming systems which this study could base on to meet its objectives within the time and resources available for it.

Figure 3 General Structure of Nutrients Sub-Model

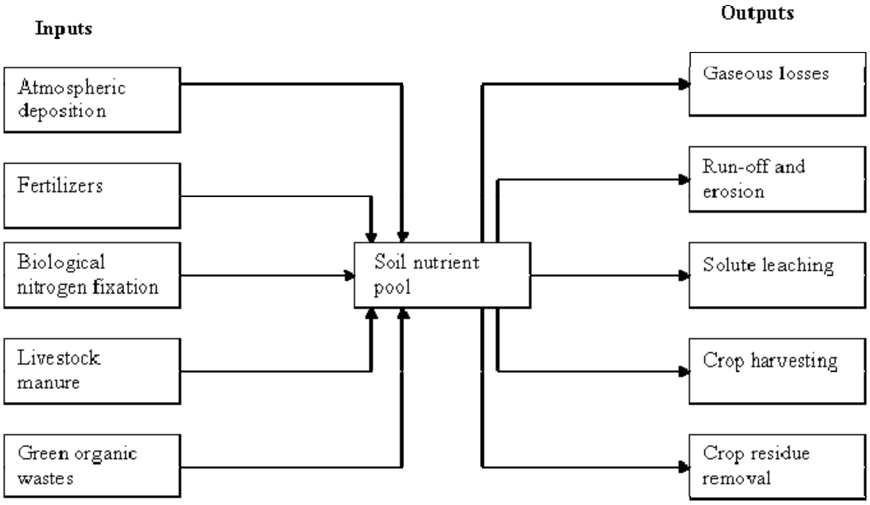

Figure 3 represents the structure of the nutrients sub-model used in this study. This structure borrows significantly from earlier works by FAO, (2004); Roy et al, (2003); Stoorvogel, and Smaling, (1990) and Smaling and Dixon (2006).

In this sub-system, the organic stock of nutrients is fed by green fertilizers like compost, plant residue as well as manure (animal wastes). These together with inorganic nutrients (chemical fertilizers) contribute to the total fertilizer pool in the system arising from anthropogenic activities. Other sources of inputs are from biological fixation; and atmospheric deposition (see the parameters on Table 3). Nutrients leave the system when they are harvested from plants; through erosion; leaching; and gaseous losses.

Nutrient Input-Output Analysis: To assess the nutrient balance of each household farming unit, there is need to put together the total input and output of nutrients within a given period (in this case a year). Three data sets are required for this analysis: data on crop nutrient requirements; data on the quantity of nutrients used by the household within the year in question as well as that made available by natural processes within the system; and data on the outputs of nutrients from the system for that period.

Table 3 Parameter Table for the Nutrients Sub-model

Parameter	Description, Value and Units	Source
Nutrient equivalents of manures animal wastes (fresh weight)	Cattle dung = 0.35% nitrogen Sheep dung = 0.80% nitrogen Goat dung = 0.65% nitrogen Chicken droppings = 2.87% nitrogen	Source: FAO (1982a; and 1982b)
Nutrient equivalents of crop residues (fresh weight)	a Maize residues = 9.7 kg N/ton b Sugarcane residues = 0.3 kg N/ton c Potato residues = 2.3 kg N/ton d Sugar beets = 4.4 kg N/ton	Roy et al (2006)
Crop foliage removed from the farm	a Maize residues = 90% b Sugarcane residues = 60% c Potato residues = 20% d Sugar beets = 90%	Field work
Natural nutrient transfer processes	Atmospheric deposition = 6 kg/ha/year Biological nitrogen fixation = 8 kg/ha/year Solute leaching = 41 kg/ha/year Runoff and erosion = 37 kg/ha/year	Smaling et al. 1997

Data on the quantity of nutrients applied to farms was gathered through questionnaires during the survey carried out in 2006 and 2007. Household nutrient supply comes both from the organic nutrients they generate through agriculture and other daily activities, and from the organic and inorganic nutrients they obtain from other sources and apply on their farms[9]. To computerize the actual nutrient yield of waste materials, crop residues and manure generated in the system, data of nutrient yield from previous studies FAO (1982a; and 1982b) was used. This data is summarized in Table 4.

Table 4 Nutrient Content of Some Organic Waste Materials

Category	**Source**	**Nutrient Content (%)**		
		N	P_2O5	K_2O
Animal Wastes	Cattle dung	0.30 – 0.40	0.1 – 0.15	0.15 – 0.20
	Sheep dung	0.80	0.01 – 0.02	0.50 – 0.70
	Goat dung	0.65	0.5	0.03
	Chicken droppings	2.87	2.9	2.35
Crop Residues	Maize residues	0.59	0.31	1.31
	Sugarcane residues	0.35	0.04	0.50
Compost	Rural compost	0.50 – 1.00	0.2	0.50
	Urban Compost	1.50 – 2.00	1.00	1.50

Source: FAO (1982a; and 1982b)

Farms also benefit from nutrients that are derived from biogeochemical processes in-situ. These are processes of biological nitrogen fixation, atmospheric deposition and weathering.

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[9] It must be noted that not all nutrients generated from farming activities (like crop residues and animal wastes) end up being used as farm fertilizers. Fieldwork data obtained for this study reveals that crop and animal remains may end up as fuelwood, forage, etc.

The contribution of both symbiotic and non-symbiotic biological nitrogen fixation to soil nutrients has been elaborated in a number of studies (Roy et al. 2006 and 2003; De Jager et al 1998; Giller and Cadisch. 1995; Peoples and Crasswell, 1992).

Atmospheric deposition of nutrients in the tropics usually occurs in two ways: in rain water and Harmattan dust. With the absence of data on the amount of Harmattan dust registered in Kenya computations to nutrient inputs through atmospheric deposition have been limited to rainwater. With the absence of specific data on Kenya, the tropical world average given by the FAO (2004) is used. It holds that the average quantity of N, P, and K in rainwater is 3.94, 0.01 and 1.17 g/ha/mm respectively. Hence the total amount of nitrogen for example that is derived from Nyandarua with an average rainfall of 960mm (Mandere, 2003) will be: 3.94g/ha * 960mm/ha = 3782.4g N/ha (approximately 3.7 kg N/ha).

Nutrient outputs are expressed either as outputs of crops and residues from the farm system of through biogeochemical processes. Nutrient outputs from individual crops are expressed as nitrogen equivalents of quantities of those crops leaving the system. In the same light, the amount of nutrients leaving the system is expressed as nitrogen equivalents of quantities of those residues. Biogeochemical processes take out nutrients through solute leaching; gaseous losses; and runoff and erosion (see the parameters on Table 3).

1.4.5 Model Validation

One of the most common problems that the validation of models faces is that of the availability of data (Robinson, 2004; Rykiel, 1995). Obtaining time series data for the same parameters from the study area to validate this model has been a difficult task. For this reason, the data published by FAO (2004) for the Embu District is used. This district is geographically very similar to Nyandarua (both are highlands, having many small-scale farmers growing almost similar cash and food crop and raising similar livestock). Figure 4 compares model results to FAO (2004) data. One must begin by noting that there is an absence of mineral fertilizers in the model data and values for biological fixation from the FAO (2004) data set (these are not zero values, but rather the non-existence of values).

Figure 4 Comparing Model Results to FAO Data for the Embu District

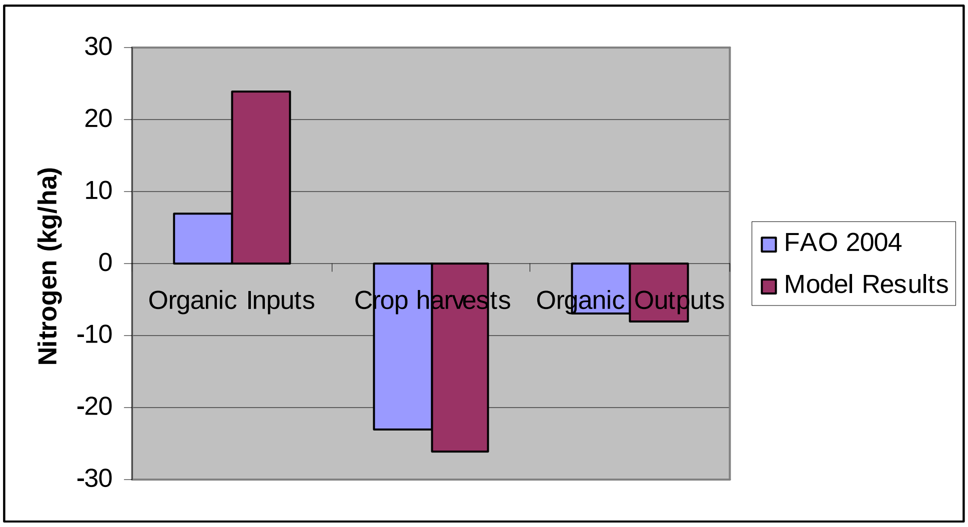


Figure 4 reveals demonstrates that model generated data on organic outputs and crop harvests compares closely to FAO (2004) data. There is however, a larger difference in the data on organic inputs. One possible reason for this difference could be the fact that unlike FAO (2004), the model assumes that all farmyard manure is recovered and ploughed back into crop production. Another possible source of this difference may lie in the model's definition of an ideal small-scale farmer. It is assumed that the farmer has three hectares of land, rears four types of livestock and grows two food crops and two cash crops. This was designed to capture the most of the diversity of income sources in rural Kenya. In as much as the conditions could be regulated to mirror different levels of assets, those attributed to the ideal small-scale farmer in rural Kenya may seem ambitious. The amount of land under cultivation reflects the amount of plant residues that can be generated, and coupled with the number of animals owned by each farmer, the total organic inputs in the model become visibly greater than those of FAO (2004).

As Robinson (2004) observes, the process of validating a model is not a matter of proving whether the model is correct or incorrect, it is a process of attributing some level of confidence in the tool. He also argues that data (source and accuracy) is potentially a source of inaccuracy in a simulation model.

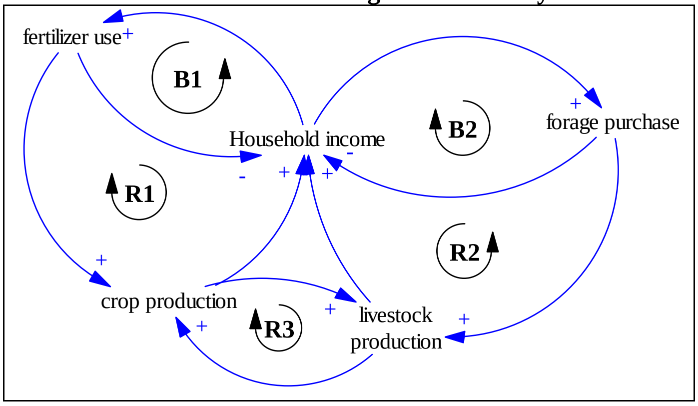
2. ANALYSIS

This part of the paper will first examine the situation that is prevalent in small-scale farming systems in Kenya at present. This will be followed by explaining the role low external input strategies can play the system. The discussion will then shift to the system that can emerge if low external input practices are fully adopted or benefits from them properly optimized (the best case scenario). It will end with an examination of the scopes and challenges inherent in attaining the best case scenario of low external input driven farming system.

2.1 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. One can therefore say that limited household income limits growth in agricultural productivity which in turn limits growth in household income. This is the scenario presented in Figure 5.

Figure 5 Business As Usual Scenario of Small-Scale Farming in Rural Kenya



In Figure 5 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. B2 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 grow.

The challenge of sustainable agriculture is among other things to, strike a balance between soil conservation (environmental protection) and economic profitability (Peel, 1998). A number of studies have shown that such a challenge can be met using low external input practices like: agroforestry (Buresh and Tian, 1997; Cooper et al., 1996; and Young, 1989); crop rotation (Carsky et al, 1999; Kwesiga and Coe, 1994); and intercropping (Sullivan, 2003; and Reinjtjes and Waters-Bayer, 1992).

2.2 The Place of Low External Input Strategies

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). This has led to the emergence of terms like “low external input agriculture/farming” Ruben and Lee, (2000); “organic farming” Dima and Odero, (1997); “sustainable agriculture” Reinjtjes et al., (1992); etc. Ruben and Lee, (2000) hold that what is common among all these definitions is the fact that: “farmers often eschew agrochemicals and other off-farm inputs, and instead develop integrated cropping and livestock systems, including agroforestry-based systems that permit improved nutrient cycling and biological control of pests and diseases.” In this study, three low external input strategies are considered: crop rotation, intercropping and agroforestry.

2.2.1 Crop Rotation and Intercropping

With nitrogen being the main limiting nutrient in the enhancement of agricultural output in sub-Saharan Africa, significant research effort has been invested in investigating balances for this nutrient that may be expected under a number of farm management practices. One of such areas of farm management is in crop rotation. It is defined as the successive cultivation of different crops in a specific sequence on the same land area, in contrast to a single-crop system or to haphazard crop successions. According to Sullivan (2003) 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.

Within this domain one area of focus has been 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). This value has 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 5 shows the fertilizer nitrogen replacement values derived from preceding legumes on maize yield .

Table 5 Residual Effect of Preceding Legume on Maize Yield 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)[10].

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[10] Only a few of the legumes grown on rotations with maize and with growth potentials in Mumias and Nyandarua are selected from a longer list.

A well planned rotation will besides increasing soil nitrogen also reduce the build-up of crop diseases pests[11], 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)[12].

Small scale farmers in rural Kenya 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[13]. 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.

To optimize the benefits of crop rotation (irrespective of how it is practiced), the system has to be carefully planed such that the right choice of crops succeeds one another and the right rotation cycle is maintained (Sullivan, 2003). Existing literature seems to suggest that the length of the rotation cycle could be partly influenced by the total number of crops that take part in the rotation cycle. It is fair however to expect that small scale farmers with limited economic potentials will prefer shorter rotation cycles in the face of limited cultivable land. Peel (1998) gives insights into what should be expected when planning a crop rotation system. He shows that there is need to balance the process of nutrient production and conservation (determined by the design of the crop rotation system) with that of nutrient mining (determined by the choice of crops within the system).

2.2.2 Agroforestry

Young (1989) defines agroforestry as: “a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants crops, pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system”. In a sense, this definition encompasses the three strategies of low external input strategies being investigated in this paper (crop rotation, intercropping, and agroforestry). While acknowledging the multiple benefits agroforestry can offer to small-scale farming systems, many studies have stressed the role it plays in ameliorating the situation of soil nitrogen - the main limiting nutrient to crop yields in tropical agriculture (Sanchez, 2002; Oswald et al, 1996; Young, 1989) Single tropical species like leucaena which can be easily available and grown can significantly change the level of deficiency suffered by small-scale agricultural systems in Kenya. Table 6 shows the contributions to soil nitrogen that can be added through the complete incorporation of four common agroforestry species into the soil from hedgerow prunnings.

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[11] According to Peel (1998), crop rotation alone could be used to partly or completely control diseases like scab, smut and seedling blight which attack maize as well as verticullium wilt and sclerotinia (white mold) which attacks potatoes. It could also be used to fight pests like sugar beet maggot and root aphid which attacks sugar beet; and corn root worm which attacks maize.

[12] Results of such experiments can be found in Peel (1998) and in Jensen and Weiser (1971).

[13] Field observations reveal that farmers with limited land (<2 ha) tend to driven more by seasonal changes to rotate from one set of crops to another while those with larger farm holdings are driven more by economic considerations. Farmers with small land holdings therefore tend to prefer the cultivation of food crops which they could also sell and which have a shorter growing cycle (like beans, maize, and potatoes) while those with large farm holdings venture more into purely market oriented crops (even with longer growing cycles) like sugarcane.

Table 6 Some Green Manure Crops and Their Nitrogen Contribution to the Soil Under Optimal Conditions

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

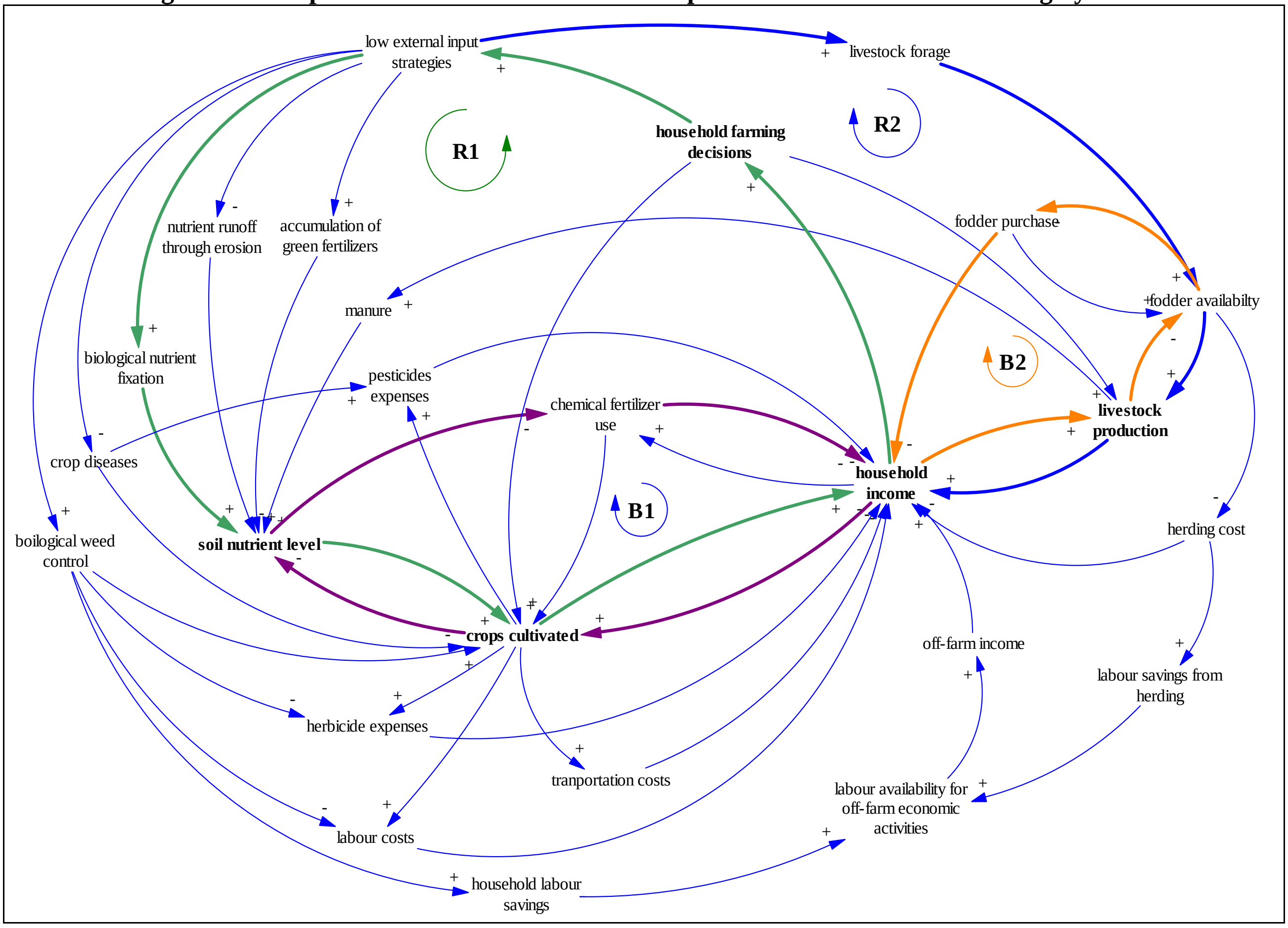
Source: Roy et al., 2006

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-pack an estimate of 30-80 kg N/ha/year as being the likely contribution to crop of hedgerow prunnings. 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.

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

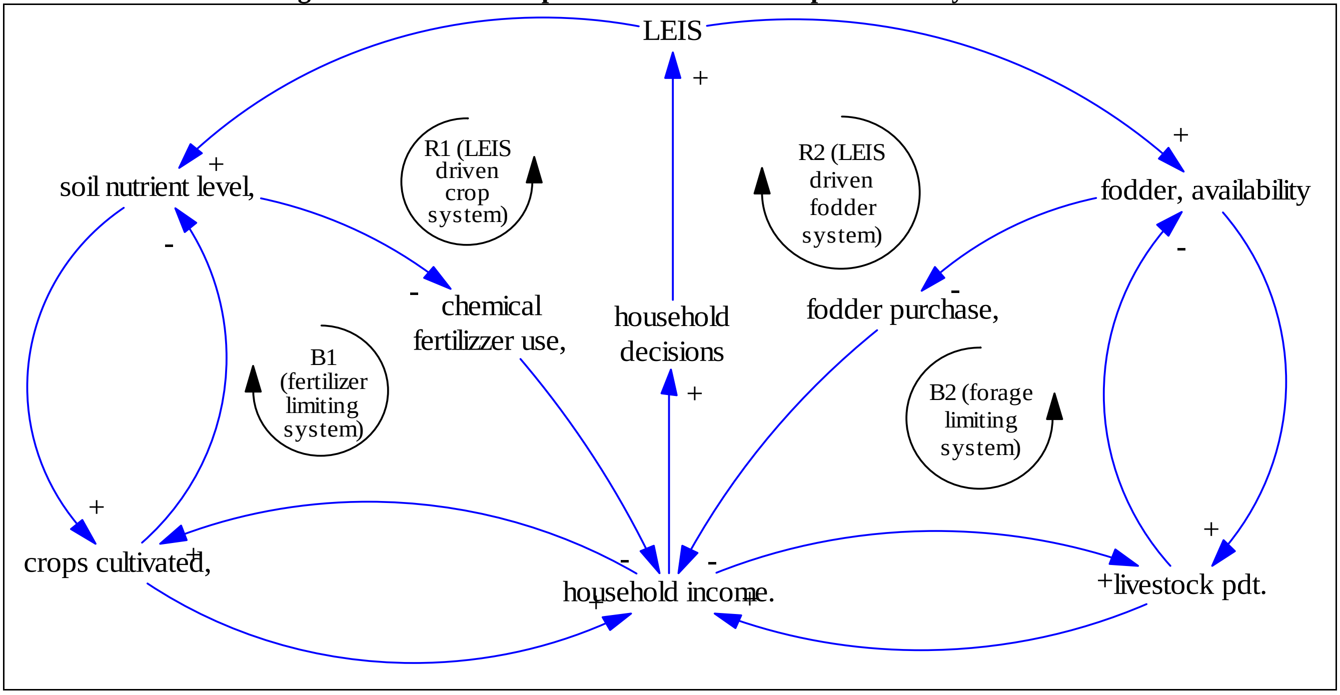
Figure 6 is a conceptual model of the small-scale household farming system with possible outcomes of the adoption and implementation or optimization of low external input practices. The figure shows that through agroforestry, soil erosion can be controlled and nutrient runoff associated with it will then be checked. In the same light, the accumulation of green fertilizers will ameliorate the soil organic nutrient content which will improve crop yields. Improved crop yields mean increased income for farmers. Such a positive reinforcing effect can be traced too from the effects of intercropping and crop rotation on biological nutrient fixation and soil erosion control on yields. Other benefits that can be derived are biological weed control which will liberate time from the farms which could be used for other non-farm income generating activities as well as costs that may have been incurred in taking care of this activity. Benefits can also be derived through financial savings from the biological control of crop pests.

Figure 6 Conceptual Model of a Low External Input Driven Small-Scale Farming System



Low external input practices also lead to the availability of livestock forage which saves household income that would have been used to buy fodder. Fodder availability also reduces herding costs and saves labour that could be used for other income-generating activities within the household. Important loops within this system have been identified and presented in Figure 7 for a more detailed analysis. These loops include: B1, the “fertilizer limiting system” which represents the limits to crop growth imposed by limited access to chemical fertilizers; R1, the “LEIS driven crop system” represents the system in which dependence on chemical fertilizers for increased crop production is off-set by the provision of foil nutrients through low external input practices; B2, the “forage limiting system” to increased livestock productivity; and R2, the “LEIS driven fodder system” in which low external input practices off-set the dependence on purchased forage for expanding livestock productivity.

Figure 7 Dominant Loops in a Low External Input Driven system



A feedback loop analysis of Figure 7 can reveal the prospects available for attaining the challenge of sustainable agriculture though adopting or optimizing benefits from low external input practices. One of the indicators used to determine sustainability in small-scale agricultural production is household income. Since crop and livestock income are the main sources of income under consideration, the feedback loop analysis will seek to evaluate possibilities increasing crop and livestock yields without depleting household income[14].

Increasing Crop Production and Household Income Simultaneously. One possibility for attaining this in the absence of low external input practices is by providing chemical fertilizers at rates that are low enough for farmers to afford. In Figure 7, this means reinforcing the balancing loop B1. According to Sanchez, (2002), a number of problems have plagued governmental bodies in most parts of sub-Saharan Africa in meeting this challenge. Their inability to meet this challenge has resulted in the stagnation of agricultural productivity that is experienced in the region to this day. The problem can also be solved by by-passing the use of chemical fertilizers (eliminating the balancing loop B1) or laying emphasis on the use of LEIS as opposed to the use of chemical fertilizers (which means either weakening the strength of the balancing loop B1 or strengthening the reinforcing loop R1). Strengthening the LEIS-driven system R1 would mean introducing and/or optimizing agronomic practices like intercropping, crop rotation and agroforestry. Such contributions are highly spatially variable and could depend on a large number of factors – one of which is precipitation (Roy *et al*, 2003).

Increasing Livestock Production and Household Income Simultaneously. The loop B2 of Figure 7 represents limits to the growth of household income imposed by the need to buy fodder to meet any increase in the production of livestock. As is the case of crop production where failed attempts have been made by governments of sub-Saharan Africa to stimulate increases in yields through better access to fertilizers, limited attempts have also been made in Kenya to provide farmers with adequate access to fodder. Farmers then tend to depend on crop residues to serve as feed for livestock. Figure 8 shows that most parts of crop residues of the most bulky plants (maize and sugarcane) are used to feed animals. The amount of nitrogen that leaves the soil through these sources are: 9.7 kg/ton and 0.3 kg/ton respectively for maize and sugarcane.

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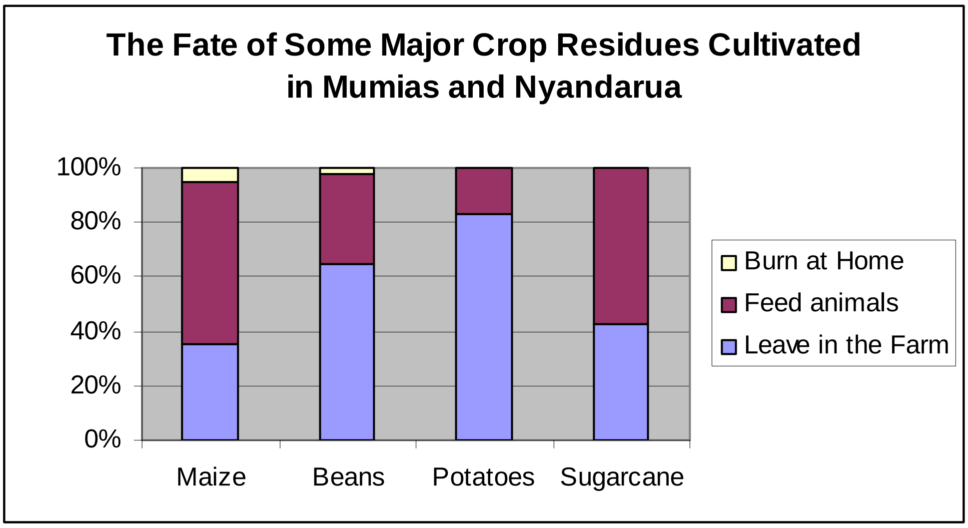
[14] It should be remembered that in Figure **5**, crop and livestock yields could only be increased at the expense of household income.

Figure 8 The Fate of Crop Residues in the study Area



Source: Fieldwork 2007

This is to the disadvantage of the soil nutrient balance given that not all of the livestock manure returns to the farms to replace the nutrients that were removed. More so, in the best case scenario, feeding animals with crop residues cannot increase livestock production in the long term because in this system, the expansion of crop production itself is limited by low soil fertility.

To solve the problem here, the limiting loop to increased livestock production B2 (in Figure 7) can either be eliminated or weakened by strengthening the loop R2. This can be done by designing the LEIS to incorporate the need for meeting fodder demand. One of the reasons why LEIS has been recommended as an ideal package for meeting the problems of nutrient deficiency in poor regions of the tropical developing world is because it comes with a package of side benefits. Some of these benefits have been explained by Shepherd and Soule (1998).

The model developed for this study is used to test the hypothesis that low external input practices can lead to sustainability in agricultural production. Household income is used as an indicator of economic sustainability while soil nitrogen balance is used as an indicator of environmental sustainability. Figure 9 shows the system before the introduction of leucaena while the simulated result of such an introduction is presented in Figure 10. This simulation shows the response of soil nitrogen input and output to the introduction of leucaena on intercrops and using the entire plant as a mulch pool in agriculture[15]. It is based on the assumptions: that the contribution of nitrogen by leucaena through fixation and prunnings to the farm will stand at 100 kg of N/ha/year (Table 6 shows that even more could be expected).

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[15] According to Young (1989), besides producing abundant biomass averaging about 17500 kg of dry matter per hectare per year, *Leucaena leucocephala* fixes between 100 to 500 kg/N/year, while it leaves contain 2.5 to 4.0% of nitrogen (meaning a high rate of return of nitrogen in litter and/or mulch prunnings.

Figure 9 Net Soil Nitrogen Balance before the Introduction of Leucaena

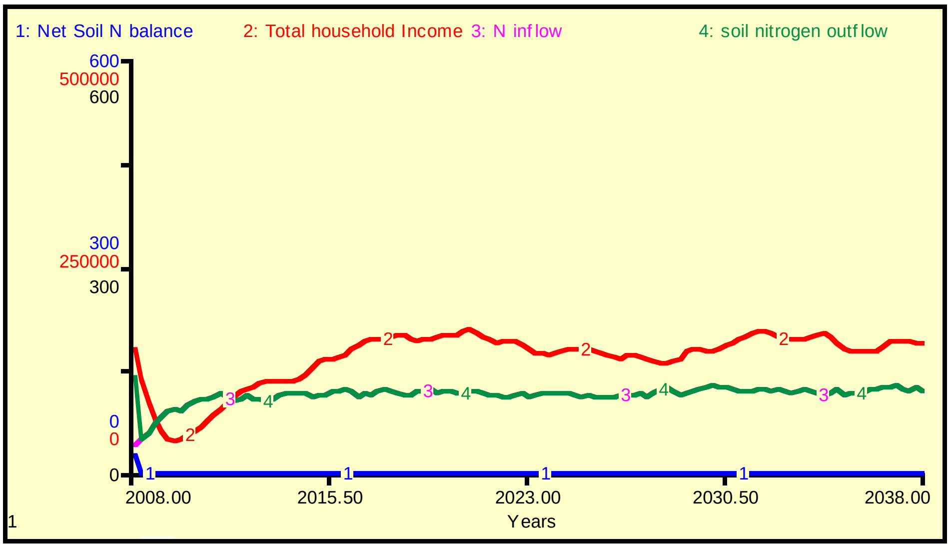
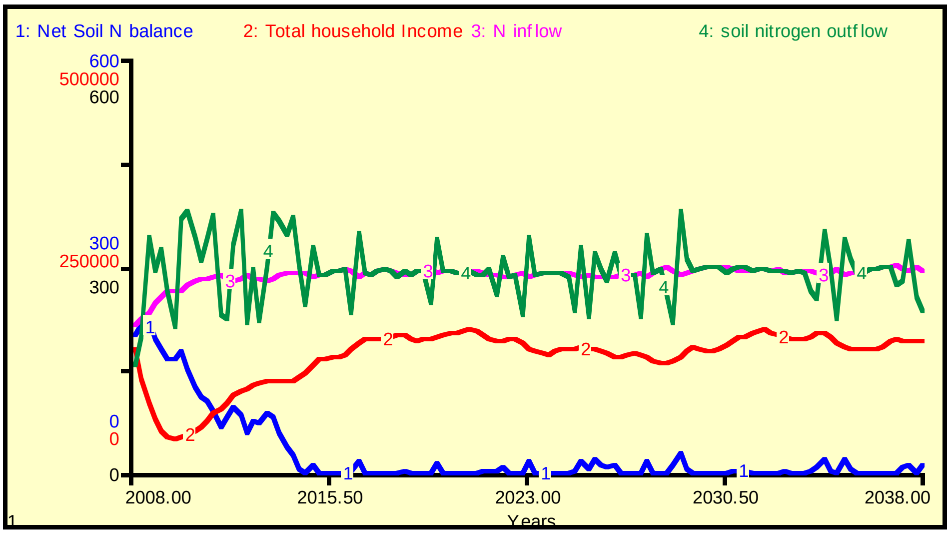


Figure 10 Net Soil Nitrogen Balance after the Introduction of Leucaena

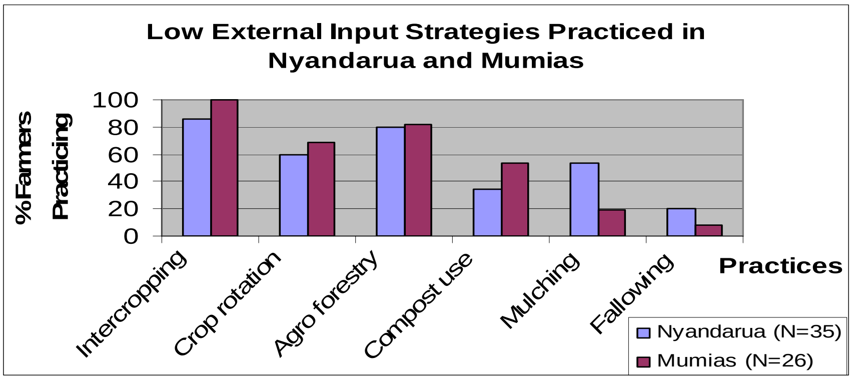


There is no net annual gain in nitrogen in the soil before the introduction of leucaena. After the introduction of leucaena, the total circulation of nitrogen within the system increases significantly while the net soil nitrogen balance begins showing signs of periodic positive accumulations. The effects on household income within a thirty year period are very minimal.

2.4 Scopes for the Optimization of Low External Input Strategies

Figure 11 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.

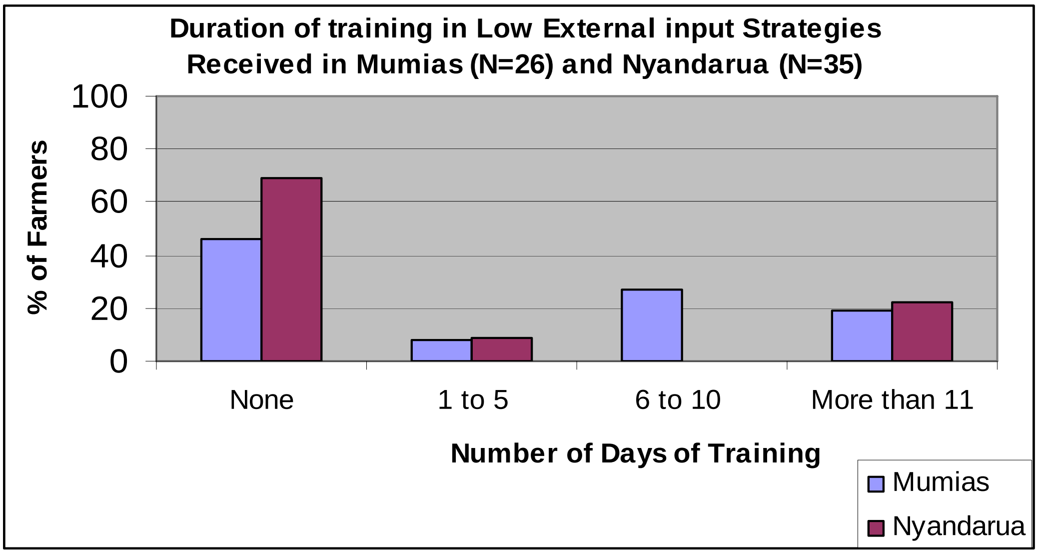
Figure 11 Percentage of Farmers Practicing Low External Input Strategies



Source: Fieldwork 2007

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 12 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.

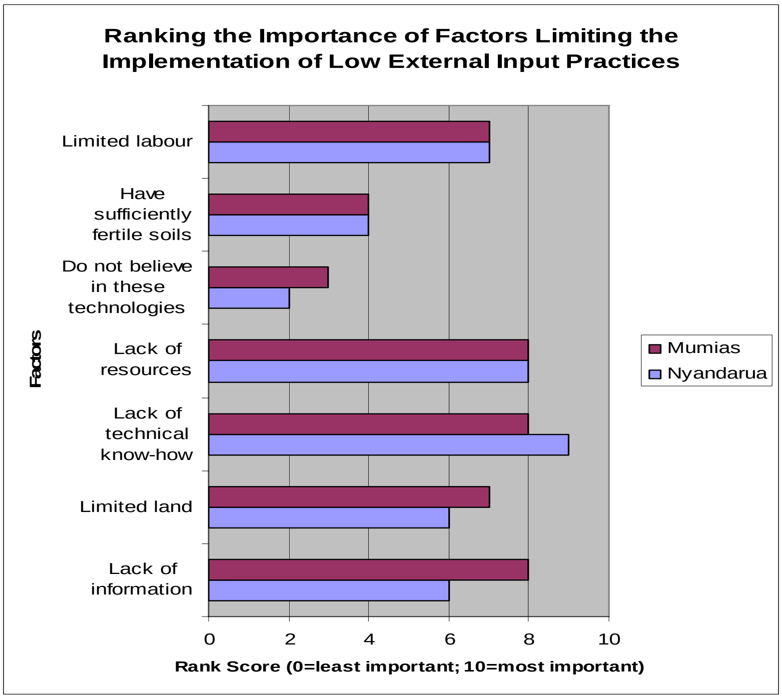
Figure 12 Duration of Training on Low External Input Strategies in Nyandarua and Mumias



Source: Fieldwork 2007

It follows therefore 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 13 Limits to the Practice of Low External Input Strategies[16]



Source: Fieldwork 2007

More insights into the problems associated with optimizing benefits from low input strategies are presented in Figure 13 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. The limited information may explain the reason why a small portion of farmers tend not to believe in the benefits of low external input practices or to think that their soils are sufficiently fertile to need these practices.

3. EXPLORING SCENARIOS IN SMALL-SCALE KENYAN FARMING SYSTEMS

Several trends have been observed as being influential in small-scale African agriculture in recent years. A few of them (observed by literature to be important) are price fluctuations (Naiman and Watkins, 1999); and the effects of erratic climatic manifestations (Sivakumar, 2007). These trends have been tested using scenarios formulated as questions. The intention is to measure the effect that such trends could have on the economic and ecological sustainability of small-scale agriculture in the study area.

3.1 Scenario of a Fall in the Price of Cash Crops

Notable among these have been the fluctuation of cash crop prices in the world market with a general trend towards decline (Naiman and Watkins, 1999). For small-scale farmers, the impacts of such fluctuations are much more severe given that their small agricultural capital cannot easily absorb the shock of declining prices. 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

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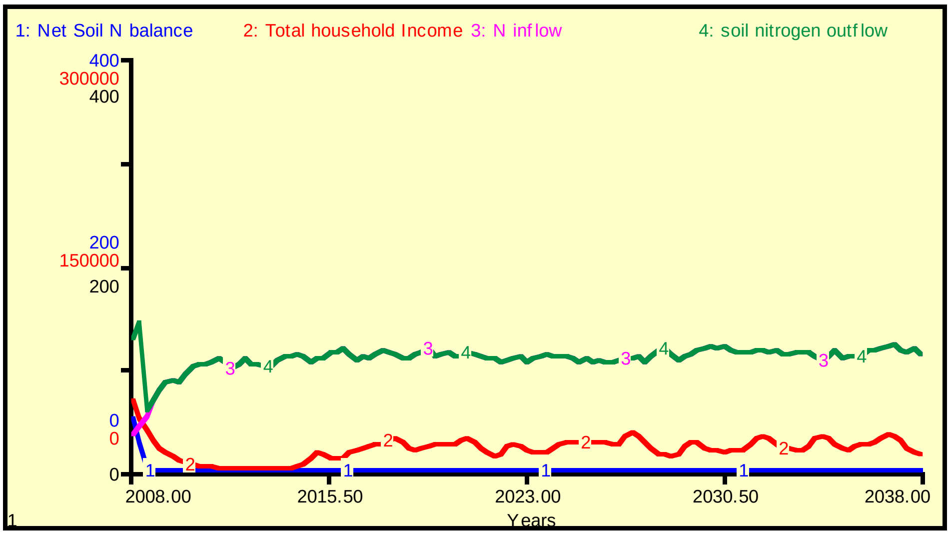
[16] To get an overall rank of the factors, farmers were asked to rank the factors in terms of their importance (1=most important to 10=least important). These ranks were then attributed weights (from 10 for rank factors ranked as most important to 0 for those deemed not important at all). The sum of the weights were divided by the number of responses to get the overall rank per factor.

are expected. According to Jayne (1994), there is empirical evidence to suggest that cash crops provide higher returns to land and labour than food crops in semi-arid regions of Africa and may therefore provide opportunities to raise the income of small-scale farmers. 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[17]. 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 data, 2007). Figure 14 shows the effects of a conversion of land from cash crop production to food crop production on soil nitrogen and total household income. The effects of the absence of cash crops on household income can be seen by comparing this figure withFigure 9.

Figure 14 Soil Nitrogen and Household Income without Cash Crops and without Low External Input strategies



When land for cash crops is converted to food crops, there is a significant fall in household income. This should be due to the fact that the food crops under consideration fetch a lower market price per unit area cultivated than cash crops. While the net balance in soil nitrogen remains negative in the presence or absence of cash crops, greater quantities tend to be circulated in the farm in the presence of cash crops (compare Figure 14 with Figure 9). This is because the system under study had sugarcane which is a "semi-permanent cash crop". Such a crop will reduce the amount of nutrients that are cycled within the farms since its cultivation cycle is much longer.

3.2 Scenario of Increased Climate Variability

The problem of erratic weather associated with climate change has been one of growing concern on agriculture in tropical Africa in recent years[18]. It is observed that sub-Saharan Africa is going to be one of the hardest hit regions of the world as the phenomenon of climate change unfolds (Sivakumar, 2007). Already, there are complains of infrequent rains, floods and higher-than-normal winds (Fieldwork, 2007). One scenario tested by the model is to measure the response of household incomes to erratic weather. Here, the weather factor used is precipitation and random weather manifestations are generated from a mean value of 700mm for Mumias. The output is shown in Figure 15 and Figure 16 Household income falls and nutrient inflows and outflows become more variable. The fall of incomes is a reflection of the fall of harvests that associates erratic weather.

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[17] Source: Field interviews.

[18] According to Sivakumar, (2007), sub-Saharan Africa is loosing cropping land in the order of 0.5% to 1% annually as a result of climate change.

Figure 15 Response to Soil Nitrogen and Household Income in Conditions of Erratic Climate Without LEIS

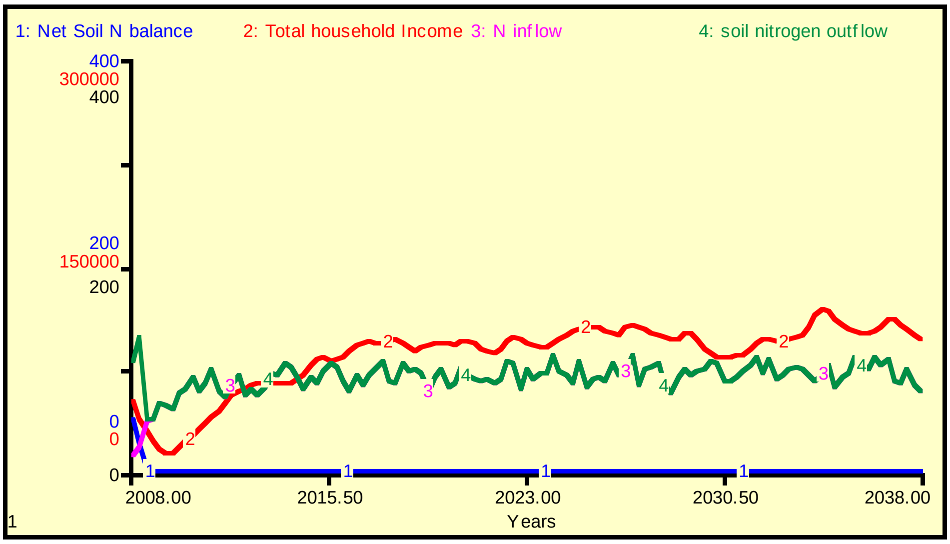
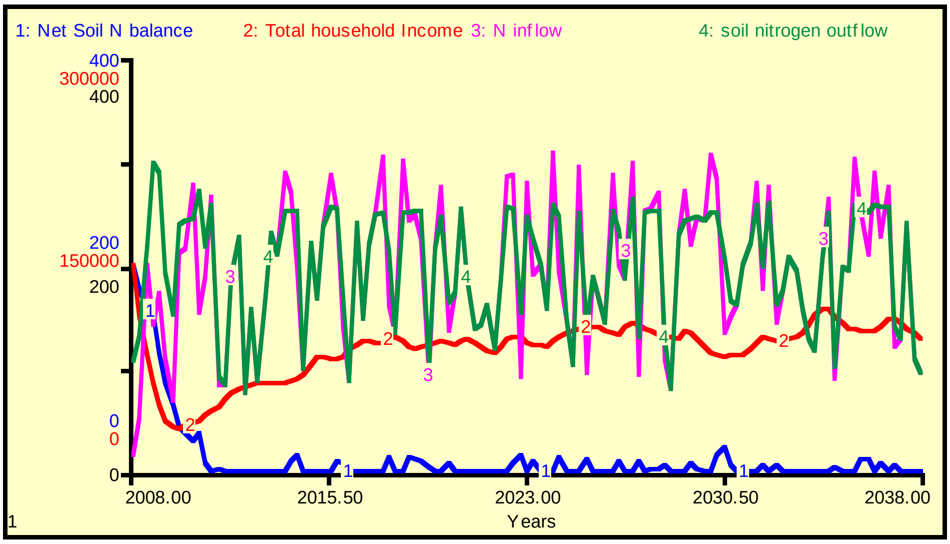


Figure 16 Response to Soil Nitrogen and Household Income in Conditions of Erratic Climate with LEIS



The simulations reveal an increase in the fluctuation of soil nitrogen balance with no net gains within the 30 year period of simulation. Total household income also fluctuates reaching greater lows than is observed during the simulation of stable weather.

Simulations of the response of individual crop yields to erratic weather however reveal more drastic fluctuations. In Figure 17 and Figure 18, the response of maize yields to erratic weather shows a significant drop in total yields with more pronounced annual differences.

Figure 17 Maize Harvest in Stable Climatic Conditions

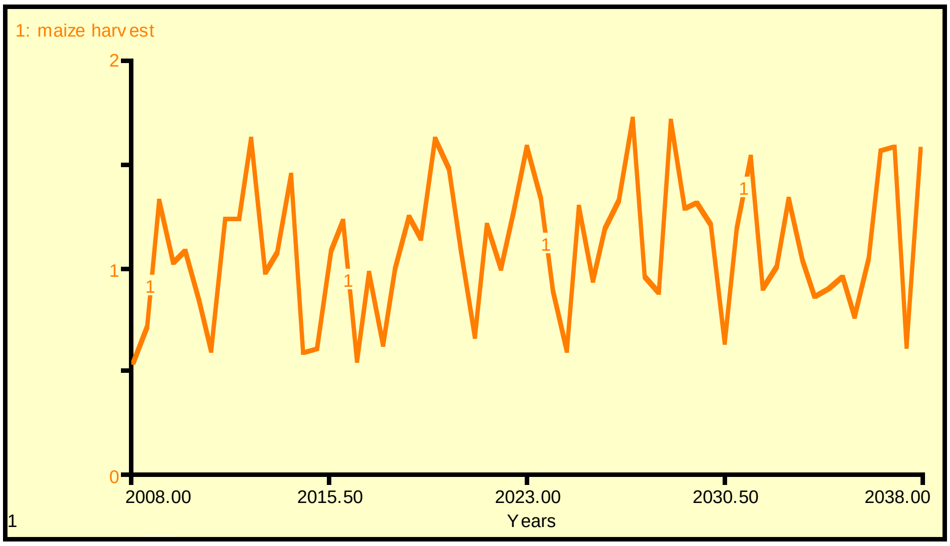
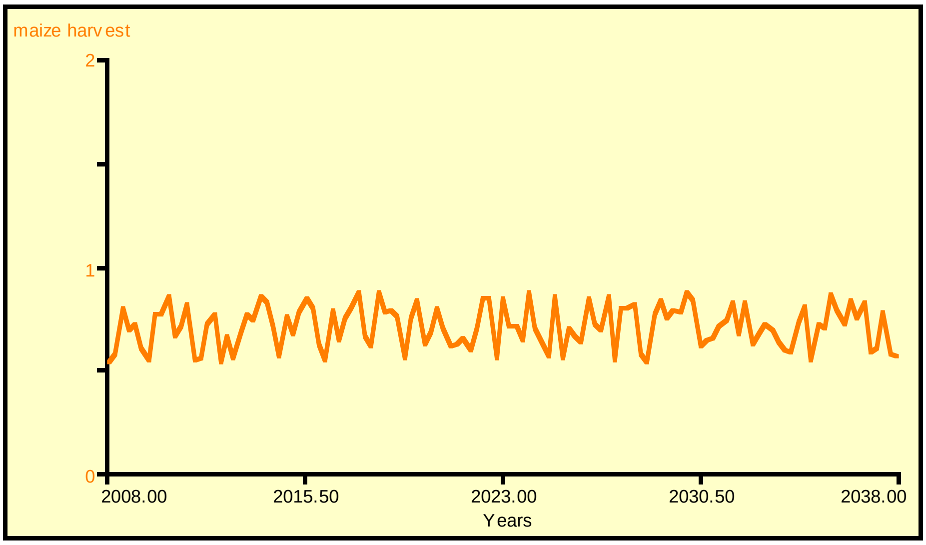


Figure 18 Maize Harvest in Conditions of Erratic Climate

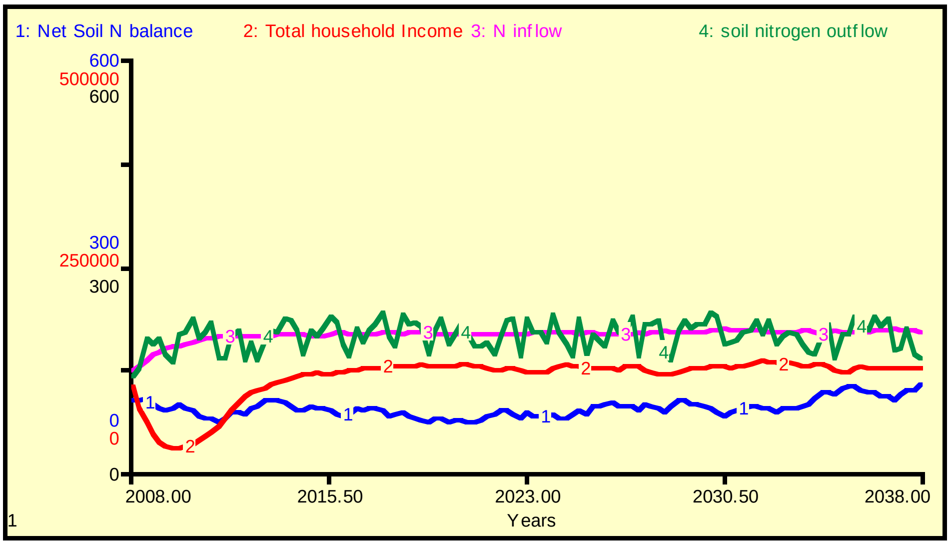


The fluctuation in maize yield is reflected in the contributions that maize incomes would make to the total household income. These fluctuations are however not immediately evident on household income because of the stabilizing effect of other crops which may not suffer the same effects of climate change as maize. The fact that fluctuations in the yield and income of an individual crop is not manifested to the same magnitude in the total household income is at the heart of some of the most cherished reasons for advocating low external input agronomic practices. One of these reasons is the fact that low external input practices diversify agricultural output in farming households and by so doing, spreads the risk of crop failure (owing to adverse weather or otherwise) over a variety of agricultural resources (Ellis, 1998(a); 1998(b); Dose, 1997; Binswanger, and McIntire, 1987;).

3.3 Scenario of Large-Scale Adoption of Low External Input Strategies

At national and provincial levels, the government of Kenya has undertaken different projects that are aimed at improving agriculture in Kenya’s rural landscape. Some of these initiatives include: the Drought Recovery Programme; the Biofertilizers Project; the Agricultural Technology and Information Initiative; the Special Programme for Food Security; and the Programme for the Promotion of Private Sector Development in Agriculture (Ministry of Agriculture Kenya, 2000, 2001, 2002, 2003, 2004, 2005). One essential component of these programmes has been to incorporate sustainability into Kenyan agriculture by maximizing yields through the optimization of low agricultural input strategies. Even though success has been minimal with these programmes (Ministry of Agriculture Kenya, 2000, 2003), it is plausible to envision a scenario in which such efforts were more successful. Figure 19 shows the output of simulating such a scenario.

Figure 19 Best Case Scenario of Soil Nitrogen and Household Income in Optimum Conditions of Soil and Climate with LEIS



When Figure 19 is compared to previous results (Figure 9), it is found that the adoption of LEIS leads to a fall in household income. While this could be considered as negative economical effect for the farmer, one must also note that it fluctuates less from year to year. The fall in income may be explained by the fact that part of the land surface that was formally used for crop production has now been dedicated to the development of low external input practices. The fall in income is more pronounced here than in Figure 10 because more resources (land in particular) has been dedicated in this case for the development of LEIS. In Figure 10, only leucaena is used as a LEIS resource and used as a sparsely cultivated intercrop. The best case scenario described in Figure 19 assumes the existence of other LEIS practices like erosion control contour hedges which take up more crop cultivation space. It could also be that investments in low input strategies are long-term investments in environmental welfare (ecologically sound agriculture) whose returns may not be significantly expressed in household income within a thirty year period. Finally, it may be that economic returns to the learning curve of this new technology are slow to come.

4. DISCUSSIONS

The practice of low external input agriculture is a common feature in the Kenyan rural landscape (seeFigure 10). 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 instruction 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 11). 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.

The scenario of falling prices tested in the model may be criticized as being a bit extreme. A fall in cash crop prices may not automatically lead to an automatic allocation of food cash crop land to food crops. This is because there may be alternatives cash crops to those with fallen prices to which farmers may allocate land. It may also take a much longer time to phase out a cash crop with farmers anticipating that the fallen prices may rise again. Notwithstanding these shortcomings, this scenario has been important in demonstrating the importance cash crops play in contributing to household income and the soil nutrient balance. It is important to note the fall in the nitrogen inflow and outflow values that are experienced when cash crops are eliminated from the system. This could be explained by the fact that one of the cash crops that were being grown were plants with a long cycle (sugarcane with a 6-year growing cycle). Within this period, they reduce the rates at which nutrients are being cycled (and lost) within the system.

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. The environmental effect of such a best case scenario is however directly evident. The net inflow of soil nitrogen surpasses net outflow and a positive soil balance begins being experienced from the first year. Even though this is not immediately translated into increased 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.

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 bench marks 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.

The modelling process has led to a deeper understanding of the small-scale farming system in rural Kenya and the implications on household income and soil nitrogen balance of the optimization of low external input strategies. One main feature of the model is that it provides a holistic framework for assessing the impact of land-use management practices on soil nitrogen and household income. It must be acknowledged that land-use management practices will have consequences far beyond soil nitrogen and household income which can be important for the small-scale rural household in Kenya. Capturing a more in-depth interplay of low external input strategies and economic as well as soil variables may require a more detailed set of studies. Lockeretz (1989) did outline some of the difficulties inherent in making a detailed analysis of the economic benefits of low external input agriculture: definition of the concept of “low input agriculture”; scale of application; indicators of success/failure; the question of who’s success is being discussed or evaluated (the farmer, the community, or future generations)?; and the problem of comparing these successes/failures (which scales and units are appropriate for such comparisons?).

Notwithstanding this, the model can be used to understand the effects of changing patterns of land-use associated with the adoption of low external input strategies on soil fertility and household income at local scale. This is an important consideration in designing policies which address soil fertility and livelihood policies at local level. The study can also be used to translate management practices into natural (nitrogen) and financial (household income) indicators of sustainable livelihoods for rural households[19].

5. 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 the main hindrance to reaping optimal benefits from these practices. Model outputs show 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, household income from agriculture is seen to fall with adoption of low external input practices. It is however argued that in the long-term, 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.

Three scenarios are tested with the model. In the scenario of the conversion of cash crop land to food crops, greater quantities of nitrogen tend to be circulated within the farm system while the annual net nitrogen remains negative while household income falls significantly in the absence of low external input practices. The scenario of erratic weather shows greater effects on individual crops and income output from these crops than on the system as a whole. The scenario of an ambitious adoption of LEIS reveals that the net soil nitrogen balance as well as annual rate of inputs and outputs is higher. Generally, the low conditions of soil fertility and household incomes make the adoption and optimization of benefits from LEIS a viable option for the sustainability of agriculture in Nyandarua and Mumias.

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[19] This is an approach developed by Smaling and Dixon (2006).

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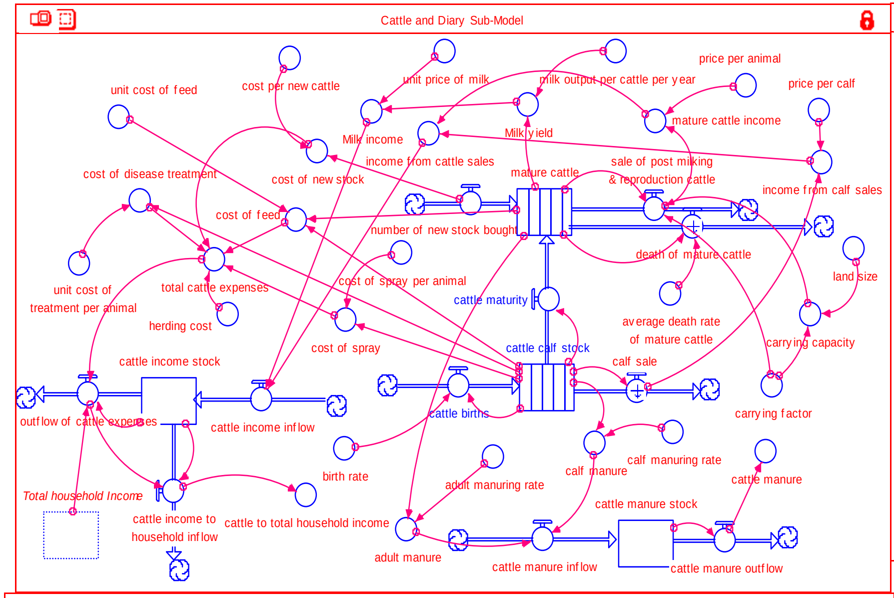
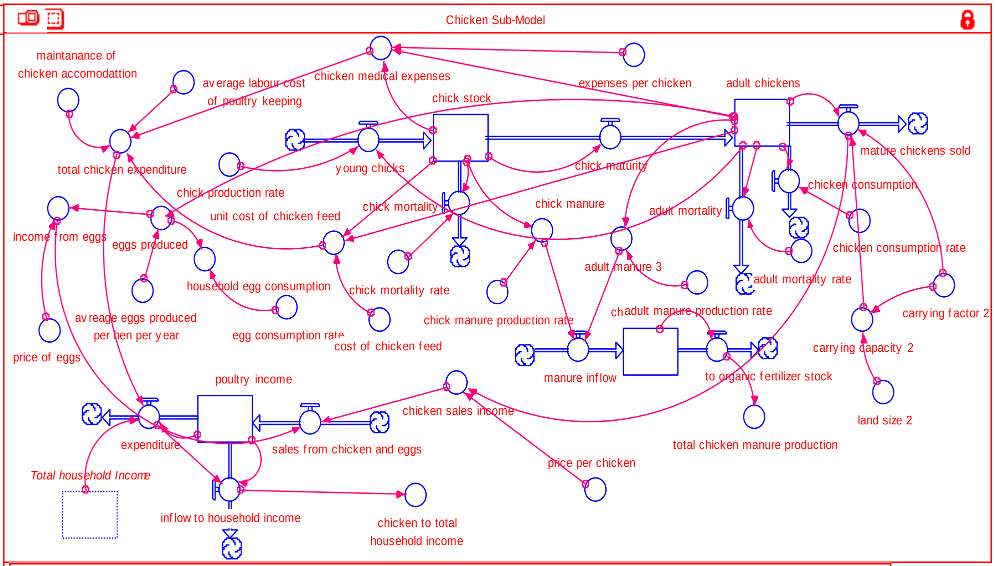
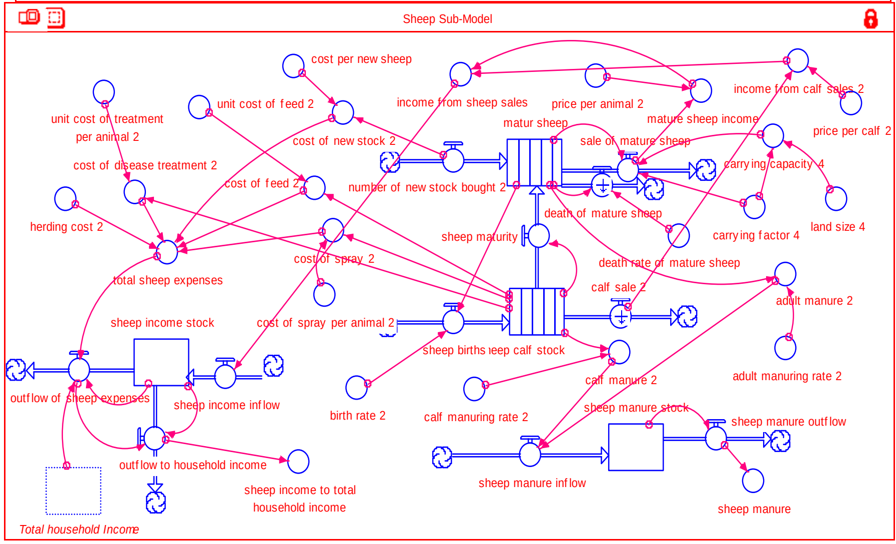
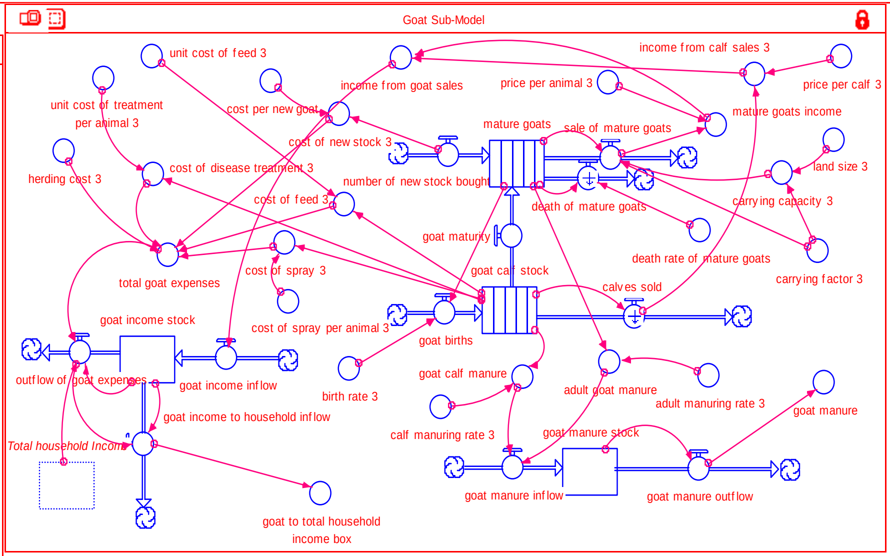
7. APPENDIX

7.1 Livestock Sub-Models

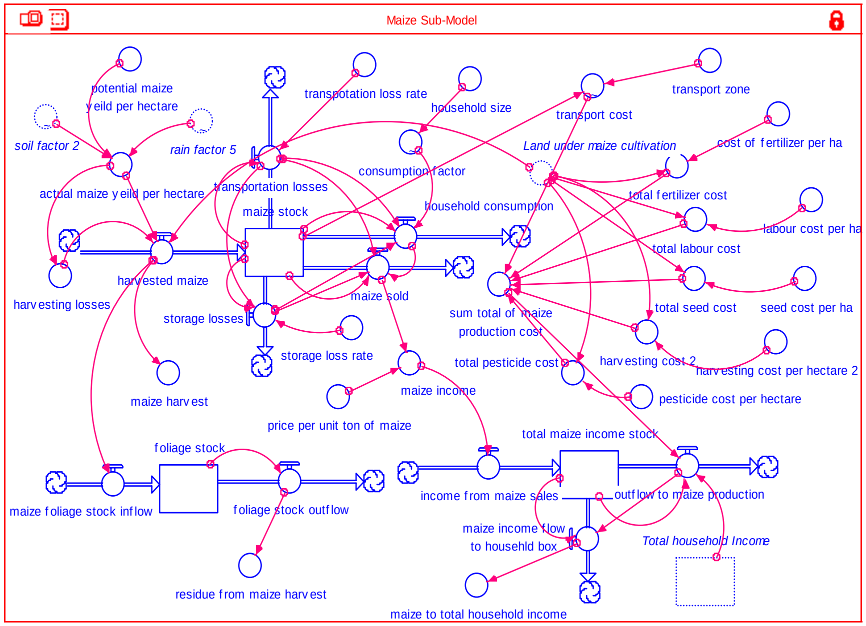


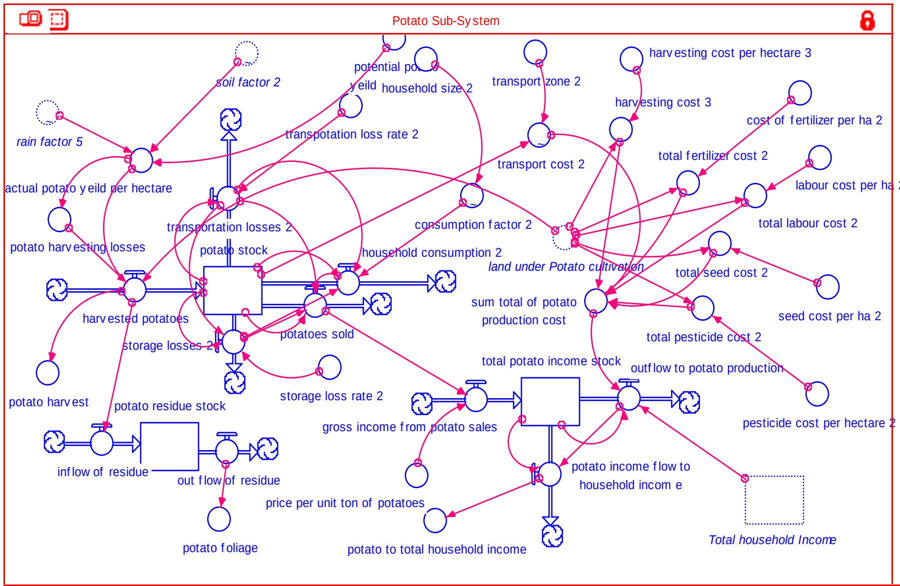


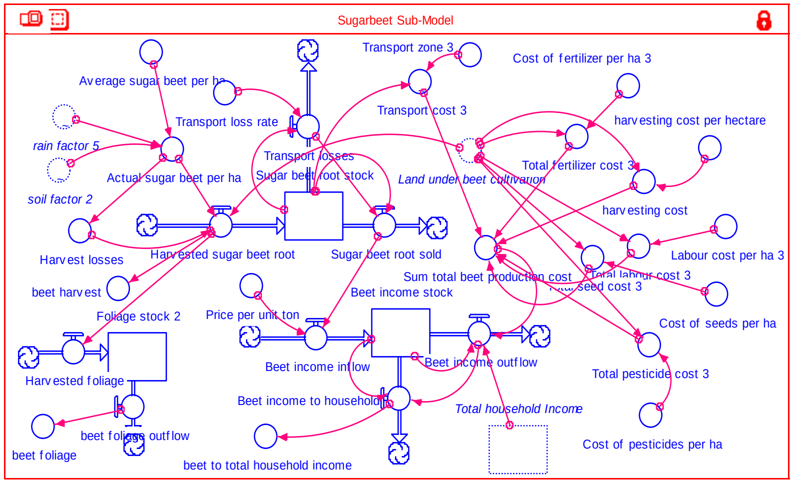


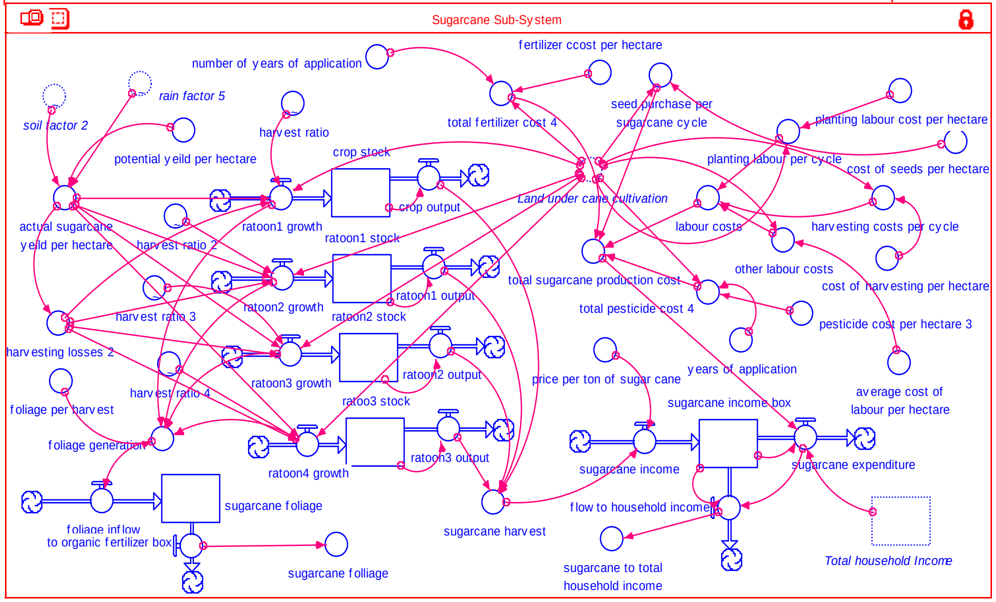


7.2 Crop Sub-Models

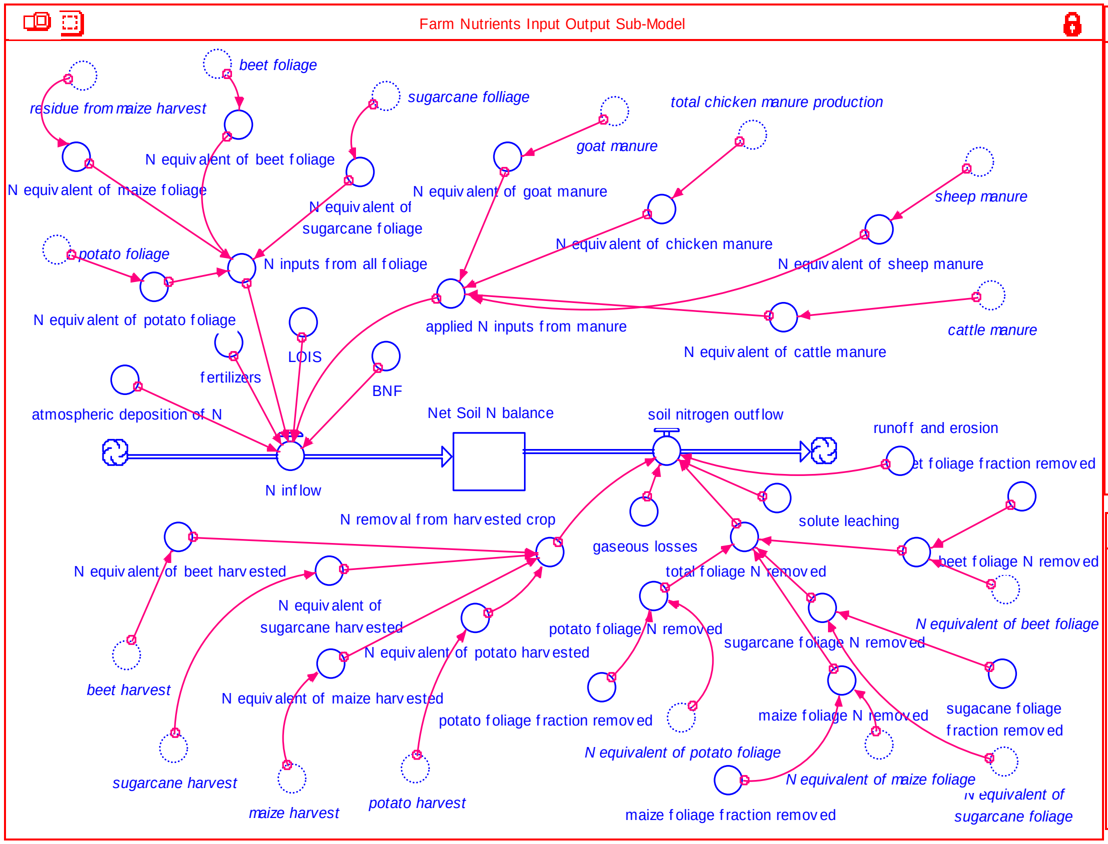


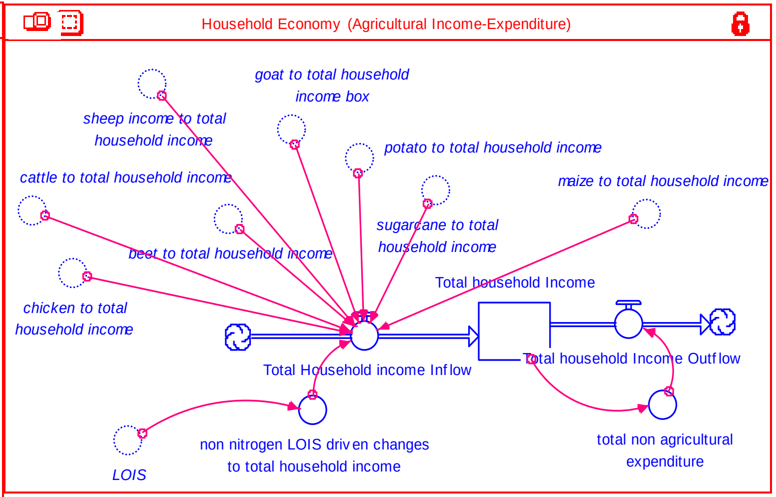


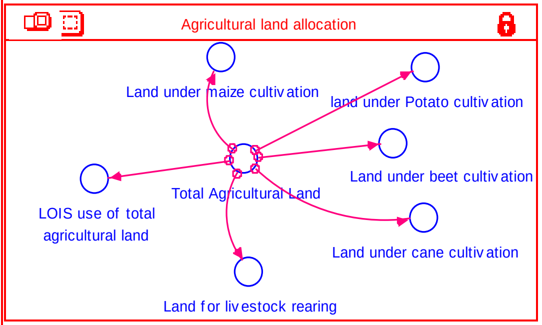


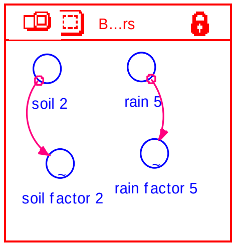


7.3 Nutrients and Household Decision Sub-Models









7.4 Questionnaire

ASSESSING THE SIGNIFICANCE OF LOW NUTRIENT INPUT STRATEGIES FOR SMALL-SCALE CASH CROP PRODUCTION IN KENYA
(A SYSTEMS ANALYSIS APPROACH)

The aim of this questionnaire is to gather information on the types of nutrient management practices carried out by farmers. The data gathered is going to serve in developing a model of the flow of nutrients in farms. The goal is to understand the situation and problems faced by farmers in managing nutrients in their farms and suggesting solutions that could ameliorate identified problems. The data will be used for scientific purposes only.

Personal Data

Respondent Name: …………………………………… **Telephone number**: ………………………………..

Household size: ……... **Who is responsible for farm decisions?** ……………. **No. engaged in farming:** ………

Gender: *male* ☐ *female* ☐ Age: ……. …. **Marital Status**: *married* ☐ *single* ☐

Academic status: *none* ☐ *primary* ☐ *secondary* ☐ *graduate* ☐

Home address: ………………………Village: ……………………………………… District: ....

Farm Management

1. What yield did you get from the following crops last year?

Crop	Area under cultivation (acres)	*Yield*
Maize		(bags)
Potatoes		(bags)
Beans		(bags)
S. Potatoes		(bags)
Sugar beets		(tons)
Sugarcane		(tons)

2. a) How much pesticide did you use last year in your farms?

Product type	Qty. used (ml)	Cost (Kshs)	Crops used on (tick)	*Yield expected without pesticides*

b) For how long have you been using pesticides (No. of years)? ……………………………

3. a) How much herbicide did you use last year in your farms?

Product type	Quantity used	Cost (Kshs)	*Yield expected without herbicides*
			Maize (bags)…………….. Potatoes (bags)…………... Beans (bags)……………... S. Potatoes (bags)………… Sugar beets (tons)………... Sugarcane (tons)…………

b) For how long have you been using herbicides (No. of years)? …………………………

4. Describe your source of labour for farm activities in 2006.

Farm type	Farm activity	Household & unpaid labour used (Kshs)	*Hired labour used (Kshs)*
	1. Land preparation		

2. Planting
3. Weeding
4. Manuring
5. Harvesting
6. Transportation

5. How much did you use for the transportation of farm produce in 2006?

Crop Type	**Month of Harvest**	*Transportation from farm to home (Kshs)*

6. How much did you incur as looses of farm produce last year?

Crop	**Harvesting Losses**	**Transport Losses**	**Storage Losses**	*Processing Losses*

Chemical and Organic Fertilizer Production and Use

7. What quantity of manure did you generate from livestock production within the last three years?

Manure type	**2004**	**2005**	*2006*

8. How much fertilizer did you use for farming of the following crops last year?

Crop	**Organic Fertilizer**			*Chemical Fertilizer*		
	Fertilizer type/origin	Qty used (bags)	Unmet Qty.	Fertilizer type	Qty used (Kg)	Unmet Qty.

10. a) Do you undertake agronomic activities which help ameliorate the nutrient status of your soil (not including chemical fertilizer use?) Yes ☐ ☐

11. Which of the following activities do you practice in your cropping system and for which crops do you practice them

Crops	*Agronomic Practices*						
	Intercropping	Crop Rotation	Agro-forestry	Use of Compost	Mulching	Fallowing	Others

12. What problems do you face with adopting or using some of the above practices which should reduce the level at which you rely on chemical fertilizers? **(Rank them: 1 = most important and 9 = least important)**

Problems	*Rank*
Lack of information (on which practice?)	
Limited available land	
Lack of technical know-how on using the technology	
Lack of materials to engage in the practice	
Have no faith in the working of such practice (s)	
Do not need the technologies	
Do not have enough labour to undertake this practice	
Other reasons:	

13. a. Have you received any training in practices that could reduce your reliance on chemical fertilizers (such as agroforestry, crop rotation, intercropping, use of green fertilizers and manures?). Yes ☐ No ☐

b. If yes, indicate the source of your training.
NGO **(1);** Farmers' group **(2);** Formal education **(3);** Informal education **(4);** Farmer training centers **(5);** Church training centers **(6)** **Note!! The same number can be used more than once.**

Type of Training	**Organizers of the Training**	*Duration(in days)*
Agroforestry		
Crop rotation		
Intercropping		
Mulching		
Compost preparation		
Contour farming		
Others:		

Decision Making And Resource Allocation

14. Please give details of the area used by crops that you have cultivated these last three years.

Crops	**Area used (in acres) 2004**	**Area used (in acres) 2005**	*Area used (in acres) 2006*

16. a) Has there been a change in the area allocated for the cultivation of any of the crops? Yes ☐ No ☐

b) If yes, give reasons. (Fill in the number that corresponds to the reason for change in crop area against the crop).
Declining productivity **(1);** Pest infestation **(2);** Fall in profitability **(3);** Lack of market **(4);** Inadequate labour **(5);** Land converted to other activities **(6)**

Crop	*Reason for Change in Crop Area*

17. Which factors do you take into account in allocating land for different food crops?
(Rank them: 1 = most important and 10 = least important) **Note!! A rank can be used only once.**

Factors	*Rank*
Land size	
Cost of crop production	
Access to market	
Profitability in the production of particular crops	
Labour requirement	
Seasons	
Soil type	
Household size	
Others (list and rank them):	

19. Please tell us what becomes of different plant residues after you harvest them.
Leave them on the farm **(1),** Feed animals with **(2),** Burn at home **(3),** Consume by household **(4)** Other **(5)**

Crop	*Type and fate of residue*	
	Leaves	
	Stalks	
	Stems	
	Fruits	
	Roots	

20. Which other economic activities do you undertake and how much did they yield in 2006?

Economic Activity	*Income in 2006 (Kshs)*
None	

Casual work
Shop-keeping
Masonry
Carpentry
Others:

Thank You Very Much!!!