Chapter 15

Sustainable Land Management and Technology Adoption in Eastern Uganda

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Under the regimes of Idi Amin (1971–79) and Milton Obote (1980–85), Uganda's economy plunged into a prolonged crisis with negative real growth rates of GDP (Baffoe 2000). In 1987, under Yoweri Musevini, the Ugandan government introduced an economic recovery program in cooperation with the IMF and the World Bank, aiming at market liberalization, privatization, and decentralization. Although these reforms have had positive effects on the Ugandan economy (the GDP real growth has averaged 6 percent per annum), productivity in the agricultural sector has either stagnated or declined (APSEC 2000). Land degradation is generally seen as a major factor contributing to declining agricultural productivity as well as to poverty and food insecurity. Recent studies in eastern and central Uganda have revealed high negative nutrient balances for most cropping systems (Wortmann and Kaizzi 1998).

To address the issue of sustainable intensification of agriculture, the Ugandan government has published a Plan for Modernization of Agriculture (PMA) as part of the Poverty Eradication Action Plan with the vision of "poverty eradication through a profitable, competitive, sustainable and dynamic agricultural and agro-industrial sector" (Government of the Republic of Uganda 2000). The priority areas for action are improving access to rural finance, improving access to markets, increasing research and technology development, promoting sustainable natural

*The views included in this chapter are those of the author and do not necessarily represent those of the World Bank.

resource utilization, and providing opportunities for management and educational training in agriculture. This chapter analyzes the constraints that eastern Ugandan farm households face in the adoption of new technologies. It employs a bio-economic model to test which policy instruments may induce farm households to adopt ecologically sustainable farming practices.[1] Some policy conclusions are drawn on how to implement specific policy programs so as to overcome the household-level obstacles.

The causes of land degradation, including very low use of inorganic and organic fertilizers, declining fallow periods, deforestation, and crop production on steep slopes with limited investments in terraces or other conservation measures, are relatively well known, but the core of the land degradation problem is of an economic nature. Poor rural households in Uganda have to cope with stagnant or declining land productivity and farm incomes. Financial constraints and imperfect market conditions compel many farm households to adopt livelihood strategies that contribute to nutrient depletion. Ecologically sustainable intensification of agriculture is not pursued. Additionally, labor and land constraints limit the households' ability to invest in land improvements. It is therefore a difficult but important task to design agricultural policies that make these technologies affordable and adoptable, especially to poor farmers.

In their review of empirical studies, Feder, Just, and Zilberman (1985) analyzed the determinants that influence the adoption of technologies in general, including farm size, land tenure, risk, and farmers' age and level of education. However, what specific constraints the farm households face to the adoption of ecologically sustainable farming practices, what the optimal levels of adoption of these practices are, and what their effects on household income and natural resource conditions are remain unclear. This study was carried out to improve the understanding of key economic factors affecting land management decisions at the farm household level in the context of soil nutrient depletion, resource constraints, and fertilizer application.

The empirical research objectives were to

- assess, from the farm households' point of view, the feasibility of land management practices leading to nonnegative nutrient balances,
- identify the most binding factors affecting land use practices and adoption of new technologies (e.g., labor shortages, capital constraints, imperfect capital markets, distorted input and output prices, transaction and information costs),
- investigate the main reasons for the contrast between the current level of agricultural development and development opportunities in the study region, and

- explore the potential effects of policy and institutional interventions mentioned as priority areas in the PMA (e.g., development of local credit markets and promotion of improved technologies) on economic and ecological indicators.

Problem Setting in the Study Region

The agricultural market environment in Iganga District, as in most parts of eastern Uganda, is highly distorted. A market study by the International Fertilizer Development Center (IFDC 1999) reported inefficiency in procurement, high transportation costs, and absence of competitive pressure leading to unreasonably high input prices, especially for fertilizers. Since the initiation of market liberalization in Uganda, the government policy has been to leave the import of fertilizers entirely to the private sector. The fertilizer market, however, is still in a very early stage of development. There are only four fertilizer importers and wholesalers and surprisingly few business relationships with Kenyan traders, the potential suppliers of imported fertilizers for Uganda.

Fertilizer prices could be substantially reduced by improving the market environment and marketing chain. The "Soil Fertility Initiative Concept Paper" (FAO 1999) reports that by the end of 1998, the average price of fertilizer in Mombassa (Kenya) was US$250 per ton, freight to Kampala (Uganda) was about US$100 per ton, to which US$50 was added for clearance at the border, transloading, storage, and import charges. Therefore, the total CIF price in Kampala was about US$400, which is very high compared to prices in Kenya and other neighboring countries. It is estimated that fertilizer CIF prices in Kampala would fall by a quarter if the import quantities increased to a level that would justify imports by shiploads and/or trainloads. Most fertilizer is delivered to dealers in 50-kilogram bags. The fertilizers are repacked into smaller units of 5 kilograms and 1 kilogram, leading to a 100 percent price increase. According to the FAO (1999), exploiting economies of scale in transportation and avoiding the costs of repacking fertilizers would result in a fertilizer price amounting to 37.5 percent of the current price. A further reduction in input prices could be attained through market regulation policies aimed at fostering competition on the fertilizer market.

The marketing chain in Iganga District involves middlemen in villages, local buyers in trading centers and in Iganga town, and traders from Kenya and Mbale, Busia, and Kampala. The prices offered to the farmers for their produce by middlemen depend on the prices set by local buyers in towns or in trading centers, which in turn are determined by the prices offered by foreign buyers. A study carried out by Vredeseilanden-Coopibo-Uganda (1998) indicated a 60 percent price markup from farm gate to retail in Iganga District. Survey data from Woelcke

(2003) revealed even higher price differences among farmers, wholesalers, and retailers. In 2001, the average price markup of maize between farmer and wholesaler was 62 percent, and between farmer and retailer 212 percent. Farmers often face information asymmetries when selling their produce at the farm gate because they are often unaware of the prices offered at higher levels of the market chain. These examples are indicative of the influence that reduced transaction costs could have on farm-gate prices in the study region.

The model scenarios, to be presented in the next section, focus on how and to what extent the market environment in eastern Uganda could be improved so as to provide sufficient incentives to simultaneously reach the policy goals of growth and sustainability. The main question put to the model is: Is it realistic to expect farm households to attain these goals without direct market intervention in output price policies (e.g., taxes, subsidies, fixed prices), input policies (e.g., subsidies, input delivery systems), and marketing policies (e.g., monopoly parastatals, trader licensing)?

The identification of research objectives and the discussion of the specific problem setting in the study region led to the selection of the following policy scenarios:

- Binding constraints and feasibility of nonnegative nutrient balances under current market conditions.

- Economic and ecological effects of promoted technologies under market improvements such as decreasing fertilizer prices, increasing agricultural output prices, introduction of credit, or improvement of price relations and promotion of labor exchange.

Integrated Approach to Bioeconomic Modeling

Sampling Procedure

The International Food Policy Research Institute (IFPRI) identified the predominant development domains in Uganda. Three factors were used for the stratification: agricultural potential, market access, and population density.[2] Development domains can be used to identify potential profitable pathways of development, based on the comparative advantages that exist in a particular region.[3] For our study, we selected two villages in Iganga District, characterized by a program-induced development pathway with relatively high market access, high agricultural potential, and high population density. The district is located in the Lake Victoria Basin in eastern Uganda, about 120 kilometers northeast from Uganda's capital Kampala.

Table 15.1 Selected output prices and input prices for Iganga District, 2001

Output prices (at farm gate) (USh/kg)		Input prices (Iganga market) (USh/kg)	
Maize	200	Urea	800
Beans	300	TSP (triple-super-phosphate)	800
Sweet potatoes	120	NPK fertilizer	850
Millet	250	Rock phosphate	100
Sorghum	200	CAN (calcium-ammonium-nitrate)	660
Coffee	400	Ambush (insecticide) (USh/liter)	12,000
Cassava	100	Round-Up (herbicide) (USh/liter)	12,500
Bananas	100	Ripcord (insecticide) (USh/liter)	11,000

Source: Authors' survey.

Note: USh, Uganda shilling. Average exchange rate in 2001: US$1 = USh 1,788.

The traditional food crops are maize, bananas, sweet potatoes, cassava, beans, millet, and sorghum, and the traditional cash crops are coffee and cotton (Table 15.1 indicates output and input prices for Iganga District in 2001). The primary goal of the low-input and -output farm production is home consumption for the majority of farm households (Esilaba et al. 2001). Obviously, these low-intensity production systems are at variance with the development opportunities that exist in eastern Uganda. Another important characteristic of the region is the presence of numerous nongovernmental organizations (NGOs) and International Agricultural Research Centers (IARC), which focus on fostering agricultural and rural development. The International Center for Tropical Agriculture (CIAT) and Africa 2000 Network (A2N) are promoting different technologies aimed at sustainable intensification of agricultural production based on a participatory research approach in selected communities of the study region.

A listing of households in both villages indicated that approximately 7 percent of the households conducted agricultural technology trials in cooperation with the CIAT and A2N.[4] For the first round of the household survey, stratified random sampling was performed in order to capture the correct proportion of farm households participating in trials within the sampled population. Principal component analysis and subsequent cluster analysis were used to identify the following four representative household types: subsistence farm households (30 percent of all households), semisubsistence farm households (52 percent), trial farm households (7 percent), and commercial farm households (10 percent).[5]

Table 15.2 provides information about the characteristics of these household groups. Trial farm households were among the first to adopt a mosaic virus–resistant cassava variety, and this is seen as an indicator of their general innovativeness. These farmers form the only household group that conducted farm trials in cooperation with CIAT and A2N. They applied the highest amounts of inorganic fertilizers and other agrochemicals and are the only group of farmers who participated in a significant number of different types of training. Furthermore, farmers in this group adopted the highest number of technologies within the last 10 years. Only the household heads and spouses of the commercial farm households had more years of schooling than those of trial farm households. Commercial farm households achieved the highest mean values for the following variables: value of residence and other structures of the household, value of agricultural equipment per person involved in farming, total value of agricultural production, value of agricultural production per acre cultivated land, years of schooling of household head and wife, value of radios, intensity of land use, and quantity of total agricultural production sold. These values indicate a relative abundance of human and physical assets as well as a relatively high degree of market orientation, although the low participation in different types of training reveals a lack of regular contact with programs, organizations, and extension services between 1990 and 2000.

That this group of farmers adopted the mosaic-resistant cassava variety later than others can be explained by the facts that (1) cassava is not important as a cash crop, and therefore not of major interest to commercial farmers, and (2) wealthier households are excluded from the communication process of the average farm household (Miiro, Esilaba, and Soniia 2002). Subsistence and semisubsistence farm households attain relatively low mean values for the following variables: years of schooling of the household head and spouse, value of household assets, quantity of total agricultural production sold (especially low value for the subsistence farm household), value of agricultural production (total and per acre of cultivated land), and number of inorganic fertilizers and other agrochemicals applied. These values reveal a shortage of human and physical assets, low productivity, and low degrees of innovativeness and market orientation. Furthermore, subsistence farmers were confronted with long distances to the nearest output markets and were late in adopting new technologies. Moreover, the highest value of labor-land ratio is reported for this group indicating a relative abundance of unskilled labor and relative scarcity of land. The number of different types of training undergone within the last 10 years is insignificant for both of these groups.

Out of each group, the households closest to the cluster centers were selected for the second round of the household survey. The main objective of the second round was to collect biophysical data at plot level, detailed input–output coefficients, estimates of farm income, and information on household preferences, decision rules, and goals. Additionally, CIAT provided farm trial data from four seasons in 2000 and 2001, together with soil data for the estimation of yield responses to fertilizer application.

Table 15.2 Characteristics of the identified household groups

Characteristic	Subsistence farm households (30%)	Semisubsistence farm households (53%)	Trial farm households (7%)	Commercial farm households (10%)
Education				
Years of schooling head	5.5	4.4	7.7	12.4
Years of schooling wife	3.3	4.3	5.6	8.1
Number of different types of training participated in since 1990	0.3	0.7	4.2	1.0
Household assets				
Value of residence and other farm structures (10^3 USh)[a]	1,267	837	1,951	7,601
Value of radios (10^3 USh)	16	22	43	74
Value of agricultural equipment per person involved in farming (USh)	4,358	5,261	5,778	9,739
Agricultural production				
Total value of agricultural production (10^3 USh)	455	833	1,066	1,635
Value of agricultural production per acre cultivated land (10^3 USh)	182	182	207	224
Quantity of total production sold (%)	23	52	35	64
Perceived walking time to output market (minutes)	142	45	81	64
Intensity of land use[b]	0.9	1.2	1.1	1.4
Labor-land ratio[c]	260	131	159	165
Innovativeness				
Time of adoption (improved cassava variety) compared to opinion leader (years)[d]	+4.6	+0.7	–2	+5.8
Time of adoption (improved cassava variety) compared to personal agricultural information network (%)[e]	66	41	33	73
Number of technologies adopted within the past 10 years	5	5	8	6
Number of trial types conducted	0	0	7	0

Source: Woelcke (2003).

[a]USh, Ugandan shilling.

[b]Intensity of land use: The ratio of the land area cultivated in the past 12 months to the total land size.

[c]Labor-land ratio: The ratio between labor use on farm (person-days) and cultivated land size.

[d]Opinion leader: An individual who leads in influencing others' opinions about innovation (Rogers 1995).

[e]Personal agricultural information network: The network of people with whom farmers discuss agriculture related issues. In the case of subsistence farm households, 66 percent of the farmers who are in the personal network of this household type adopted the improved cassava variety before this type itself decided to adopt the new technology.

Modeling Approach

Bioeconomic models combine socioeconomic factors influencing farmers' objectives and constraints with biophysical factors affecting production possibilities and the effects of land management practices (Oriade and Dillon 1997).[6] The bioeconomic modeling approach chosen for this study helps to identify the optimal level of technology adoption and its effect on household welfare and natural resource conditions for heterogeneous household agents (normative analysis). The model consists of three major components: a mathematical programming model at the farm household level, to reflect the decisionmaking processes under different constraints; artificial neural networks (ANN)[7] as a yield estimator; and nutrient balances as sustainability indicators.[8] The household's decisionmaking problem is based on a lexicographic utility concept; that is, the household first satisfies the consumption needs of its members before the household income is maximized. Household income includes both on-farm and off-farm activities.[9] The mixed-integer linear programming models developed for each of the four representative household types consist of 507 variables and 201 constraints. The main activities captured are crop production, livestock production, consumption and selling of agricultural products, permanent off-farm employment, hiring in/out temporary labor, labor exchange,[10] labor transfer, hiring a tractor, investment activities (e.g., treadle pump for irrigation), credit application, and technology options based on CIAT farm trials. The main resources and constraints considered are total land area, crop rotation, labor, nutrient requirements of household members, consumption preferences, capital constraints (including credit limits), and nutrient balances as a sustainability indicator. The results of the yield estimator and computations of nutrient balances are incorporated into the comparative static programming model.

Policy Scenarios and Results

Scenarios on Binding Constraints and Feasibility of Nonnegative Nutrient Balances under Current Market Conditions

In the following we discuss whether, under current conditions, the private goals of farm households, that is, the satisfaction of basic food needs and the maximization of incomes, and the social goal of conserving soil fertility, measured by nonnegative nutrient balances, can be reached simultaneously. Additionally, we explore whether the relaxation of technical constraints (through introduction of new technologies promoted by CIAT) and capital constraints (through provision of credit) can harmonize private and social goals. For this purpose the bioeconomic model is used to run different scenarios for all household types (scenarios 1–6 are defined in Table 15.3).[11]

Table 15.3 Feasibility of private and social goals under current market constraints

Scenario	Subsistence farm household	Semisubsistence farm household	Trial farm household	Commercial farm household
Current constraints				
Income (10^3 USh)	1,299	1,490	2,395	4,800
N balance (kilograms/hectare)	–28	–52	–43	–77
P balance (kilograms/hectare)	–8	–12	–11	–15
K balance (kilograms/hectare)	–39	–62	–47	–71
+ Sustainability constraint				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	Not feasible
N balance (kilograms/hectare)				
P balance (kilograms/hectare)				
K balance (kilograms/hectare)				
+ New technologies				
Income (10^3 USh)	1,310	1,524	2,452	5,204
N balance (kilograms/hectare)	–29	–66	–60	–96
P balance (kilograms/hectare)	–6	+24	+21	+58
K balance (kilograms/hectare)	–40	–83	–69	–100
+Sustainability constraint +new technologies				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	Not feasible
N balance (kilograms/hectare)				
P balance (kilograms/hectare)				
K balance (kilograms/hectare)				
+Sustainability constraint +new technologies +credit				
Income (10^3 USh)	Not feasible	Not feasible	Not feasible	3,373
N balance (kilograms/hectare)				0
P balance (kilograms/hectare)				+47
K balance (kilograms/hectare)				0
+New technologies +credit				
Income (10^3 USh)	1,356	1,633	2,575	5,223
N balance (kilograms/hectare)	–39	–79	–69	–104
P balance (kilograms/hectare)	+12	+59	+35	+56
K balance (kilograms/hectare)	–51	–94	–81	–106

Source: Woelcke (2003).

Note: The new technology options are available only for maize. For more details refer to Woelcke (2003).

The model's objective function value, the household income, is used as an indicator for household welfare, and the nutrient balances are used as an indicator for ecological sustainability. The scenario results reveal difficulties in achieving the goal of nonnegative nutrient balances under current market conditions, especially for the subsistence, semisubsistence, and trial farm household types. For all household types, current land management practices lead to high negative nutrient balances under present constraints (scenario 1).

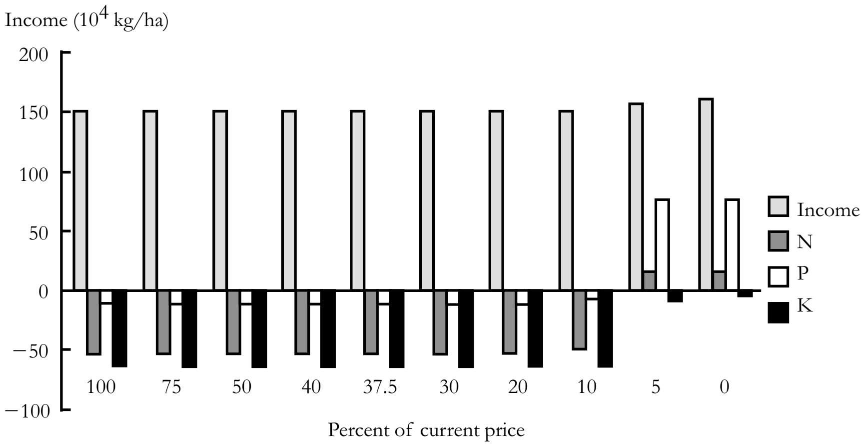
Because of higher yields and consequent higher nutrient losses from fields as a result of produce and stover removal, the nutrient balances for commercial farm households are more negative than those for other farm household types. For no household type did the introduction of the sustainability constraint of nonnegative nutrient balances lead to feasible model solutions (scenario 2). Sensitivity analyses indicate that consumption preferences and consumption needs, articulated during household interviews, would have to be adjusted significantly to halt nutrient depletion.[12] In most cases, neither the relaxation of technical constraints nor the relaxation of capital constraints contributes to reaching the goal of ecological sustainability (scenarios 3–6). The reason for this model result is the nonprofitability of the promoted technologies under existing market conditions. Yield increases are not sufficient to contribute to positive net benefits of technology adoption. The simultaneous introduction of new technologies and credit enables only the commercial farm household to attain nonnegative nutrient balances (scenario 5). A comparison of the household income levels of the commercial farm household in scenarios 5 and 6 reveals trade-offs between economic and ecological goals. The household income in scenario 5, where the household is forced into nonnegative nutrient balances, is much lower than that in scenario 6, where the sustainability constraint is relaxed again.

Effects of Promoted Technologies under Market Improvements

Because the social goal of nonnegative nutrient balances could not be reached in most of the above scenarios, and direct market interventions are not considered to be appropriate policy instruments for Uganda, the subsequent model scenarios deal with the potential of market improvements to simultaneously increase household welfare and nutrient balances. The results of these scenarios are presented only for the semisubsistence farm household, the most frequent household type in the study region. For the other three remaining household groups, the reader may consult Woelcke (2003).

Effects of decreasing fertilizer prices. This group of scenarios focuses on the economic and ecological influences of a stepwise decrease of fertilizer prices. Sensitivity analyses were conducted to identify critical levels of fertilizer prices at which a significant improvement of nutrient balances could be achieved. Results from these sensitivity analyses were then compared to the potential decrease in fertilizer prices through changes in the market environment. The changes in household income and nutrient balances (nitrogen, phosphorus, and potassium) in response to stepwise decreased fertilizer prices are illustrated for the semisubsistence farm household type in Figure 15.1. The table below the diagram indicates the percentage of

Figure 15.1 Sensitivity analysis of fertilizer price for semisubsistence farm households



Percentage of current price	100	75	50	40	37.5	30	20	10	5	0
"Reduced costs" (10^3 USh)										
Maize+N1	505	392	279	234	222	189	143	72	118	151
Maize+NP1	833	606	380	290	267	200	109	3	12	26
Maize+NPK1	1154	841	528	403	372	288	153	20	0	0
Maize+N2	464	351	238	193	182	148	103	69	94	127
Maize+NP2	792	566	340	249	227	159	69	0	0	14
Maize+NPK2	1114	801	488	363	331	237	112	17	0	0
Area adopted (ha)	0	0	0	0	0	0	0	NP2 0.08	NPK1 0.76 NP2 0.13 NPK2 0.83	NPK1 0.76 NP2 0.96

Source: Woelcke (2003).

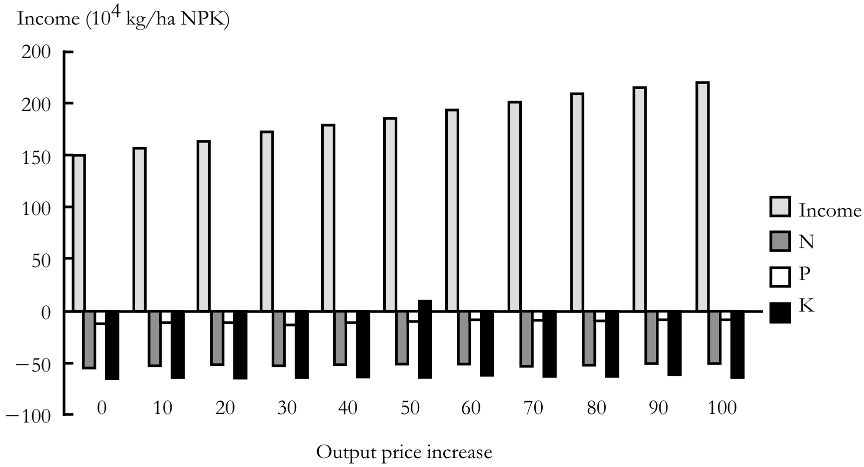
Abbreviations: Maize+N1 = nitrogen fertilizer application on maize in season 1; Maize+NP1 = nitrogen and phosphorus fertilizer application on maize in season 1; Maize+NPK1 = nitrogen, phosphorus, and potassium fertilizer application in season 1. Maize+N2, Maize+NP2, and Maize+NPK2 indicate the same fertilizer application in the second season.

fertilizer price reduction (first row), the level of "reduced costs"[13] of farming activities involving fertilizer application (second row), the type of fertilizer applied, and the total area of application (third row). Even though fertilizer prices are reduced substantially, the "reduced costs" for production activities involving fertilizer application remain high, indicating that these activities are far from being included in the farm plan. Sensitivity analyses show that fertilizer prices have to be cut down to 10 percent of the current price level before the semisubsistence farm household profitably adopts one of the new technologies. Fertilizer prices have to decrease to 5 percent of the current price or less to achieve nonnegative nutrient balances.[14] The balance for potassium would still be negative, but the high negative value of –63 kilograms/hectare in the baseline scenario could be reduced to –8 kilograms/hectare. Under this price scenario, NPK fertilizer could be adopted profitably on 1.59 hectares, and NP fertilizer on 0.13 hectare.

The overall effect of fertilizer price reduction on household income is very modest, reaching a 5.5 percent increase when fertilizer prices are reduced to 5 percent of the current price. Free availability of fertilizer would lead to further slight increases of income and nutrient balances. Considering the extreme fertilizer price reduction needed to induce farmers in eastern Uganda to switch to a more sustainable intensification of agricultural practices, policy options focusing only on input market improvements would probably not be a promising strategy. However, even direct fertilizer subsidies alone will probably not provide sufficient incentives for the semisubsistence farm households to adopt improved practices.

Effects of increasing agricultural output prices. The next group of scenarios focuses on the effect of stepwise increased agricultural product prices on household welfare, ecological sustainability, and production structure. Figure 15.2 illustrates the results for the semisubsistence household type as an example. The table below the diagram indicates how the production structure changes in response to changing output prices. Sensitivity experiments reveal that higher agricultural product prices alone do not lead to a profitable adoption of new fertilizer technologies. In comparison to the baseline scenario, the household income would increase by 23 percent with an output price increase of 50 percent, and by 47 percent with an output price increase of 100 percent. The production structure of the semisubsistence farm household type remains relatively stable because of a relatively low degree of market orientation. A significant change of the production structure of the semisubsistence farm household is observed when output prices are increased by 70 percent. The area under improved maize would then increase from 0.21 to 0.37 hectare, whereas the area under intercropped coffee and bananas decreases. This

Figure 15.2 Sensitivity analysis of output prices for semisubsistence farm households



Percentage of output price increase	0	10	20	30	40	50	60	70	80	90	100
Production structure (ha)											
Maize	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.37	0.37	0.37	0.37
Maize/cassava	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.73	0.73	0.73	0.73
Sweet potato	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Millet	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Sorghum	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Coffee/banana	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.2	0.2	0.2	0.2

Source: Woelcke (2003).

change in production structure is induced by changes of the relative competitiveness of production activities and leads to a slight deterioration of nutrient balances.

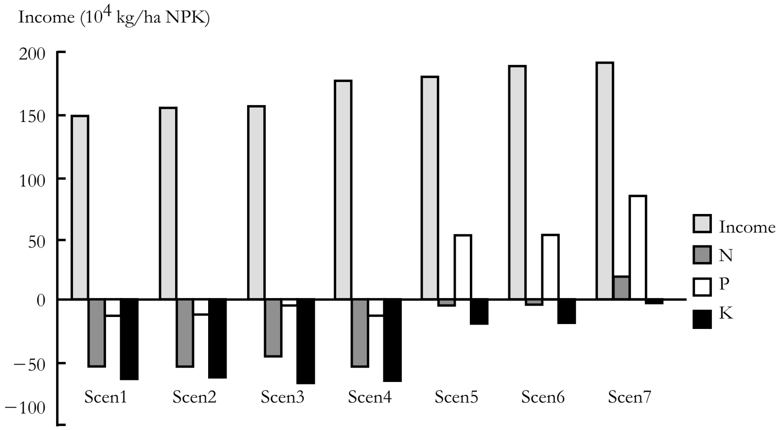
Introduction of credit, improvement of price relations, and promotion of labor exchange. The sensitivity analyses discussed above indicate that neither a sole decrease of fertilizer prices to a realistic degree nor a sole increase of agricultural output prices will lead to the harmonization of private (household welfare) and social (ecological) goals. In the following we examine whether combined price effects and additional policy interventions, such as the provision of credit or the promotion of alternative forms of labor acquisition, could improve the current situation, which is characterized by highly negative nutrient balances.

For this purpose, sensitivity experiments of both decreasing fertilizer prices and increasing agricultural product prices are conducted to identify those price relations that would potentially induce farmers to apply more fertilizers and improve their nutrient balances. Again, we show only simulation results for the semisubsistence farm household and refer the reader for the other household types to Woelcke (2003). Results for the semisubsistence household are of special relevance in Uganda, not only because of its frequency but also because of the government's objective of commercializing farm production.

Figure 15.3 illustrates the potential effects that technology adoption and reduction of market distortions will have on household welfare and ecological sustainability. The reduction of market distortions is represented in the model through changes of input and output prices to the levels discussed above. Provision of credit is included for assessing the influence of removing capital shortages on the adoption of new technologies. Another constraint frequently quoted as a major obstacle to the adoption of new technologies is the shortage of farm labor, especially during peak periods of the vegetation cycle. Farm labor exchange, a traditional form of labor acquisition in the study region, was included in the model to investigate whether it would be an appropriate option to overcome the problem of labor shortages. The table below the diagram defines the scenarios considered and indicates the area on which specific technologies have been adopted. The first scenario reflects the current socioeconomic conditions and includes the provision of new technologies. The second scenario is identical to the first scenario except that it assumes prices changes for fertilizers and outputs (fertilizer prices are reduced to 30 percent of the current prices, and output prices are increased by 10 percent of current prices). Scenario 3 assumes the same input and output prices but does not assume credit constraints. In scenario 4, credit constraints are introduced again, but the extent of prices changes have been increased. Scenarios 5 and 6 are identical except that the latter assumes slightly higher output prices. Finally, scenario 7 introduces labor exchange.

The model results suggest that improved input–output price relations in combination with provision of credit and labor exchange can induce a simultaneous significant improvement of household incomes and nutrient balances. In addition to credit provision, input prices will have to be reduced to at least 30 percent of the current price level, and output prices increased to 110 percent before the semisubsistence farm household type profitably adopts NP fertilizer on 0.21 hectare. NPK fertilizer adoption becomes profitable when input prices are decreased to 25 per-

Figure 15.3 "Combined effects" scenarios for the semisubsistence farm household type



	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Characteristics	Current conditions trial technology	Trial technology input price 30 percent of c.p. Output price: +10 percent	Trial technology input price 30 percent of c.p. Output price: +10 percent credit	Trial technology input price 25 percent of c.p. Output price: +40 percent	Trial technology input price 25 percent of c.p. Output price: +40 percent credit	Trial technology input price 25 percent of c.p. Output price: +50 percent credit	Trial technology input price 25 percent of c.p. Output price: +50 percent credit labor exchange
Area adopted (ha)	0	0	NP 0.21	0	NPK 1.28	NPK 1.28	NPK 1.72

Source: Woelcke (2003).

Abbreviation: Percent of c.p. = percentage of current price.

cent of the current value, output prices are increased to 140 percent, and credit is provided. The application of NPK fertilizer on 1.28 hectares significantly increases nutrient balances (nitrogen –2 kilograms/hectare, phosphorus +53 kilograms/hectare, potassium: –17 kilograms/hectare). Labor exchange seems to be an interesting option to overcome technology adoption constraints, especially for the semisubsistence farm households. Although this household type is partly engaged in off-farm activities, it still can offer enough labor for labor exchange, which enables it to receive agricultural labor support in seasonal peaks. Scenario 7 in Figure 15.3

illustrates that labor exchange in combination with credit provision, input price decreases (25 percent of current price), and product price increases (to 150 percent) lead to an adoption of NPK fertilizer on 1.72 hectares. This fertilizer application would have increasing effects on household income (increase by 27 percent in comparison to the baseline scenario) and the nutrient balances, of which only the K balance would remain slightly negative (–2 kilograms/hectare). Although increases in output prices might be realistically achieved through price information systems, an input price reduction to this extent is difficult to attain. In regard to the discussion above on feasible changes of fertilizer prices, economies of scale in transport, improvements in the marketing chain, and increased competition would have to be attained simultaneously.

Summarizing the normative simulation experiments, we conclude that the central reason for nutrient depletion at the household level is the nonprofitability of ecologically sustainable farming practices under current socioeconomic and agro-ecological conditions. Low economic incentives to adopt improved land management practices are caused by market imperfections reflected by high transaction costs. In addition, insufficient access to credit markets reduces the ability to adopt technology. Consequently, the necessary condition for technology adoption, positive net benefits, is not satisfied for inorganic and organic fertilizers, which could contribute to more positive nutrient balances. Significant improvements of the socioeconomic environment are essential for successful promotion of more intensive and ecologically sustainable farming practices.

The scenario results reveal that a fertilizer price reduction to about 25 percent of the current prices and an agricultural product price increase of about 50 percent are simultaneously needed to achieve significant improvements of household welfare and nutrient balances. Considering the high price mark-ups from farmers to wholesalers to retailers, a producer price increase to this extent might be attainable if farm households would have access to relevant market information (see above). A fertilizer price reduction to the extent indicated above might be more difficult to achieve. Exploiting economies of scale in transport and removing marketing inefficiencies might reduce the fertilizer price to 37 percent of current prices. To contribute to further price reduction, increased competition on the input market is needed (FAO 1999). It should be taken into account that improved effects of promoted technologies on yields could reduce the extent of price changes needed for reaching economic and ecological goals at the farm household level. However, isolated improvements of price relations are not sufficient. Improved access to financial markets is simultaneously needed for promotion of sustainable land management practices.

Summary and Conclusions

This chapter presents the results of a bioeconomic simulation model that reflects the objectives and constraints of farm households in the Iganga District of eastern Uganda. In terms of the defined research objectives, the developed static bioeconomic model is an appropriate and straightforward model choice. The model computes the optimal choice of farming activities and quantifies the financial consequences for heterogeneous household agents in a changing socioeconomic environment. It also includes a yield estimator and nutrient balances to simultaneously assess the ecological influences of these farming practices. The developed model provides useful insights for policy development because it identifies unprofitable production activities and therefore eliminates these unlikely alternatives. The simulation experiments show that under current constraints, the farm households have no alternatives but to deplete their soils' nutrients. Even with the introduction of new fertilizer technologies and the provision of credit, nonnegative nutrient balances are not feasible for most households. Only very drastic changes in input and output prices would induce the farm households to conserve their soil nutrient stocks while simultaneously satisfying their consumption needs.

Several preliminary policy conclusions can be derived from the bioeconomic model. First, the model results strongly encourage the completion of market reforms in Uganda based on an improved regulatory and legal framework. The process of market liberalization has removed some major distortions but has not been sufficient to create a business environment fostering private sector activities and trade, nor has it succeeded in linking small farms to high-value markets.[15] As discussed, there exists an enormous potential to significantly improve price relations for farmers through reduction of transportation costs, increased marketing efficiency, and increased competition on the fertilizer markets. Second, the model results emphasize that the provision of credit alone does not necessarily lead to the adoption of sustainable farming practices. However, improved credit access for small-scale farmers is one essential reform pillar if provided in combination with other measures. Therefore, more creative thinking and innovative approaches are needed to overcome the household's capital constraints. Developing a legal and regulatory framework governing microfinance and improving operating capacity of microfinance institutions should be of high priority. Third, more agricultural research is needed for new and better-targeted technologies that will provide farm households with the opportunities to intensify their agricultural production without increasing nutrient extraction. Several national research institutions are currently carrying out encouraging field experiments, but significant efforts and new ways of funding are required to revitalize the National Agricultural Research System in Uganda. Participatory research approaches, as conducted by CIAT and A2N in the study region, are certainly a promising tool to improve responsiveness to farmers' needs. Nonetheless, it obviously involves a long-term learning process for both researchers and farmers to make this approach more effective. To close the gaps among research, farmers, and markets, an effective agricultural advisory service has to be implemented. Fourth, access to agriculture-related market information is essential to overcome information asymmetries and attain higher output prices for farm households. Promising options to spread relevant information through modern information and communication technologies already exist (Bertolini et al. 2002). Miiro, Esilaba, and Soniia (2002) confirmed the importance of social networks for the diffusion of information in the study region.

It should be noted again that these policy conclusions depend on the model specification. First, the bioeconomic model does not capture the effect of increased production levels on local market prices. Second, it does not capture nutrient dynamics in the soil and the feedback effects among nutrient depletion, soil nutrient content, and crop yield. Capturing these links is essential for further research in the field of sustainable land management. It is clear that high negative nutrient balances reduce crop yields in the long run, but it is less clear how the size of negative nutrient balances is related to output levels. International and national researchers, extension staff, and policy makers assume that the perceived decline of yield levels in Uganda is mainly caused by nutrient depletion. To our knowledge, long-term yield data are still lacking on which to confirm or reject this hypothesis. The question of the critical rate at which nutrient depletion causes irreversible and not manageable soil deterioration still remains. If the farm households operate with modest levels of nutrient extraction below this critical rate, they may be able to invest returns from agricultural production in physical, human, or social capital and increase yield levels and household income in the long run.

Notes

1. In this chapter ecologically sustainable agriculture is referred to as the achievement of nonnegative nutrient balances. This definition is related to the "strong" sustainability definition that does not allow for substitution of different forms of capital and implies constant stocks of natural resources (Hazell and Lutz 1998). The "weak" definition of sustainability, in contrast, permits substitution and thus more flexibility between growth and sustainability objectives. Nutrient imbalances are just one chemical process beside other chemical, physical, and biological degradative processes (e.g., acidification, crusting, soil biodiversity reduction). However, because of their comprehensive role in evaluating the biophysical effects of land management and importance as a major determinant of yield levels, nutrient balances are widely accepted as sustainability indicators (Lynam, Nandwa, and Smaling 1998).

2. For more details see Pender et al. (2001b).

3. Hence, identified development domains can deliver valuable information for the selection of relevant policy scenarios.

4. A detailed description of the farm trials in the Iganga District is given in Esilaba et al. (2001).

5. Stratified random sampling was used to select 107 households for the identification of representative household types. Details of the statistical data analysis and the sampling strategy can be found in Woelcke (2003).

6. For more details on the modeling approach see Woelcke (2003).

7. The concept of ANN is described in Bishop (1995) and Principe, Euliano, and Lefebvre (2000). As far as the authors know, neural networks have not been used for yield estimation purposes before. Park and Vlek (2002) examined the possibility of predicting soil property distribution with ANN.

8. The appropriateness of nutrient balances as an indicator for soil productivity and sustainability assessment has been intensely debated in the literature (Lynam, Nandwa, and Smaling 1998). However, for normative and comparative-static analyses as in this chapter, the indicator is useful despite its well-known limitations.

9. Permanent off-farm activities were included as binary variables if the interview indicated relevance of the question. These activities can be of essential economic importance (e.g., in the case of the commercial farm household, permanent off-farm activities contribute about 60 percent to the household income).

10. Labor exchange is a traditional form of labor acquisition, where men or women form working groups, based on the idea of overcoming the labor constraints of its members. It is not common among group members to pay for labor: occasionally labor is paid in kind.

11. Table 15.3 indicates the model results for the four farm household types on the predominant soil class. The model results for all identified soil classes in the region are presented in Woelcke (2003).

12. For more details see Woelcke (2003).

13. The "reduced costs" indicate how far each activity is from entering the optimal model solution. That is, they indicate by how much the objective function value of each activity would have to be improved before the activity would be selected as part of the farm plan. The second row in the table of Figure 15.1 provides a list of potential activities and the changes in their "reduced costs" in response to changing fertilizer prices. As an example, Figure 15.1 indicates reduced costs of 69,000 Ush for the introduction of the production activity "Maize+NP2," assuming the current fertilizer prices are reduced up to 20 percent of the current prices. This means that the costs of this production activity have to be reduced by 69,000 Ush before it is profitable to be included in the farm plan.

14. It should be emphasized that high positive nutrient balances also have negative impacts on the environment (eutrophication). This effect is neglected in this study because of its low relevance in the study region.

15. For more details see Woelcke (2003).