Available online at www.sciencedirect.com

SCIENCE DIRECT®

Agricultural Systems 90 (2006) 243–271

AGRICULTURAL SYSTEMS

www.elsevier.com/locate/agsy

Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya

M.M. Waithaka [a,*], P.K. Thornton [b,c], M. Herrero [b,c], K.D. Shepherd [d]

[a] *Eastern and Central Africa Programme for Agricultural Policy Analysis, P.O. Box 765, Entebbe, Uganda*
[b] *International Livestock Research Institute, P.O. Box 30709, Nairobi, Kenya*
[c] *Institute of Atmospheric and Environmental Sciences, University of Edinburgh, West Mains Road, Edinburgh EH9 3JG, UK*
[d] *World Agroforestry Centre (ICRAF), P.O. Box 30677, Nairobi, Kenya*

Received 14 July 2004; received in revised form 7 December 2005; accepted 30 December 2005

Abstract

Arable land in western Kenya is under considerable pressure from increasing human population. Rural households depend on farming for at least part of their livelihood, and poverty rates are among the highest in Kenya. Land is often depleted of nutrients, and for most farmers, access to inputs and markets is poor. There is a need to identify options that are manageable within the context of the farmer's resource base and the household's objectives that could improve farm household well-being. In this study we integrated qualitative informal participatory approaches with quantitative mathematical programming and biophysical simulation modelling. Households in four sub-locations in Vihiga District were clustered and pilot cases identified. Meetings were held with farmers to elicit their perceptions of what their *ideal farm* would look like, and how its performance might compare with their own farm's performance. With farmers' help, a range of scenarios was analysed, relating to changes in current enterprise mixes, changes in current farm sizes, and changes in prices of staples foods and cash crops. A considerable mismatch was found between farmers' estimates of their own farm's performance, and what was actually produced. There seems to be a threshold in farm size of

* Corresponding author. Address: International Livestock Research Institute, Old Naivasha Road, P.O. Box 30709, Nairobi, Kenya. Tel.: +256 41 322276/+254 20 630743; fax: +256 41 321777/+254 20 631499.
E-mail addresses: m.waithaka@asareca.org, mm.waithaka@cgiar.org (M.M. Waithaka).

0308-521X/$ - see front matter
doi:10.1016/j.agsy.2005.12.007

0.4 ha, below which it is very difficult for households to satisfy their income and food security objectives. Even for larger farms whose households are largely dependent on agriculture, the importance of a cash crop in the system is critical. There is a crucial role for extension services in making farmers aware of the potential impacts on farm revenue of modest changes in their farm management systems. We are monitoring nine households in the district, whose farmers have made some changes to their system in an attempt to increase household income and enhance food security.

Keywords: Participatory modelling; Farmer perceptions; Household model

1. Introduction

Many arable areas in sub-Sahara Africa are under severe pressure to increase productivity to feed a rapidly increasing human population. This is happening more so in degraded or low potential areas that are generally characterized by physical soil loss from erosion, nutrient deficiency, low organic matter, aluminium and iron toxicity, crusting and moisture stress (Place et al., 2003). In addition, poor soil fertility management and continuous cropping exacerbate soil nutrient depletion. Because it is not possible to increase the area under production in the higher-potential areas, effective technologies and/or interventions are required that increase farm productivity and enhance sustainability and thereby improve human well-being.

Smallholder farming is difficult and problematic, but often it is the only option for a large proportion of rural populations in sub-Saharan Africa. Among the difficulties is the need to strike a balance between competing needs: to maximize labour productivity, provide livelihoods and yet reduce land degradation and avoid falling into poverty traps in the wake of declining farm size and endemic low soil fertility. Poverty characterizes many subsistence households and threatens the hope of transforming rural populations to achieve a better standard of living. Options to improve this well-being do not lie with increasing land areas because most cultivable land is already in production, but rather lie in improving efficiency with existing resources and the current technology base. However, many farmers practice low-input subsistence farming with the aim of satisfying food requirements and basic income demands. For such systems both productivity and sustainability are at risk unless there is some use of external resources. We consider sustainable agricultural production in terms of the ability of food systems to meet current and future demand, thereby integrating production and distribution (Lynam, 1994). Additionally, smallholders have to find a balance between investing in inputs for crop and livestock production, growing food for the household, and generating income to buy food that cannot be grown on the farm and for health, education, and other household and social needs. Adoption of economically sustainable land management practices and technologies is constrained by shortage of land and capital resources (Shepherd and Soule, 1998). For example, improved fallows are constrained by land shortages (Place et al., 2003); use of high value seeds and fertilizers by capital and access to markets (Salasya, 2005; Omamo et al., 2002); intensive dairying and horticulture by high transport costs (Omamo, 1998) and poor market access (Staal et al., 2002; Ehui and Pender, 2005); late maturity cash crops such as tea or coffee and soil erosion control measures by land tenure. Other factors that limit adoption of technologies are access to advice and credit. The main sources of income are sale of farm produce and income generated from off-farm activities such as earnings from self-employment, wage employment and remittances. While off-farm activities may provide much-needed income to augment farming activities, they may take away productive labour from farms. When farmers sell their labour, they do so at the expense of their own farm activities and in the process, they may delay in preparing their own land for planting, weeding and/or harvesting, resulting in sub-optimal yields. The results of recent poverty mapping in Kenya places Vihiga among the poorest districts in the country (CBS, 2003). With high poverty levels, farmers do not use high-return inputs such as certified seeds, fertilizers, disease and pest control measures, and rotations, but are limited to low-input, low-return enterprises.

Mixed smallholder farming systems are generally highly complex, and are difficult to study satisfactorily. We lack methods that can be used to demonstrate to farmers the impacts of employing different technologies and/or interventions on their well-being, while taking a holistic farming systems' perspective. Many approaches only look at particular components of the farm, and do not do justice to the reality of farmers' decision-making, given the many and complex alternatives that abound. The major objective of this study was to help identify and develop viable technology options for targeted production systems that would help farmers to weigh up, in an ex ante sense, the impacts of different options. It was also anticipated that the outputs of comparative analysis of different scenarios would help to inform policy, research and extension efforts. Some policy-related questions hinge on sustainable land use in the face of ever declining farm sizes. Research and extension issues relate to enhanced adoption of technologies that promote productivity and sustainable land use. The aim of this study was to improve understanding of farmers' conditions through the use of participatory approaches that incorporated simulation modelling, with a focus on farmer learning. This was considered necessary to ease adaptation of many of the complex, management–intensive techniques being developed in soil fertility, pest, crop and livestock management (Lynam, 2002). Farmers should then be better able to evaluate for themselves potential benefits and trade-offs.

In this paper, we discuss outcomes of farmers' perceptions of what may be an *ideal farm* versus what has been practiced on existing farms. Implications of modifying the *ideal farm* are compared with real farm situations, with respect to various scenarios of interest to farmers: changes in current enterprise mixes, changes in current farm sizes (further sub-division of larger pieces of land and/or consolidation of smaller pieces of land), and changes in prices of staples and cash crops. We address the question, whether farmers are aware of the potential of alternative interventions, and if they are, what hinders or encourages their adoption. A second question addressed in this paper is whether there are options that are manageable within the context of the farmer's resource base that could be utilized to improve farm household well-being in a sustainable manner.

2. Methodology

The methods used in this study integrated household survey data, participatory identification of suitable interventions, and bio-economic modelling, because the actions of farmers are determined by interactions with the ecosystem on the one hand, and with the socio-economic environment on the other. The approach is being used in a wider study (named PROSAM or "System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high potential areas of East Africa") that seeks to improve ways of targeting interventions that improve the well-being of smallholders in mixed farming systems of east Africa through prototyping and impact assessment (Booltink et al., 1999). The participation of farmers was seen as critical in identifying potential options and scenarios, and in validating the results.

While most farm-scale models are often biased towards economic or biophysical aspects, this work seeks to integrate qualitative informal participatory approaches with quantitative and rigorous mathematical programming and biophysical simulation modelling. What we desired to achieve was a holistic view of the farming system, rather than a view of single components (Stoorvogel, 1995; Jones et al., 1997). We followed the general approach taken by Castelán-Ortega et al. (2003a,b): the use of a ruminant model to simulate alternative feeding systems for cattle (Herrero, 1997) and the use of a mathematical programming model to deal with the allocation of resources in the farming system (Herrero et al., submitted for publication). To date we have not made use of crop simulation models, primarily because we do not have access to appropriate models of all the crops that are grown on smallholders' plots in Vihiga.

The basis of the methodology is prototyping. Prototyping was developed by Vereijken (1994) as a participatory approach that helps farmers improve their farming systems by continuous design and testing with the aim of reaching desires objectives. The process involves the development of a prototype that is then tested and possibly improved as a pilot case study. Options are assessed in terms of their likely impact on these different and sometimes competing objectives. Instead of using extensive experimental work to define the prototypes, as was done by Vereijken (1994), we used a process of clustering to characterize systems and participatory modelling to quantify, analyse and evaluate the behaviour of farming systems over a year. Simulation modelling of crop-livestock interactions at the farm level and scenario analysis allows us to assess and fine-tune farm management scenarios before testing them on-farm (Booltink et al., 1999).

The framework for this integrated participatory modelling methodology (Fig. 1) is adapted from Herrero (1997). The starting point is characterization of the system at different levels of aggregation. At the farm level, data related to land-use practices, crop and livestock management practices are collected through surveys and are used to identify prevailing production systems. Experiments and longitudinal monitoring of farm household activities, management practices, and economic performance of the systems are carried out in farms representing clusters of different systems. Farmers participate in selection of potential strategies, evaluation of their impacts on a

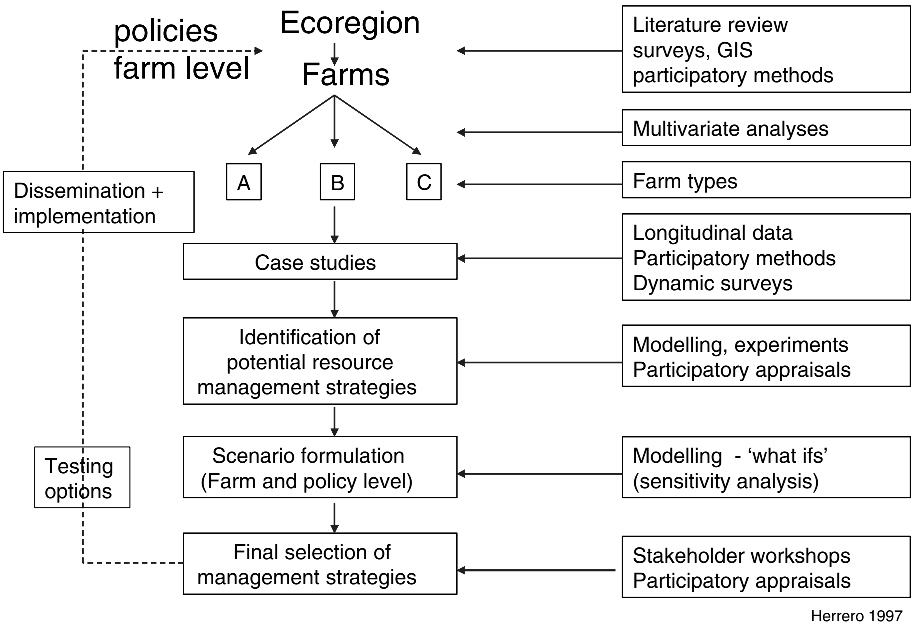

Fig. 1. Integrated participatory modelling framework (adapted from Herrero, 1997).

range of farmers' objectives and attitudes to risk, and sensitivity to the key management practices. The final selection of the suitable interventions is carried out in participatory stakeholder workshops where the results of the simulations are presented to groups of farmers, extension agents, researchers and policy makers.

Once the optimal resource management strategies have been selected, they are disseminated at two levels: farm and policy. At farm level, the selected pilot case study farms are used as demonstration farms to show the impact of the selected strategies. At a more aggregated level, the bio-economic analysis of the strategies selected are used to target and prioritize development policies at the regional level, such as credit schemes for local farming organizations and improvements in infrastructure, for example.

Last in the dissemination phase is monitoring and evaluation of the outcomes and the impacts of the selected strategies once they are implemented at farm or policy level (Herrero, 1997). Implementation of the methodology then becomes cyclic: as external or other conditions change (weather, prices, access to markets, etc.) the models are rerun or adapted, and new strategies are discussed and selected by stakeholders for implementation.

In this study, a small number of pilot farms were then identified, that could be taken as being "typical" of each farming system type. The pilot cases so defined represent subsistence, semi-subsistent and semi-commercial farming systems (ISNAR, 2004; Waithaka et al., 2004). The subsistence group is driven by diversified production mainly for household food requirements, while the semi-commercial group is driven more by market orientation for inputs and outputs, with a resultant tendency towards specialization. The semi-subsistent group lies in between the other two. These farming system types were defined on the basis of cluster analysis that took into account structure, conduct and performance variables (Waithaka et al., 2004). A total of 10 farms representing all clusters were monitored over time, and with the use of participatory modelling, scenarios that could help them achieve their farming objectives were explored. The modelling process took an interactive and iterative approach that involved livestock enterprise simulations with specific requirements on a daily basis for water, labour and nutrients, and quantification of the external and internal inputs required.

The study area was located in Vihiga district. Vihiga district lies between 1300 and 1500 m above sea level and is predominantly in the upper midland one (UM1) agro-ecological zone (Jaetzold and Schmidt, 1983), with well-drained nitosols that support the growing of various cash and food crops. The area receives adequate bimodal rainfall that ranges from 1800 to 2000 mm/year. Although western Kenya is similar to other higher-potential areas such as central Kenya with respect to agroclimatic potential, access to technologies, technical assistance and land tenure, the region faces two main challenges: high population density and poor market access, which both condition prevailing production systems (Ehui and Pender, 2005). Market access is a more important factor than population density in determining differences between central and western Kenya in dairy and crop production (Salasya, 2005; Place et al., 2003; Staal et al., 2002). The average household has 15 persons living on 0.89 ha of land, creating a very high dependence on agriculture (Central Bureau of Statistics (CBS), 2001). Farming is mainly low-external-input subsistence production with most of the farm area devoted to maize and other food crops while, the local Zebu is the predominant livestock in open grazing systems. Tea is the main cash crop and horticulture is not well developed. Horticulture and intensive dairying are limited by poor access to large urban or export markets and the nearest urban markets are not large enough to stimulate surplus production. Due to limited growing of cash crops and hybrid maize, fertilizer use averages 10.7 kg of fertilizer per hectare, which is much lower than the already low Kenyan average of 46 kg/ha (Waithaka et al., 2003). Fertilizer use in Kiambu in central Kenya, which is close to a large urban market (Nairobi with over 3 million people – CBS, 2001), is 122 kg/ha (Salasya, 2005). The urban centres closest to Vihiga (Kisumu and Kakamega) have a combined population of some 200,000 people (CBS, 2001). Vihiga has a high poverty incidence with 60% of the households living below the poverty line (CBS, 2003). Average total income is KSh 56 per household per day (1 US$ was equivalent to KSh 77 in mid-2005). The main sources of this income are wages and remittances, with an average of KSh 11,096 per year, while food and cash crops and other farm produce provide an average income of KSh 5928 per year (Waithaka et al., 2003).

The project area was located in four sub-locations (Fig. 2). Gavudunyi is in the north-eastern part of Vihiga, Mahanga is in the south and Magui and Mbihi are in the north-western fringe. While all areas are suitable for tea, dairy and maize production, in Gavudunyi and Mahanga tea is more prominent than dairying, in Magui both are prominent, while in Mbihi dairying is prevalent and there is no

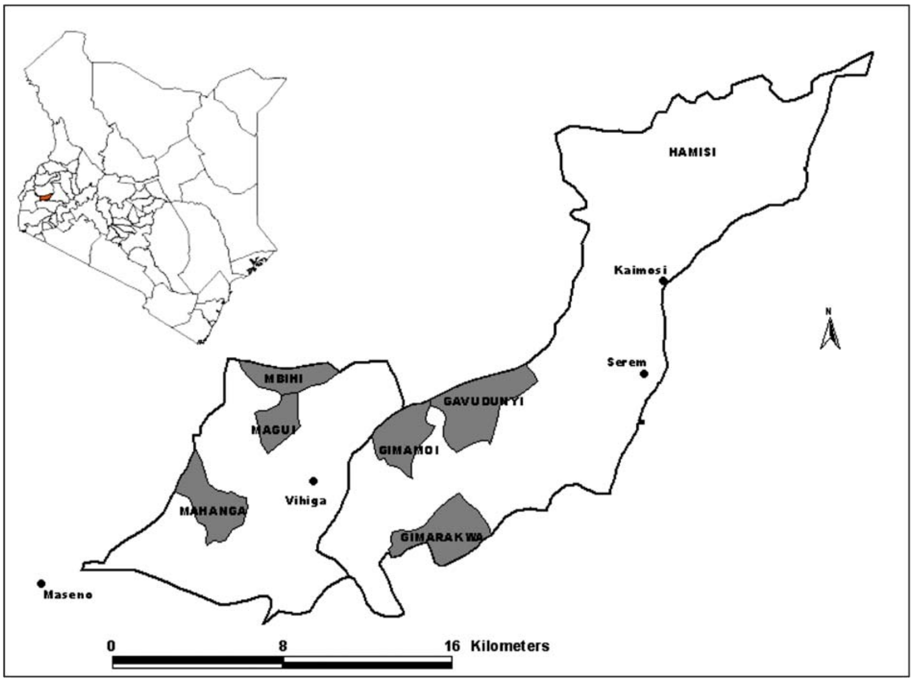

Fig. 2. Kenya map showing Vihiga District (inset map) and Vihiga project sub-locations (main map).

tea production. Farmers' groups in these four sub-locations were asked to depict an *ideal farm* based on a typical farm size in the sub-location. These groups included the pilot case farm (i.e., the farm taken as being characteristic of that type) and their surrounding neighbours. The *ideal farm* was defined as one with a certain level of resource endowment, and a certain number of key crops and livestock, and production techniques, e.g., intercropping of maize and beans, stall feeding of exotic cattle and confinement of exotic chicken. Crop and livestock enterprises would be mixed in ways that would satisfy the two major objectives that farmers have in farming here, namely, food security and basic income (Waithaka et al., 2002).

The groups depicted the farms in drawings and for each plot, identified key crop and livestock enterprises and determined the input levels that would be required to reach the yields desired (Tables 1a and 1b). The outcomes were compared with typical farms representing the theoretical prototypes being developed with farmers in the PROSAM project (Booltink et al., 1999). These nine farms (Fig. 3) represent typical households and include households with grade cows; households with maize only; households with tea and maize; and households with sugar cane and maize (Table 2).

From the differences that were observed, farmers identified the constraints that hindered them from achieving *ideal farm* status and proposed interventions that would help them overcome the constraints. Through this approach, multiple

Table 1a
Major characteristics of ideal farms (named and variables in bold) and case study farms (numbered)

	Prototype	Household characteristics (numbers)				Farm area (ha) and allocation to different enterprises						Main crops	
		Size	Adults	Children	Farm manager[a]	Farm size	Food crops	Cash crop	Napier grass	Homestead	Pasture/ Trees	Food	Cash
Gavudunyi		**8**	**4**	**4**	**1**	**0.60**	**0.25**	**0.10**	**0.05**	**0.10**	**0.10**	**Maize**	**Tea**
198	sc[b]	9	4	5	1	1.16	0.40	0.32	0.08	0.12	0.24	Maize	Tea
162	sc	9	2	7	1	0.32	0.04	0.20	0.04	0.01	0.03	Maize	S cane
43	sc	8	2	6	0	0.88	0.32	0.16	0.08	0.08	0.24	Maize	Tea
17	ss	5	3	2	0	0.97	0.77	0	0	0.20	0	Maize	Maize
Mbihi		**8**	**4**	**4**	**1**	**0.40**	**0.24**	**0**	**0.08**	**0.08**	**0**	**Maize**	**Dairy**
242	ss	11	8	3	1	0.52	0.28	0.08	0.12	0.04	0	Maize	Tea
214	s	4	4	3	0	0.52	0.28	0	0.08	0.07	0.09	Maize	Maize
Magui		**10**	**4**	**6**	**1**	**0.80**	**0.33**	**0**	**0.20**	**0.10**	**0.05**	**Maize**	**Dairy**
107	ss	12	8	4	0	0.16	0.07	0	0.01	0.08	0	Maize	Dairy
Mahanga		**10**	**4**	**6**	**1**	**0.80**	**0.28**	**0.34**	**0.1**	**0.05**	**0.04**	**Maize**	**Tea**
87	sc	8	4	4	0	0.49	0.12	0.20	0.08	0.04	0.04	Maize	Tea
150	s	10	6	4	1	0.77	0.49	0.04	0.04	0.04	0.16	Maize	Tomato

[a] 1 = male, 0 = female.
[b] sc is semi-commercial, ss is semi-subsistence and s is subsistence.

Table 1b
Major characteristics of ideal farms (named and variables in bold) and case study farms (numbered) continued

	Livestock numbers					Actual output realized					
	Lactating cows	Heifers	Calves	Shoats	Chicken	Milk litres/cow/day	Maize bags/ha	Beans bags/ha	Banana bunches/stool	Tea, kg/bush/year	Napier grass cuts/year
Gavudunyi	**2**	**0**	**0**	**0**	**20**	**12**	**36.8**	**4**	**6**	**1**	**8**
198	2	0	1	0	13	1.5	1	0.3	3	0.7	8
162	2	0	0	0	8	1.5	0.7	0.4	5	0	6
43	1	0	0	0	20	0	1.3	0.4	2	1.6	5
17	1	1	0	0	20	3	1	0.3	4	0	9
Mbihi	**1**	**0**	**0**	**0**	**30**	**18.8**	**18**	**4**	**9**	**0**	**8**
242	1	0	2	0	20	4.5	1.7	0.2	3.6	0	7
214	1	0	1	0	10	4.5	1.8	0.3	50	0	21
Magui	**2**	**0**	**0**	**3**	**50**	**13.5**	**17.6**	**2.4**	**10**	**1.3**	**5**
107	1	0	1	0	7	10.5	2.1	0.6	10	0	21
Mahanga	**2**	**0**	**2**	**0**	**20**	**10.5**	**0.8**	**0.4**	**10**	**1**	**6**
87	2	0	2	0	20	12	6.4	0	10	1	9
150	1	0	0	0	9	0	0.8	1	10	0	5

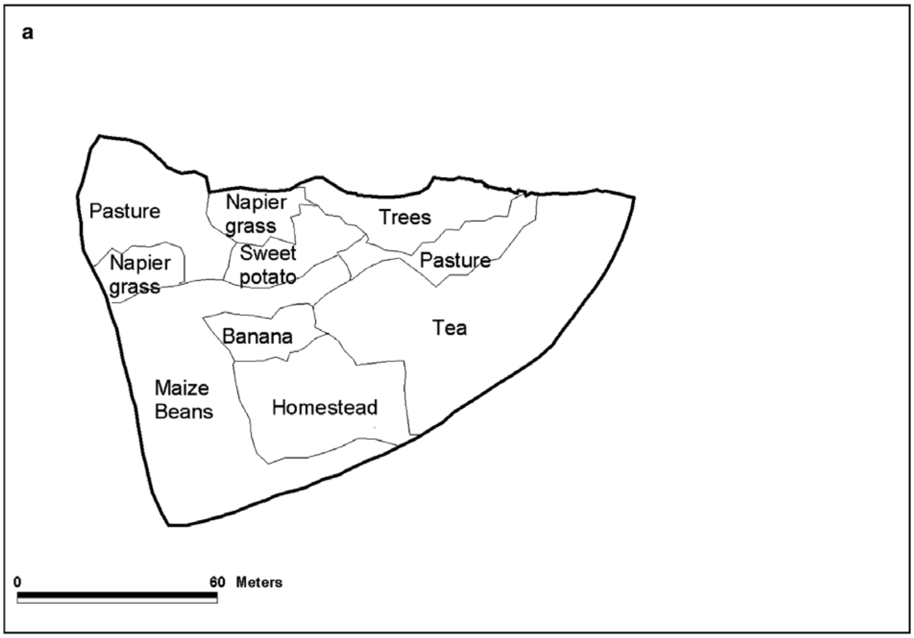

Fig. 3. Real farms in Vihiga: (a) Farm 198 (1.17 ha, tea based), (b) Farm 162 (0.32 ha, sugarcane based), (c) Farm 043 (0.88 ha, tea based), (d) Farm 017 (0.97 ha, maize based), (e) Farm 242 (0.53 ha, maize based), (f) Farm 214 (0.53 ha, maize based), (g) Farm 107 (0.16 ha, milk based), (h) Farm 087 (0.49 ha, tea based), (i) Farm 150 (0.77 ha, tomato based).

scenarios were tested within a selected year to evaluate the effects of interventions (evaluation of long-term effects of a single scenario over multiple years, to study the sustainability of a farming system, is possible but this has not been attempted as yet). For longer-term studies, the prototypes can be improved, new targets can be set, methodologies adapted, new sets of management scenarios defined, and then these can be modelled in an interactive and participatory way until the threshold values of the desired objectives are met.

Comparisons between what farmers considered to be *ideal farm* situations and what they currently practiced on their farms were made using the Integrated Modelling Platform for Animal-Crop Systems (IMPACT) tool developed by the University of Edinburgh and the International Livestock Research Institute (ILRI) (Herrero et al., 2002, submitted for publication; Castelán-Ortega et al., 2003a; Herrero and Fawcett, 2002). A key objective of IMPACT is to understand the effects of different management and policy interventions on smallholder farmers. To achieve that it adopts a holistic view of farms by considering: resources at the disposal of households – land, labour and capital assets; household objective of generating income and satisfying food requirements and allows buying of items that are in shortfall and selling of excess produce. IMPACT is not quite generic since generic systems do not exist. However, it has a set of routines to update and append new

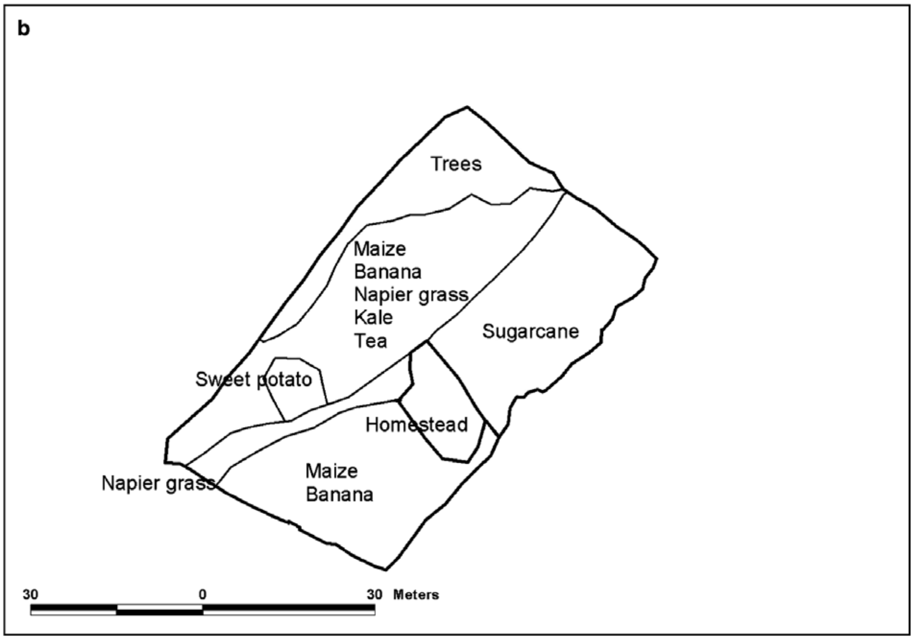

Fig. 3 (*continued*)

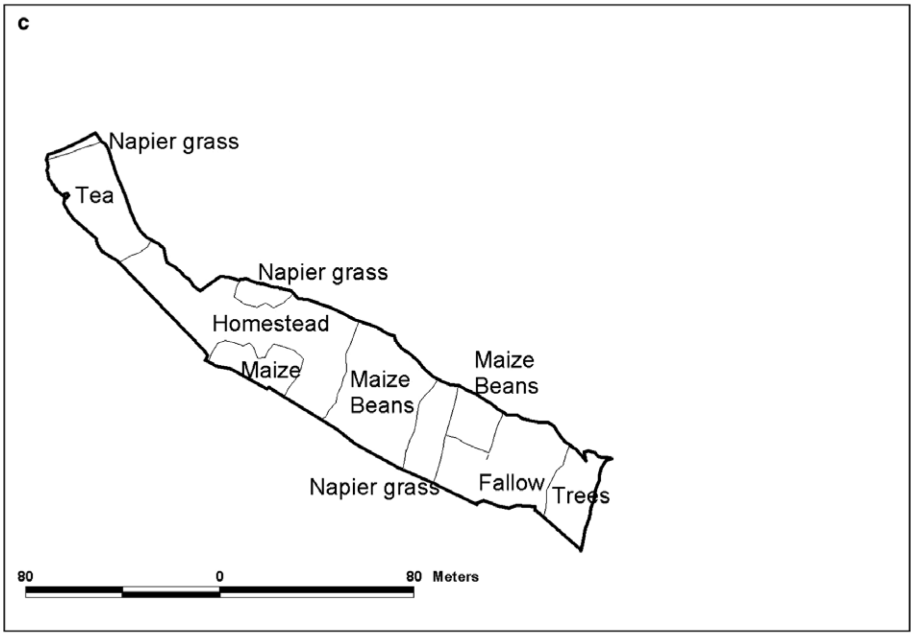

Fig. 3 (*continued*)

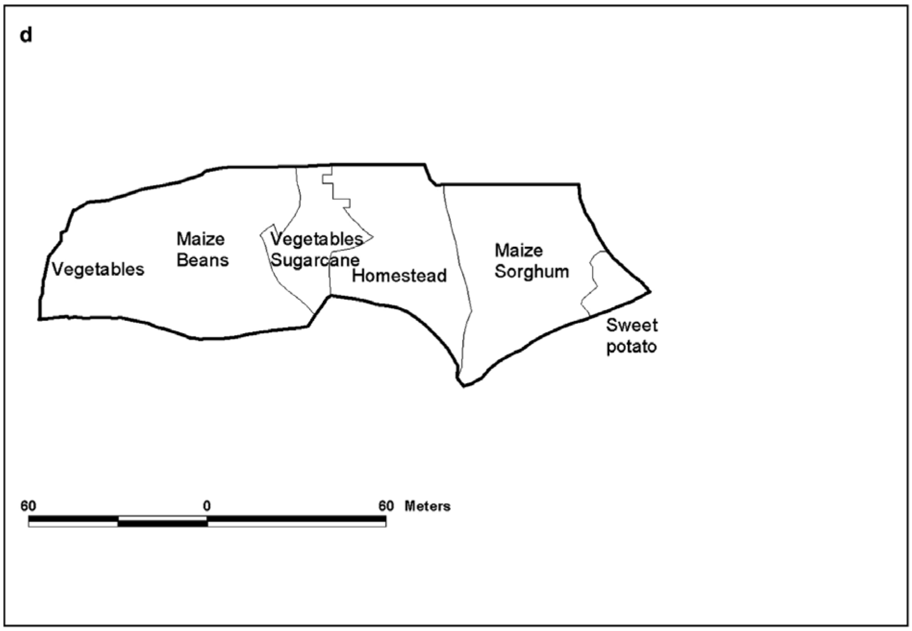

Fig. 3 (*continued*)

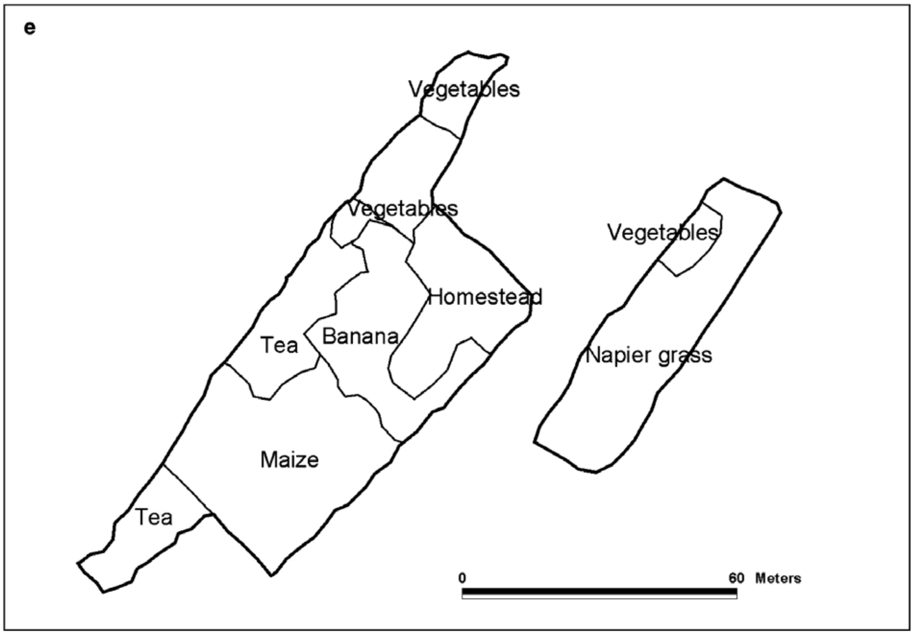

Fig. 3 (*continued*)

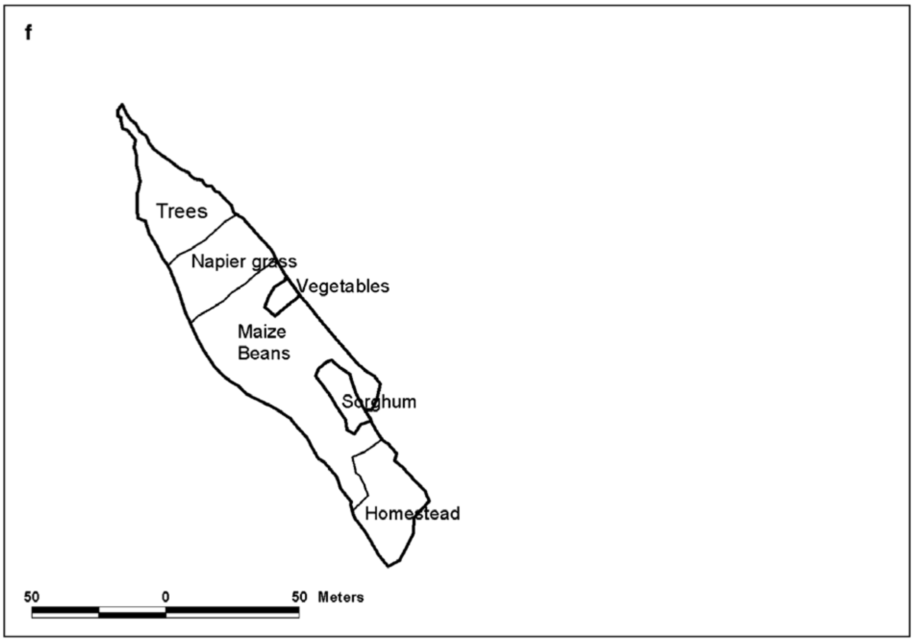

Fig. 3 (*continued*)

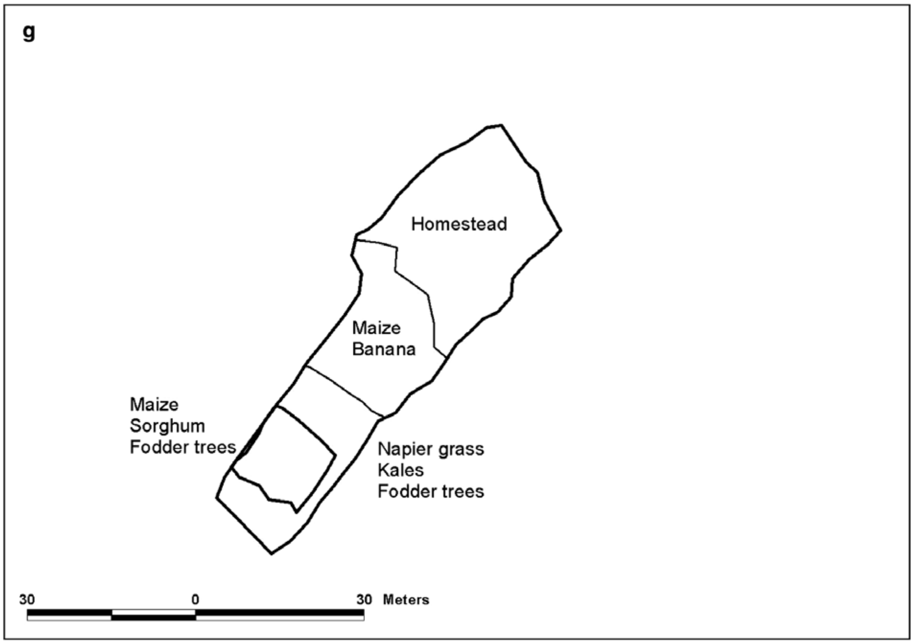

Fig. 3 (*continued*)

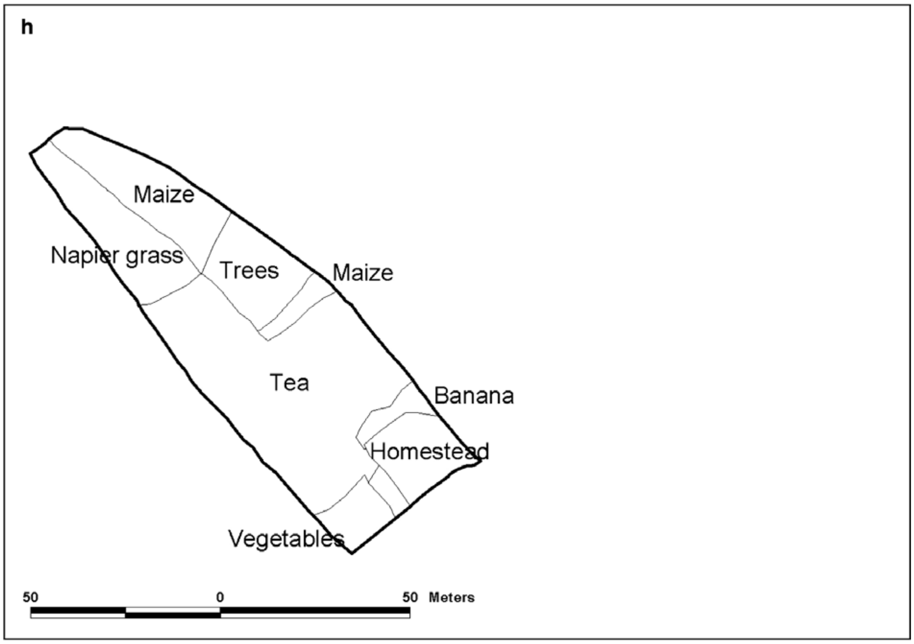

Fig. 3 (*continued*)

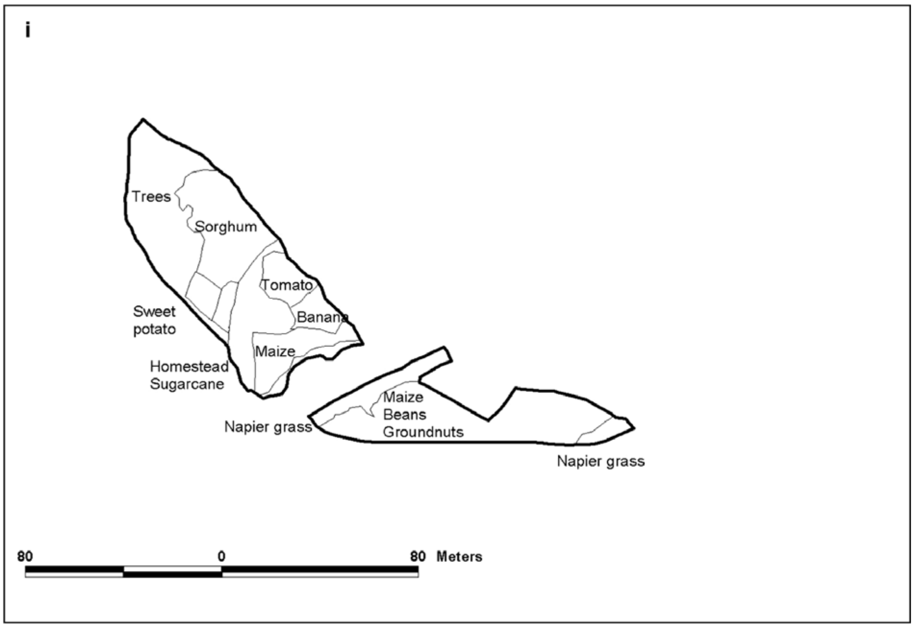

Fig. 3 (*continued*)

Table 2
Optimal solutions with model restrictions and with relaxed land allocations

Ideal farm (name) and real farms (numbers)	Current optimal state (KSh)	Optimal state with free plot allocation (KSh)	Net margins from monitoring data (KSh)	Annual farm and (off-farm) income (KSh)
Gavudunyi (0.60 ha)	−57,535	33,342	–	–
017 (0.97 ha)	−9953	31,226	−19,940	42,000 (45,000)
043 (0.88 ha)	18,499	114,682	29,146	72,500 (0)
162 (0.32 ha)	−80,657	−75,639	−42,400	5000 (0)
198 (1.17 ha)	29,158	126,623	89,478	144,300 (0)
Mbihi (0.4 ha)	−60,974	−29,231	–	–
214 (0.53 ha)	−11,671	7763	−44,660	3000 (12,000)
242 (0.53 ha)	−87,236	−75,556	−47,955	29,535 (22,400)
Magui (0.80 ha)	−47,264	−37,747	–	–
107 (0.16 ha)	−158,680	−153,098	−99,370	15,000 (12,000)
Mahanga (0.80 ha)	−14,616	−8700	–	–
087 (0.49 ha)	39,435	51,302	−38,400	54,000 (108,000)
150 (0.77 ha)	−55,991	−37,999	−46,660	19,200 (96,000)

1 US$ is approximately KSh 77 (mid-2005).

information thus allowing it to be used in almost any system. Since IMPACT is a self-contained database which can also be linked to a wide suite of other analytical tools, it facilitates a better understanding of the way farming systems can be applied in pursuit of sustainable agriculture in developing countries (Herrero et al., submitted for publication). From applications such as the one presented in this paper, a working version of IMPACT is available on CD ROM. On the limitations side, the model as used in this study only deals with an annual cycle, it does not deal explicitly with risk and requires understanding of optimization to build realistic scenarios and to interpret the results.

Data sets stored in IMPACT describe the land, labour, and crop-livestock enterprise characteristics of a household, and these data can be exported to a mathematical programming household model that provides a holistic view of a farm by integrating soils, crops and livestock interactions and is run using the software Xpress^{MP} (Guéret et al., 2000). The household model was adapted to the smallholder systems in western Kenya by modifying the enterprises and integration between them, e.g., pasture and livestock, maize and bean intercrops, maize in the first season and maize and or sorghum in the second season. The livestock model was used to simulate milk output in response to various diets, including Kikuyu grass (*Pennisetum clandestinum*) pasture, maize stover, and Napier grass (*Pennisetum purpureum*). Essential characteristics of the mathematical model include an objective function that maximizes the household's net cash income after satisfying household food requirements, subject to a set of constraints (e.g., size of farm and plots, number of animals, household labour available) and variables that describe farming activities (e.g., labour allocation by enterprise by month, and crop and livestock production costs) and a set of technical coefficients representing the variables' productive responses, e.g., crop yields per hectare, milk yield per lactation, and input–output prices (Herrero et al., submitted for publication). Cattle were used as a hedge against risk; the model was constrained to allow animals to remain on the farm, rather than being sold off after each trial period. Model runs were not assessed over multiple time periods, because of the primacy farmers gave to food security and income, regardless of whether from farm or non-farm sources. For the same reason, analyses did not focus on returns to resources, and no explicit account was taken of risk, as farmers did not perceive this to be a key issue.

3. Ideal farms

3.1. Visualization

The *ideal farm* was divided into a maximum of seven plots of single enterprises or enterprise mixes and management practices (Table 3). The first plot – the homestead – had the farmhouse, a patch of pasture where cattle were tethered, cattle sheds, and chicken coops. The other six plots were allocated to the main enterprises: tea, Eucalyptus trees, maize, beans, sorghum, bananas, vegetables, sugar cane, orchard and Napier grass. Maize and beans were intercropped in the first season and pure maize

Table 3
Allocation of enterprises by plot in "*ideal farms*"

	Plot 1 (Homestead)	Plot 2 (Maize and beans)	Plot 3 (Local vegetables)	Plot 4 (Napier grass)	Plot 5 (Tea)	Plot 6 (Pasture and orchard)	Plot 7 (Trees)
Gavudunyi (0.60 ha)							
Area in hectares	0.10	0.15	0.10	0.05	0.10	0.05	0.05
Details	20 Local chicken, 2 local cows		20 Banana stools		750 Bushes		500 Eucalyptus
Mahanga (0.80 ha)							
Area in hectares	0.05	0.20	0.08	0.10	0.34		0.03
Details	20 Local chicken, 2 grade cows		10 Banana stools, cassava, fruit trees, sugar cane, sweet potato		4000 Bushes		500 Eucalyptus
Mbihi (0.40 ha)							
Area in hectares	0.08	0.16	0.08	0.08			
Details	10 Local chicken, 1 grade cow, 100 eucalyptus trees		50 Banana stools, sweet potato, cassava, sugar cane		750 Bushes		
Magui (0.80 ha)							
Area in hectares	0.10	0.20	0.10	0.20	0.10	0.05	0.05
Details	50 Broilers, 50 layers, 20 local chicken, 2 grade cows, 3 goats		10 Banana stools		750 Bushes		500 Eucalyptus

or sorghum was grown in the second season. From the farmers' point of view, such farms would be able to satisfy a household's food and income requirements.

Monthly labour requirements for crop and livestock management were calculated from monitoring surveys of the pilot cases and other typical households in Vihiga. Women provided 10 h of their time daily, while men and children provided six and two hours, respectively. Males were not generally involved in the homestead, and women normally undertook family chores, such as cooking and fetching fuel wood and water, as a first priority. Children spent most of their time in school. Farmers also specified the amounts of fertilizer and manure used per enterprise and plot, which were used as indicators of soil nutrient balances.

Farmers proposed crop yields and livestock off-take on a monthly basis, and these were compared with data obtained from existing farms in the monitoring surveys. The farmers also provided estimates of production costs for all enterprises based on expected yields, and these again were compared with the costs derived from the monitoring surveys. For products that could be traded, market buying and farm gate selling prices were used.

Dietary preferences were considered in estimating energy and protein requirements based on World Health Organization (WHO) standards (Ministry of Health, 1993). These requirements were equivalent to 80% of the WHO standards, and adult equivalents were used to cater for differences in household composition. Forage production was linked to Napier grass, maize straw and natural pastures, which were allocated differently to the different cattle types (bulls, dry cows, calves, and lactating cows).

3.2. Basis of the ideal and real farms

The *ideal farm* in Gavudunyi was 0.6 ha, had two crossbred dairy cattle, 20 local chickens, vegetables, maize and beans, bananas, tea, Eucalyptus trees and arrow roots (Tables 2 and 3). Some seven farmers attended the group discussions: all were less than 50 years old and two of them were women who managed their farms. Four of the five farmers who had some off-farm income relied more on off-farm income than on income from farming. Three out of six farmers with farm income relied more on farm income than off-farm income. The *ideal farm* in Mbihi was 0.4 ha in size, had one grade cow, 10 local chickens, bananas, vegetables, sweet potatoes, maize and beans, and Napier grass. Eight farmers attended the group session: two of the eight men were over 60 years old. All farmers had both off-farm and farm income. Half of them relied more on off-farm income than farm income. The *ideal farm* in Magui was 0.8 ha in size, had two grade cows, 50 broilers, 50 exotic layers, 20 local chickens, three goats, bananas, vegetables, pasture, Napier grass, maize and beans, tea and Eucalyptus trees. Four farmers attended the group sessions: one woman and man were over 60 years old and the other men were in their thirties. The *ideal farm* in Mahanga was 0.8 ha in size, had two grade cows, 20 local chickens, bananas, vegetables, pasture, Napier grass, maize and beans, tea and Eucalyptus trees. There were 10 farmers in the group sessions: of these, five were women and there were four farmers over 60 years old.

4. Results

4.1. Ideal farms

From the outset, the farmers indicated that key farm products such as maize, beans, milk, bananas, fuel wood and vegetables were readily available from their neighbours or their nearest market centres throughout the year. It was also possible to sell all the products to larger markets beyond the local markets. There was a tea-processing factory in the vicinity with elaborate collection networks in all sub-locations, and fertilizers are available on credit to tea growers. The factory was operating at half capacity at the time of the survey. There was no organized milk marketing system such as a cooperative, and farmers had to rely on their own marketing system.

From the larger characterization survey (Waithaka et al., 2002), all farmers indicated that their first objective was food supply. Some 72% indicated that basic income and profit was their second objective. This was further confirmed in the delineation of plots in the *ideal farms*, since most of the farm was allocated to food crops. There was considerable diversification in the crops grown (food, cash and fodder crops and trees to provide energy), as well as intensification through integration of crops and livestock, whereby manure would be put on crops and animals fed on crop residues. The values of livestock in providing manure as well as income through the sale of milk, and the provision of milk to the household, were universally recognized.

There was a rigid perception that a successful farm must produce the staple food maize even when it was readily available in the local market. However, the idea of selling surplus produce to neighbours or the local market was seen to be desirable. The implication of this was that large tracts of land were devoted to maize alone, even when yields were only sufficient to feed a household for two to six months in a year (Waithaka et al., 2003).

There was close correspondence between farmers' output and what farmers expected from their *ideal farms* with reference to year-round production of vegetables, the number of bunches of bananas expected from a stool, kilograms of tea produced per bush per year and the number of times Napier grass would be cut in a year. Generally, there was limited understanding of input–output relationships for key enterprises, and farmers placed high expectations on yields with minimal or no inputs. Expected per-unit yields of the main enterprises were over-estimated: bottles (0.75 l) of milk per cow per day from a grade cow were 10 times higher than those achieved by the farmers; estimates of bags of maize produced per hectare were up to 20 times the values actually realized by the farmers (Table 2). Estimates of daily Napier grass requirements per cow were grossly under-estimated.

The reasons given for the apparent discrepancies between what the *ideal farm* would offer and what farmers were able to achieve on their own farms highlighted various issues: lack of technical skills for key enterprises; lack of good access to inputs and output markets, and high cost of inputs such as fertilizers, seeds and labour; lack of livestock breeding facilities and markets; small farm sizes and lack of capital. They also cited late planting arising from cash flow constraints and insistence on keeping low-yielding Zebu animals for cultural purposes (dowry payments), although climatic conditions favour the keeping of grade cattle.

Although raising a few grade cattle was the dream of every farmer, there was a strong perception that they were too susceptible to tick-borne diseases and demanded too much attention. The upgrading of local cattle was rejected on the basis that artificial insemination (AI) was too costly and was not cost effective when compared with buying mature grade animals. The value of livestock in providing manure was universally accepted, as was the value of their providing income through sale of milk and provision of milk to the household.

An interesting outcome was that all farmers highlighted the need for technical advice along with the formation of self-help groups to facilitate training and encourage exchange of ideas and marketing of produce. They also accepted the idea of producing high-quality compost to replenish soil nutrients.

4.2. Household model results

The results of the household model runs below generally reflect how farmers perceive their goals in farming and how they organize themselves to achieve them. The study could not mirror the real situation exactly, as it is very difficult to model household objectives and attitudes in a comprehensive fashion.

The first model runs were carried out for the four *ideal farms* with restricted allocation of land to specific enterprises as depicted by the farmers. The optimal solutions in terms of annual net income were negative in all situations (Table 2). In all instances, the farms had to purchase the staple foods (maize, beans and bananas). They were selling vegetables, Napier grass, eggs, milk and chicken, and tea in Gavudunyi, and trees in Magui. When the restriction on land allocation was relaxed and the model was allowed to optimize farm size and enterprise combinations, there was a large positive jump in the optimal solution in Gavudunyi to KSh 33,342 per year, and modest changes in Magui, Mahanga and Mbihi, which were still negative. In all instances, there was a reduction in the area allocated to the staple foods – maize and beans – and increased allocation of land to cash crops – Napier grass, tea and vegetables. In all cases, the household was first utilizing household labour, did not allow household labour to earn wages off-farm, and there was no hiring of external labour.

Although the outcomes of the *ideal farms* depended substantially on the composition of farmers who attended the discussions, they were illustrative of the realities of farming in Vihiga. Farmers in Gavudunyi were relatively younger, educated beyond primary school level, were working full time on their farms, and were more experienced with key enterprises such as tea production and dairying. Out of the four cases reported, only one had any off-farm income, emphasising the importance they placed on farming for their livelihoods. It was thus not surprising for this group to realize positive optimal solutions for their *ideal farm*. Unlike in Gavudunyi, most farmers involved in the other *ideal farms* relied more on off-farm income than on farming; there were a few over 60 years old and the majority were not educated beyond primary school level.

In the real farm situations, positive optimal solutions in terms of annual net income were obtained for farms 043, 087 and 198 (Table 2). All these farms were larger than 0.8 ha, and three of them were growing tea. These farms were purchasing maize, beans, bananas, vegetables and eggs, and, for farm 043, milk. Farms 198, 242 and 087 were selling tea, milk, chicken, Napier grass and vegetables. The farms with the highest losses (negative balances) were farm 107 (−KSh 158,680), farm 242 (−KSh 87,236), farm 162 (−KSh 80,657), farm 150 (−KSh 55,991) and farm 214 (−KSh 11,671). The maize-based farm 017 was selling maize, beans, vegetables and chickens. Farms 107 and 162 were 0.16 ha and 0.32 ha in size, and while farm 242 was 0.5 ha, it had scanty and poorly managed tea. These farms were purchasing the staples maize, beans and vegetables, and additionally bananas, eggs and milk. As in the case of the *ideal farms*, the real farms were also buying in staple foods and selling eggs, milk, Napier grass, milk, tea and trees. When the restriction on land allocation was relaxed, the optimal solutions increased sharply for farms 198, 043 and 017, while farm 087 showed a modest increase to KSh 51,302 and farm 214 to KSh 7763. The highest increases were for those farms that were already growing tea, and these increases occurred when the model reduced the area under maize. There was a marginal increase for farm 242, while the small farms 107 and 162 did not show any significant change.

As part of the sensitivity analyses undertaken, farm size was reduced by a half and then by a further half on those farms exhibiting positive optimal states. For farms 198 and 043, the optimal states turned negative when farm size approached 0.2 ha at the current land allocation, but turned positive when the plots were set free and the model increased the area under tea. Incidentally, for those farms with less than 0.4 ha, the optimal solutions improved marginally when all the land was put under vegetables.

As part of the validation process, the results were compared with annual income from farm activities, off-farm income and net margins obtained from the longitudinal monitoring surveys (Table 2). The net margins were derived by subtracting food costs from total income from farming activities. Two out of three farms with no off-farm income had positive optimal returns (043 and 198), farm 162 being the exception. The first two farms were growing tea, while the latter had just started with a tea nursery and some seedlings that would mature in three years' time. Five out of six farms with off-farm income had negative optimal returns (017, 107, 150, 214 and 242), while farm 087 was the exception. Farm 087 had well-maintained tea, while farm 242 had poorly maintained tea and a large household.

The household model results tracked well on all farms except farms 150 and 017. No positive optimal solution could be found for farm 150 with increasing output prices or specialization in one main enterprise. This can be attributed to its limited area for useful cropping, as most of the land is steeply sloping and is only suitable for pastures and trees. On the less sloping part, the soils are extremely poor sandy loams that would require large quantities of manure to improve water holding capacity and replenish nutrients. Although the farm was diversified in terms of growing maize, beans and groundnuts, sorghum, sugar cane and Napier grass, it relied on one crop of tomatoes in the short rains. Expansion into more profitable enterprises was limited on farm 017 because the current users of the farm had moved in three years ago, did not own the farm, and so could not venture into perennial crops such as tea and Napier grass.

During the longitudinal surveys, observations were made on which aspects of the *ideal farms* farmers adopted. One year after joint evaluation of potential enterprise combinations with the farmers, six out of nine farmers (017, 043, 087, 162, 198 and 214) had made positive changes on their farming activities, indicated by the making of high-quality compost, and replacing maize with either Napier grass (043, 087 and 198) and/or vegetables for the market (017, 043, 087, 198 and 214), and/or tea (087 and 162). Farms 107 and 242 had made progress only in making high-quality compost. Farm 150 did not make any high-quality compost or any other noticeable changes on the farm. All pilot case households had formed groups with neighbours through which they were demanding services from the extension and other services, and also engaging unemployed youth in gainful activities such as working in a tree and vegetable nursery, keeping dairy goats, and vaccinating chickens.

None of the *ideal farms* would satisfy farmers' objectives of either food supply or income, in the form perceived by farmers. This can be traced back to poor understanding of the technical aspects of enterprises and the technology options available. For example, farmers under-estimated the amount of Napier grass that would be required to sustain a grade cow, under-estimated potential egg and chicken production, and overestimated the optimal production from tea. They were not aware of the availability of vaccines within the district that can reduce chicken mortality. They were, however, quite close in their estimates of the production of staple food crops that they are used to. The implications of this are that farmer education and effective extension services are still critical for uptake of technologies. The positive influence of education level of the household head appears often in the technology adoption literature (Waithaka et al., 2003; Staal et al., 2002; Omamo et al., 2002; Barrett et al., 2001). For instance, an additional year of education raises the probability of adopting dairy cattle, Napier grass and concentrate feeding by more than 1% in central and western Kenya (Staal et al., 2002). In the same study, education level of household head was also found to be more significant that experience in farming. This might be related to increased ability to manage technologies and use information. Education can provide an avenue out of poverty as it promises better opportunities beyond the rural areas.

In Vihiga district, there are over 100 agricultural extension agents (14 in Vihiga division with 18,000 households and 14 in Tiriki east division with over 15,000 households). In comparison, there are only 16 livestock extension agents in the district, with only two staff members per division. For a district with over 105,000 farm households, this translates to one agricultural extension agent to more than 1000 households and one livestock extension agent to 6600 households. At the divisional level this translates to one livestock extension agent for between 7500 and 9000 households. It would take one extension worker four years to cover all households if s/he were to target five each day. Poor facilitation, especially in transport, further dampens their effectiveness. To overcome some of these limitations, the extension service is being transformed to be able to provide demand-driven extension, include private sector participants, and use participatory approaches (Ministry of Agriculture (MOA), 2004).

5. Discussion

Enterprise diversification promotes economic resilience, reduces risks, and helps to supply more regular farm income. However, this cash comes in different quantities and different levels while farmers prefer regular, lump-sum payments that are also predictable. In Vihiga, the only crop that offers that is tea. It has a guaranteed market, payments are made monthly (at KSh 6/kg) and annual bonuses (at KSh 17/kg) based on total annual production are provided at the end of the year. The factory also provides the major input (fertilizer) on credit. However, tea requires high initial capital outlay for setting up a nursery for raising seedlings or for buying ready seedlings; one has to wait for three years for the crop to mature and to start giving reasonable yields. The Kenya Tea Development Agency (KTDA), a former parastatal that is a successful producer-managed organization decentralized to the factory level, also provides one well-facilitated extension agent in each division to deal with tea matters.

Dairying seems to be potentially attractive, as western Kenya is a milk deficit area (Waithaka et al., 2002). Farm size is not a constraint to dairy production, as feed and fodder can be purchased rather than grown (Staal et al., 2002). Thus, dairying is an option for smallholders, as long as market conditions allow.

Napier grass is important to many farmers because of ready markets and frequent and flexible harvest schedules, and it occupies a minimal area, often on marginal land and even road reserves. Even for those farmers who have no cows, it is a major source of income. However, Napier grass tends to be a heavy miner of soil nutrients, and efforts must be made to maintain soil fertility. Due to its suitability and adaptability in many regions, Napier grass has been the fodder of choice in dairy production. However, Napier grass is under threat of being wiped out by a head smut disease unless researchers find resistant clones.

In the results reported above, the farms that grew tea showed positive optimal solutions and made the biggest improvements when the model allocated more area under tea and reduced the area under the staple foods. The farm that had maize alone had a positive optimal solution and made a slight improvement with increasing maize area. In the short run, the reduction of the area under staple crops in place of the more profitable cash crops would be untenable unless access to staples foods is guaranteed at all times. While options to improve the well-being of semi-commercial households are clear, identification of options for subsistence households, particularly those with small parcels of land, poses a severe challenge.

The farms that were less than 0.4 ha in size and had no cash crops would not be able to meet their minimum consumption requirements from farming alone, even if they were to adopt the most remunerative technology is further supported by Salasya (2005).[1] This presents a grim picture, given prevailing high population growth rates and the fact that in Vihiga district it is estimated that 45% of all holdings are less than 0.4 ha, 35% are 0.4 ha, 15% are between 0.4 and 1 ha while only 5% are over 2 ha (Simon Wesechere, personal communication).

These results suggest that for purposes of farming, sub-division of land below 0.4 ha should be discouraged, as the resultant farms are simply not viable. Existing farms of this size should be encouraged to consolidate if they are to survive. This is a tall order, given the strong attachment that farmers have to land and the lack of alternative sources of livelihood. Also with high population growth, consolidation of land will not reduce pressure on land unless some people move off. However, emigration is discouraged by limited employment opportunities in the rural and urban areas and the sparsely-populated marginal areas pose severe challenges.[2]

One way to discourage against land sub-division would be through legislation against processing of land deeds for parcels of land intended for farming below a certain threshold, such as 0.4 ha in Vihiga. For slightly larger farms, the same legislation could discourage sub-division of given classes of land through, say, higher fees. However, such legislation would only work if it provided incentives for maintaining large land holdings. Such incentives would be multi-sectoral and would involve all factors that would improve livelihoods in the rural areas and make farming profitable.

Opportunities for existing holdings that are less than 0.4 ha appear to lie more in development innovations (niche markets such as organic farming and/or supplying fresh produce to local markets) and not in technology intervention. However, sustainable intensification that would allow smallholders to raise crop yields and/or livestock without depletion of soil fertility, will require investments in organic and inorganic technologies, soil and water conservation. The downward spiral of declining soil fertility, productivity and income in western Kenya is not likely to be broken by the availability of technologies but by improved maize prices relative to input costs a function of market access and infrastructure (Ehui and Pender, 2005). High costs transportation costs discourage farmers from venturing into distant deficit markets where they might obtain better prices when they have surpluses, such as soon after harvest time (Omamo, 1998). Imperfect competition in input markets where only a handful of traders are involved, makes it easy for them to collude to keep prices high (Omamo and Mose, 2001). For the poor, credit advances for inputs and guaranteed output markets are very attractive as they reduce risks. In the absence of such ventures, collective action could help by reducing transactions costs and marketing risks for bulky and highly perishable products. This involves creation of linkages with the market place, traders and transporters, as has been achieved with dairy cooperatives in central Kenya, for example (Staal et al., 1997). Some NGOs have had some success in these pursuits, e.g., mini-packs for seeds and fertilizers in western Kenya (Seward

[1] The same study shows that in central Kenya, farms that are less than 0.4 ha can still be profitable if kale and potatoes are the main crops because of availability of a large market.

[2] These range from harsh climatic conditions, competition from wildlife, low and erratic rainfall, poor access to markets, and general lack of basic facilities.

and Okello, 1998) and dairy goats exchange and animal health by the Kenya Dairy Goats Association in central Kenya and Farm Africa in eastern Kenya (www.farmafrica.org.uk/). However, scaling up of such efforts has been limited by weak institutional and policy guidelines on implementation of rural development strategies.

It is often assumed that in the rural areas, there is a constant supply of abundant farm labour. In Vihiga increased maize production is limited by cash liquidity and not labour implying that there is excess labour force in maize production should be withdrawn and more fertilizer be applied (Salasya, 2005). Often when there are no other sources of income, wage payments are made in kind, which discourages the more energetic youth who would rather be paid in cash. So at the peak labour periods of land preparation, weeding and harvesting, many households have to make do with family labour, which becomes stretched very quickly. In many cases men and older children work away from the farm (often in the urban areas) and children go to school, leaving only women and the elderly to provide the required labour.

The development of rural areas to get many people engaged in gainful employment would remove considerable pressure from farms and discourage further sub-division of small parcels. This would require research efforts to guide policy development for more attractive livelihood strategies that are responsive to the opportunities and constraints of farmers in diverse settings. Such strategies should explore provision of publicly supported facilities such as electricity, transport infrastructure, communications, health and education, and water (Maxwell, 2005; Ngigi, 2004). They should work towards the creation of enabling environments that reduce entry costs for investments devoid of burdensome licensing and regulatory requirements on micro-enterprises (Hazell, 2005). Overall, they should attract rural investments in provision of farm inputs and services, value adding and/or processing of farm produce that would open up new opportunities previously inaccessible to rural populations (De Janvry and Sadoulet, 2005; Gardner, 2005; Minot and Ngigi, 2004; Barrett et al., 2001). This would stem rural urban migration, offer employment to the local rural people close to their homes ensuring that there would still be more remittances from savings in transport, and there would be more contact with farms that would relieve some of the labour burden.

In terms of lessons for the PROSAM project, farmers showed mixed reactions to the results of the *ideal farms* versus real farms analysis, but in general they concurred with them. Most felt encouraged to undertake bold changes to their farm enterprises, such as increasing the area under tea, Napier grass and vegetables for the market by reducing the area under staple food crops. Tools such as IMPACT and the farm household model are offering farmers new and different ways of exploring complex options on their farms that take a holistic view of the farming system.

6. Conclusions

Although smallholder farming is a hard calling, there are still farmers who are successful at it. They are those with more than 0.4 ha of land and who grow a cash crop with a guaranteed market along with food staples. Many farmers are not always aware of the options available that would help them achieve their objectives and would benefit if they were exposed to different options.

The household model used in this study tracks the performance of farm households in Vihiga quite well, and as such it can be taken to capture many of the system's dynamics adequately. It is appealing when used in participatory modelling as a way of extending knowledge and allowing farmers to explore potentially beneficial opportunities more readily. Combining rigorous modelling tools with qualitative assessments increases the value of participatory research and learning. Improvements to these kinds of tools and their widespread use by both researchers and extension agents can improve decision-making at the household level, and provide feedback to research design and development as well as to policy making.

Previous studies have suggested that sub-optimal land management, high rates of sub-division, and high dependence per unit of land are important constraints in land policy. In terms of sub-optimal land management, this study supports the crucial role that extension plays by helping to make farmers more aware of potential technologies and what they involve. Such knowledge allows farmers to make informed judgments on choice of enterprises and ways to increase farm productivity of their land and capital, including purchase of inputs, and general improvement of management practices. Investing in universal primary education and exposing farmers to better husbandry methods through revamped extension services, can improve farm management and may lead to improvements in income. This is more critical for the smaller farms further from markets. More and better-facilitated extension agents are needed in the rural areas to improve farmers' access to education and innovations.

Even where farmers are aware of the potential benefits of alternative technology options, they are constrained by market failure and the heavy burden of providing for many people who depend solely on small farms. Overall, rural development strategies aimed at improving market access for both inputs and outputs and adding value are critical to improving income generation and therefore land and labour productivity in rural areas. Policy research on strategies that would enhance scaling up of successful innovations and further development of rural areas should be encouraged.

Acknowledgements

This work was carried out when the first author was a researcher at the International Livestock Research Institute (ILRI). This research was supported in part by the Eco-regional Fund to Support Methodological Initiatives of the Dutch Government, to whom we are grateful. We wish to thank Vihiga district extension staff Simon Wesechere, Simon Muhindi, Alex Adala, Ezakiel Ngairah and Peter Noyi for their assistance.

References

Barrett, C.B., Reardon, T., Webb, P., 2001. Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics and policy implications. Food Policy 26, 315–331.

Booltink, H.W.G., Thornton, P.K., Waithaka, M.M., Shepherd, K.D., Jones, J.W., 1999. System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa. A proposal to the Ecoregional Fund to Support Methodological Initiatives. Wageningen University, The Netherlands. Available from: <http://www.cgiar.org/ilri/prosam>.

Castelán-Ortega, O.A., Fawcett, R.H., Arriaga-Jordán, C., Herrero, M., 2003a. A decision support system for smallholder campesino maize-cattle production systems of the Toluca valley in Mexico. Part I – integrating biological and socio-economic models into a holistic system. Agricultural Systems 75, 1–21.

Castelán-Ortega, O.A., Fawcett, R.H., Arriaga-Jordán, C., Herrero, M., 2003b. A decision support system for smallholder campesino maize-cattle production systems of the Toluca valley in Mexico. Part II – emulating the farming system. Agricultural Systems 75, 23–46.

Central Bureau of Statistics (CBS), 2001. 1999 Population and housing census. Counting our people for development. Vol. I. Population distribution by administrative areas and urban centres. Central Bureau of Statistics, Ministry of Finance and Planning, Nairobi, Kenya.

Central Bureau of Statistics (CBS), 2003. Geographic dimensions of well-being in Kenya. Where are the poor? From districts to locations. Vol. 1. CBS, Ministry of Planning and National Development, Nairobi, Kenya.

De Janvry, A., Sadoulet, E., 2005. Achieving success in rural development: towards implementation of an integral approach. In: Colman, D., Vink, N. (Eds.), Reshaping Agriculture's Contributions to Society. Proceedings of the 25th International Conference of Agricultural Economists held at Durban, South Africa, 16–22 August 2003. Blackwell Publishing, Oxford.

Ehui, S., Pender, J., 2005. Resource degradation, low agricultural productivity, and poverty in sub-Saharan Africa: pathways out of the spiral. In: Colman, D., Vink, N. (Eds.), Reshaping Agriculture's Contributions to Society. Proceedings of the 25th International Conference of Agricultural Economists, 16–22 August 2003, Durban, South Africa. Blackwell Publishing, Oxford, pp. 225–242.

Gardner, B., 2005. Causes of rural development. In: Colman, D., Vink, N. (Eds.), Reshaping Agriculture's Contributions to Society, Proceedings of the 25th International Conference of Agricultural Economists, 16–22 August 2003, Durban, South Africa. Blackwell Publishing, Oxford, pp. 21–41.

Guéret, C., Prins, C., Sevaux, M., 2000. Application of optimization with Xpress-MP. Dash Optimization Ltd.. Available from: www.dashoptimization.com.

Hazell, P.B.R., 2005. Is there a future for small farms? In: Colman, D., Vink, N. (Eds.), Reshaping Agriculture's Contributions to Society, Proceedings of the 25th International Conference of Agricultural Economists, 16–22 August 2003, Durban, South Africa. Blackwell Publishing, Oxford, pp. 93–101.

Herrero, M., 1997. Modelling dairy grazing systems: an integrated approach. Ph.D. thesis, University of Edinburgh, Edinburgh, Scotland.

Herrero, M., Fawcett, R.H., 2002. A generic household model for assessing the impact of interventions in crop-livestock systems. In: Proceedings of the 17th Symposium of the International Farming Systems Association, 17–20 November 2002, Lake Buena Vista, FL, p. 106.

Herrero, M., Thornton, P.K., Hoogenboom, G., Ruiz, R., Fawcett, R.H., Jones, J.W., 2002. IMPACT: An integrated modelling platform for animal-crop systems. In: Proceedings of the 17th Symposium of the International Farming Systems Association, 17–20 November 2002, Lake Buena Vista, FL, p. 107.

Herrero, M., Gonzalez-Estrada, E., Thornton, P.K., Hoogenboom, G., 2005. IMPACT: Integrated modelling platform for animal-crop systems. In: Kirby, D., Quiros, C. (Eds.), Version 1.1. Users Manual. International Livestock Research Institute, Nairobi, Kenya, p. 130.

ISNAR, 2004. Method in our Madness. Making Sense of Ecoregional Research with Modelling Tools and Processes. International Service for National Agricultural Research (ISNAR), The Hague, The Netherlands.

Jaetzold, R., Schmidt, H., 1983. Farm Management Handbook of KenyaNatural Conditions and Farm Management Information, vol. 2. Ministry of Agriculture, Nairobi, Kenya.

Jones, J.W., Thornton, P.K., Hansen, J.W., 1997. Opportunities for systems approaches at the farm scale. In: Teng, P.S., Kropff, M.J., ten Berge, H.F.M., Dent, J.B., Lansigan, F.P., van Laar, H.H. (Eds.), Applications of Systems Approaches at the Farm and Regional Levels, vol. 1. Kluwer Academic Publishers, Dordrecht, pp. 1–18.

Lynam, J.K., 1994. Sustainable growth in agricultural production: the links between production, resources and research. In: Goldsworthy, P., Penning de Vries, F.W.T. (Eds.), Opportunities, Use and Transfer of Systems Research Methods in Agriculture to Developing Countries. Kluwer Academic Publishers, Dordrecht, pp. 3–28.

Lynam, J.K., 2002. Book review of "A history of farming systems", edited by M. Collinson. Agricultural Systems 73, 227–232.

Maxwell, S., 2005. Can we rescue rural development before it's too late?. In: Colman D., Vink, N. (Eds.), Reshaping Agriculture's Contributions to Society. Proceedings of the 25th International Conference of Agricultural Economists, 16–22 August 2003, Durban, South Africa. Blackwell Publishing, Oxford, pp. 61–73.

Ministry of Agriculture (MOA), 2004. Strategy for Revitalising Agriculture. Ministry of Agriculture, Nairobi, Kenya.

Ministry of Health (MOH), 1993. National Food Composition Tables and the Planning of Satisfactory Diets in Kenya. Ministry of Health, Government Printer, Nairobi, 200 pp.

Minot, N., Ngigi, M., 2004. Are Kenya's horticultural exports a replicable success story? In: Building on Success in African Agriculture. IFPRI 2020 vision. Focus 12. Brief 7.

Ngigi, M., 2004. Smallholder dairy in Kenya. In: Building on Success in African Agriculture. IFPRI 2020 vision. Focus 12. Brief 6.

Omamo, S.W., 1998. Farm-to-market transaction costs and specialization in small-scale agriculture explorations with a non-separable household model. Journal of Development Studies 35, 152–163.

Omamo, S.W., Mose, L.O., 2001. Fertilizer trade under market liberalization: preliminary evidence from Kenya. Food Policy 26, 1–10.

Omamo, S.W., Williams, J.C., Obare, G.A., Ndiwa, N.N., 2002. Soil fertility management on small farms in Africa: evidence from Nakuru district, Kenya. Food Policy 27, 159–170.

Place, F., Barrett, C.B., Freeman, H.A., Ramisch, J.J., Vanlauwe, B., 2003. Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Policy 28, 365–378.

Salasya, B.D.S., 2005. Crop production and soil nutrient management: an economic analysis of households in western and central Kenya. PhD thesis, Development Economics Group, Wageningen University, The Netherlands.

Seward, P., Okello, D., 1998. SCODP's mini-pack method – the first step towards improved food security for small farmers in western Kenya. Sustainable Community-Oriented Development Programme (SCODP), Sega, Kenya.

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

Staal, S.J., Baltenweck, I., Waithaka, M.M., de Wolff, T., Njoroge, L., 2002. Location and uptake: integrated household and GIS analysis of technology adoption and land use, with application to smallholder dairy farms in Kenya. Agricultural Economics 27 (3), 295–315.

Staal, S.J., Delgado, C.L., Nicholson, C.F., 1997. Smallholder dairying under transactions costs in East Africa. World Development 25, 779–794.

Stoorvogel, J.J., 1995. Integration of computer-based models and tools to evaluate alternative land use scenarios as part of and agricultural systems analysis. Agricultural Systems 49, 353–367.

Vereijken, P., 1994. Designing prototypes. Progress Report 1. Research network for EU and associated countries on integrated and ecological arable farming systems. Wageningen University, Wageningen, The Netherlands.

Waithaka, M.M., Nyangaga, J.N., Wokabi, A., Muriuki, K., Staal, S.J., Njoroge, L., Njubi, D., 2002. Characterization of dairy systems in the western Kenya region. Smallholder Dairy (Research & Development) Project Report, Ministry of Agriculture and Rural Development, Kenya Agricultural Research Institute and the International Livestock Research Institute, Nairobi, Kenya.

Waithaka, M.M., Salasya, B.D., Thornton, P.K., Shepherd, K.D., Staal, S.J., Ndiwa, N.N., 2003. Factors influencing enhanced soil fertility management in Vihiga, western Kenya. Best Poster Finalist. In: 25th International Conference of IAAE, Durban, 16–22 August 2003.
Waithaka, M.M., Herrero, M., Thornton, P.K., Shepherd, K.D., Ndiwa, N., 2004. Characterizing farming systems in Vihiga in western and Kilifi in coastal Kenya. Project Paper, ILRI, Nairobi.