Improved Decision-Making for Achieving Triple Benefits of Food Security, Income and Environmental Services through Modeling Cropping Systems in the Ethiopian Highlands[1]

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Abstract

Food security in the enset-based Ethiopian highlands is constrained mainly by land degradation, land fragmentation and limited access to technologies and skills. Enset (Enset ventricosum) is a perennial herb with edible corm, supporting about 13 million people in Ethiopia. A household survey, supported by field measurements, was conducted over three years (2000–2002) with 24 representative farmers to identify their production objectives and to quantify their available land resources, cropping system, crop yields and market price, for developing models to facilitate their decision making. Farmers identified three major production objectives depending on their household priorities, socio-economic status and resource base. In Scenario I, farmers were primarily interested in producing enough food from their farm. In Scenario II, they wanted food security and to fulfill their financial needs. In Scenario III, farmers were interested solely in generating cash income, regardless of its effect on food production. On average, the current cropping system is deficit in most nutritional components, and fulfils only 72%, 40%, 35%, 33%, & 25 % of the energy, protein, calcium, zinc and VitA of the recommended daily allowances (RDA), respectively. More over, the net cash income of the current production system was 624 Ethiopian birr cu^{-1} yr^{-1}. Using an optimization model it was possible to fulfill Scenario I by reducing the land area allocated to sweet potato, coffee, wheat and legumes by 11%, 45%, 22% and 63%, respectively and increasing the land area of enset (from 9 to 17%) and kale (from 2.4 to 7.6%). To satisfy Scenario II, there was a need to increase the proportion of coffee, potato, beans and enset by 30, 15, 8 and 3%, respectively, over the current land allocation. This shift would double the cash income, to 1200 birr cu^{-1} yr^{-1}. Scenario III was fulfilled by full replacement of the cereals and root crops by coffee (80.2%) and teff (19.8%), which would generate 2012 birr cu^{-1} yr^{-1}. This option drastically reduced household food production. The change from current production systems to Scenario I offers high quality livestock feed, while Scenario III offers low quality livestock feed whereby about 84% of the feed is coming from coffee husk. Moreover, a shift from the current system to Scenario I would not have any effect on the level of soil erosion, while a shift to Scenario II and III will reduce soil erosion by about 39 and 52%, respectively, mainly as a result of expansion of the area of perennial crops.

Keywords: Food security, Income, Livestock feed, Erosion, Land allocation, Optimization, Trade-off analysis

Introduction

Rural poverty is a major national and international concern in Ethiopia which has been aggravated by conflicts, recurrent drought, land degradation and many local and international policy barriers. Various policy options have been suggested to reverse the recurring food shortage and poverty, the most recent being a shift from growing food crops for household consumption towards producing cash generating enterprises based on market demands. However, farmers' decisions on choice of enterprises is constrained by poverty, limited access to technologies, lack of stable markets and weak institutional capacity to respond to environmental and market shocks.

The prevalence of malnutrition in Ethiopia continues to increase, affecting primarily women and children. The most important documented forms of malnutrition were protein-energy malnutrition and Vitamin A (VitA), iodine and zinc deficiencies (Kaluski et al., 2002). The prevalence of stunting of children is the third highest

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after Bangladesh and Mauritania (UNICEF, 1993). However, the different regions of the country have different resources, opportunities and culinary habits and consequently differ in how they can change their production systems to achieve food security. For example, in terms of VitA deficiency, the highest rates were found in children residing in pastoral areas and the lowest rates were documented in Enset based systems, where root crops are commonly eaten with bean sauce or kale, which is rich in carotene (Kaluski et al., 2002). The current malnutrition could be reversed through combination of various strategies namely, enriching food crops through application of micronutrients, selection of crop species and varieties with high micronutrient content, use of indigenous high nutrient crops (Welch, 2001), which could also be supplemented by animal products. Nutritional quantity and quality could be also improved by enhancing soil fertility status, integrating germplasm with high nutrient use efficiency (Graham and Welch, 2000) and through maneuvering the existing production systems by expanding the land allocated for high yielding and nutrient rich alternate crops (Amede et al., 2004; McIntyre et al., 2001).

Optimization modeling can be used to identify alternative production options to achieve household food and nutrition security by changing crop combinations. This strategy demands a thorough analysis of the components of the current production system, to identify nutrients in excess or in deficit, and to modify the cropping strategy, so as to fulfill nutritional demands with or without considering cash incomes. Earlier work in Uganda showed that improved nutrition of the banana-cropping system could be achieved through a 69% decrease in the proportion of land devoted to banana; a 100% increase in land allotted to maize and a 600% increase in the proportion of land allotted to legumes (McIntyre et al., 2001). Similarly, food security could be achieved in barley-based systems of Ethiopia by reducing the land allotted to barley by 50% and expand the land area allotted for enset, kale, and faba beans by 25.3%, 17.7% and 15.6%, respectively (Amede et al., 2004). Although the households' food demands in both cereal-based and enset-based systems of Ethiopia were fulfilled using the existing resources of land, rainfall and labour through reallocation of land for more productive crops (Amede et al., 2004) the earlier analysis did not consider other production objectives beyond household food security.

In situations where farmers are keen to exploit emerging market opportunities, while producing enough food, there is also a need to develop a responsive model that encompasses both nutrition and cash generation trade-offs and that can respond to trade-offs in terms of livestock feed availability and resource use. The possible acceptance or rejection of proposed changes in the cropping system may also largely depend on the possible effect of the change on cultural values, food habits, labor requirement, input demands and soil fertility management options. Therefore, any apparent modification of the current cropping system should consider its direct or indirect implications on other system components. For instance, the crop sub-sector strongly interacts with the livestock sub-sector, mainly through draught power, feed availability and manure supply. Moreover, a change in crop species or variety will affect the amount and quality of animal feed, which in turn may affect the amount and quality of manure produced. Changing the plot size of one crop and reallocating to another may also a practical implication on land management and soil erosion as the change in crop type may affect soil water infiltration, run-off, evapo-transpiration and plant water budget (Bergsma, 1999; Roggoro & Toderi, 2000).

The objective of this study was therefore to, 1) quantify the cash income and food security status of enset-root cropping systems, 2) develop cropping strategies that can improve cash income and nutritional quality using optimization models, and 3) evaluate the implications of the change in crop enterprise choice on soil erosion, biomass production and livestock feed quantity and quality.

Materials and Methods

SITE DESCRIPTION

The research site Areka (37^{o} 39' E and 6^{o} 56 N), is located in south-western Ethiopian highlands. The farming system is characterised by a multiple cropping system with diverse annual and perennial crops (Table 2). It is one of the most populated districts in the country (>400 people km^{-2}), with average land holdings of less than 0.5 ha per household. The area has a mean annual rainfall of 1300 mm, an average temperature of 19.5 ^{o}C and is 1880-1960 m asl. Rainfall is bimodal, with a short rainy season (belg) from March-June and the main rainy season (meher) from July-October. The dominant soils are Eutric Nitisols, deep, P-fixing and acidic in nature, characterised by higher concentrations of nutrients and organic matter within the top few centimetres of the soil. These soils originated from kaolinitic minerals which are inherently low in nitrogen and phosphorus. Soil fertility gradient decreases from homestead to the outfield due to local land management practices, whereby farmers apply 90% of the organic manure to food security crops grown around the homestead (Amede et al., 2001).

DATA COLLECTION

A household survey was conducted over three years (2000–2002) with 24 representative farmers, grouped into three social categories, based on the size of land holding, number of livestock, perennial crops grown, sources of income and production objectives (Table 1). The major data considered for the household model analysis were, size of land holding, household family composition by age and sex, crop land allocation, household food consumption, household food allocation/distribution among family members, yield of crops and crop residue, and crop purchase or sale. Household food consumption was monitored in each household on a weekly basis, by interviewing the women. Input and product price was established based on the average of local market surveys in February, June and October, in 2002 and 2004. The consumption unit (CU) of each household was calculated using FAO designations (FAO, 1990), by adding the consumption unit value of each household member. Secondary data was also collected on, for example, average crop and biomass yield in the district and the nutritional composition of each crop (Table 2). For crops where reliable data was not available, measurement of yield, moisture content and estimation of edible components was done on-farm at harvest. The amount of crop residue produced was also estimated by taking samples from representative farms and converting to dry weight after drying it to constant weight. The protein and energy content of crop residues was adopted from the FAO data base of animal feed resources information system (www.fao.org/ag/aga/agap/frg/afris).

Table 1. Characterization of representative households in different production objective scenarios in Areka during 2002 (n = 8)

Parameters	Scenario I	Scenario II	Scenario III
Farm size(m^2)	4830.8	10486	6128
Family size (CU)	4.7	7.2	3.8
Food deficit months/year	5	1	3
Age of HH head	45	36	29
Education (Grade in regular school)	0	9	6
No. Of livestock	2	4	1
Source of additional income	none	Retail trade Selling animals	Selling eucalyptus Retail trade
Expenditure (birr/year)	175	1550	572
Three major constraints	Food insecurity, Soil fertility decline and Lack of cash	Low market price Soil fertility decline Lack of cash	Market fluctuation Lack of cash Soil fertility decline

Since the bimodal rainfall is supporting at least two crops per year at Areka, land size per household was considered as a sum of land used for growing crops in both seasons per year. Hence, the farm size presented here is larger than the actual land size. Intercropping and relay cropping practices have complicated establishment of land area and yield per individual crops. For the purpose of this exercise, we followed a similar procedure as presented by McIntyre et al. (2001), whereby the dominant crop is assumed to occupy the entire area if the companion crops were sparsely populated, and the area occupied by the companion crop was calculated from the current plant population density and optimal population density. If none of the crops were dominating in the mixture, crop area was calculated based on the proportional areas occupied and their ratio within the crop mixture. Nutrient yield of annual crops was determined by measuring edible yield per area, and analyzing nutrient contents of their products (EHNRI, 1998) and by converting it to household nutrient supply

Table 2. Nutritional content (EHNRI, 1998) and yield of major crops grown in Areka (n=24)

		Nutrient Content per kg Edible Yield							
Crops	**Yield**	**Energy**	**Protein**	**Zn**	**Fe**	**Ca**	**Thiamin**	**Vit A**	**Ascorbic acid**
	qt/ha	kilocalories	g/kg	mg/kg	mg/kg	mg/kg	mg/kg	ug/Kg	mg/kg
Enset (kocho)	223.41	2111	6	6	37	320	0.3	0.2	0
Taro	89.6	1038	13	1.4	20	550	0.4	0	90
Pumpkin	60	249	11	1.9	9	400	0.3	0	40
Kale	150	401	25	8.6	22	50	0.4	112.5	13.2
Sweet potato	120.7	1370	0.7	2	7	130	0.2	0	14.2
Irish Potato	53.77	840	15	4	36	184	0.1	0.4	2.83
Maize	16.54	2234	41	13.3	20	80	0.2	0	0
Teff	4.55	1620	41	11	115	690	0.3	0.03	0
Wheat	9.93	2220	68	2	27	270	2.1	0.8	0
Barley	6.46	2020	44	15.8	35	160	2.1	0	0
Pea	7.75	2071	109	24.6	31	450	2.4	10.5	0
Faba bean	7.52	2759	164	13.8	43	870	1.9	1	0
Common Bean	7.26	1700	91	3	33	560	2.6	0.6	
Sorghum	9.23	2360	50	4.9	49	150	2.2	1.1	0

as the sum of all consumable crop products of the household in the respective systems. Besides the annuals, the system comprises perennial crops (e.g. Enset ventricosum) of various ages. Nutrient yield of perennial crops *in-situ* was determined by estimating harvestable crop yield per plant through measuring corm height and circumference of plant of various ages as described by Shack & Ertiro (1995) supplemented by sample weighing and multiplied by the nutrient content of the product (EHNRI, 1998) and the number of plants to be harvested per year.

An additional survey was done with the same 24 households to identify their immediate production objectives (scenarios) using open ended questions. In this survey, farmers' opinions to accept or reject modified cropping systems were identified and used as constraints in the model described below. For establishing cash income the major household expenses, namely costs of external inputs (seeds and fertilizer) were considered. Enset production is the most labor intensive enterprise in the system (Brandt et al., 1997, Tsegaye. 2002), which was also confirmed by farmers' interview. Thus, about 50% of the labor in enset processing and management is considered as hired labor following local wages.

Farm Erosivity Index (FEI) was calculated as the cumulative value of vegetative cover of the farm by considering the C-factor in terms of cover effect on soil erosion, after Amede et al. (2004):

$$FEI = \frac{\sum CF * \text{Optimised crop land area}}{\sum CF * \text{Current crop land area}}$$

Whereby:

FEI = Cumulative Farm Erosivity Index
CF = Crop factor of respective crop species

DESCRIPTION OF THE MODEL

An optimization model was developed using Solver in Microsoft Excel and used to analyze the different scenarios of cash income and/or human nutrition through cropland allocation. Recommended daily nutritional allowance as per world Health Organization (WHO, 1999) was used to calculate food security. The objective functions used in the model were energy availability CU^{-1} day^{-1} (Scenario I and II) and cash income CU^{-1} yr^{-1} (Scenario III). For Scenario I and II the model is presented as follows:

$$\frac{\sum_{i=j}^{N} LSj * EYj * DMj * NCj}{CU * 365}$$

Whereby:
LS = land allocated for crop i
EY = Edible yield of crop i
DM = Dry matter yield of crop i
NC = Nutrient content of crop i
CU = Consumption unit in the house hold (unit of people eating in the house)

For Scenario III the objective function for optimizing cash income is:

$$\frac{\sum_{i=j}^{N} LSj * EYj * NIj}{CU}$$

Whereby:
LS = land allocated for crop i
EY = Economic yield of a particular crop i
NI = Net cash income after production costs are deducted i
CU = Consumption unit in the house hold (unit of people eating in the house)

For Scenario III the objective function for optimizing cash income is:

$$\frac{\sum_{i=j}^{N} LSj * EYj * NIj}{CU}$$

Whereby:
LS = land allocated for crop i
EY = Economic yield of a particular crop i
NI = Net cash income after production costs are deducted i
CU = Consumption unit in the house hold (unit of people eating in the house)

The constraints for each Scenario differ as the priorities of households in each social categories varied. The constraints for Scenarios I & II were set to ensure that the households continued to cultivate their current stable crops.

<u>Constraints for Scenario I</u>
Total farm land $\leq$ 1765 m^2/CU
Land size of Enset $\geq$ 300 m^2/Cu
Land size of kale $\leq$ 150 m^2/CU
Land size of maize $\geq$ 100 m^2/CU
Protein $\geq$ 37 g/day/cu
Vit C $\geq$ 25 mg/day/cu
Zinc $\geq$ 15 mg/day/cu
Calcium $\geq$ 528

<u>Constraints for Scenario II</u>
Total farm land $\leq$ 1765 m^2/CU
Land size of Enset $\geq$ 200 m^2/Cu

Land size of kale ≤ 150 m^2/CU
Land size of maize ≥ 200 m^2/CU
Land size of beans ≥ 155 m^2/CU
Land size of coffee ≤ 870 m^2/CU
Protein ≥ 37 g/day/cu
Vit C ≥ 25 mg/day/cu
Zinc ≥ 15 mg/day/cu
Calcium ≥ 528 mg//day/cu
Cash income≥ 1000 birr/cu/annum

Constraints for Scenario III
Total farm land ≤ 1765 m^2/CU
Land size of teff ≥ 350 m^2/Cu
Land size of kale ≤ 150 m^2/CU

Results

DESCRIPTION OF SCENARIOS

The households in the area are characterized by an average family size of 6.3, with about 50% of men and 50 % of women, with a land holding of about 0.52 ha. However, there are differences in family size, land size, income and food security among the different scenarios (Table 1). Scenario I represented farmers who are interested to maintain diverse crops in their farms, produce enough food for their household consumption, whilst minimizing the risk of drought and land degradation. In this case, most of the farm labour was used for food production on their own farm. Currently, farmers in this group could produce enough food for only about 7 months of the year (Table 1) and the remaining five months are covered by food aid and other sources. In Scenario II, households produce enough food for their household and sell part of their farm produce to generate income. In this group, farmers already produced most of their household food but were exposed to malnutrition due to deficiency of specific nutrients, e.g. calcium and zinc (Amede et al., 2004). They also experienced cash shortages to buy inputs and other household necessities. In Scenario III, farmers did not fully rely on own food production for their household consumption but generated money from different sources, e.g. off-farm income by selling their labor in nearby towns (Table 1).

FOOD SECURITY OF CURRENT SYSTEMS

The current cropping system is highly diversified with Enset (Enset ventricosum), yam (Discorea bulbifera), pumpkin (Cucurbita pepo), kale (Brassica oleracea), sweet potato (Ipomea batatas), potato (Solanum tubersom), maize (Zea mays), teff (Eragrostis abysinica), sorghum (Sorghum bicolour), pea (Pisum sativum), faba bean (Vicia faba), common bean (Phaseolus vulgaris), and Coffee (Coffee arabica). Sweet potato, maize, potato and enset cover most of the farm land, with 24.5, 19.6, 15.4 and 9.2% of the total area, respectively (Table 3). Of this, only about 6% is allocated for cash crops.

Despite high diversity in the production system, the current root crop-based system was in deficit of most of the nutritional components (Table 4). The system failed to supply enough nutrients for the household with the major nutrients in deficit, namely energy, protein, zinc and calcium being significantly lower than the recommended daily allowance (Table 4). It fulfilled only 72, 40, 35, 33, & 25 % of the energy, protein, calcium, zinc and VitA demand, respectively. More over, the net cash income from crop production was about 624 Ethiopian birr cu^{-1} yr^{-1}, obtained mainly from coffee.

Table 3. Land allocation in the root-crop based systems for various field crops, currently and after optimization with priority for human nutrition (Scenario I), human nutrition and cash income (Scenario II) and cash income (Scenario III).

	Crop land allocation m^2/cu			
Crops	Current allocation	Scenario I	Scenario II	*Scenario III*
Enset	162.02	299.99	200.00	*0*
Yam	46.19	36.82	0	*0*
Pumpkin	1.07	0	0	*0*
Kale	42.96	134.78	50.00	*0*
Sweet potato	432.41	393.37	0	*0*
Potato	271.52	277.23	533.13	*0*
Maize	346.78	323.63	200	*0*
Teff	147.11	105.59	0	*350*
Wheat	103.31	74.52	0	*0*
Sorghum	2.35	0	0	*0*
Pea	74.7	55.35	0	*0*
Faba bean	17.33	6.36	0	*0*
Beans	11.22	0	155.00	*0*
Coffee	*105.4*	*57.32*	*626.86*	*1415*

Table 4. Nutrient budget and cash income of households in an enset/root-crop based system for the current cropping systems and after the system was optimized primarily for human nutrition (Scenario I), human nutrition and cash income (Scenario II) and cash income (Scenario III). 1 USD = 8.6 Ethiopian birr.

	Current situation			**Scenario I**		**Scenario II**		**Scenario III**	
Nutrients	**RDA**	**Current**	**Difference**	**Nutrients**	**Cash income** (birr/cu)	**Nutrients**	**Cash income** (birr/cu)	**Nutrients**	**Cash income** (birr/cu)
Energy (kcal)	2000	1448	- 552.00	4139.80		2235.00		101.75	
Protein (g)	37.5	15.02	- 22.48	39.73		37.84		2.57	
Zinc (mg)	15	5	- 10.00	15.78		10.86		20.69	
Calcium (mg)	528	183	- 345.00	568.68		406.85		43.34	
Vit A	10.00	2.45	- 7.15	62.85		23.79		0.001	
Income (birr)		684			488.71		1200		2011.98

MODELING RESULTS

Scenario I

In this Scenario the primary objective of the households was to fulfill the nutritional requirement of their family members. The model suggested this could be achieved by reducing the land area allocated for sweet potato, coffee, wheat and legumes by 11%, 45%, 22% and 63 % and increasing the land area allocated for enset and kale from the current allocation of 9 and 2.4 % to 17 and 7.6%, respectively (Table 3). This reallocation would maintain crop diversity and the household food preferences. By implementing this reallocation the energy supply increases from 1450 to 4140 kilocalories cu^{-1}, while the protein supply was improved from 15 to 39 g day^{-1} cu^{-1}, significantly higher than the recommended daily allowance (Table 4). Moreover, the supply of VitA, zinc and calcium was also significantly increased. However, this change towards fulfilling household's nutritional demand decreased the cash income from 624 to 449 birr cu^{-1} yr^{-1} (Table 4).

Scenario II

This was a priority for middle-aged family heads, with larger land holding, more available labor and more willing to take the risk to test and adopt new technologies. In this Scenario the primary objective of the households was to fulfill both the nutritional requirement and cash income of the family. To fulfill these requirements there was a need for a partial shift from growing cereals towards perennials and root crops. There was a need to increase the proportion of coffee, potato, beans and enset by 30, 15, 8 and 3%, respectively over the current land allocation (Table 3&4). This shift towards coffee/enset-dominated system would double the cash income, from 624 birr to 1200 birr cu^{-1} yr^{-1}. It would also fulfill the calorie, protein and Vit A demand while improving the availability of the other nutrients considerably (Table 4).

Scenario III

In this Scenario the main objective of the household was to maximize the cash income of the households regardless of its effect on household food production. This production objective was favored by young, single farmers who are already engaged in retail trading and those who preferred specialization over diversification. This cash requirement was fulfilled with the replacement of the cereals and root crops solely by coffee and teff with a proportion of 80.2 and 19.8%, respectively (Table 3). The expansion of the coffee and teff fields was able to generate 2012 birr cu^{-1} yr^{-1} but it drastically reduced the household nutrient production (Table 4).

IMPLICATION FOR LIVESTOCK FEED

Whenever farmers are exposed to choices of crop species and varieties they consider not only grain/tuber yield for human consumption but also consider crop residue for animal feed, cooking fuel and soil fertility management. The current production system considered diverse crops with cereals occupying about 40% and enset occupying less than 10% of the farm land. Where the optimization model suggested a shift from cereal farming to root crops, enset and coffee, the crop residues changed from cereals straw, to enset roughage and coffee husk. Though the total amount of biomass produced with the various Scenarios did not differ in quantity (Fig 1), Scenario I offers high quality feed predominantly coming from cereals and root crop residues, with only 3% of it comes from coffee husk, while Scenario III offers low quality livestock feed whereby about 84% of the feed is coming predominantly from coffee husk (data not presented). When translated into nutrients there was a decline in quality of feed due to increased proportion of less digestible components in the system, mainly coming from Enset and Coffee. There was no decline in total production in crude protein with the optimized Scenarios, except for Scenario II whereby the protein supply was reduced by about 20% (Fig 1). However, there was a significant decrease in energy, whereby the total energy supply was reduced by about 24 and 37% for Scenarios II and III, respectively, in addition to the decline in feed quality because of the very high concentration of caffeine, tannins and potassium in coffee (www.fao.org/ag/aga/agap/frg/afris).

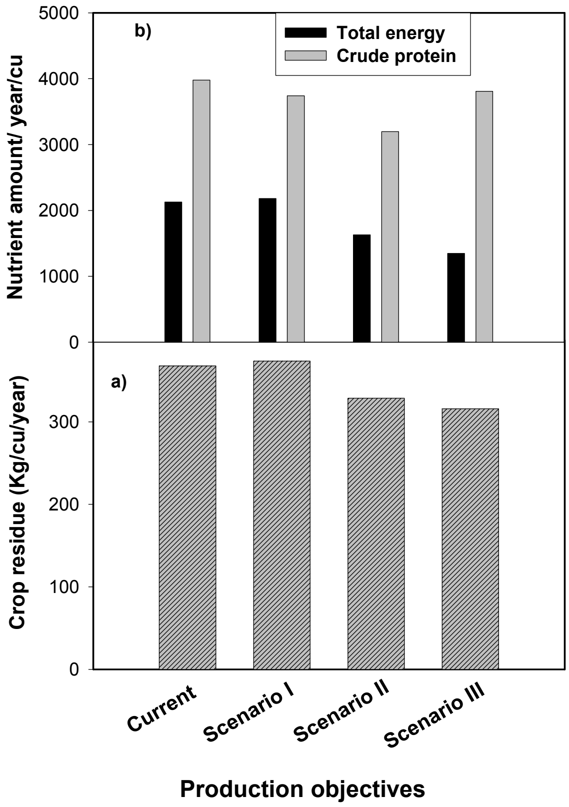

Figure 1. Crop residue production (kg/cu/year) (a), energy (MJ/cu) and Protein (Kg/cu) in Areka under the current production systems and after optimization; with priority for human nutrition (Scenario I), human nutrition and cash income (Scenario II) and cash income (Scenario III). (n =8).

IMPLICATION FOR SOIL EROSION MANAGEMENT

The current production system allocated perennial crops (enset, coffee) and planting materials (sweet potato and spices) around the homestead and mainly cereals and root crops in the midfields and outfields (Amede and Taboge, 2004). A shift from the current system to Scenario I would not have any effect in terms of erosion effects (FEI of 110 vs. 93), while a shift to Scenario II and III will reduce soil erosion by about 39 and 52% respectively (Table 5), due to the positive contribution of enset and coffee in minimizing erosion. In Scenario II the replacement of erosion-prone cereals and sweet potato by coffee and enset would reduce the FEI significantly, by about 40%. As the number of crops was reduced from about 14 to only 2 in Scenario III, with coffee predominant, reduction in erosion effects further could be enhanced by intensification of the coffee fields.

Discussion

HOUSEHOLD NUTRITION AND INCOME

The current enset-root crop production system, which is supporting about 13 million people, is characterized by malnutrition (Tables 1 and 4) as also reported by Kaluski, et al., (2002). In addition to protein and energy malnutrition, which was only 40 and 70% of the RDA, the diet was particularly low in VitA, Zinc and Calcium (Table 4). This can be explained by several factors affecting productivity, e.g. declining soil fertility; decreasing land size, and deterioration of alternative income sources (Kaluski et al., 2002). As a consequence the system has heavily relied on food aid for the last two decades, particularly in the hunger months of March, April and May. Food insecurity is severe in the resource poor households, as they concentrate on annual crops while the more resource-rich farmers allocate larger areas to enset (Tsegaye and Struik, 2002). Scenario modeling shows that for these resource-poor farmers to be food self-sufficient there is a need to allocate at least 25% of their land to Enset. However, enset is a perennial plant and takes about five years to reach maturity (Brandt et al., 1997), therefore poor farmers may lack the initial investment and risk carrying capacity to wait for enset to establish and produce enough food unless external support is provided. On the other hand, in Scenarios II and III expansion of the enset field could be facilitated by creating market linkages that buffer the households in the short term. Enset could be used as a source of industrial quality starch and glucose for pharmaceutical uses, which could be used as a financial incentive to accelerate enset systems.

As the model favored a reduction in crop diversity and an expansion of few perennial crops like enset and coffee in Scenarios II and III (Table 3), the shift to these new production objectives will affect system resilience and increase market risks. Whilst this is the optimized model output, further refinement is needed to include elements of risk in the analysis. Furthermore, more dialogue with farmers is needed to investigate which option is attractive to them and what level of risk to include in the modeling.

On the other hand, enset system is already supporting 10-13 million people in Ethiopia as a staple, or co-staple with cereals and root crops (Tsegaye and Struik, 2002). Hence increasing its land area would be accepted by most of the respective communities, particularly where land and labour are not limiting. The current farmers' experience also showed that whenever drought occurs, and people are exposed to food deficit, they mainly rely on enset as a food security crop when all the other annual crops have failed. There is a living proof in the few communities, as it is the case in Gedio, about 250km away from the research site, whereby farmers allocate about 90% of their land for enset/coffee mixtures and remained food self sufficient for generations without external support. Hence, the practical implication of shifting to enset-based systems will be increased resilience and stave off hunger particularly in mountainous terrains which otherwise could be liable to erosion and famine (Kippe, 2002) though the enset field in the region is decreasing year after year due to recurrent food shortage that encouraged households to consume it at the juvenile stage; before it accumulates enough biomass.

The current financial benefits obtained from Scenario II & III may change with changes in price of products, particularly coffee, which currently has a low, but increasing world, price. However, the recent move in Ethiopia towards getting accredited as 'organic coffee' and the possibility of fetching premium price may increase the benefits of scenario III farmers. Moreover, there is a possibility of intercropping beans and/or sweet potato under the expanding coffee and enset fields in the suggested Scenarios, which may enhance the nutritional and financial benefits. The money generated from scenario III could buy about 2 tones of maize and 0.4 tones of beans with the current market price, which could fully cover the energy and protein demand of the consumption unit for a period of a year. Although growing only coffee in Scenario III may give a financial benefit of up to 3000 birr/cu, farmers favoured teff on at least 20% of their land to minimize market and environmental risks. Therefore, any new marketable enterprise that may be integrated into these systems by governments or other actors should be at least as profitable and compatible to the systems of Scenarios II & III.

EFFECT ON OTHER SYSTEM COMPONENTS

Although the model suggested the expansion of the perennial components at the expense of cereals, implementation of this model could be constrained by low soil fertility status of the outfields and lack of household labour in peak farming months. A recent report showed that an expansion of the enset from its traditionally fertile homestead plot to the less fertile outfields reduced crop yield by up to 70% (Amede and Taboge, 2004). This is because the traditional enset fields are very rich in organic matter content, about 6%, while the outfields are relatively poor in organic matter (1.5%) due to preferential application of organic manures to the food security crops (Amede and Taboge, 2004). As these crops demand soils with high organic matter (Kippe, 2002) the possibility of farmers to expand the land allocated for these perennials should be accompanied by soil fertility management innovations to enhance the productivity of the middle and the outfields.

In the analysis, Scenario II was more realistic for the majority of farmers, not only in terms of fulfilling both nutritional and cash demands (Table 4), but also in fulfilling social preferences of food choice. This Scenario was also effective in reducing soil erosion by up to 40% (Table 5) thanks to the expansion of enset and coffee with low crop cover values (Bergsma, 1996) that are effective in increasing vegetative cover and minimizing run-off effects. In this case, crop diversity was reduced by about 50%, from about 13 to about 6, which may have negative implication on risk and biodiversity.

Moreover, the expansion of Enset/coffee would affect the livestock system in multiple ways. Firstly it produced relatively low quality animal feed with a significant decline in the energy supply, particularly in Scenario II and III (Fig 1) and reduced nutritional quality with increased supply of lignin, caffeine and tannin contents (www.fao.org/ag/aga/agap/frg/afris). Secondly, the new Scenarios may inhibit free movement of animals and free grazing of stubble after crop harvest. It may also demand a complete shift to cut-and-carry system, which may have a significant implication on labor and number and type of animals to be managed. Thirdly, since manure availability is a prerequisite for growing enset and organic coffee, its expansion could be constrained by ever decreasing number of animals to produce enough organic fertilizer for this sub-system. The direct use of crop residues of enset/coffee as an organic fertilizer could be also hindered by its slow decomposition rate thanks to the high content of phenols in the coffee residue. However, the reduced feed quality could be corrected by growing high value legumes and grasses as intercrops and cover crops in the expanding enset/coffee fields. These cover crops could produce a significant amount of high quality feed without affecting the yield of perennial crops (Amede et al., 2001).

For enset and coffee, the first good harvest is possible only after five years of planting and hence farmers may need a short term policy support to have a good start and sustainably manage their systems and build their skills in sustainable management, quality and in accessing reliable markets. Although enset is favoured by the communities for its stress resistance, food availability at any time of the year, for maintaining land productivity and for very high carrying capacity, processing is one of the most labour intensive operations, particularly for women (Brandt et al., 1997). Hence, there is a need for low cost enset processing machine that would save labour and increase efficiency.

Conclusions

The current enset-based production system in Areka does not achieve food security or income sufficient income for the households farming this land. This study has shown the utility of an optimization modeling approach to investigate the reallocation of land and existing resources to address food security. The modeling approach was also used to develop scenarios for combining food security needs with income generation. Whilst changes in the production system are possible to achieve optimum outcomes, this study has shown that a deeper understanding of farmers' attitudes to risk, vulnerability and access to resources and labour is needed before any one of these solutions can be promoted as potential options for addressing food insecurity, income generation and improving environmental services.

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