Poverty and natural resource management in the Central Highlands of Eritrea

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Chapter 8

Base Run and Sensitivity Analysis

8.1 Introduction

In this chapter, results of the multi-annual bio-economic model presented in Chapter six will be discussed. First, for each of the study villages the model will be run using parameter values discussed in Chapter seven. This model is called the 'base model'. Benchmark outcomes obtained from our base model – which we call the 'base results' are presented in the following section. The base results reflect land use and technology choice decisions that maximize village level net income subject to resource and subsistence constraints discussed in Chapter four. The base run model is executed for the three study villages. The results of the base model for each village are compared with current practices in that village as well as the base results of the other villages. Similarities and differences are used to explore the impacts of socio-economic, biophysical and institutional factors on farmers' decisions. The results of the base model will serve as a reference with which results of various scenarios discussed in Chapter nine will be compared. Sensitivity analysis is made for different rates of discount and different wood prices. The linear programming model is formulated in GAMS version 2.25 and solved with MINOS (see Brook *et al.,* 2003).

8.2 Results of the base model

It is reminded that the villages were selected based on their differences in population density, climate, topography, land cover and proximity to major urban centres that influence their access to off-farm employment opportunity and the transaction costs involved (see Chapter four and Table 8.1). Before presenting the results of the base model, we briefly comment on the characteristics and values presented in Table 8.1 that reflect the differences between the three villages included in this study.

Altitude and average annual rainfall of the study villages were used to estimate crop yields of the study villages (see Section 7.4.1). Access to off-farm employment, which in a number of ways affects rural household decisions, varies considerably among the study villages. Generally access to off-farm employment is higher the closer a village is to major urban centre. However, due to the border conflict and the resulting mass mobilization of able-bodied persons for military conscription, estimation of access to off-farm employment was not possible during the fieldwork. Thus the figures given in Table 8.1 are rough estimations based on subjective estimation of some respondents.

Access to additional grazing area is based on the observed practice of livestock migration to the eastern escarpments. We estimate the amount of feed requirement for livestock in each village from the seasonal migration pattern in the respective villages. In Embaderho and Maiaha livestock migrate for more than 6 months every year. However, to account for livestock that remain in the village throughout the year, it is assumed that 40 percent of livestock feed could be obtained from sources outside the village territory. The area that remains fallow is also determined based on current practice. While croplands are cultivated continuously in Zibanuna, about 25% of the croplands are assumed to remain fallow every year in Embaderho and Maiaha (see Chapter five).

Farm gate prices of crops and livestock are often much lower than consumer prices due to the costs involved in the processes of exchange. These costs, referred to transaction or marketing costs, among other things, include costs incurred by intermediaries plus their profit margin[46]. Large differences of crop and livestock prices in different cities of the country as well as seasonal price differences show the evidence of the significance of transaction costs. These costs are influenced by the distance between the village of production and the major consumption areas (the major urban centres) and the type and conditions of roads. Based on transportation costs from each village to Asmara, and price differences in Asmara and local markets nearest to the study villages, the farm gate prices of crop and livestock in Embaderho, Maiaha and Zibanuna are estimated to be 85, 65 and 75 percent of the prices in Asmara.

Table 8.1 Main characteristics of the study villages and values of parameters used in the base model

	Embaderho	Maiaha	Zibanuna
Total land per household (ha)	1.72	5.46	2.24
Average rainfall (mm/year)	540	540	600
Altitude (meters above sea level)	2400	2200	2000
Access to off-farm jobs[1]	35	0	15
Access to additional grazing[2]	40	40	0
Marketing cost[3]	0.85	0.65	0.75
Fallowing requirement	0.25	0.25	0.0

[1] percentage of the adult male population with access to off-farm employment
[2] percentage of livestock feed requirement that may be obtained from sources outside the village
[3] marketing cost is expressed as the ratio of farmgate price to the market price

[46] For a discussion of transaction costs refer to Ruijs (2002).

Benchmark outcomes were obtained for the three villages based on the characteristics described in Table 8.1 and model parameters estimated in Chapter seven (see Table A1 summary of parameters). These results will be discussed in the following sections.

Whenever possible, model outcomes are compared to current practices and similarities and differences are discussed. However, due to reasons stated below, such comparisons are not always possible. While our model is a multi-annual model, we do not have a time series of historical data with which we can compare these results. Moreover, continuous state of war has disrupted smooth economic and demographic trends in the country that current farming practices in all villages may deviate from optimal strategies. Furthermore, the base results of the model reflect choices that maximize net aggregate income of the villages. In reality, however, households with differing, and sometimes conflicting, interests are involved in these decisions (see Chapter four)[47].

The above paragraph reveals the reasons why model results could not always be compared with current practices or possible reasons for a deviation from them. In general, the results seem to describe the real situation fairly well. There are also some diverging results. These results can, however, be explained and provide interesting insights to possible improvements and policy suggestions. Converging and diverging results will be discussed below. The discussion starts with the description of simulated crop, livestock and tree-planting practices. Later we will discuss income and food availability situation in the study villages.

8.2.1 Land use

Land use decisions and the choice of technology influence rural income as well as the sustainability of land use. The decisions on land use and choice of technology are influenced by various economic, institutional and biophysical factors, which vary from one village to another in our study area. We present the base run results of allocation of land use in each village in Table 8.2 and compare the results in light of village characteristics described in Table 8.1 as well as in Chapters 5 and 7.

Cropland

The results of the base model (see Table 8.2) indicate that Embaderho has the highest area of land under crop cultivation but the lowest cropland per

[47] Results of a household level model that takes into account household level constraints and interactions among households are briefly presented for comparison purposes (Section 8.7).

household. This is to be expected given the high population density in the region. The opposite is true in Maiaha, where population density is lower (see Table 8.1) and land less suitable for cultivation (see Chapter seven).

The changes in land use over time differ among the study villages. In Maiaha the area under cultivation increases at almost the same rate as population growth throughout the planning period. Cultivated lands in Embaderho and Zibanuna, on the other hand, increase at a slower rate than population growth. The reasons of these phenomena are discussed below. On average, cultivated land in Embaderho increases at a rate of 1.3 percent per year but remains the same in Zibanuna. The evolution of simulated land use during the seven-year planning period for the three study villages is given in Figures 8.1 to 8.3.

Expansion of cropland in response to population growth may be limited due to lack of working animals, lack of land suitable for cultivation or lack of labour, if a significant proportion of the additional labour can get employment outside agriculture. In Maiaha, there is no access to off-farm employment and the needs of the rising population have to be met by agriculture. Thus, it can be well understood that cultivated land increases proportional to population growth. Lack of working animals is not an immediate constraint in Embaderho and Maiaha. The base results show that the villages maintain some cattle (cows), which may be reduced in favour of oxen, if needed for ploughing. The base results in Zibanuna, on the other hand, show that the village keeps only working animals. This is because, unlike Embaderho and Maiaha, which have access to additional grazing in the eastern escarpments, livestock in Zibanuna entirely depend on the village territory for grazing. Finally, the relatively lower population density in Maiaha leaves a relatively wider room for expansion of cultivated land. Thus while the increased demand due to population growth in Maiaha is met merely through proportional expansion of agricultural land, higher demand in Embaderho and Zibanuna is fulfilled by both expansion of land, and using more inputs per unit of land (see also Section 8.2.2), as well as engaging on off-farm activities.

Figures 8.4 to 8.6 show the simulated land use by slope category for the three study villages. Generally soils with gentle slopes are predominantly used for crop production. This is because crop yields are higher on the gentle slope land categories where soils are deeper and more water is available for plants compared to crop yields on steeper slopes where soils are shallow and considerable amount of water is lost due to run-off. However due to the shortage of sufficient land on gentle slope land categories, substantial areas of steeper slopes are cultivated both in Embaderho and Maiaha. This is also the current practice in the Central Highlands of Eritrea in general and the above-mentioned villages in particular.

Table 8.2 Some results of the base model

	Embaderho	Maiaha	Zibanuna
Land use (year 1)			
Cropland (ha)	1039	221	310
cropland (% of total)	43	21.7	39.5
cropland per household (ha)	0.74	1.15	0.93
Grassland (ha)	1139	387	453
Woodland total (ha)	214	489	8
natural woodland (ha)	0	427	0
E. plantation (ha)	214	62	8
Crop (year 1, ha)			
barley	243	44	48
millet	-	30	71
pulses	88	3	0
sorghum	257	57	47
wheat	243	43	0
taff	-	-	145
fallow	208	44	0
Livestock (year 1, head)			
oxen	537	110	172
cattle	496	243	0
donkeys	213	35	54
TLU			
Soil Conservation % (year 7)			
by land use			
cropland	25.1	29	90
grassland	0	0	2
woodlands	0	0	0
by land type			
s_1	100	-	100
s_2	25.6	62	27
s_3	0	15	46
s_4	0	0	-
Average Loss of Nitrogen (kg/ha/year)	- 21.13	-28.06	-18.9
Average Soil Loss (tons/ha/year)	11.34	13.5	4.45
Av. Soil loss from cropland tons/ha/year	17.8	24.75	9.02
Total soil loss tons/year	27010	13714	3460
Average per capita income (Nakfa)	345	330	645

Generally, the simulated choice of crops is similar to current practices in all villages. The most important crops in terms of area of land cultivated are barley, pulses, sorghum and wheat in Embaderho; barley, sorghum, millet and wheat in Maiaha; and taff, barley, millet and sorghum in Zibanuna. The simulated cultivation of sorghum, particularly in Embaderho, seems to be higher than the current practice. Farmers in Embaderho have indicated that cultivation of sorghum has considerably declined in the past years due to the decline in the early rains in March and April. When the possibility of sorghum production in Embaderho is excluded, simulated area of croplands declines substantially and becomes closer to the actual cultivated land in the village. Farmers have now to choose only between short-cycle crops and all activities have to be done at the same time. This shows that changes in rainfall patterns do not only constrain farmers' strategy of dealing with risk, but also their ability to cultivate enough land or devote sufficient labour input on the crops they cultivate.

Grazing land

Livestock graze on grazing land, fallow lands, croplands (after harvest) and on woodlands older than five years. New woodlands are restricted for grazing but grass may be collected. The simulated area of grazing lands constitutes the largest proportion of land in all the three villages: 47%, 74% and 58% percent of the total land in Embaderho, Maiaha and Zibanuna[48] (Table 8.2). This is in line with the general practice in the study villages where grazing lands cover more than 50 percent of the total land area. Maiaha has the highest proportion of grazing land because of lower population density and topography that makes most land unsuitable for cultivation. Moreover, livestock is an important component in crop production that even in Zibanuna, where land is generally more fertile, grazing area covers considerable area. The simulation results show that, when available, the steeper slope lands are used for pastures (see Figures 8.4 and 8.6).

Woodlands

The simulated areas of woodlands in the first year cover 40%, 8.9% and 1% of the total land areas in Maiaha, Embaderho and Zibanuna respectively. Although land is much more scarce in Embaderho than in Zibanuna, the simulated area of woodland is much lower in Zibanuna. By the end of the planning period, woodland areas decline to 19 percent of the total land area in Maiaha and to 6.9 percent in Embaderho. All trees are cleared in Zibanuna. There are two reasons for less area of woodlands in Zibanuna. First, land is generally more fertile in Zibanuna and the cost of tree planting in terms of forgone crop production is much higher than in the other two villages where substantial part of the land is barely suitable for crop production. Second, as stated above, while additional grazing land is available in the eastern escarpments for Maiaha and Embaderho, livestock in Zibanuna entirely depend on the village territory for grazing. Thus a larger proportion of the land has to be maintained for grazing of livestock that are vital in crop production activities.

[48] In the case of Maiaha, these include the natural woodlands established before the planning period.

Figure 8.1 Simulated land-use in Embaderho

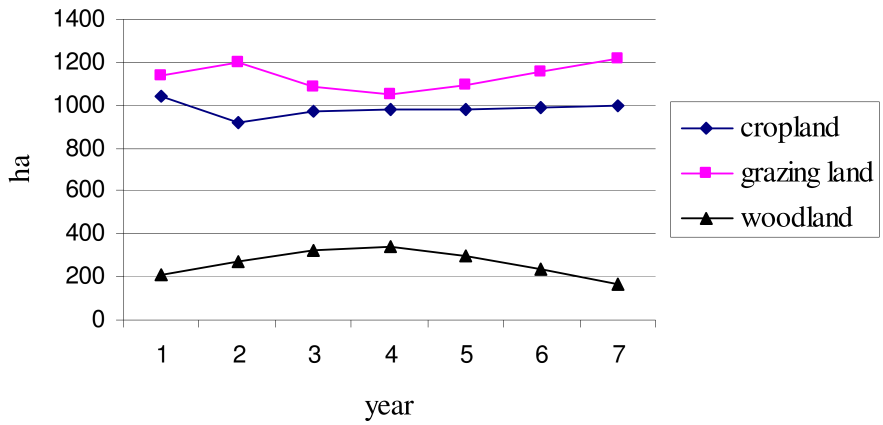


Figure 8.2 Simulated land-use in Maiaha

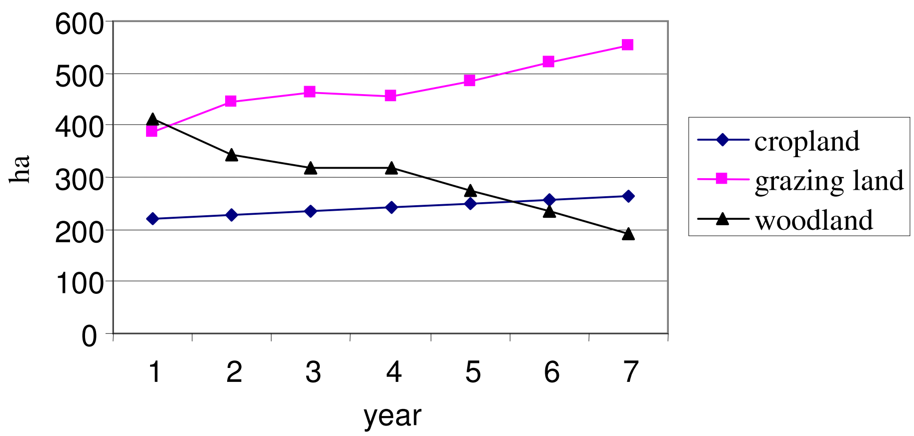


Figure 8.3 Simulated land-use in Zibanuna

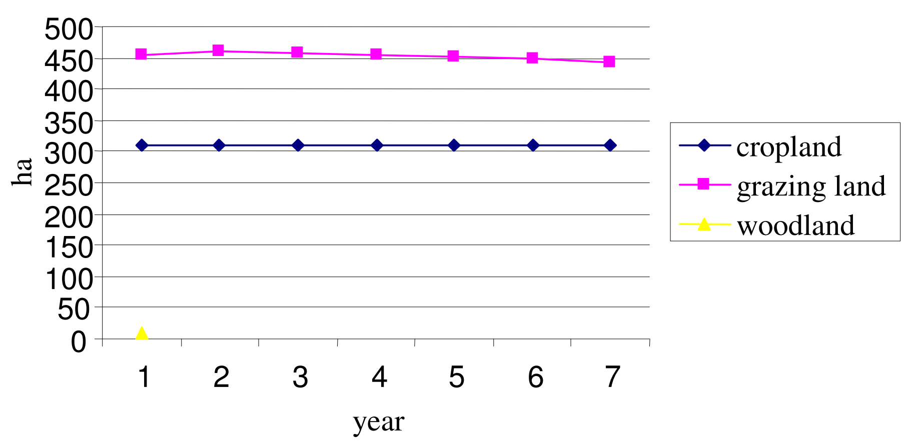


Figure 8.4 Simulated land-use by land type: Embaderho

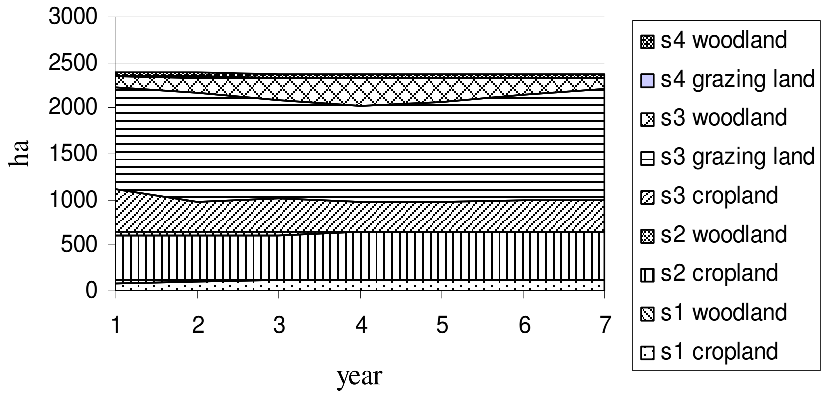


Figure 8.5 Simulated land use-by land type: Maiaha

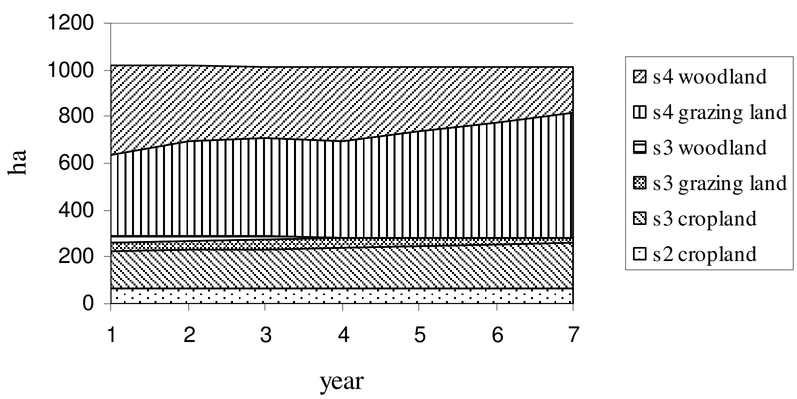
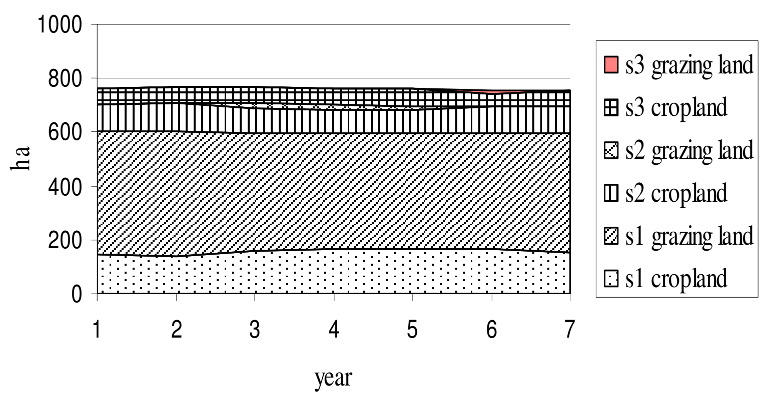


Figure 8.6 Simulated land-use by land type: Zibanuna



The base results show that new native woodlands are not established in any of the villages. This is remarkable in that natural regeneration of woodlands is suggested as a promising approach of rehabilitating the degraded woodlands in the country. Such optimism is based on the encouraging regeneration in the few permanent closures undertaken in the country as well as the lower cost of establishing them (see Section 3.3). However, no systematic evaluation has been undertaken from the view of the major stakeholders – the farmers. The results of the base model show that fast-growing eucalyptus plantations contribute more to rural income and, therefore, are more likely to be accepted. The area of native woodlands declines continuously in Maiha, the only village of the three study villages where native woodlands exist. This is partly compensated by new eucalyptus plantations.

Two key differences between model assumptions and current practices that result in differences between actual and simulated area of woodlands include:

a. The *diesa* system of communal land ownership does not allow farmers to plant trees on their croplands or any other place. Since recent years, however, in few villages degraded hillsides are parcelled out to individual households for tree planting. No such constraints are included in the base model.
b. The model assumes that wood, like crop and livestock products, can freely be produced, harvested and marketed. In reality, cutting trees from natural woodlands is strictly prohibited in Eritrea and even trees on individually owned plantations can only be cut with permission from the Ministry of Agriculture. The results of our fieldwork indicate that farmers plant trees mainly for own use.

We have conducted sensitivity tests to examine how the absence of a market or a lower price of wood affects farmers' tree planting decisions. The results are presented in Section 8.6

8.2.2 Soil conservation

As the construction of stone bunds is a labour-intensive activity it can be done only on an incremental basis every year. Thus, it is more meaningful to compare results at the end of the planning period. The extent to which stone bunds are constructed varies across the different land types in all the three villages.

Interestingly, simulation results of our base model show that stone bunds are constructed on gentle-slope lands and on croplands in contrast to the practices of the Soil and Water Conservation projects by MOA and other NGOs which focus on steep slope hillsides. This reflects the differences in objectives: while the major objective of the government and NGOs is to control land degradation, farmers build stone bunds only if it contributes to their objectives of income maximization and/or securing basic needs. The cost of undertaking soil conservation activity increases considerably with slope both in terms of labour required to construct the stone bunds and the area of land occupied by the bunds. This reduces the returns to investments on soil conservation. This fact is in conformity with current practices that farmers, although to a limited extent, build stone and soil bunds on their croplands. On the other hand, unless financed by government or NGOs, no such conservation structures are undertaken on grazing or woodland areas.

The simulated level of soil conservation also varies considerably among the study villages (Table 8.2). Relative availability (scarcity) of labour and access to off-farm employment opportunity explain the differences in construction of stone bunds among the villages. The simulated area of cropland on which stone bunds are constructed is lowest in Embaderho followed by Maiaha. This is because male labour in Embaderho and Maiaha is considerably reduced between January and May due to migration to the eastern escarpments (in search of grazing land and additional land for cultivation). Better access to off-farm jobs in Embaderho further reduces the labour available for soil conservation activities. Secondly, as discussed in Section 8.2.1, land is relatively more abundant in Maiaha that, when more labour is available (due to population growth), expanding agricultural land is more profitable than the construction of stone bunds.

8.2.3 Organic and inorganic fertilizers

Compared to actual practice, the simulated levels of fertilizer application in the Central Highlands of Eritrea is very high. All crops in Embaderho, Maiaha and Zibanuna are cultivated with the application of maximum dose considered in the model and mulching is applied on 18.5 percent of the cultivated area in Embaderho.

Despite the heavy subsidy on fertilizer, actual levels of fertilizer application are much lower than the simulated levels (see Section 5.5.3). This can be due to various factors. The literature has several explanations for low rates of adoption of innovations which can be broadly classified as sociological factors such as awareness and perception and economic factors such as access to markets, risks involved and liquidity constraints (see Section 2.5). Problems relating to fertilizer distribution and insufficient extension could be some of the factors that contribute for the low levels of fertilizer use in Eritrea. Average annual fertilizer imports in Eritrea in the period 1992-2000 were less than 5 kg per hectare of cultivated land (see Chapter two).

Low levels of fertilizer application in the Central Highlands may also be due to economic reasons, particularly risk and liquidity constraint. Since the low and erratic rainfall may significantly reduce normal absorption of nutrients by plants, the effect of fertilizer application on yield is not always guaranteed. Our field survey results show that farmers consider insufficient rainfall as the major reasons behind their low levels of fertilizer application. They believe that the application of chemical fertilizer is a risky investment due to the highly unreliable rainfall (see Section 5.5.3). Since our model is constructed for average rainfall conditions, the uncertainties caused by the high levels of rainfall variability are not taken into account. This could be an important reason for simulated levels of fertilizer application that are much higher than the actual levels.

The difference between the simulated and actual levels of fertilizer application in the study villages may also be a result of our choice of the scale of analysis. Resource constraints at a village level are not as binding as at household level. While many farmers in the study villages are too poor to afford even the highly subsidized fertilizer, this constraint is not as binding in our model as it would be in a household level model. The simulated number of oxen needed to cultivate croplands is much lower than the current number of oxen in the study villages (see Section 8.3). Thus, a large number of livestock are sold in the first year of the planning period providing the financial means to purchase chemical fertilizer and cover other expenses. The survey results, however, indicate that a large proportion of the farmers in the study villages do now own livestock. In the following section we will explain why even relatively wealthier farmers who own livestock, in practice do not want to sell their livestock to invest on fertilizer.

The base results show that manure is not applied on croplands in any of the study villages. All manure is used for fuel. In practice, as well, manure is mostly used for fuel. The results of our fieldwork show that while manure from cattle are used for fuel in all villages, manure from sheep and goats are mainly used as fertilizer.[49]

8.3 Livestock

The simulated numbers of livestock as well as the composition of livestock in the study villages differ from the livestock currently held by the villagers. The number of livestock (in TLU) ranges from 32% to 52% of the current number of livestock in the study villages. The base results indicate that oxen and donkeys

[49] In Embaderho and Zibanuna even part of the manure from sheep and goats is used as fuel.

constitute 52%, 46% and 100% of the total number of livestock in Embaderho, Maiaha and Zibanuna respectively. The proportion of oxen and donkeys in the total livestock is even higher in Embaderho and Maiaha where both types of livestock combined constitute 84% and 67% respectively.

In the first year, large numbers of livestock are sold in all the three villages resulting in a considerable difference between the simulated and actual number and composition of livestock. This is because of one or combination of the following two reasons: 1) the land cannot support current level of livestock at the suggested feed rate, 2) it is in the interest of rural households to sell livestock and purchase fertilizer, and 3) working animals (oxen and donkeys) are utilized more efficiently. We discuss these points one by one in the following paragraphs.

First, the actual level of feed consumed by livestock is lower than the suggested rate of animal feed we use in our model. In the Central Highlands of Eritrea there is an acute shortage of animal feed particularly during the dry period during which livestock are generally underfed. It is reported that livestock are let undernourished for about five to six months of the year (FAO, 1997). This is reflected in late maturity, high mortality rate and low productivity of livestock. Since grazing land is owned communally, it may be in the interest of individual households to keep as many livestock as possible resulting in overstocking of livestock over and above the carrying capacity of the land (see Chapter three).

Second, given the fertilizer-yield relationship used in this study, village income may be higher if livestock are sold and the proceeds are spent on fertilizer. The return to investment in fertilizer, however, will decrease if the possibility of lower yield (or even complete crop failure) due to uncertain rainfall is taken into account. While drought affects returns to livestock as well, the impact on livestock is likely to be lower because farmers may respond by early migration of livestock, purchase of animal feed or selling the livestock. Livestock are in fact a highly valued asset for rural households not only because they are critical inputs in crop production and/or generate considerable income but also they serve to cushion the impact of drought. Thus for farmers in the Highlands of Eritrea who, given the level of poverty, are more likely to be risk averse, keeping more livestock may be more rewarding investment than buying fertilizer.

Finally, the fact that we are using a village model means that oxen and donkeys will be fully utilized. Thus only the minimum number of working animals required for land cultivation and transport are kept. In practice however each household keeps its own animals if it can afford it. Ownership of oxen means agricultural activities, particularly sowing, can be done at the right time resulting in the best yields. This results in higher proportion of oxen and donkeys than the base results of our village model.

8.4 Soil erosion and nitrogen balance

8.4.1 Soil erosion

The average simulated amount of soil loss from croplands is 18.5, 26.5 and 7.2 tons/ha/year for Embaderho, Maiaha and Zibanuna respectively. The average soil loss from all land area of the village is 11.6, 12.4 and 3.7 tons/ha/year for the three villages respectively. Maiaha and Zibanuna have the highest and lowest level of soil erosion respectively due to the combined effect of topography and proportion of land where stone bunds are constructed (see Section 8.2). The average rate of soil loss declines substantially in Zibanuna as stone bunds are constructed on larger areas of the village land. On the other hand, soil loss in Maiaha remains very high as the benefits from the construction of stone bunds are offset as woodlands are cleared and larger proportions of the steeper land categories are brought into cultivation (see Figure 8.7).

Figure 8.7 Simulated average soil loss from croplands

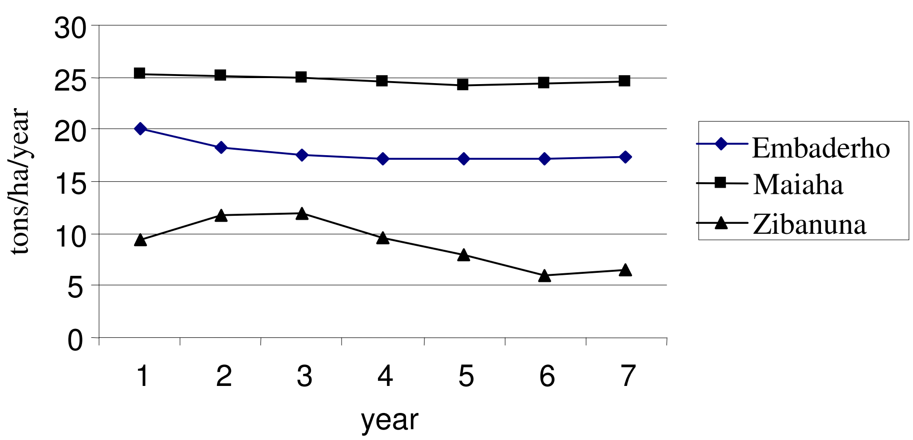
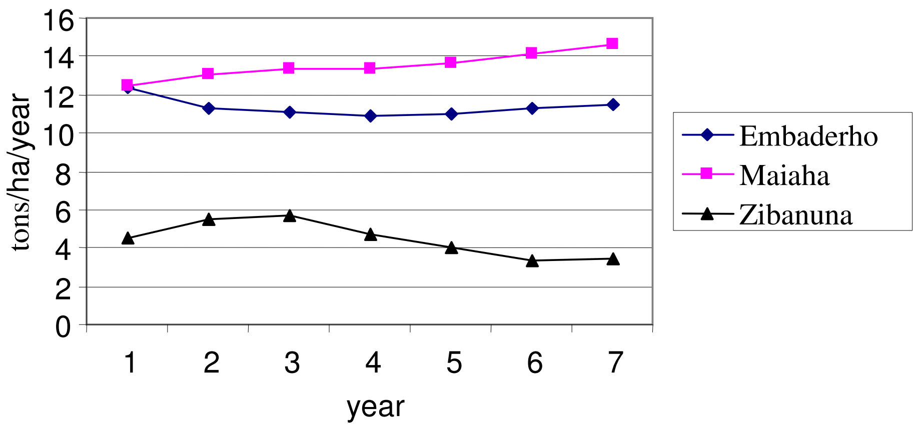


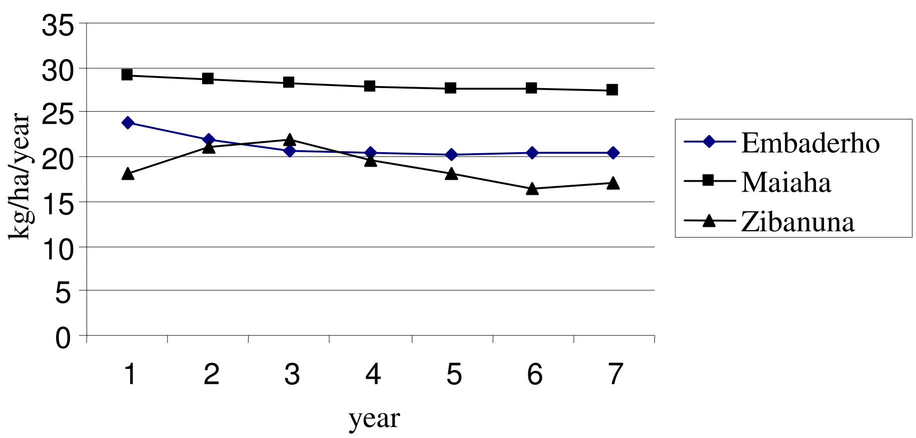
Figure 8.8 Simulated average soil loss



8.4.2 Nitrogen loss

In most cultivated soils of Eritrea, fertility has been declining, as nutrients are lost through soil erosion and removal of harvested products and crops residues without replenishment by addition of organic or chemical fertilizers. The average simulated nitrogen losses from croplands are 21.3, 28.3 and 18.3 kg per ha per year in Embaderho, Maiaha and Zibanuna respectively. Figure 8.9 shows that nitrogen loss slightly declines overtime. The differences in nitrogen losses are mainly explained by the level of soil erosion in the villages under study (Section 8.4.1). This is because the simulated level of fertilizer use is similar in all the villages.

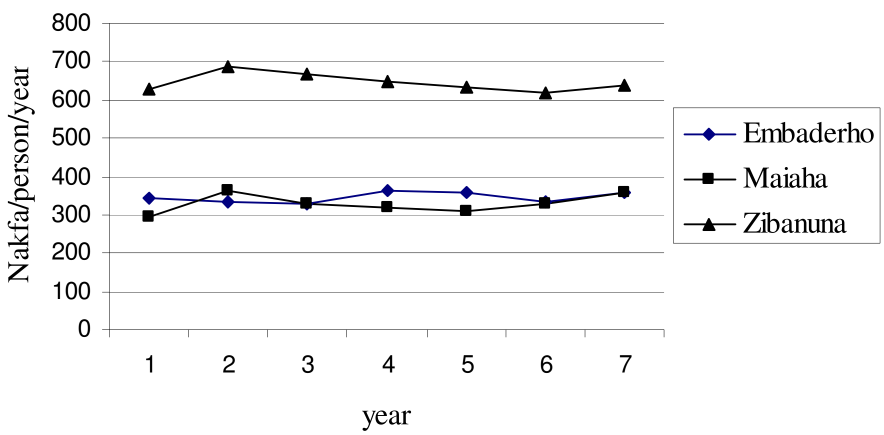
Figure 8.9 Simulated nitrogen loss from croplands



8.5 Income

The Linear programming model maximizes net income subject to the fulfilment of subsistence consumption and energy (fuel) needs. Thus the net per capita income presented here refers to what is called as the supernumerary income i.e., the income, which remains after all minimum subsistence needs are satisfied. The average per capita income, as expected, is the highest in Zibanuna, while Maiaha has the lowest level of income. All three villages have a positive net income throughout the planning period (Figure 8.8). This is not surprising for Embaderho and Zibanuna villages, where relatively higher levels of chemical fertilizers are applied. In addition, Zibanuna has relatively more fertile land and households in Embaderho have better access to off-farm jobs. The results, however, seem to be too optimistic for Maiaha. This is because, actual levels of fertilizer application are the lowest in this village and there is no access to off-farm employment opportunities.

Figure 8.10 Simulated per capita income



The base results show that two of the three villages (Maiaha and Zibanuna) produce sufficient grains and some surplus for the market. Embaderho, on the other hand, has a shortage and additional cereals are bought to fill the gap. This is mainly due to high population pressure and the resulting smaller size of land per household. These results are remarkable in that for the average rainfall and with optimal land and crop management in most areas of the Highlands of Eritrea, farmers have the potential for self sufficiency and to produce some marketable surplus. However, due to unreliable rainfall and the risks involved in investments on fertilizer, fertilizer application remains very low that farmers can only cover part of their cereal consumption from own production.

In all cases, crops with higher price are sold except a small fraction which is kept for the next year's seed requirement. Barley and sorghum, which have the lowest price, are bought for consumption. This is an obvious result that follows from our model formulation because household preferences towards different crops are not taken into account. Nevertheless, the results confirm the actual practice of farmers in the Central Highlands of Eritrea. Selling relatively expensive crops and purchasing cheaper cereals for consumption is a common strategy of rural households to cope with food shortages.

8.6 Sensitivity analysis for some parameters

The results presented in the foregoing sections of this chapter can be generalized for the parameters described in Chapter seven and in the appendices. The number of parameters is very large as can be seen in appendix 1. Doing a rigorous sensitivity analysis over all these parameters is very tedious, and in this analysis only the discount rate and the price of wood are dealt with. The rate of discount is often very difficult to estimate. However, the returns to long-term investment such as soil conservation and tree-planting and hence the decision of rural households to undertake these activities may be influenced by the choice of the discount rate. The reason we chose to conduct a sensitivity test on the price of wood is that at present farmers are not free to harvest and market wood products (see Chapter three) and it is difficult to anticipate the market price if such a ban is lifted.

As expected tree planting declines considerably both in Embaderho and Maiaha with an increase in the rate of discount and a decrease in the prices of wood[50]. Land use in both villages changes slightly with the areas of woodlands declining and grazing lands increasing. Thus the number of livestock in both villages increases. The impact on land management such as the use of fertilizers and soil conservation does not change significantly. It is interesting to note that the construction of stone bunds, which is considered as long-term investment does not change with changes in discount rate. This is due to the fact that the benefits from the construction of stone bunds begin to accrue from year one due to the importance of the moisture conserving impact.

While tree planting in Maiaha continues to decline with the decline in the selling price of wood, in Embaderho the level of tree planting ceases to decline and farmers continue to plant trees even when the selling price is very low. This is due to differences in relative availability of biomass fuels in the two villages.

[50] Sensitivity tests was not carried for Zibanuna as no trees were planted in Zibanuna in the base scenario.

Unlike in Embaderho natural woodlands, from which farmers can collect fuelwood, exist in Maiaha. The simulated number of livestock per household, and hence the supply of manure, is also higher in Maiaha (see figures in A3-A7 for the impact of discount rates and fuelwood price on tree planting in the two villages).

8.7 Household-level model

The reason for choosing a village level model as unit of analysis in this study was discussed in Chapter four. Nevertheless, the limitations that arise from aggregation have been highlighted. It has been noted that if household levels of resource endowments and constraints are not taken into account, important issues relating to food security and land management may be masked. In this section, we present the results of a household level model for Maiaha. The objective is to compare the results from the village level model and household models.

Rural households in the Central Highlands of Eritrea are generally poor and income disparities are not very noticeable. Nevertheless, some distinction of household level of income can be made depending on the ownership of key resources, particularly male-labour and livestock. Land distribution among households is egalitarian that land ownership does not account for household income disparities. However, many households lack either labour or oxen or both to cultivate their land. This opens a room for exchange of resources; however, the market for the inputs in rural areas of the Central Highlands is thin. As discussed in Chapter five, various forms of cooperation and exchange of resources take place. Households that lack labour and/or oxen may overcome this constraint(s) by a) hiring the services one or both of the resources, b) exchanging the service of one input for the other, c) ox-pairing d) renting out their land and e) relying on the assistance of relative or neighbour. A summary of these exchange processes for the three regions in the Central Highlands is presented in Table 8.3

Table 8.3 Number of households by source of labour or oxen for crop cultivation in the Central Highlands

	Labour			Oxen		
	ZM	ZDE	ZDW	ZM	ZDE	ZDW
Own Resource	59	70	61	41	56	40
Labour-labour or oxen-oxen	2	1	0	21	22	16
Hire resource for cash	5	3	4	0	0	0
Ox-Labour exchange	1	3	5	1	3	5
Rent land	8	12	16	9	11	20
Favour from relatives	6	18	0	16	17	5

Source: General Survey.

Table 8.3 shows that despite various options by which households may adjust croplands to factors such as labour and draft power, social relationships and land rental markets are the major factors adopted to adjust the different land-factor ratio among households. This is in accordance with previous observations as well (Tiquabo, 2003). The markets for the services of labour and oxen are imperfect and adjustments through buying and selling of the service of these factors is very limited. Ox pairing (traditionally known as *lfntee* literally meaning coupling) is a common practice when households own only one ox, but hiring the service of oxen for cash is not yet developed. Exchange of the service of male labour to the service of oxen is practised to a limited extent. One of the commonly cited reasons for this is the need to supervise the person using the oxen on rental basis to prevent maltreatment or overworking of animals.

Despite variations by region and type of resource, the fact that significant proportion of households in the Central Highlands depend on relatives and neighbours for the resource they lack (with nothing to pay in return) makes it difficult to build household-level model and include these non-economic interactions among households. A household-level model that is based on the assumption that all exchange of resources among households is guided by economic interest is therefore a considerable deviation from the reality

Based on the field survey in the study villages, three categories of households were identified based on the ownership of oxen and labour. We will call these households as poor, less poor and non-poor households. The initial labour and livestock endowment of each household category are given in Table 8.4. We also assume:

1. Households may borrow oxen, hire labour and/or rent land
2. If poor or less poor households do not have enough male labour or oxen to work the land they choose to cultivate, they will pay one day

service of a male person for every ox-day they rent in and a one day service of an ox for every male labour they hire[51].

3. If households choose to rent out their land, the tenant is responsible for all activities (except soil conservation) and supplies all inputs (seeds and fertilizer). The tenant and the owner of the land share output at the rate of 2:1 respectively.
4. If trees are planted in the village, all households contribute equal amount of labour and share output equally
5. Grassland is utilized communally

Table 8.4 Characteristics of the various household categories in Maiaha

	Poor	Less poor	Non-poor
Number of households	60	50	80
Number of persons	208	187	300
Number of adult males	21	29	56
Number of oxen	0	47	120
Number of cows	0	30	157
Number of donkeys	15	30	92
Number of sheep and goat	50	150	300

Source: Own survey

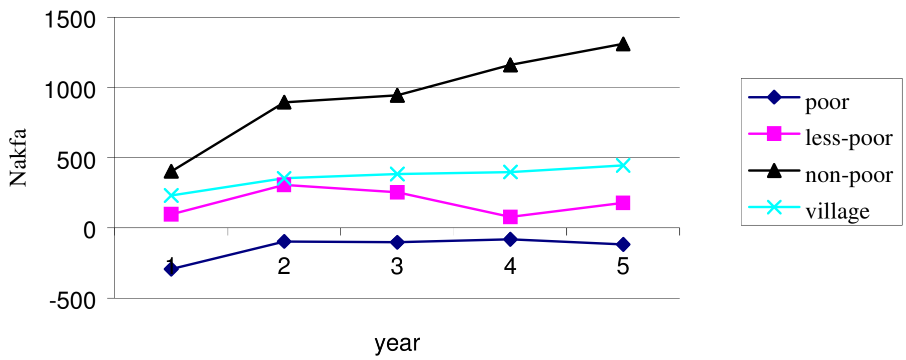
8.7.1 Results of the household model

The discounted net income used in the objective function is the weighted sum of all household categories. The weights used are proportional to the number of households in each category. Due to the low levels of endowments of labour, oxen and other livestock, the poor households are not able to meet the minimum requirements food and other subsistence needs unless some external assistance is provided. Thus food aid is introduced only for the poor households. To prevent unbounded solution and to obtain a realistic level of income that can be compared with that of other household categories, the value of food aid is deducted from the objective function.

As expected, the total discounted income of the village declines by 35 percent when a household model is used. More importantly, there is a wide gap among the incomes of the poor, less poor and non-poor households. The annual net per capita income of poor households remains negative throughout the planning period showing that this category of households is not able to produce the minimum subsistence requirements. Figure 8.11 shows the net per capita income of the three household categories from the household model and the average per capita income from the village model

[51] Exchange of resources is not only dictated by economic interest in the Central Highlands but mainly by social responsibility for those lacking the key resources for farming activities (male-labour and oxen).

Figure 8.11 Net per capita income: comparison of village and household models



The divergence between the average per capita income and the per capita income of the different household categories shows that household level analysis is crucial to understand the issues of poverty and food security problems. The differences in net per capita income among different household categories are due to a combination of factors, particularly differences in cultivated area and livestock. In addition, poor households obtain substantial amount of food aid to be able to cover subsistence needs and to purchase oxen. As discussed earlier, this is deducted from the objective function resulting in lower net per capita income for this group of households. Table 8.5 shows the simulated levels of croplands and livestock for the three categories of households.

Table 8.5 Simulated levels of cropland (ha) and livestock (head) by type of household in Maiaha

	Poor	Less-poor	Non-poor
Own cultivated land	52.9 (0.88)	40.6 (0.81)	89.5 (1.12)
Rented in land	0.0 (0.00)	0.0 (0.00)	23.6 (0.30)
Rented out land	8.8 (0.15)	14.8 (0.30)	0.0 (0.00)
Oxen	25.0 (0.41)	24.0 (0.48)	64.0 (0.80)
Donkeys	9.0 (0.15)	8.0 (0.16)	22.0 (0.27)
Cattle	0.0 (0.00)	36.0 (0.72)	309.0 (3.86)
Sheep/goats	66.0 (1.10)	198.0 (1.96)	90.0 (1.12)

* Figures in brackets represent cropland or livestock per household

The cultivated land per household (own cultivated land plus rented in land) is considerably higher for the rich household. The poor households are able to cultivate most of their cropland because with the help of the external assistance (food aid) they purchase oxen. The poor and less-poor households have generally lower number of livestock per household compared to the non-poor households. Moreover, the poor and less-poor households sell all but working animals by the third year while the livestock held by the non-poor households more than double by the end of the planning year.

Land use and land management

The simulated area of cultivated land in the household level model is slightly (7%) lower compared with the village model. We note here two factors that could have implications for the area of cultivated land. First, the fact that households with relatively more abundant resource(s) make their resources available for use by others (merely for social reasons) is not taken into account. This would probably result in larger area being cultivated by poorer households. Second, poor households are allowed to obtain food aid, which enables them to acquire oxen and cultivate more land. These two factors have offsetting influences on the cultivated land but the relative importance of each factor is not known.

The effect of using a household model on the woodlands is mixed. As stated earlier, land is communally owned in the Central Highlands and individual tree planting is possible only if community members agree to have parcels of for this activity. Thus it is assumed that all households contribute equally to tree planting and share output equally. Thus, both the establishment of new plantations and harvesting of wood from native woodlands are lower in the household model than in the village model. Consequently, while the area under woodlands at the end of the planning period is higher (less harvesting) in the village model than in the household level model, the area under eucalyptus plantations is lower (less planting) at the household model. All in all, the total area of woodlands in the village is lower in the household model than in the village model.

In both household and village level models, all croplands are cultivated with the use of either manure or chemical fertilizer. However, the proportion of cropland where manure is applied is much higher in the household model (45% in the household model compared to 23% in the village model). This is because non-poor households that own relatively larger number of livestock produce and apply more manure in the household-level model. In the village, on the other hand, all the manure belongs to the village and hence all of it is used as fuel. As we would expect, the non-poor households apply more manure while the poor and less-poor households rely more on chemical fertilizer.

The area of land where soil conservation structures are constructed is considerably lower in the household model compared to the village model (6.3 % compared to 28.9%). Interestingly, the proportion of cropland on which soil conservation structures are built is not very much different for the non-poor households who are better endowed with labour and poorer households who are less endowed with labour. This is due to the fact that the non-poor households keep more livestock and cultivate more land (renting in from other households) both of which require more labour.

8.8 Conclusions

The analysis presented in this chapter demonstrates that the village-level mathematical model developed in this study is a useful tool to explore the appropriateness of various technologies for the different regions of the study area. The model is run for three villages representing regions with different population density, market access and agricultural potential.

A comparison of model outcomes with empirical observation was also carried out. The model has fairly reproduced the allocation of land among various land uses. There were divergences between simulated and actual land management decisions such as the use of fertilizer and the construction of stone bunds. The deviations are understandable as some important conditions in the Central Highlands (for e.g. the communal ownership of land tenure, and the fact that fuel wood is not commercialized) were not explicitly taken into consideration. Moreover, while land management decisions are undertaken at the household level, for reasons discussed in Chapter four, the model developed in this study is a village level[52]. Despite some discrepancies found between model outcome and empirical data, the model can be used as a bench mark to undertake some scenario analysis in Chapter nine.

Key findings indicate that the use of inorganic fertilizer and the construction of stone bunds have positive economic returns in all the study villages. On the other hand, dung and crop residues are used for fuel and animal feed respectively. Moreover, due to high population density and the resulting expansion of cultivated land (a decline in grazing land), the number of livestock is too small to produce enough manure. The amount of manure available for use is further reduced as livestock from most parts of the study area migrate outside the village during some months of the year. Tree planting is a feasible investment most parts of the highlands except in areas of higher agricultural potential. The simulated level of tree planting is considerably higher than current practices. The *diesa* system of land tenure and the restrictions in marketing fuelwood are the major factors that result in lower levels of tree planting than is economically feasible. Sensitivity analysis shows that the choice of discount rate and a price of wood does significantly influence simulated levels of tree planting but other model outcomes are fairly insensitive to the choice of these parameters.

[52] A household model was also developed and results were compared with the village model. As the complex interactions among rural household in the Central Highlands of Eritrea are difficult to model, these model did not perform better in reproducing actual farm behaviour in the study area.