Poverty and natural resource management in the Central Highlands of Eritrea

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Chapter 4

Model Structure and Approach

4.1 Introduction

Farm household modelling approach is a widely used tool of analysing the economic behaviour of rural smallholders. It has been used to evaluate the impact of various technologies and policy interventions on rural economies of developing countries.

The major problems that characterize the Central Highlands of Eritrea - poverty, food shortages and land degradation – cut across various disciplines requiring an interdisciplinary approach to address the problem. Bio-economic modelling, which allows simultaneous examination biophysical and socio-economic dimensions of the problem can be a useful tool for such an interdisciplinary analysis.

In this chapter, we will first discuss theoretical foundations of the farm household modelling. Next, we will briefly discuss different bio-economic models (BEMs). Finally, the basic structure of our bio-economic model (Chapter six) will be described and various components of the model will be discussed.

4.2 Theoretical foundations of farm household modelling

Traditionally economists used to consider rural households as typical business firms and applied the profit function to explain decisions regarding production and resource allocation. Microeconomic theory shows that in a perfect competition setting firms will employ inputs until the marginal value product of an input is equal to input price. Since both inputs and outputs can be purchased at the market price, the levels of employment of inputs are not influenced by the entrepreneurs' resource endowments. Similarly, consumptions preferences of households do not have any bearing on production decisions.

In rural areas of developing countries production decisions of the household influence its consumption choices. In consumer theory, the consumer maximizes utility under given set of prices and fixed income. In farm-household models, on the other hand, household income, which includes farm profits is endogenous and depends on the production decisions of the household. As a result policies that affect commodity prices may have different impact on household consumption when consumption and production decisions are considered simultaneously than when only the consumption side is taken into account. For example, in the standard consumer theory, when the price of a normal good increases the negative "income effect" reinforces the negative "price effect" and results in unambiguous decline in the consumption of the commodity in question. However, since rural households engaged in the production of the commodity will enjoy higher income from higher price of the good (termed as profit effect), there will be a positive "profit effect". Thus when the production and consumption decisions of the farm household are taken into account, the net effect of an increase in price may be positive or negative (Singh *et al.,* 1986; Taylor and Adelman, 2003).

When perfect inputs and outputs market exist, there is only one-way link from production to consumption (as discussed in the above paragraph). As households can buy and sell commodities at the market price their consumption decisions will not influence the level and composition of their output. Similarly, as labour can be freely bought and sold in the market, the amount of labour households use in production depends neither on the labour endowment of the household or the decision of the household to allocate family labour between work and leisure. In this situation, the farm-household's objective can reasonably be taken as maximization of profits.

However, rural economies in developing countries are characterized by imperfections in input and output markets and credit and liquidity constraints. The absence or imperfection of output market means that households can only consume their own output (when the good is not traded) or they choose to consume own produced good to market-purchased good (because of high transactions costs). In this case, farm profits include implicit profits from goods produced and consumed by the same household. Similarly, household decisions on the allocation of labour influence its production decisions. Since labour markets are thin, a decision by the household to consume more leisure means less labour for crop production and hence a decline in production. Rural households also largely depend on their own sources for other non-labour resources as they have no or little access to credit. Thus, the proposition that profit maximization is the main objective of the farm household does not hold. Production decisions of the farm household are influenced by its consumption and labour allocation decisions (Singh *et al.,* 1986; de Janvry *et al.,* 1991; Delforce, 1994).

Thus, when the assumption of separability of production decisions from consumption and labour allocation decisions do not hold due to absence or imperfection of input and output markets, the need to meet subsistence needs from farm produce, liquidity problems etc., a non-separable farm-household model that simultaneously considers production and consumption decisions is needed to understand the microeconomic behaviour of farmers and to evaluate the relative merits of alternative policies and technologies.

4.3 Bio-economic modelling approaches

From the 1980s, the concept of sustainability was high on the agenda of researchers and policy makers. But there were serious difficulties to define and operationalize the concept. The most widely quoted Brundtland Commission defines sustainable development as one “that meets the needs of the present without compromising the ability of the future generations to meet their own needs” (WCED, 1987: 103). Barbier (1987:103) states that sustainable development is an economic development with the primary objective of “reducing the absolute poverty of the world’s poor through providing lasting and secure livelihoods that minimize resource depletion, environmental degradation, cultural disruption, and social instability”.

Operationalizing the concept of sustainable development is an even more challenging task. Sustainable development has several dimensions that incorporate economic, social and ecological goals that may complement or conflict with each other. In the 1980s, bio-economic models were developed to operationalize the concept of sustainable development. These models integrate the socio-economic component related to household behaviour, market structure, institutional arrangements and policy incentives and environmental component such as soil erosion, nutrient depletion, crop and animal growth etc. Bio-economic models are helpful tools to explore the complex interactions between agro-ecological and socio-economic phenomena and make it transparent for policy debates (Kruseman, 2000).

4.3.1 Classification of bio-economic models

Bio-economic models can be classified into different categories based on different criteria such as a) emphasis on biophysical component or economic component, b) time scale, c) level of aggregation.

Bio-economic models vary in terms of their emphasis on the economic or biophysical components in the model. Brown (2000) identifies the following categories: i) biophysical processes models to which an economic analysis component is added; ii) economic optimization models that include a biophysical component; iii) integrated bio-economic models.

Biophysical models are primarily designed to simulate agro-ecological processes involved in various systems such as crop production, livestock, agroforestry and soil and nutrient. Such models may be a detailed description of a single component or model the major inter-linked components of a particular ecosystem. Most biophysical models also incorporate some socio-economic issues and accounting equations that enable to calculate the benefits and costs of alternative scenarios.

Economic optimization models that involve decisions related to production and resource use cover a wide range of models that differ on the way the biophysical components are included in the model. Some economic optimization models take a simplistic approach in which the model basically optimises farm income but includes some biological equations that measure the sustainability of the system being modelled. Others are more complex in that they attempt to account for the possibility of multiple objectives (economic and sustainability) by taking into account the dynamic relationships through the use of multi-period modelling approach. Barbier and Carpentier (2000) distinguish two ways in which environmental problems are included in BEMs. The most common way is to simulate the effects of economic decisions on the environment without taking into account the feedback effect of the change in the condition of the environment on the production function of the model. The second and more difficult way is to model the feed back of natural resource degradation on agricultural production. Integrated BEMs refer to the later type of models in which the economic features of economic optimization models and the biophysical processes are adequately taken into account.

The issues of rural poverty, food security and NRM involve intertemporal decisions. The aim of the study influences the temporal period to which a model refers. Depending whether the aim behind developing a model is descriptive, explorative or planning (predictive), a static (one year) or dynamic (multi-annual model) can be developed. The choice of static or dynamic models also depends on whether the objective of the study is to explore adoption process and welfare and environmental processes or just the total potential impact of new technologies and policies (Kruseman, 2000; Holden, 2004).

Bio-economic models also differ in the level of aggregation at which the study takes place. They may be constructed at different levels such as field/plot, farm/household, village, watershed or region. As stated earlier, BEMs may emphasize biophysical aspects or socio-economic analysis and the criteria used for selection of the level of aggregation vary between different disciplines. From the viewpoint of economics, the level at which decisions are made is the most appropriate level to build a model (Kruseman, 2000). Holden (2004) provides a typology of village economies, which could be used as a basis in selection of the level of aggregation. The major factors to be considered are a) the degree of differentiation in resource distribution and specialization of activities within a village and b) the extent to which the village is integrated in or isolated from the outside markets (i.e., the transaction costs involved). In cases where the village is isolated from outside markets (e.g. no linkage to an external labour market) and distribution of resources within village is uniform, a single farm household model may be sufficient. However, if resource distribution among households is significant, a model with several interacting households may be necessary.

Okumu *et al*. (2000) maintains household level assessment of production and conservation technologies could be too restrictive because it ignores the natural delineation of the landscape and hence the biophysical scale of the problem as well as the importance of community participation in solving general externalities arising from household agricultural production. It is argued that aggregation of household decision making at a village or watershed level could be better alternatives particularly in situations where community level management of resources is in place.

Village or watershed level models, however, have their own shortcomings associated with aggregation. Socio-economic variations within the village are ignored due to averaging of resource availability (Holden, 2004; Okumu *et al.,* 2000). Brown (2000) also maintains that models that fail to explicitly include variations in resource endowments tend to mask issues related to food security and NRM. It is argued that policies often have different impact on different groups of households that even when overall welfare is optimised, there will be some winners and losers. Both the effectiveness of various interventions in terms of their economic and environmental effect and the likelihood of their adoption depend on who is directly affected (Shepherd and Soul, 1998; Brown, 2000). Thus, even higher-level models should include households of various resource endowments.

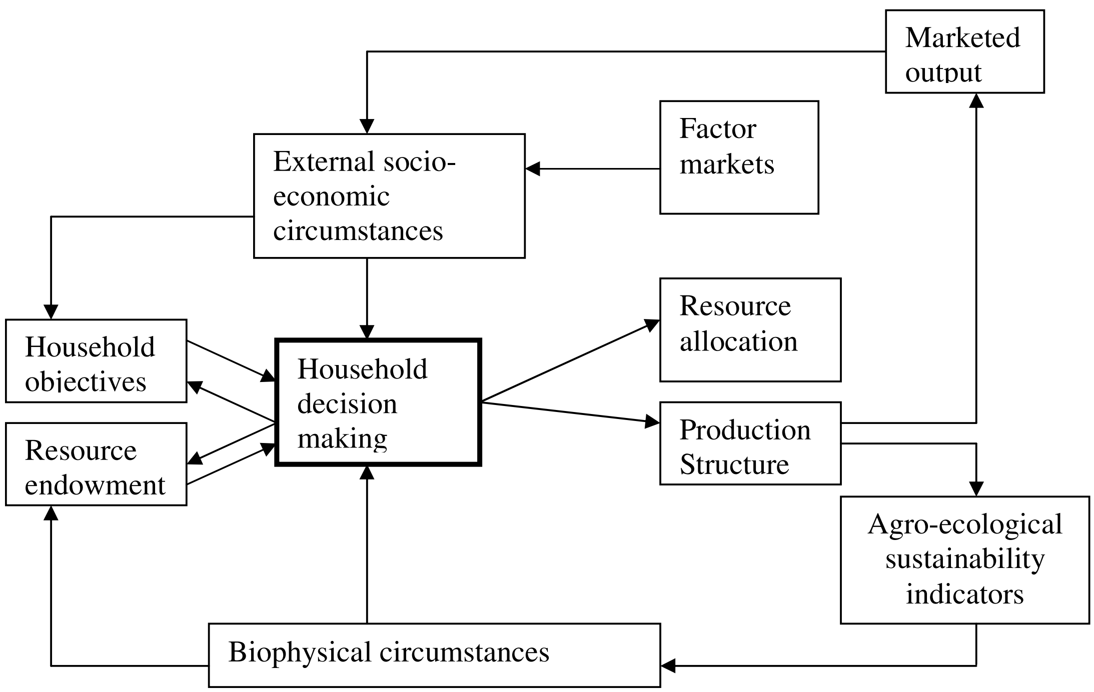
4.4 The structure and major components of the BEM of the farming system in the Highlands of Eritrea

This study develops a village level dynamic mathematical model of production and conservation decisions (see Chapter six). The model maximizes aggregate discounted future stream of net income subject to a large set of constraints (see next section). As in most developing countries, consumption and production decisions are interrelated in rural areas of Eritrea. This is taken into account in the model by including resource constraints and constraints reflecting the need to meet a minimum consumption requirement. The reason for selecting the village rather than the household as our unit of analysis is based on a number of factors. First, land is communally owned in all the study villages and the decision on the allocation of the land among various uses is made by the community. Second, grazing lands and woodlands are used communally and even croplands are open for common grazing after each harvest. Third, land degradation problems such as deforestation and soil erosion occur at a larger scale than the individual farm. The methods to reverse or curb the problems are more effective if undertaken at a larger scale than at the individual farm. Finally, members of the villages in Highlands of Eritrea have close family ties and share key agricultural resources among themselves. Therefore, resource constraints are not as binding at the farm level as they are at the village level[11].

4.4.1 Structure of the bio-economic model

Household decisions are influenced by household resource endowments, household objectives, existing market and policy environment as well as biophysical characteristics.

Figure 4.1 Household decision-making



Source: Based on Kruseman (2000)

[11] As discussed in the previous section village levels have their own limitations. Thus, for the purpose of comparison, a household-level model that distinguishes between poor, less poor and non-poor households is developed. The results of the village and household models are compared to evaluate the impact of the choice of the scale of analysis (see Section 8.6).

These decisions, in turn, affect the economic conditions of rural households and the biophysical environment on which they depend. Figure 4.1 shows the main factors that influence land use and resource allocation decisions that form the basis of the bio-economic model developed in Chapter six.

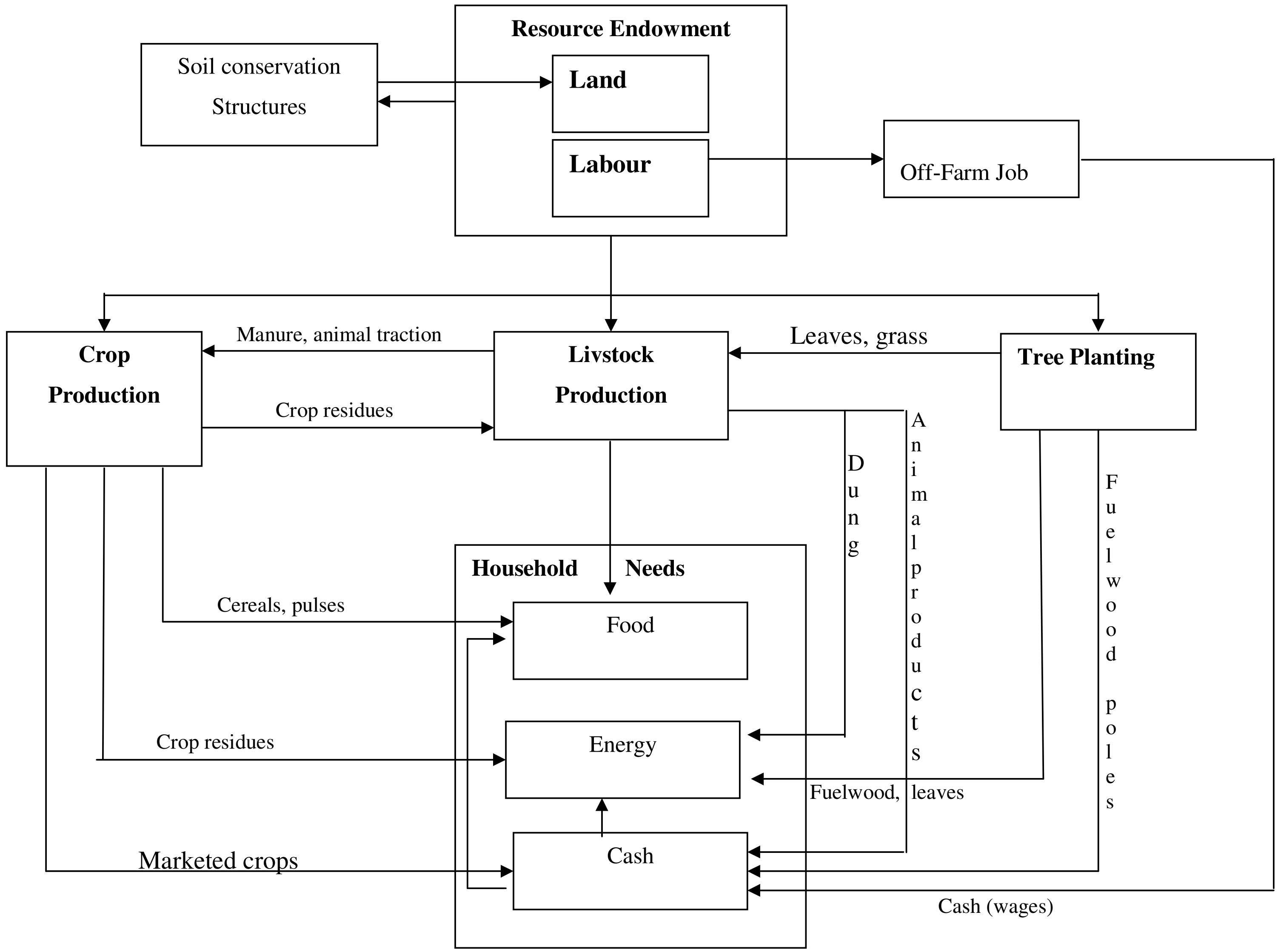
4.4.2 Interactions between various components of the model

Central element in developing the model is the interdependence of the economic activities in which the rural people are engaged and the linkage among those activities, as well as the relevant NRM (or farming) technologies and their linkages with the economic objectives and the state of the natural resources. The interdependence of the various economic activities of the rural population is mainly due to the following reasons.

1. All economic activities and soil conservation practices compete for the limited resources of the farmer such as labour and land. Rural households have a limited area of land (with different land categories) at their disposal, which has to be allocated to crop production, grazing, tree planting (or natural woodlands), or soil conservation structures.
2. The output of one economic activity serves as an input to the other economic activity. E.g. crop residues are used as animal feed; animal dung and animal power are used as inputs in crop production. Leaves from trees serve as animal feed and the availability of more trees provides sufficient fuelwood so animal dung can be used as fertilizer in crop production.

Figure 4.2 shows the linkages between household resource endowment, household objectives and the various economic activities.

Figure 4.2. Linkages between household resource endowment, household objectives and the various economic activities



4.4.3 Socio-economic components of the bio-economic model

Since farmers make decisions, socio-economic conditions that surround household decisions are as important as biophysical conditions in terms of their effects on both rural income and resource conditions. Socio-economic components included in this study include household goals and objectives, resource and other constraints, and economic activities such as crop production, livestock production, and tree planting. We will briefly describe these components below.

Household goals

Although farmers in the highlands of Eritrea depend on the market for many basic goods that cannot be produced on the farm, they produce at or near-subsistence level so that their major objective can be better described as securing basic needs from the farm than profit maximization. Thus, the dominant objectives of a representative household include securing sufficient food (cereals and pulses) for the family and sufficient energy for cooking. Farmers also strive to generate sufficient cash for the purchase of important non-farm items (such as clothing, kerosene for lighting, stationery and school fees, transportation etc). Farmers in developing countries often reduce risks by diversifying their agricultural activities. In the Central Highlands, this is reflected in the combination of crops farmers grow as well as the diversification of their activities on crop production, livestock and other non-farm activities. For this reason, we will include diversification of income in the socio-economic objectives of the farmer. Subject to the above conditions, farmers will maximize their net-discounted income from their farm and non-farm activities.

Crop production

Various types of crops are grown in various parts of the Central Highlands of Eritrea. These crops include cereals such as barley, sorghum, wheat, millet and taff as well as pulses such as beans and chick-peas (see Chapter two). The model allows selection from five crops each in the three study villages. Potatoes can also be produced in the irrigation scenario. Crops can be grown on three land types using two options of land management (with and without stone bunds) and six types of fertilizers, which include inorganic fertilizer, manure, mulching and/or some combinations of them.

The production function in the linear programming model represents the average expected response to different types and levels of fertilizer application, mulching and the construction of stone bunds. The production functions are specified for each type of crop, each village, and each type of soil type (see Chapter seven).

Livestock activities

Cattle, donkeys, sheep and goats are the major types of livestock in the study area. The composition of livestock farmers choose is dictated by a number of considerations including the need for animal power, availability of animal feed, the availability of labour and cash. The choice of the number and composition of livestock, in turn, determines the income flow from this activity.

The model simulates the size and management of herds of each type of livestock. Herd growth is determined by natural growth (birth-mortality), and the buying and selling decisions of households. Each type of livestock unit requires labour time, veterinary expenses and forage throughout the year. Feed requirements for livestock are defined in terms of dry matter. Animal feed may have its source from grazing land and woodlands within the village, cut and carry from woodlands where grazing is not allowed, or from crop residues. Livestock in two of the three villages may also migrate to the eastern escarpments in certain months of the year.

Oxen are used for land preparation, donkeys for transportation and cattle and sheep/goats for producing milk and meat. Livestock can also be sold to generate cash.

Tree planting

The model considers two types of woodlands: native woodlands and eucalyptus plantations. Native woodlands are established by simply restricting the area from cultivation and grazing. Thus labour required to establish these woodlands is insignificant. Eucalyptus plantations, on the other hand, require considerable amount of labour. The volume of wood on woodlands is a function of the existing volume of wood, natural growth (yield) and wood harvest. Yields of wood vary by land type and land management (construction of stone bund). The yields of wood from eucalyptus plantations are much higher than that from native woodlands. Trees can be harvested 5 years after planting. When trees are cut the land may be replanted with trees or converted to grazing or croplands.

Model constraints

Farming households make their decisions under various sets of constraints. The constraints in our model include limited availability of resources (land, labour and oxen), subsistence constraints, constraints relating to market conditions (such as prices of inputs and outputs and non-farm produced goods, access to credit, etc.), biological constraints (such as the relationship between fertilizer and crop yield, soil conservation and crop yield etc), and logical constraints such as specifying the amount of manure used for fertilizer and fuel cannot exceed the amount of manure produced in the farm.

In the Central Highlands of Eritrea, where little modern agricultural inputs and technologies are used, labour continues to be the most important input. Both the supply and demand for labour in the study area varies in different periods of the year. Thus, labour constraints are applied for each period. Demographic factors such as total number of households in a village, average family size, household age and gender composition, as well as cultural (religious) and schooling calendar were considered to determine labour availability in each period. Since some farming activities have to be particularly done by adult males, separate constraints are used for total labour supply and for the supply of adult male labour. Limits on the number of days rural households can have a paid off-farm job in each period were also imposed for each village, depending the distance of the study villages from major urban centres.

Land constraints are formulated by land type and by type of conservation. The area of land of a given type used for crop production, grazing and tree planting cannot exceed the total area of land of that type. Other resources such as cash, oxen, manure, and crop residues are endogenous to the model as they depend on farmers' decisions. However, the use of these resources in any given period cannot exceed their supply.

Constraints on subsistence needs were defined in terms of minimum calorie requirements. To reflect current consumption patterns only part of the calorie requirement can be obtained from cereal consumption. Constraints were also imposed to ensure that households have enough energy for cooking and lighting. Cash expenditure on all inputs and consumption goods cannot exceed the total amount of cash earnings.

4.4.4 Biophysical components of the bio-economic model

Biophysical conditions such as land quality and climate determine the suitability of a region to various economic activities and the potential production. Biophysical conditions are partly influenced by management decisions of economic agents who utilize them. Thus important biophysical possibilities and constraints and possible sources of data were identified.

Three regions were identified in the Central Highlands based on their agricultural potential, population density and market access condition. Three representative villages were selected, one from each region, for which land capability classification was made. The biophysical components that are of direct importance to our study include climate (mainly rainfall), land size, land type (including topography and soil depth), land use and land cover. Climatic data for the villages were collected from the nearest metrological stations. Land classification for the three study villages was made with the help of experts and four soil types were identified (see Section 6.4).

Soil erosion, nutrient depletion and deforestation are the major environmental problems in Eritrea which have a negative impact on crop yield and hence on the economic situation of the rural poor (see Chapter two). Thus the biophysical components of our bio- economic model include soil erosion, nitrogen balance, and vegetation components.

The rate of soil erosion is determined by climate, topography, land use, and land management practices. Soil erosion is calculated separately for croplands, grazing land and woodlands. Soil loss from croplands is a function of land type, crop, type of soil conservation and type of fertilizer applied. The rate of soil loss from croplands under different land management practices is estimated using the Technical Coefficient Generator developed for the highlands of Ethiopia (see Section 7.4). Soil loss from grazing lands and woodlands were modelled as a function of soil type and type of soil conservation applied. Long-term empirical data from experimental plots in Afdeyu Research Station were used to obtain soil loss from other land use categories. These data were extrapolated to soil loss from various land categories using the Universal Soil Loss Equation adapted to the Ethiopian conditions as shown in Chapter seven.

As in other parts of Sub-Saharan Africa, nitrogen is the most important nutrient that limits crop yields in Eritrea (Hubbell, 1995). Nitrogen balance in a given year depends on endogenous and exogenous sources and processes. The major sources of nutrient inflow are the application of mineral as well as organic fertilizers. Major mechanisms of nutrient removal, on the other hand, include the harvests of crops and residues as well as the washing away of nutrients from croplands due to soil erosion. An initial pool of nitrogen is estimated a certain fraction of which is mineralized and becomes available to crops each year. The stock of nitrogen in the soil and hence the amount of nitrogen that will be available to crops from endogenous sources declines over time at different rates depending on the type of fertilizer applied. This is discussed in Chapter seven.

4.5 Conclusions

The rural areas in the Highlands of Eritrea, as those in most developing countries, are characterized by absence or imperfection of input and output markets as well as credit and liquidity constraints. As a result rural households make their production and consumption decisions simultaneously. This means a non-separable farm-household model is required to explore rural household land use and land management decisions.

Due to the communal land tenure system in the study area important decisions are made both at a village and at household level. Moreover, rural household in the villages in the Central Highlands have close family ties and share key agricultural resources such as labour and oxen. Resources are therefore not as binding at the household level, as they are at a village level. Moreover, the problem of land degradation, a key issue in this study, occurs at a larger scale than the specific plot cultivated by a household and efforts to tackle the problem often include a community participatory management approach. Thus a village model is developed to explore land use and land management decisions in the study area.

Since low agricultural productivity and land degradation are the two major and closely related problems in rural areas of Eritrea, we develop a bio-economic model with economic and biophysical components. In this chapter, the linkages between the various components of the model and the major constraints are described.