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EDRI Working Paper 005
November 2011

Economic and Environmental Benefits of Forage Legume-Cereal Intercropping in the Mixed Farming System: A Case Study in West Gojam, Ethiopia

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Paper citation: Kassie, Menale. 2011. Economic and Environmental Benefits of Forage Legume-Cereal Intercropping in the Mixed Farming System: A Case Study in West Gojam, Ethiopia. Addis Ababa, Ethiopia: EDRI.

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Abstract

Fodder shortage and land degradation in the form of soil erosion and nutrient depletion remain the major constraints to agricultural productivity in the Ethiopian highlands. Forage legumes have the possibility to provide high quality and quantity of feed, to increase soil nitrogen, to accumulate an extra income to farmers, and to reduce soil erosion when they are intercropped with cereals; therefore intercropping legumes offer a ray of hope for small-scale, resource-poor farmers in developing countries. Despite these multiple benefits, few empirical studies have been done to advance evidences highlighting the effects of intercropping forage legumes with cereals on agricultural productivity and soil conservation. The forage legume-cereal intercropping system needs to be economically feasible and needs to meet the household food requirements in order to be adopted and sustained. In this study we attempt to fill this gap by assessing both the economic and the soil conservation implications of introducing legume-cereal intercropping in the mixed farming systems of the north-western Ethiopian highlands. Using a bio-economic linear programming model we generated an optimal farm which incorporated crop production jointly with livestock production, according the mixed farming system. The model combines household surveys with experimental data. The empirical results indicate that introducing forage legume-cereal intercropping into a traditional mixed farming model increases farm household income and resource productivity, and reduces soil erosion and pressure on grazing land. Farm income and resource productivity increase in the range of 52-75 percent and 10-14 percent, respectively. In addition, soil erosion and the marginal value productivity of grazing land decreases in the range of 8-9 percent and 65 percent, respectively. In a sensitivity analysis of alternative model scenarios farm income was higher and more stable for forage legume-cereal intercropping farming systems than with the traditional mixed farming model. In sum, results imply that development interventions realizing the economic and environmental potential of forage legumes will help achieve a double goal of enhancing the livelihoods of rural households and at the same time preventing land degradation.

Key words: Forage legume-cereal intercropping; farm income, soil conservation; bio-economic modeling; Ethiopia

1. Introduction

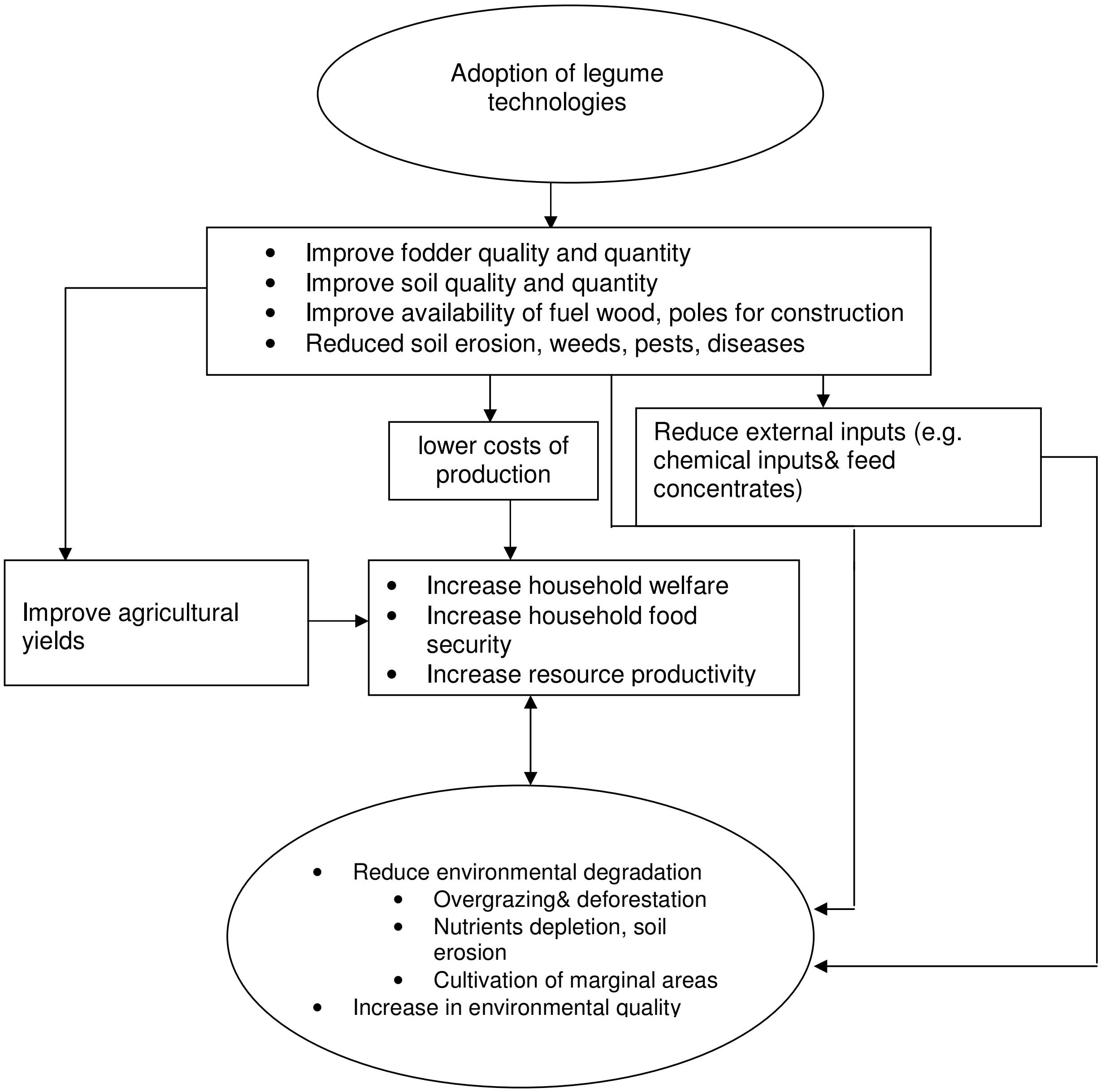
Crop and livestock production in the Ethiopian highlands is constrained by low soil fertility and by low quality and quantity of feed resources (Kruseman et al. 2002; Tangka et al. 2002). Feed shortages can be attributed to factors such as conversion of grazing land to cropland, overgrazing, high price and lack of feed concentrates, scarcity of feed during the dry season, and the generally low quality of available pasture and crop residues. On the other hand, escalating prices, access and price uncertainty, and unavailability at the crucial moment limit the use of inorganic fertilizers in improving soil fertility (Lakew et al. 2000; Ahmed et al. 2003). The use of organic fertilizers to enrich the soil is also very limited, leading to further deterioration of soil fertility, and subsequently to lower productivity.

The use of forage legumes (hereafter legumes) integrated with food crops and livestock is often advocated to minimise external inputs as well as to improve the productivity and sustainability of crop-livestock production in developing countries (e.g. McIntire et al. 1992; Humphreys 1994; Giller 2001; Peters and Lascano 2003). Legumes are known to perform multiple functions. Grain legumes provide food and feed and facilitate soil nutrient management. Herbaceous and tree legumes can restore soil fertility and prevent land degradation while improving crop and livestock productivity on a more sustainable basis. Thus the adoption of such dual-purpose legumes, which enhance agricultural productivity while conserving the natural resource base, may be instrumental for achieving income and food security, and for reversing land degradation. In particular the integration of legumes into cereal-based systems can provide services such as high quantity and quality fodder production, soil erosion prevention, and soil fertility restoration. Enhanced availability of livestock feed can reduce degradation of grazing lands. The demand for forage and the opportunities for diffusion of forage technology may be high where livestock response to improved feed technology and profitability from livestock enterprise is high. Farmers are responsive to the amounts of economic incentives provided by the new technology (Stevens and Jabara 1988).

Experimental research throughout the developing world have shown the benefits of different kinds of legumes (Nnadi and Haque 1986, 1988; Khalili et al. 1994; McIntire et al. 1992; Humphreys 1994; D'Mello and Devendra 1995; Omiti 1995; Umunna et al. 1995; Giller 2001; Peters et al. 2001; Mpairwe et al. 2002, 2003). For example legume adoption could increase yields through breaking cycles of pests and diseases, through improved soil structure, or through increase of organic matter (Fujita et al. 1992). However, most often residual benefits can be attributed to an improvement in the Nitrogen (N) economy of soils (Wani et al. 1995); for example results in Ethiopia showed that vetch, *lablab*, and clovers are capable of leaving 30-60 kg N/ha through their root systems when they are intercropped with cereal crops (Nnadi and Haque 1986, 1988).

Legumes have been shown to improve both the quantity and quality of fodder, and thus sustain feed production during the dry season and increase livestock productivity. Experiments in Ethiopian highlands showed that forage legumes did not reduce the barley grain and straw yield, but significantly increased the total fodder yield – barley straw plus forage (Zewdu 2004); similar results were found for maize (Zewdu 2003). Average fodder yields of 14.2 and 3.4 tons per hectare of maize-vetch and barley-clover, respectively, were reported compared to 9.3 and 2.3 tons per hectare of sole maize and barley, respectively (Zewdu et al. 2000). The average crude protein content of crop residues is about 3.8% of dry matter, whereas legumes crude protein content on average vary between 14-24% of dry matter (Annido et al. 1994; D'Mello and Devendra 1995; Mpairwe et al. 2003) (see Figure 1.1 for summary of the benefits of legumes). In Ethiopia, Crossbred cows given an oats-vetch diet produced on average 1.40kg/day more milk than those given hay diet (5.54 vs. 4.14 kg milk/day) (Khalili et al. 1992). Legumes mixed with crop residues also increase other livestock production parameters (see Appendix A.5).

Figure 1.1. The potential for legumes adoption to household welfare (income) and environmental conservation



Source: Author's own compilation

Soil conservation is an important benefit of intercropping. Studies on the impact of legume-cereal intercropping on soil erosion control are very scarce. In Nigeria, experimental results conducted at 5% slope showed that soil loss declined from 87 ton/ha/year to 50 ton/ha/year when cassava is grown alone and intercropped with maize, respectively (Lal 1984).

However, despite these multiple benefits, adoption of legumes, especially for feed and soil management, is very poor in developing countries (Gryseels and Anderson 1983; Saka et al.

1993/1994; Thomas and Sumberg 1995; Zewdu et al. 2000; Ahmed et al. 2003). Farmers and policy makers need information on how alternative production practices, such as forage legume-cereal intercropping systems, affect farm household incomes.

Research to date has focused more on technical feasibility (yield and biomass) of intercropping legumes and cereals with little emphasis given to the economic and environmental feasibility in a mixed farming context taking into consideration farm operators' management and farm resource constraints. Research on the economics of legumes in Africa has tended to focus on the comparison of bare land with alley cropping or on growing of leguminous trees with annual crops to improve livestock production and soil fertility (Ehui et al. 1990; Jabbar et al. 1994). Economic analysis on growing annual legumes with food crops in South-Eastern Ethiopia showed that growing legumes with food crops was more profitable than growing food crops alone (Kassie et al. 1998). This study, however, did not account for the link between annual legume-cereal intercropping and soil conservation benefits. It also lacks estimation on the marginal value of soil fertility due to nitrogen fixation by legumes.

In light of the aforementioned gaps in the existing literature, the objectives of the paper is to examine the potential economic gains from the adoption of annual forage legumes in the mixed farming systems of the North-western (NW) Ethiopian highlands using an optimal mixed farming planning model. The main purpose is to assess the effect of maize-vetch and barley-clover intercropping on household income and soil conservation. To achieve this objective we use a bio-economic linear programming (LP) model.

The contribution of the paper is threefold. First, to our knowledge, it is the first empirical paper to assess the link between annual legume-cereal intercropping and soil conservation benefits while examining the economics of legumes. Second, we account for the impact of legume-cereal intercropping on soil fertility and soil erosion and thereby on household income by estimating the marginal user cost of soil erosion and marginal value of soil fertility due to nitrogen fixation by legumes. Third, given the limited studies in this area, policy makers may find this information useful when they consider the development of alternative profitable enterprise combinations for low input farmers in the highlands of Ethiopia. Additionally, information on the economics of alternative production practices can guide decisions by researchers and research administrators on future agricultural research programs. However, this study has limitations. The study area is restricted and the survey data come from farming systems where the dominant crop is maize. Further research is necessary to investigate whether our results are applicable to farming systems where other cereals such as wheat, barley or *teff* are the dominant crop. The other limitation of the study is the use of relatively old data which may have repercussion on some of the parameters we used and on the quantitative results. Although this may not change the qualitative results and recommendations, we encourage future study to analyze determinants of forage adoption and its economic impact using nationally representative new data and check robustness of our results.

2. Methodological framework

2.1. Conceptual framework

Households in the study area both produce and consume their agricultural products. Our conceptual approach is based on the theory of the farm household model (Singh et al. 1986). The household utility maximization function consists of three basic components: income, leisure, and basic food requirements. Normally, leisure and income decisions are non-separable. Sampled households in the study area belong to the Orthodox Church, strictly respecting religious holidays. Work on the farm on religious holidays is prohibited[1]. These holidays must be subtracted to get actual number of available working days for farm work. Any day that is not a religious holiday is used for farm work. Leisure is then a part of the church holidays and can be assumed fixed and separable from income in the utility function.
Rural households rely more on their own production for food supplies than on external resources (e.g. markets). We assumed pre-determined minimum food requirements based on an adult equivalent basis and these are treated as scalars and separable from income. Holding religious holidays constant and assuming pre-determined minimum food requirements leave the income as the only argument in the utility function.

2.2. Model parameters and basic assumptions

The impact of legume-cereal intercropping on soil fertility and erosion is computed as follows. Using *teff* yield data collected by Soil Conservation Research Project (SCRP) in the highlands of north-western Ethiopia we approximated the effect of soil erosion on crop yield (see Annex A.1)[2]. We used soil depth as a proxy for soil quality (productivity)[3]. A loss of 1 cm of soil depth per hectare (ha) was estimated to reduce yields by 17.2 kg/ha[4]. A loss of 1 cm of soil depth is approximately equivalent to 100 ton/ha soil losses (Shiferaw and Holden 1999). The marginal value product of soil depth is the marginal user cost of soil, the discounted value of future productivity losses resulting from a unit of soil erosion. The total user cost of soil erosion is thus the marginal user cost of soil multiplied by the level of soil erosion. A discount rate of 12 percent is used, which is the current interest rate of short-term inputs (e.g. fertilizer and seed) in the study area.

Legumes fix nitrogen in their root systems. From various experiments in the Ethiopian highlands, legumes (*lablab*, clover, and vetch) were found to leave 30-60 kg N/ha in their root systems that will be available for uptake by the next crop (Nnadi and Haque 1986, 1988). It is assumed that legume-cereal intercropping produces 45 kg N/ha for the benefit of the next crop. To account for the lagged effect of legumes the discounted shadow prices of soil fertility (marginal value product of nitrogen fertilizer) is estimated based on the above discussion.

We assumed that nitrogen added through legumes is available for the next crop season although there could also be nitrogen transfer to cereals during the current season. The effect of nitrogen

[1] Holidays divided into two: strict church holidays and less strict church holidays. During strict holidays farmers are not allowed to do any kind of work. On the other hand, during less strict holidays farmers are allowed to do other activities such as preparing farm equipments, splitting fuel-wood and off-farm activity, but farming activities are not allowed.
[2] The experiments do not cover all crops. It focused only on *teff*, barley and faba bean crops. However, it is *teff* which has enough observations to run regression and estimate effects of soil erosion on yield.
[3] We assumed current soil depth is an indicator of past erosion and used it as a proxy indicator for soil quality (productivity).
[4] It can be easily derived from Annex A.1 at the mean value of each variable except the trend variable. The elasticity is calculated year by year and we took the average. After the elasticity, marginal value of soil depth is calculated by multiplying the marginal product of soil depth by *teff* output price to obtain the marginal monetary loss due to soil erosion.

fixation by legumes (organic nitrogen) on yield of the subsequent crops is estimated from barley and maize responses to inorganic nitrogen fertilizer. The barley fertilizer response function (Equation 1 – Annex A.2) was based on the estimates of Ho (1992), and we estimated the maize fertilizer response function (Equation 2 – Annex A.2) using three years on-farm fertilizer trials conducted by Adet Agricultural Research Centre (AARC)[5]. A one kg increase in nitrogen fertilizer, adding phosphorus constant, was estimated to increase barley (local variety) and maize (improved variety) yields by 6.2 and 29 kg/ha, respectively. The marginal value product of nitrogen fertilizer is the marginal benefit (shadow price) of soil fertility, the discounted value of future productivity gains resulting from an additional unit of soil fertility. The total benefit of soil fertility (nutrients) is thus the marginal benefit of soil fertility multiplied by the level of nitrogen fixed by legumes. The discounted marginal user cost of soil erosion and marginal soil fertility benefits are thus entered on the soil erosion and organic nitrogen production activities of the objective function (see Annex A.3).

Soil loss for each crop activity was estimated using the Universal Soil Loss Equation (USLE) modified for the Ethiopian conditions (Hurni 1987). In consultation with forage experts and agronomists in the AARC, dense intercrop was considered as management factor (I_J) (see Annex A.3).

2.3. Empirical model

The farming system investigated involves the production of various crops jointly with animal husbandry. Thus, the study necessarily involved whole-farm analysis of a mixed farming system in the highlands of Ethiopia. In a whole-farm planning, Linear Programming (LP) is one of the most widely applied analytical methods. We used a bio-economic LP model that integrates both biophysical (soil erosion and organic nitrogen) and economic data for simulating micro-level responses to technology changes. Such an optimization technique allows for evaluating successively more profitable whole-farm plans until the optimal plan is determined, subject to various farm and farm household constraints. Additionally, given that subsistence farmers in the study area are primarily concerned with both producing enough food for household needs and generating cash income for buying inputs and other household purchases, constrained optimization models to allow for incorporating such farmer objective into a mathematical programming model. The mathematical programming approach has also the ability to generate economic information such as the opportunity cost implications of allocating scarce farm resources to different enterprises within the family farm and stability of optimal solutions over a range of farm activity levels (Yiridoe et al. 2006). Adoption of maize-vetch and barley-clover intercropping will affect the maize and barely sectors, and in addition will have implications for other farm household activities and enterprises.

The LP model maximizes current cash farm income (gross return minus variable costs) from crop and livestock production, plus the present value of future income gain due to yield increase as a result of enhanced soil fertility, less the present value of future income loss caused by yield losses resulting from soil erosion subject to various constraints (see Equation 1 in Annex A.2). The mathematical formulation of each activity and constraint is shown in the Annex A.3. An aggregated tableau for the model is also shown in Annex A.3; the entries are model coefficients, labeled as $'A'$.

[5] Inorganic fertilizer may not correctly approximate the productivity effect of organic fertilizer but may serve as rough approximation.

A positive coefficient indicates activity demand for a resource, while a negative coefficient represents activity supply for a resource.

The model includes seven major activities. These include five crop and forage production activities, including maize-vetch and barley-clover intercropping, livestock production activities, household and livestock consumption activities, sale and purchase activities (crop and crop by-products, and livestock and livestock products), borrowing, and land rental activities. The detailed activity descriptions and assumptions used to generate coefficients are available in Annex A.4). Crop and livestock production parameters are reported in Annex A.5 and A.6.
Additionally, the model include seven major constraints, namely, land constraints (land owned, rented, communal, and private grazing land), labour constraints, draft power constraints, livestock feed and household consumption constraints, crop balance (grain, fodder, and nitrogen), livestock and livestock product balance, livestock transfer constraints, soil erosion, credit, and capital constraints. Similarly, detailed constraint descriptions and assumptions used to compute coefficients are presented in Annex A.4.

2.3.1. Model scenarios

In order to simulate the situation with and without technology intervention the following farm plans were constructed. These plans represent specific scenarios and are obtained through adjustments of the basic structure model. The specific scenarios are summarized as follows:

Base plan: Actual situation simulation
To assess the economic and soil conservation implications through adopting legume-cereal intercropping (LCI) we run the model with and without legume-cereal intercropping. The actual situation represents farming activities without LCI intervention (traditional mixed farming system). It helps as a basis for comparison with plans having changes in the system. This is the base plan (traditional mixed farming model) from which the following improved plans are derived.

Plan I: Forage legume-cereal intercropping intervention
It is the same as the base plan but LCI is introduced. The objective of this scenario is to determine: (1) the economic and soil conservation implications of adopting LCI within a mixed farming system; and (2) the implication for optimal farm inputs allocation and resource conservation.

Plan II: Crossbred cow technology intervention
It is the same as Plan I but we introduced crossbred cows using the existing farm household resources. The objective of this scenario is to determine the economic and soil conservation implications of adopting LCI and crossbred cow into a mixed farming system.

2.3.2. Risk and sensitivity analysis

The LP model assumes that input-output coefficients are invariant, i.e., non-stochastic. However, many of the coefficients used in the model are in reality subject to variation. Price of outputs and inputs may vary in a largely unpredictable way. Hence it is necessary to carry out sensitivity analysis to examine the impact of variation on farm income of the legume-cereal intercropping system.

Sensitivity analysis involves changes to model coefficients within reasonable bounds of the original estimate and is often used to determine if the original ranking of alternative plans is affected (Dillion and Hardaker 1993). In this study, it is also applied to assess the stability of the objective values and cropping patterns of improved plans compared to the base plan.

Even though direct incorporation of risk is not possible due to data limitation, maximizing farm income under the condition of satisfying the pre-determined food and feed requirements from crops grown could be considered an indirect mechanism to account for some aspects of risk, as this was a common strategy farmers used as a means of risk management. We tried to capture other elements of risk such as market and production variability using sensitivity analysis.
The sensitivity test is performed on: (1) 50% reduction in the price of the major crop (maize). Price of maize is sensitive to change since its production can be easily increased due to availability of improved seed compared to other crops (*teff*, millet, barley), in addition maize is not a staple food by the majority of urban people; (2) 50% reduction in the amount of nitrogen fixed by forage legumes that will be used for subsequent crops; (3) 50% reduction in the price of fodder; and (4) the last scenario combines scenario (1) and (2). We focused on output prices since the major challenge in surplus producing areas, including our study area, is a fall in prices of crops. The government often sets the major input prices (e.g. fertilizer and improved seed varieties).

3. Notes on the data

The data used to generate the parameters applied in the empirical model were collected in Bahir Dar Zuria district, West Gojjam zone of North-Western Ethiopian highlands. Experts of the socio-economic and livestock forage production divisions of Adet Agricultural Research Centre (AARC) collected the survey data in 2002 for the 2001 cropping calendar, to investigate the factors affecting the introduction and use of forage crops (e.g., vetch, clover, elephant grass) in the North-Western Ethiopian highlands. The area was selected based on its forage adoption rates compared to other districts in the West Gojam zone. 96 farmers were randomly selected, 12 from each of 8 sample villages. For the present study, we considered 87 farmers from whom a complete data set is available. The data have information on livestock holding, own farm size, rented in and out land, private grazing land, crop production, crop area, feed sources, family labour, family size, milk production, labour and draft power use for each crop, number of days available for-off farm activities, and available farm working days per month. Mixed farming systems are the dominant production systems in the area. This system involves complementary interactions between crop and livestock production, such as using animal traction and manure for cropping, and feeding crop residues to livestock. Farmers in the area grow a combination of crops including maize, finger millet, *teff*, barley, rough pea, and niger seed; and have on average three local cows, two work-oxen, one equine, one sheep, and one goat – different types of livestock to support crop production and to provide animal products for home consumption. On average a farmer has about 1.61 ha of cropland and 0.55 ha of private grazing land. The cropland is dominated by Nitosols (90%) followed by Vertisols (10%) (Wereda Agricultural Office 2002). The area has one rainy season and the average annual rainfall is 1000 mm. The surveyed farmers have good access to road, transport, and output markets, as they are located nearby the capital city of the Amhara regional state (Bahir Dar town).

In addition, we depend on secondary data sources to compute some of the coefficients needed for the model. Coefficients for LCI activities were obtained from on-farm and on-station experiments (Zewdu et al. 2000). The experiments include two years cereal grain and fodder production with and without intercropping legumes. The intercropping activities include maize-vetch (on-station) and barley-clover (on-farm). About 37 percent of the sampled households practiced maize-vetch intercropping, but farmers never practiced barley-clover intercropping.
Other data including rainfall, total communal grazing area, number of households in the study areas, plot slope and length, soil depth, price data for crop outputs and inputs, crop residues[6], dung cakes, livestock, and livestock products are compiled from the district (Wereda Agricultural office 2002), Adugan and Said (1991), and Mengistu (1994).

The nutrient content of each feed type, milk production, manure production, calving rate with and without improved forage fodders, economic life span of livestock, mortality rates of livestock, and labour requirements for livestock keeping were constructed from data obtained from Adet Agricultural Research Centre survey data, GoE (1986), Tedla et al. (1992), Nordblom et al. (1992), Panin and Brokken, (1993), Annido et al. (1994), Omiti (1995), Buta and Kassa (1998), Betew and Addis (2003), and Mpairwe et al. (2003).

Soil loss coefficients for the cropping activities were calculated using Universal Soil Loss Equation (USLE) modified for the Ethiopian condition (Hurni 1987).

[6] The AARC survey did lack crop residues data.

4. Empirical results

In this section we present and discuss the empirical results obtained using the Generalized Algebraic Modelling System (GAMS).

4.1. Actual land use patterns and base plan outcomes

The 2001 actual and predicted land use patterns are indicated in column 1 and 2 of Table 4.1. The observed and predicted land use patterns are close to each other with a standard deviation of 0.23 and correlation coefficient of 0.91[7]. However, there is a bias towards maize production. The bias arises due to the combined effects of higher grain and stover yields production. About 62.8% of the cropland was under maize production while the rest was shared among finger millet cultivation (19.8%), *teff* (11.6%), grass pea (2.5%), barley (2.8%), and niger seed (0.7%). Households generate income from sale of maize and finger millet crops. The area allocated to other crops was influenced to a great extent by the need to satisfy subsistence requirements. The high marginal value productivity [8] (Table 4.2) in the base plan indicates that grazing land was an important feed source both in terms of quality and quantity. In contrast to the households in Plan I and II, households under the base plan do not have surplus fodder production. As a result they purchased on average 33 kg Noug cakes to supplement the feed shortage, especially protein shortage.

Table 4.1. Actual and model estimated values of land use (in hectare)

Crop type	Farmer's practice (in 2001)	Base plan	Plan I	Plan II
Sole Maize	0.860	1.368	0.000*	0.000*
Teff	0.500	0.252	0.252	0.252
Finger millet	0.530	0.429	0.524	0.607
Sole barley	0.120	0.060	0.000*	0.000*
Grass pea	0.070	0.054	0.054	0.054
Niger seed	0.100	0.016	0.016	0.016
Maize-vetch intercrop	-	-	1.307	1.224
Barley-clover intercrop	-	-	0.026	0.026

Source: Author's calculations
Note: *0.000 means the crop is included in the model but not selected in the optimal plan.

Table 4.2. Marginal value productivity of resources

Resources	Base plan	Plan I	Plan II
Own cultivated land (Birr/ha)	2093	2281	2281
Rented-in land (Birr/ha)	873	436	436
Private grazing land (Birr/ha)	2199	779	779
Communal grazing land (Birr/ha)	1094	388	388

Source: Author's calculations

[7] It measures the degree of association between predicted and actual land use value. It is defined as:

$$r = \frac{\sum_{i=1}^{N}\left(X_i^p - \overline{X}^p\right)\left(X_i^a - \overline{X}_a\right)}{\sqrt{\sum_{i=1}^{N}\left(X_i^p - \overline{X}^p\right)^2 \sum_{i=1}^{N}\left(X_i^a - \overline{X}_a\right)^2}}$$

, where p and a stands for predicted & actual land use values, respectively,

X_i^p & X_i^a stands for mean value of predicted & actual land use, respectively.

[8] Marginal value productivity is the additional value of output resulting from one additional unit of input (for example, one hectare of land). In case the input is land, calculated MVP represents the opportunity cost of one unit of land. If farmers have to rent or sale this land the minimum price they should ask is the MVP.

In the following section, two scenarios are run to examine the potential impact of legume intercropping adoption on household income and soil conservation.

4.2. Improved plans outcome

The introduction of legume-cereal intercropping (LCI) into the traditional cropping system increased per capita income (hereafter income) considerably. The results indicate that per capita income increased by 51.7% (from 1149 to 1743 Birr) over the base plan scenario only by introducing LCI (Plan I) into the traditional mixed farming model (base plan). This was accompanied by a 9.4% decline in soil loss (from 11.7 to 10.6 ton/ha/year) compared to the base plan (see Table 4.3). The increase in income is substantial considering the only change occurring is LCI. This is due to an increase in sale of butter, dung cakes, surplus fodder products, reduction in soil loss, and productivity gain because of nitrogen fixation.

The income increase as a result of the introduction of LCI and crossbred cows (Plan II) was 74.5% (from 1149 to 2006 Birr) compared to the base plan (Table 4.3). This was accompanied by a decline of 7.7% decline in soil loss (from 11.7 to 10.8 ton/ha/year) compared to the base plan. Introduction of crossbred cows (CBC) increases income by 15% in plan II compared to plan I without CBC. Crossbred cows produce higher amounts of milk and dung compared to local breeds.

Table 4.3. Household per capita income, soil loss, and resource productivity

Parameters	Base plan	Plan I	Plan II
Farm income (Birr) from	6159	9342	10750
Crop	4909	7149	6104
Livestock	1250	2193	4646
Farm income (Birr)			
Per capita	1149	1743	2006
Per cropped area (ha)	2990	4185	4931
Per person day employed on the farm	4.84	7.51	8.35
Per total person days available	2.30	3.50	4.02
Soil loss (ton/ha/year)	11.7	10.6	10.8
Total nitrogen fixed (kg)	-	60.01	56.29

Source: Author's calculations

The estimated land use patterns are shown in Table 4.2. The principal land use pattern difference from the base plan is that the mono-cropping activities (maize and barely) are replaced by intercropping maize-vetch and barley-clover activities.

In the improved plans, households produce surplus fodder over livestock demand. In the base plan the on-farm fodder production (which is in fact obtained solely from crop residues) is entirely used for livestock and on average 33 kg of oil seed cake is purchased to supplement the protein deficiency of the existing feed sources. Although excess fodder over livestock demand was transferred to selling activity in the present study, it can serve other purposes such as mulching, freeing grazing lands for crop cultivation, and/or recovering overgrazed lands, especially the communal grazing lands. Further research on these alternatives may be important to exploit the potential of forage legumes.

The productivity of resources (return per unit of resource) increases with introduction of forage legumes and CBC (Table 4.3).

Legumes and CBC generate more employment opportunities to the household. Labour use increases by 9.7% (1133 to 1243 person-days) in plan I and by 13.6% (1133 to 1287 person-days) in plan II, compared to the base plan.

The marginal value productivity (MVP) of grazing lands decreased in the improved plans in relation to the base plan (Table 4.2). This is a result of an increase in feed dry matter availability from intercropping. Increased high quality dry matter feed from intercropping may reduce the problem of overgrazing and hence may reduce soil erosion and compaction of arable land. On the other hand, the MVP of own cropland increased in the improved plans compared to the base plan, because the overall productivity has increased. The introduction of crossbred cows does not change the MVP of land compared to Plan I without crossbred cows, perhaps because there is still surplus fodder production under this scenario. The MVP of labour and oxen, however, is zero. This is not surprising for three reasons. First, the dominant crop is maize with resource requirements very low compared to other crops. Second, employment opportunity outside farm is low. Third, there is limited oxen rental market to hire out surplus draft power over own farming. Introducing labour intensive technologies may help to utilize the abundant labour. Multipurpose animal traction can be introduced to reduce excess draft power. For instance, Buta and Kassa (1998) showed that crossbred cows could serve as draft power without affecting milk production. This can also reduce pressure on feed sources.

4.3. Sensitivity analysis

The impact of changes in the price of outputs and nitrogen output on income and land use are indicated in Tables 4.4 and 4.5. A decrease in maize price by 50% reduced the income of the household in each plan. The drop in income was lower for plan I (27%) and II (22%), compared to the base plan (38%). The land use pattern and sources of farm income after the change were close to those before the change in the improved plans. But the base plan was unstable with this shock, as indicated by the standard deviation of the change in land use pattern: the standard deviation was 0.42, 0.11 and 0.11 for the base plan, plan I, and II, respectively. High yield from livestock due to legumes may serve as insurance when there is a shock on crop production.

Table 4.4. Sensitivity report for per capita income (Birr) due to price and nitrogen output changes

Change		Base Plan	Plan I	Plan II
Before change	Income	1149	1743	2006
50% maize price reduction	Income	707	1272	1569
	Change	-442	-471	-437
	%Change	-38	-27	-22
50% Nitrogen output reduction	Income	NA	1658	1926
	Change	NA	-85	-80
	%Change	NA	-4.9	-4
50% maize price reduction &50% nitrogen output reduction	Income	NA	1135	1492
	Change	NA	-553	-514
	%Change	NA	-31.7	-25.6
50% fodder price change	Income	1149	1601	1940
	Change	0	-141	-66
	%Change	0	-8.1	-3.3

Note: NA = not applicable

Table 4.5. Sensitivity analysis report for land use (ha) changes due to price and nitrogen output changes

Crop type	50% maize price reduction			50% nitrogen output reduction	
	Base Plan	Plan I	Plan II	Plan I	Plan II
Sole Maize	0.784	0.000*	0.000*	0.000*	0.000*
Teff	0.127	0.204	0.204	0.252	0.252
Finger millet	1.139	0.597	0.680	0.524	0.607
Sole barley	0.060	0.000*	0.000*	0.000*	0.000*
Grass pea	0.054	0.054	0.054	0.054	0.054
Niger seed	0.016	0.016	0.016	0.016	0.016
Maize-vetch intercrop	-	1.282	1.199	1.307	1.224
Barley-clover intercrop	-	0.026	0.026	0.026	0.026
Crop type	**50% maize price reduction & 50% nitrogen output reduction**			**50% fodder price reduction**	
	Base Plan	Plan I	Plan II	Plan I	Plan II
Sole Maize	0.784	0.000*	0.000*	0.000*	0.000*
Teff	0.127	0.127	0.127	0.576	0.252
Finger millet	1.139	0.715	0.798	0.175	0.524
Sole barley	0.060	0.000*	0.000*	0.000*	0.000*
Grass pea	0.054	0.054	0.054	0.054	0.054
Niger seed	0.016	0.016	0.016	0.016	0.016
Maize-vetch intercrop	-	1.241	1.158	1.332	1.307
Barley-clover intercrop	-	0.026	0.026	0.026	0.026

Note: The base plan sensitivity analysis for straw was not reported since there was no surplus fodder over livestock demand.
*0.000 means the crop is included in the model but not selected in the optimal plan.

Reducing the amount of nitrogen fixed by legumes by 50% had only reduced the income of the household. The decrease in income was higher in plan I (5%) compared to plan II (4%). The land use pattern and sources of income remained unchanged, indicating the models were stable. The resulting farm incomes were still higher for the improved plans compared to the base plan. This is due to the fact that more manure and surplus fodder were sold under improved plans, unlike the base plan where there was no surplus fodder over livestock demand.

With a 50% maize price and nitrogen output reduction, household income decreased by 31.7% under plan I without CBC and by 25.6% under plan II with CBC. The land use pattern remained unchanged, indicating the models were stable. However, the improved plan with crossbred cows (plan II) was more stable than plan I. The standard deviation was 0.21 and 0.16, respectively for plan I and plans II. Compared to the base plan, the household income was only higher in plan II.

The effect on income of decreasing fodder price by 50% was higher for plan I (8%) compared to plan II (3%). Crossbred animals use more fodder and convert it into higher value products. The land use for plan I and II is stable compared to the base plan, except for *teff* and finger milet.

These results show that the economic benefits from all plans decline when output prices and/or the amount of nitrogen fixed by legumes decreased. Yet, the improved plans remain profitable and the relative profitability of the plans remained the same compared to the plans before change.

5. Conclusions

Declining soil fertility and increasing soil erosion continue to limit crop yields in the Ethiopian highlands while poor quality and quantity of feed limit livestock production. Adoption of forage legumes has been proposed as a strategy that can help alleviate these problems. However, despite their proposed potential in dealing with these challenges, adoption of forage legumes by smallholder farmers is still limited. This paper sought to investigate the impact of forage legume-cereal intercropping on household income and soil conservation, using a bio-economic linear programming model combining household surveys with experimental data from the Ethiopian highlands.

Our results indicate that the introduction of legume-cereal intercropping into mixed farming systems increases farm income and reduces pressure on land resources. Farm income is further enhanced when legume-cereal intercropping was combined with crossbred cows for milk production. The marginal value productivity of grazing lands decreases with the introduction of forage legumes into the farming system. This is a result of an increase in feed dry matter availability from intercropping. Increased high quality and quantity of feed dry matter from intercropping may reduce the problem of overgrazing and hence may reduce soil erosion and compaction of arable land by livestock.

Thus the results imply that development interventions encouraging adoption of forage legumes will achieve a double advantage of enhancing the livelihoods of rural households and at the same time prevent or mitigate land degradation.

Finally, the results of this study have to be interpreted with caution because it has some limitations. First, the study area is restricted and the survey data come from farming systems where the dominant crop is maize. Further research is necessary to investigate whether our results are replicable when other cereals such as wheat, barley and *teff* are dominant. Second, the study uses relatively old data which may have repercussion on some of the parameters we used and on the quantitative results. In addition, the method of linear programming has its limitations. Fourth, we encourage future study to analyze the economic and environmental impacts of forage adoption along with their adoption determinants using comprehensive nationally representative data.

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Annex

Annex A.1. OLS estimates of the effect of soil depth on teff yield (Dependent variable: logarithm of teff yield ton/ha)

Explanatory variables	Estimated Coefficients	Robust p values
Level variables		
Trend variable in years	9.460	0.215
Frequency of ploughing	156.514***	0.000
Soil depth in cm	12.492***	0.004
Slope in percent	1.031	0.886
Rain fall in mm	172.655***	0.002
Squared terms		
Trend variable in years	0.577***	0.000
Frequency of ploughing	0.452**	0.046
Soil depth in cm	0.235*	0.076
Slope in percent	0.166	0.193
Rain fall in mm	-8.313**	0.030
Interaction terms		
Soil depth*trend variable	0.358**	0.014
Soil depth*rain fall	-1.871***	0.005
Soil depth*slope	0.336***	0.010
Soil depth*frequency of ploughing	-0.756	0.145
Slope*trend variable	0.353**	0.017
Slope*rain fall	-0.268	0.780
Slope*frequency of ploughing	-0.956*	0.099
Rain fall*frequency of ploughing	-20.545***	0.000
Rain fall*trend variable	-2.091**	0.044
Frequency of ploughing*trend variable	1.245***	0.002
Constant	822.377***	0.000
Observations	184	
R-squared	0.665	
Average *teff* yield	0.95 ton	
Average soil depth	95 cm	
Average slope	7.5%	
Average ploughing frequency	5	
Average rain fall	1000 mm	

Source' Author's calculation on data of the Soil Conservation Research Project (SCRP) in the highlands of north-western Ethiopia
Notes: all variables are expressed in natural logarithms, and * significant at 10%; ** significant at 5%; *** significant at 1%

Annex A.2. Fertilizer response functions

Equation 1

Barley (local variety) fertilizer response

Barley (kg/ha) = 965 + 7.74N + 24.12P – 0.0637N^2 - 0.1695P^2 + 0.0693NP

t-value: (2.5)* (7.8)** (-4.5)** (-1.7) (1.8)

R-square = 0.97 , observations = 704

Farmers average N and P application rate is 34 and 40 kg/ha, respectively.

Source: Ho (1992)

Equation 2

Maize (improved variety) fertilizer response

$$maize(kg/ha) = 2191.18 + 53.04N + 56.82P - 0.217N^2 - 0.280P^2 + 0.085NP$$

Robust p-value (0.000) (0.000) (0.000) (0.000) (0.000) (0.034)

R-square = 0.56, Observations = 160, F(5, 154) = 55.8(0.000)

N = nitrogen in kg/ha, P = phosphorus fertilizer in kg/ha. The average N and P application rate by farmers is 64 and 46 kg/ha, respectively

Source: We estimated the maize fertilizer response function using three years on-farm fertilizer trials conducted by Adet Agricultural Research Centre (AARC)

Annex A.3. Aggregated representation of Linear Programming Model

		Activities												
		Production					Buying	Selling	Feed consumption			Home consumption	Borrowing (BOW)	RHS
		Crop & Feed	organic nitrogen	grazing	Soil loss	Livestock, livestock product, transfer	Feed, Land-rental	crop, fodder, livestock & livestock product	DM	DCP	ME			
Constraints	Units	Ha	Kg			Head/kg	Kg					kg/liter	Birr	
Croplands	Ha	+ 1					- 1							$\leq$ L
Pasturelands	Ha			+ 1										$\leq$ pasl
Feed consumption- DM	Kg								+ 1					$\leq$ Max
DCP	Kg									+ 1				$\geq$ Min
ME	Mcal										+ 1			$\geq$ Min
Human labour	PD	+ A												$\leq L_s$
Ox labour	OD	+ A												$\leq O_s$
Home consumption	Kg											+ 1		$\geq$ Min
Capital constraint	Birr	+ A				+ A	+ A						- 1	$\leq$ OF
Credit limit	Birr												+ 1	$\leq$ CRL
Soil erosion	ton/ha	- A			+ 1									$= 0$
Nitrogen balance	Kg	- A	+ 1											= 0
Crop & feed balance	Kg	- A		- A			- 1	+ 1/+A	+ 1	+ 1	+ 1	+ 1		$< = > 0$
Livestock balance	Head/ Kg					± A/± 1		+ 1				+ 1		≤ 0
Objective: Max .gross farm income	Birr	$-C_j$	λ_n		$-\lambda_e$	$-C_j$	$-C_j$	P_j					$-i$	=Z

Where: C indicates unit cost, P_j is unit revenue, PD is person-day, OD is ox day, DCP is digestible crude protein content, ME is metabolaizable energy, DM is dry matter and Mcal is mega calorie, Min & Max are mininum & maximum requirements respectively; and other variables are defined below.

Annex A.3. Continued

$$1)\ Max\pi = \sum_{j=1}^{m}\sum_{k=1}^{B} p_{jk}Q_{jk} - \sum_{i=1}^{h}\sum_{j=1}^{m} p_i X_{ij} A_j + \lambda_n N - \lambda_e E + \sum_{l=1}^{D} p_l X_{lcs} + \sum_{p=1}^{L}\sum_{l=1}^{D} p_{pl}Q_{lp} - \sum_{g=1}^{E}\sum_{l=1}^{D} p_{gl} X_{lg} - iBOW$$

$subject$ to :

2) Land constraints

$$\sum_{j=1}^{m} A_j \le L$$

3) Pasture land constraints

$$A_p \le pasl$$

4) Human labour constraints

$$\sum_{s=1}^{6}\sum_{j=1}^{m} L_{sj}A_j + \sum_{s=1}^{6}\lambda_{sl}X_l \le L_s$$

5) draft power constraints

$$\sum_{s=1}^{3}\sum_{j=1}^{m} w_{si}A_j \le O_s$$

6) Animal feed constraints and balance

$$\sum_{j=1}^{m} N_{nj}A_j \pm N_{nj}^{ps} \ge \sum_{l=1}^{D} r_{nl}X_l$$

7) Home consumption

$$Q^c{}_j \ge Q_j^{mr}$$

8) Crop balances

$$\sum_{j=1}^{m} q_{jk}A_j - Q_j^{s} \ge Q_j^{c}$$

9) Livestock balances

$$y_{pl}X_l - sale_{pl} \ge C_{pl}^{c}$$

10) Livestock replacement and culling rate

$$cur_l X_l - X_l^{culs} \ge 0$$

$$cur_l X_l - X_l^{R} \le 0$$

$$surX_l - X_l^{surs} \ge 0$$

11) Soil erosion

$$\sum_{j=1}^{m} eros_j A_j = E$$ (total soil loss cropland)

12) Capital constraint

$$\sum_{j=1}^{m} k_j A_j + \sum_{l=1}^{D} k_l X_l - BOW \le OF$$

13) Credit limit

$$BOW \le CRL$$

where:

Q_{jk} = total quantity of output k produced by crop j activity and available for sale

p_{jk} = price of output type k (grain and fodder) from crop j activity,

p_i = price of input i (fertilizer and seed) used by crop j activity,

X_{ij} = level of input i used per hectare by crop j activity,

A_j = level of crop j activity in hectare,

λ_n = the discounted marginal benefits of soil fertility level,

N = level of nitrogen fixed by intercropping activity in kg,

λ_e = the discounted marginal user cost of soil,

$eros_j = R * K * L * S * C_j * I_j$. This is USLE and it refers to per ha soil losses under crop j activity

C_j = land cover by crop j activity, I_j is management factor under crop j, R is rain fall, $K, L, \& S$ are soil erodibility, slope length & slope gradient, respectively.

Annex A.3. Continued

p_l = selling price of type l livestock,

X_{lcs} = number of heads of type l livestock available for sale (culled (c) and surplus stock (s)),

p_{pl} = selling price of type p (manure and butter)livestock product produced by type l livestock,

Q_{pl} = quantity of livestock product p from type l livestock,

p_{gl} = price of livestock variable input g used by livestock type l,

X_{lg} = number of heads of type l livestock using type g livestock input,

L = total cropland available in ha,

$pasl$ = total pasture land available (communal and private) to farmers

A_p =total pastureland used for grazing

L_{sj} = the number of labour man-days required per ha by crop j during period s,

λ_{sl} = the number of human labour hours required to keep available livestock stock during period s,

L_s = total human labour hours available during period s,

w_{sj} = the number of oxen pair hours required per ha by crop j during period s,

O_s = total number of oxen pair hours available during period s,

$Q^c{}_j$ = household subsistence requirement from crop j activity

Q^c_{pl} = type p product from type l livestock that is consumed by household

Q_j^{mr} = the level of household consumption of crop j activity,

N_{nj} = amount of fodder type n (dry matter, protein and energy) per ha produced by crop j activity,

N_{nj}^{ps} = amount of fodder sold (s) or purchased (p),

r_{nl} = quantity of fodder type n required per head by livestock type l,

Q_j^s = quantity of crop j sold (s),

q_{ik} = per hectare yield of crop j activity,

y_{pl} = yield of animal product type p from livestock type l,

$sale_{pl}$ = sale of animal product type p from type l livestock activity

cur_l = culling rate(cur) from type l livestock,

X_l^{culs} = number of culled animal sold (culs) from type l livestock,

X_l^R = number of type l livestock born and reared on the farm to replace (R) culled livestock type l

sur_l = number of surplus stock (sur) over replacement from type l livestock,

X_l^{surs} = number of surplus stock sold (surs) from type l livestock,

k_j = working capital requirements for crop j production,

k_l = the working capital requirements for type l livestock,

CRL = credit limit,

OF = amount of own fund available

Annex A.4. Activities, constraints, and assumptions

Description of activities

The activities include cropping, livestock, feed supply, selling, purchasing, borrowing, land rental, and consumption activities. The major activities used in the model are presented below.

Crop and fodder production activities

The crop activities in the model include: crop production with and without fertilizer, and with and without intercropping. Crop yield is specified net of seed requirements except the improved maize variety. Farmers keep their own seed of local varieties from previous production for the following season. Lack of information (asymmetric information) on the quality of purchased seed of local varieties may be the reason for farmers' dependence on own produced seeds. They know best about the quality of their own seeds, which they have screened from the total production. Farmers' buy improved maize seed from the nearby service cooperatives on a loan. The crop activities incur variable costs in the objective function. These variable costs include the cost for improved maize and forage seeds, and fertilizer cost for the production of one unit (hectare). The following crop activities are included in the model: maize-vetch intercrop, barley-clover intercrop, sole maize, sole barley, finger millet, *teff,* rough pea, and niger seed. The intercropping activity includes maize-vetch and barely-clover. On-farm and on-station experimental data managed by researchers adjusted downward respectively by 10% and 20% in order to account for the difference between extra care taken by researchers on small experimental plots and the real farm condition (Ndengu 1993; Regassa 1990).

Livestock production activities

Two approaches, stationary equilibrium and multi-period linear programming model of investments, are used to model investment decisions in linear programming models (Hazell and Norton 1986). We assume a steady-state (stationary equilibrium) livestock investment where the replacement and culled rates are equal each year. Assuming a steady-state herd structure, the necessity of local breed livestock purchases is avoided. The representative household keeps three local cows, two work-oxen, one equine, one sheep and one goat. Draft power, fuel dung, milk, butter, replacement, and culling herd are the main outputs from livestock activities. Milk except for household consumption is processed to butter since it may be difficult to sell milk every day. High-yielding livestock (crossbred cows) are also introduced into the model. The district Agricultural Offices have been distributing six months pregnant crossbred heifer to farmers on a loan of Birr 1200 at interest rate of 10% per annum. Ten years breeding life of local cow and oxen (Gryseels 1988); 5 years breeding life of sheep and goat; 20 and 10% mortality rate for calves, and lambs and kids, respectively and 8 years for crossbred cow are considered (Nordblom et al. 1992; Panin and Brokken 1993). We assumed no herd change in short run due to legumes.

Sales and purchases activities

Surplus grain, straw, butter, manure, culled and surplus animals after replacement are transferred to selling activities. Any deficit feed will be met by purchase. There is market for crop residues as people living around and in Bahir Dar town demand for fodder for their livestock. Market for improved forage is not common, but we assumed the same price as crop residues (Birr 0.2 per kg). We also assumed that farmers will sale poor quality fodder and keep quality higher fodder for own livestock consumption.

Consumption activities

Households seek to maximize farm income but must generate family food requirements from on-farm production. The crop and livestock product markets are functioning well compared to other markets. However, cultural (habitual) and social issues force households to grow and store their own production for consumption purpose. When subsistence constraints are met, households often generate income by selling the available surplus. Thus, consumption is included as a separate activity.

Description of constraints
The model includes constraints on owned and rented land, communal and private grazing land, household labour, draft power, credit, crop and livestock product balance, soil erosion, household and livestock consumption requirements.

Land constraints
Four land types included: own cropland, rented-in land, private grazing land and communal grazing land. A representative household on average cultivated 1.61 ha owned land and 0.57 ha rented-in land (see equation 2 & 3). The private grazing land holding is 0.55 ha. We assumed that the household would have access to an equivalent amount of 0.53 ha of communal grazing land (Wereda Agricultural Office 2002) and dry matter grass production of 4500 kg per hectare (Panin and Brokken 1993; Mengistu 1987). However, this figure is adjusted downward by 50% to take into account the effect of trampling, fire, cattle selectivity, overstocking and wildlife (Houerou and Hoste 1977). Data on productivity of private grazing land is not available, but we assumed the same productivity as communal grazing land (4500 kg per ha) without adjusting it downward.

Labour constraints
Framers have very limited access to labour markets although they are located closed to Bahir Dar town. There are continuous flows of many labourers from rural areas to this town. There is no labour market within the villages. The family labour is the major source of workforce for farming. Labour exchanges among neighbouring households and relatives are common during harvesting and threshing.
The additional labour requirements due to legumes are taken into account. Legumes increase the labour requirements for sowing, harvesting, and transporting the fodder to homestead area. Food crops are sown first and legumes later, for instance when maize reaches knee height. But legumes are harvested first at 10-50% flowering stage and food crops at a later stage (Zewdu et al. 2000). This doubles the harvesting labour requirements for maize and barley crops. The amount of labour for each crop activity was determined by splitting the cropping year into six periods of two months (March-April, May-June, etc.), each starting from cultivation to threshing and transporting outputs (see equation 4). All the days that farmers did not work due to religious holidays were calculated and subtracted from labour hours available in each period. There was no need to consider hours spent in off-farm activities as a survey carried out by the author on these activities found to be insignificant. Farmers often use non-strict church holidays for off-farm activities (if any). On average a household works seven hours per day.

Draft power constraints
Oxen rental market is inexistent but it is common to exchange among households with one ox each. There is also exchange of oxen for labour. Cultural barriers and fear of mismanagement of oxen by renters may have attributed to the inexistence of oxen rental contracts. In order to estimate oxen pair hours, a procedure similar to the one used for human labour hours calculations was used. Working days in each month were determined which were then converted into working hours. We considered three periods (March-April, May-June and July-August) of ploughing for draft power (see equation 5).

Livestock feed demand per annum
Feed sources include private and communal pasturelands, aftermath grazing, weeds and crop residues. In the case of legume-cereal intercropping, additional feed was available from legumes. It is assumed that the feed from aftermath grazing and weeds covered 25% of the total feed requirement of the livestock in terms of dry matter (Kassie and Holden 2005). Households were also observed purchasing *Noug* cake, by-product of edible oil from niger seed, to supplement the protein deficiency of crop residues. On average they purchased 77 kg. The availability of oil seed cake is limited and expensive as well (Birr 2.26 per kg). Livestock feed requirements are for crude protein (CP), metabolizable energy (ME) and dry matter (DM) intake. These feed demands are calculated as a function of total number of livestock, their classes, functions (maintenance, pregnancy, milk production and draft power)

and weight (Kear 1982; MAFF 1984; Nordblom et al. 1992; Nicholson et al. 1994; Mpairwe et al. 2003). (see equation 6 for animal feed constraints).

Minimum consumption constraints

Based on the work of Gryseels and Anderson (1983) 200 kg of cereals, 50 kg of pulses, and 30 kg of milk are assumed as average annual subsistence requirements per adult equivalent (see equation 7). It is assumed that families consumed the produced crops to meet their subsistence requirements in the same ratio as the average cropping pattern and amount of production. Fuel dung cakes consumption is based on our survey data. A household uses 350 kg dried dung cakes per year. Other sources of fuel, crop residues, and wood are not included in the model as we lack data on these sources. The household has 5.36 adult equivalents. We assumed that in the short run the consumption pattern of the household would not change due to legumes.

Crop balance (grain, fodder and nitrogen)

These constraints are included in order to ensure that grain and nitrogen yield form crop production will be transferred to the subsistence balance and selling equations. In addition, straw and pasture yields from crop and pasture production is transferred to the livestock production, selling and purchasing equations (see equation 8). The straw yields for sole cropping activities are based on grain-straw conversion factors (Adugan and Said 1991; Mengistu 1994).

In addition to grain and fodder production in the intercropping activity, legumes fix nitrogen in their root systems. From various experiments in the Ethiopian highlands, legumes (lablab, clover, and vetch) were found to leave 30-60 kg N /ha in their root systems that will be available for uptake by the next crop (Nnadi and Haque 1986, 1988). It is assumed that legumes-cereals intercropping produces 45 kg N /ha for the benefit of the next crop. To account for the lagged effect of legumes the discounted shadow prices of soil fertility (marginal value product of nitrogen fertilizer) is estimated based on the above discussion.

Livestock balance

This restriction ensures that there is a balance between production, consumption, and marketing activities for each livestock keeping activity (see equation 9). Livestock production is a function of diet.

Livestock Transfer constraints

Transfer rows relate the output of one activity to another activity in the model. Replacement of animals will be made from the existing stock on the farm. Culled animals and surplus animals over replacement will be disposed of through sales. To keep the herd structure constants, livestock number on the right hand side of the model is formulated as an equality (integer) constraint (see equation 10).

Soil erosion estimation

Intercropping reduces soil erosion by increasing the vegetative cover of a plot. Soil loss for each crop activity was estimated using the Universal Soil Loss Equation (USLE) modified for the Ethiopian conditions (Hurni 1987). In consultation with forage experts and agronomists in the AARC, dense intercrop was considered as management factor (I_j) . The effect of soil loss (erosion) on household income was included in the model as discussed above (see equation 11).

Capital constraint

The available working capital required financing purchases of seeds, feeds, fertilizer, and other direct inputs can be an important constraint on the farm. Framers can get forage seed loan from Agricultural Offices. Some working capital may be available from the farmer's own savings, but this can be supplemented by borrowing. Households have limited access to credit to finance their input expenditures, especially fertilizer. There is no formal credit for consumption purpose in the region in general and in the study area in particular, but we do not have information on informal credit sources (see equation 12 and 13).

Annex A.5. Livestock productivity with and without forage legumes

Parameters	Animal types	Productivity	
		With traditional feed	With forage legumes
Weaning rate per year	Local cow	0.5	0.7
	Crossbreed cow	NA	1.0
	Sheep	1.2	1.6
	Goat	1.25	1.65
Manure per year (kg dry matter)	Local cow	800	965
	Crossbreed cow	NA	1172
	Sheep	70	112
	Goat	70	112
Lactation yield (kg)	Local cow	225	420
	Crossbreed cow	1153	2228

Sources: Omiti 1995; Mpairwe et al. 2002; Betew and Addis 2003; GOE 1986.
Note: NA= not available

Annex A.6. Average grain and straw yields (kg per ha)

Crop types	Grain yield		Straw yield	
	With fertilizer	Without fertilizer	With fertilizer	Without fertilizer
Sole maize	5000	NA	9300	NA
Maize-vetch	4912	NA	14200	NA
Sole barley	1653	750	2300	750
Barley-clover	1793	NA	3400	NA
Teff	1200	665	1080	599
Finger millet	1965	1200	5364	3276
Niger seed	NA	500	NA	600
Rough pea	NA	925	NA	823

Sources: Wereda Agricultural offices (2002); Mengistu (1994); Zewdu et al. (2000); Adugan and Said (1991)

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