BIO-ECONOMIC MODELING OF WATERSHED RESOURCES IN ETHIOPIA[*]

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This paper examines the theoretical and practical aspects of natural resource use in the poor tropics given limited technological and policy intervention. Results show that if farmers were to reallocate their land use activities based on land suitability, and utilize between 10-20% of their farm income to purchase and apply chemical fertilizer, their net returns could rise by over 50%. Increased specialization and application of fertilizer, however, results in a 24% increase in soil loss in the initial year as some erosive activities with high fertilizer-yield response functions are cultivated. In subsequent years, fertilizer use lowers the level of soil loss but is unable to adequately counteract the cumulative effects of erosion and hence yields decline. The best strategy in the short run is to combine fertilizer application with crop rotation based on changing land suitability. Shortfalls in on-farm staple grains supplies caused by such rotations can then be met from market purchases. Similarly, a secure land tenure policy is likely to impact positively on land conservation by increasing the farmer's time horizon.

(Key words: Bio-economic models, watershed, degradation, dynamic programming, Ethiopia).

Land degradation, low productivity, poverty and declining human welfare are the dominant problems of the crop livestock production systems prevalent in most parts of the tropical highlands. This study examines the driving forces behind these problems using a watershed framework of analysis as opposed to a farm household approach and applying a bio-economic model as opposed to a purely economic or biophysical model. To give the problem a physical dimension, degradation problems in Ginchi watershed in the central highlands of Ethiopia are evaluated. Both practical and theoretical issues involved in solving these problems are discussed and an empirical evaluation of the current situation of limited technological and policy intervention in Ginchi watershed is presented.

Two versions of the bio-economic model are generated; a) a static goal programming version b) a dynamic non-linear mathematical programming version. The static goal programming approach simultaneously optimizes both environmental and economic goals of the watershed and its results are used for validating the dynamic model. The dynamic model optimizes an aggregate watershed utility function that is indirectly linked to the biophysical aspects of the watershed through an exponential soil loss-yield decline model with single year time lags. Soil losses in one year determine yields of various crops in the following year given the ameliorative effects of fertilizer. Both versions of the model take into account easonality in input and output supplies, labour substitutability, the various roles of gender, crop and livestock constraints, minimum household food requirements, forestry activities as well as the biophysical

from four land categories found in the watershed for the years 1995, 1996 and 1997 are used to test the aspects of soil erosion arising from these activities. Cross-sectional socio-economic and biophyscal data model and are supplemented with on-station experimental data. The validated dynamic model is then used to evaluate the interrelationships between poverty, low productivity, land degradation and changes in human welfare indicators.

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Part one of the paper gives a background of the degradation problem in the Ethiopian highlands and the specifics of Ginchi watershed, part two outlines the analytical model while parts three and four present the results and policy implications, respectively.

1.0 Background

The Ethiopian highlands, lying at about 1500m above sea level, are some of the most severely denuded landscapes in the world. They comprise 46% of the country's landmass and are home to 88% of the 60 million total population. Agricultural productivity is low. Hence 80% of the population employed in this sector generates less than 50% of the GDP. These low productivity levels continue to decline due to land degradation. Current estimates of soil loss from cropped areas stand at 42 tonnes per ha per annum (Hurni, 1987), while total soil loss from the highlands are estimated at 1900 million tons per annum (FAO, 1986). Ginchi watershed typifies the degradation problem in the Ethiopian highlands. Located in the central highland massif, this watershed has experienced sizeable degradation over time. Evidence shows that in 1950, only 34% of the watershed was under crops while 60% was under pasture and woodland. The remaining 6% was under communal casual road and paths. In 1990, the situation had become totally reversed. Crops are now produced on over 61% of the land area, while pasture and woodland have declined to below half their previous size. The result has been severe erosion and drastic declines in crop yields and animal productivity. The bottomlands of the watershed also suffer from intense water-logging at the beginning of the rainy season due to the predominantly clayey vertic soils.

To arrest land degradation and revitalize the mixed crop-livestock production system in the watershed, a consortium of research and development institutions under the Joint Vertisol Project (JVP) developed a package of production and conservation technologies. The package includes improved animal drawn equipment (the Broad Bed and Furrow Maker or the BBM), new crop varieties and related agronomic practices, and agro-forestry. Adoption of new high yielding crop varieties would require higher amounts of chemical and organic fertilizer, hence more cash and/or access to credit. Also improved drainage of the watershed lowlands through adoption of the BBM plough requires more animal draught power, and its success would depend on construction of drainage channels to drain off excess water from the individual farm plots to the river channel or to a communal drain. Construction of, both the feeder and communal, drains as well as their maintenance would require collaborative action at the community level. This would put pressure on the available amount of human resources, especially labour and cash endowment. Similarly, introduction of new breeds of livestock such as cross bred cows would call for higher amounts of animal feeds with higher nutritive value than is locally available. Given the already scarce natural sources of animal fodder in the area, tremendous pressure on the existing scarce pasture would be experienced. Farmers must therefore adopt a pasture management that improves pasture productivity. This study aims at determining the most cost effective strategy of raising the watershed's productivity given the current static traditional technology in which fertilizer is the only viable form of intervention prior to adoption of the BBM technology package described above.

2.0 Analytical model

To date, most studies seeking to analyze the impact of technology on the human needs and environmental concerns utilize farm household models (Nakajima, 1986; Shiferaw, 1998). Assessment of production and conservation technologies at a household level is, however, too restrictive as it ignores the natural delineation of the landscape, and hence the biophysical scale of the problem, resource multi-functionality, multi-dimensional trade-offs and importance of community participation in solving general externalities arising from agricultural production (Rhoades, 1998). Household decisions include communal considerations at a landscape level, especially where a community participatory management approach is in place. Aggregation of household decision making at a watershed (landscape) level and use of a holistic approach to model natural resources in a manner that surpasses the capacity of a household level model are viewed as better alternatives. Dynamic bio-economic models are considered as one such approach (Hazell, 1998). They, however, suffer from aggregation problems associated with averaging resource availabilities including other structural parameters. The assumption of a perfect match between the physically delineated land unit (watershed) and the community utilizing it is also flawed. Thus the community living in the watershed may own land of different quantity and quality outside the watershed boundary and vice versa. On the average, however, the amount and quality of land owned outside the watershed by the watershed residents and the amount owned inside the watershed by non residents tend to even out. In Ginchi watershed, these limitations are minimized by the high homogeneity of the community (in terms of quantity and quality of resource endowment especially land). High inter-household interactions in terms of communal labour and animal draft sharing increase further this homogeneity and justify the assumption of a single decision maker at the watershed level.

GINCHI WATERSHED EMPIRICAL BIO-ECONOMIC MODEL

For the sake of brevity, only the dynamic mathematical programming version of the bio-economic model is presented. The dynamic model considers a watershed aggregate utility maximization objective consisting of three basic components; cash income, leisure and basic food requirements. For simplicity, food requirements are assumed to be pre-determined and hence are treated as progressively increasing constraints due to population growth. Ordinarily, leisure and income decisions are non-separable. In Ginchi watershed, where 90% of the community belong to the Orthodox Church, religious holidays account for almost half the normal working days in a year. These holidays are strictly adhered to and hence must be subtracted to get **the** actual number of available working days. Any day that is not a church holiday is efficiently used for farm work. Leisure is thus a component of the church holidays and, assuming strong separability of the utility function, it is conveniently assumed to be a static sum entrenched in the church holidays. Holding church holidays constant leaves profit or net cash income as the only argument of the utility function. This is a constrained utility function as leisure is constrained to be greater than would be preferred in the absence of so many holidays. Risk[1] is not incorporated due to limited time series data and the large size of the holistic model. The model is specified as follows;

Let aggregate watershed utility at time t be:

$$U_t = \sum_{i=1}^{P}(g_{it}.\ \lambda_i Y_{it}) \quad + \quad \sum_{i=p+1}^{S} P_i.(L_{it}-X_{it}) \qquad t = 1,\ldots,T \tag{1}$$

$$g_{it} = \ (P_{\,it}.Q_{it})\text{-}\ (P_{\,ct}.\ X_{\,cit}) \tag{2}$$

$$0\leq\lambda_i \leq 1 \text{ and } \sum\lambda_i \ = 1 \tag{3}$$

$$\text{Maximize } \sum_{t=1}^{T}(1/(1+\tau))^t U_t \tag{4}$$

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[1] One caveat of this formulation is its assumption of perfect knowledge of market prices and yields (i.e. certainty), with limited explanation of how income from each activity varies across time or how the individual activities interact to produce variable aggregate incomes. Use of cross sectional data to calculate risk is possible but it ignores inter annual price variation (Calkins, 1981). The formulation also assumes that farmers in the watershed explicitly portray an optimization behavior. This may not be the case in all instances and hence some of the model results may require external intervention to be realized.

Subject to:

$$\sum_{i=1}^{P} a_{cit}\,.Y_{it} \leq X_{ct} \qquad c = 1,\ldots r; \qquad (5)$$

$$Y_{it} \geq 0, \qquad i = 1,\ldots s; \qquad (6)$$

$$Q_{it} = q_{it}.h_{it} \text{ for activities 1 to m} \qquad (7)$$

$$q_{it} = \phi(X_{1it},\ldots,X_{cit}).e^{-\alpha\beta_{t-1}} \qquad (8)$$

$$\beta_{t-1} = \sum_{t=1}^{t-1}(E_t / W) \qquad (9)$$

$$E_t = \sum_{i=1}^{I} K_{it}.N_{it}.R_t.D_t.Z_t.S_t \qquad (10)$$

where: activities i =1 to j are crop and pasture; activities i =j+1 to m are planted trees; activities i =m+1 to p are livestock and livestock products activities; and activities i =p+1 to s are leisure activities. At any time t, Y_{it} is the level of activity i; git are the per unit net returns from activity i ; Q_{it} is output from activity i ; λ_i is weight given to activity i based on its preference by the farmer[2]; τ is the discount rate; a_{cit} are the technical coefficients of production ; X_{cit} is the total quantity of input c used by activity i; q_{it} are yield per hectare of crop, hay and pasture activities; h_{it} are hectares under activity i in time t; e is the natural log; α_t are crop specific coefficients varying with land use activity and slope; and β_{t-1} is the cumulative soil loss in tons per ha for the preceding t-1 years. The model is linked to the natural resource base by equation 8 which is empirically specified as a generalized Cobb Douglas production function adjusted for the effects of soil erosion. The functional form of the adjustment factor is derived from Lal (1981) and places more weight on loss of top soil as opposed to loss of subsequent layers of soil. Cumulative soil loss is calculated by equation (9) while annual erosion is estimated by equation (10). Equation 10 is basically a Universal Soil Loss Equation (USLE) modified for the Ethiopian conditions. In this model, E_t is the level of net erosion after considering soil deposition; W is the watershed area in hectares; K_{it} is the land cover by activity i ; N_{it} is the management of activity i ; R_t is the rainfall ; while D_t , Z_t and S_t are the soil erodibility, the slope gradient factor and the slope length respectively. In order to get over USLE's inherent weakness of failing to measure soil deposition, the watershed was delineated into four land categories, A, B, C, and D, based on slope. Each land type was observed to generally slope towards a riverine. Hence most of the eroded soil was deposited in the water channels and carried away by the river. Gross soil loss on each land type was thus equal to net soil loss on these land types given the negligible possibility of soil deposition. The model utilizes a dynamic mathematical programming optimization procedure to adjust yields every year as a function of cumulative soil loss in the past years as reflected in equation (8). Ameliorative effects of chemical and organic fertilizer application and their interaction are captured by this equation's multiplicative quadratic functional form.

3. Model Results

To put the model results in perspective, actual 1995 farmer practices are presented in column 2 of Table 1 below. The actual situation portrays a diversified land use pattern with a

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[2] Farmers prefer activities that are not only less risky but are also culturally acceptable based on their traditions.

bias towards teff production and considerable dependence on the market for essential grains. The output generated by this land use pattern is used for consumption and some is sold to provide a modest cash income to meet non-food needs. The level of soil loss generated is about 25% lower than the national average. Crop rotation and diversification as well as a modest amount of fertilizer application are currently the main practices used to reduce soil loss by enabling more prolific growth and hence better groundcover. Maize and wheat are generally less erosive than teff and pulses due to their larger canopies and better rooting systems.

In order to test and validate if the current land use pattern was optimal under the given conditions and constraints, the static goal programming model was run with maximization of cash income as the goal and assuming 1995 actual cereal consumption levels. The results shown in column 3 of table 1 indicate that the watershed community could increase cash income by about 50% by adopting a more specialized land use pattern with more emphasis on teff production than was practiced in 1995, but this would lead to a an increase in soil **erosion 35% above the** actual soil loss levels in 1995. This strategy would require more teff and wheat cultivation on land types A and B, (i.e. the fertile bottom lands), maize on the well drained but easily erodible slopes in land type C while most of the slopes in Land type D would be put under teff production. A more intensive livestock keeping system that emphasizes stall feeding during the crop season and free grazing in the post harvest dry season would also be required. This type of land use pattern results in self sufficiency in teff supplies and enables a 25% reduction in wheat purchases.

If farmers wanted to increase cash income by 50% as above but reduce soil loss by 30% from the 1995 actual levels, a further specialization of cropping and prohibition of livestock grazing **on** certain land type**s** would be required (see column 4 in table 1). Farmers need to maintain the same amount of land A, B and C in teff, wheat and maize cultivation as in the income maximization scenario but plant trees on the highly degraded slopes of land type C, practice stall feeding during crop (wet) season, restrain animals from grazing in landtype C throughout the year and fallow 70% of land type D. As expected, this land use pattern impacts negatively on the watershed's food self sufficiency levels and overall food security. Farmers must depend more on purchased staples especially teff and wheat and must reduce the diversity of crops grown as well. To simulate these scenarios, livestock numbers were kept fixed at the 1995 actual values for two reasons: a) livestock are seen to be less risky enterprises and are easily convertible into cash in time of need**;** hence their numbers are set at a certain preferred minimum over time b) The Ginchi community considers livestock as a culturally indispensable component of the household, reflecting the household's status in the society. Stocking rates, are hence not wholly based on an optimization behaviour. The fact that the farmers in the community opted for a more diversified cropping pattern, a lesser amount of cash income and a moderate rate of soil loss may indicate that they prefer producing a diverse array of foods to avoid risk and they have some concern about the soil erosive effects of specialised cropping pattern with emphasis on teff. The tradeoff is a smaller income level that limits the farmers' capacity to purchase productivity increasing chemical inputs. Production is thus for subsistence needs.

The static approach did not address the economic and biophysical sustainability issues. Moreover, it may be criticized on a number of grounds. Firstly the issues under analysis are dynamic and nonlinear with long inter temporal implications. Secondly the static results are based on a short time horizon and assume instantaneous switch from one activity to another. In order to fully analyse sustainability issues, the dynamic model, developed in section 2, that endogenizes soil erosion effects, is run based on the observation that cumulative soil losses in the previous years negatively impact on the yields of various crops in the following years. Given variability in soil depth in the four land types in the watershed, the same amount of soil loss affects yields of the same crop differently depending on where it is grown. Farmers' high and low time preferences are captured by running the model with a four and twelve year

Table.1 1995 Actual and estimated values of land use (ha), income(birr) and erosion (t/ha): Static version of the bio-economic model

TYPE OF ACTIVITY	1995 ACTUAL VALUES	1995 INCOME OPTIMIZATION	1995 TWO GOAL OPTIMIZATION
Production (by landtype)			
Teff A	26.65	20.00	20.93
Wheat A	10.38	15.00	14.07
Others A	12.80	5.00	5.00
Hay A	-	13.00	13.00
Grazing A1	3.12	-	-
Grazing A2	54.00	54.00	54.00
Teff B	67.71	98.00	95.25
Wheat B	9.86	-	2.75
Maize B	1.47	-	-
Others B	20.96	2.00	2.00
Hay B	6.50	15.00	15.00
Grazing B1	8.5	-	-
Grazing B2	105	105.00	105.00
Teff C	15.31	1	-
Wheat C	7.67	-	-
Maize C	1.00	27.00	27.00
Others C	6.02	2.00	2.00
Tree planting C	-	-	406 (No.)
Hay C	2.50	7.50	7.50
Grazing C1	7.50	-	-
Grazing C2	25.50	25.50	-
Teff D	16.15	40.00	7.85
Wheat D	2.30	-	-
Maize D	5.77	-	-
Others D	15.78	-	5.00
Hay D	7.30	12.50	12.50
Grazing D1	5.00	-	-
Grazing D2	54.00	52.50	9.24
Cows (No.)	120	120	120
Oxen (No.)	240	240	240
TEFF BUYING (Kg)	12,701	0	12,000
WHEAT BUYING(Kg)	7,106	5296	5000
CASH INCOME	149,397 Birr	225,200 Birr	225,200 Birr
	(US $21,342)	(US$ 32,171)	(US$ 32,142)
TOTAL EROSION (tons)	9,143Tons	11,357 Tons	6000 Tons
(t/ha)	(31t/ha)	(38 t/ha)	(20 t/ha)

NB. Specific slopes of these landtypes are 0-5%, 6-10%, 11-15% and over 16% for land types A, B, C and D respectively
A1, A2 refer to grazing in the wet and dry season respectively on landtype A. The same applies for the other land types, B to D.

time horizon, respectively. Results are presented in table 2 in which the mid and end period scenarios are displayed for each time horizon. In the short term (see column 3 of table 2) the model predictions of landtype A teff and wheat activities in 1996 are very close to what was actually observed in 1995. Cultivation of these crops is hence close to optimal levels. This may be related to the fact that a significant amount of on-farm research on wheat is undertaken in this area. It could also be an indication that farmers in Ginchi watershed have a high time preference and hence are interested in short term gains. Such high time preference could be caused by the existing land tenure policy which gives limited land user rights with the possibility of frequent land redistribution. By comparing results of the four year and twelve year time horizon runs of the dynamic model, the impact of land tenure policy on the natural resource base may be demonstrated. An examination of model estimated soil losses at the end of 1998 (short time horizon) and 2006 (long time horizon), indicates that soil losses in 1998 are 20% higher than in 2006. An examination of model estimated soil losses at the end of 1998 (short time horizon) and 2006 (long time horizon), indicates that soil losses in 1998 are 20%

higher than in 2006. Surprisingly, income generated in 1998 is only 2.6% higher than in the year 2006. Insecure land policy thus creates an income illusion that promotes land degradation.

The 12 years model output also helps us address the questions of whether the above model-generated increases in income are sustainable over time. Assuming no intervention except for fertilizer bought exclusively with 10-20 % of farm generated incomes, the model predicts that for the high incomes to be sustained, the following land use pattern should be pursued. Land type A should specialize in teff cultivation while maize and wheat cultivation should be concentrated on the fragile slopes in landtypes C and D. Wheat and teff should be continuously rotated on land type B with the wheat area consistently increasing at the expense of teff land. These practices should continue until the year 2001 when wheat area is almost equal to teff area. From the year 2001, the progressive increases in teff requirements for consumption purposes and constantly declining yields of wheat and maize generate less income making market purchases of teff unsustainable.

An income maximization strategy based on consumption of home produced teff must therefore be adopted. The change in strategy is also conditioned by the increasing failure of fertilizer application to mask the cumulative effects of soil loss on yields in the long run. For these reasons, wheat and maize must be consistently replaced with teff in land types B and D respectively. By the year 2006, about 85 % (or 90 ha) of landtype B should be under teff cultivation. This compares well with 95 ha predicted by the static model in table 1 column 4.

Table 3 gives a full summary of the estimated economic and biophysical results of the dynamic model. The output indicates a direct relationship between income and soil erosion, an inverse relationship between soil erosion and teff purchases and a positive relationship between wheat purchases and soil erosion. The direct inverse relationship between soil loss and income reflects the commonly observed paradox of optimizing the conflicting goals of environmental austerity and income maximization.

Table 2 Actual and estimated values of land use (ha), income (birr) and erosion (t/ha) of the dynamic version of the model

Type of activity	*1995 actual values*	*Four year time horizon*		*Twelve year time horizon*	
		1996	1998	2001	2006
Prodn. (by landtype)					
Eucalyptus* A (no)	-	-	-	2966	2910
Teff A	26.65	26.86	35.00	34.9	34.93
Wheat A	10.38	8.12	-	-	0.061
Others A	12.80	5.00	5.00	5.00	5.00
Hay A	-	13.00	13.00	13.00	13.00
Grazing A1	3.12	-	-	-	-
Grazing A2	54.00	54.00	54.00	54.00	54.00
Teff B	67.71	40.00	98.60	45.62	89.70
Wheat B	9.86	-	-	52.37	8.29
Maize B	1.47	58.00	-	-	-
Others B	20.96	2.00	2	2.00	2.00
Hay B	6.50	15.00	15.00	15.00	15.00
Grazing B1	8.5	-	-	-	-

Grazing B2	105	105.00	105.00	105.00	105.00
Teff C	15.31	-	1	-	-
Wheat C	7.67	1	-	-	0.15
Maize C	1.00	27.00	26.99	27.9	27.00
Others C	6.02	2.00	2.00	2.00	2.00
Hay C	2.50	7.50	7.5	7.50	7.50
Grazing C1	7.50	-	-	-	-
Grazing C2	25.50	25.50	25.50	25.5	-
Teff D	16.15	-	-	-	9.79
Wheat D	2.30	-	40	-	-
Maize D	5.77	40	-	40	30.205
Others D	15.78	-	-	-	-
Hay D	7.30	12.50	12.50	12.5	12.50
Grazing D1	5.00	-	-	-	-
Grazing D2	54.00	52.50	52.00	52.5	52.5
NET TEFF BUYING (kg)	12,701	36,446	-12,111	28,979	6,770
NET WHEAT BUYING (kg)	7,106	-7674	18,373.78	0	10236
CASH INCOME	149,397 Birr	253,504 Birr	232499 Birr	220956Birr	226,261 Birr
	(US$21,342)	(US$ 33,355)	(US$29430)	(US$27,969)	(US$ 29,771)
EROSION (tons)	9,143Tons	11,357	11534	8406.794	9134
(t/ha)	(31t/ha)	(38.11t/ha)	(38.44t/ha)	(28.02t/ha)	(30.65)

* Eucalyptus trees are planted around homesteads and rarely on crop land

Table 3. Summary of Ginchi watershed economic and biophysical indicators predicted by the dynamic version of the bio-economic model

Year	Income (Birr)	Soil loss (tons)	Teff consumption (kgs)	Teff buy (kg)	Wheat buy (kg)	Fert. Used on teff (kg)	Fert. Used on wheat (kg)
1995	169,330	7940	73,656	40,380	-	-	-
1996	222,764	8671	75,350	20,311	-	3219	5923
1997	222,426	8636	77,083	21,782	-	3482	5748
1998	222,191	8534	78,856	23,616	-	3763	5473
1999	221,805	8494	80,670	25,293	-	4063	5273
2000	221,394	8452	82,525	27,080	-	4383	5060
2001	220,956	8407	84,423	28,980	-	4723	4834
2002	220,491	8359	86,365	30,995	-	5083	4595
2003	221,197	8432	88,351	27,901	-	4532	4963
2004	222,504	8568	90,383	22,176	-	3512	5644
2005	224,085	8732	92462	15,252	4,533	2278	6469
2006	226,261	9134	94,589	6,770	10,237	766	7478

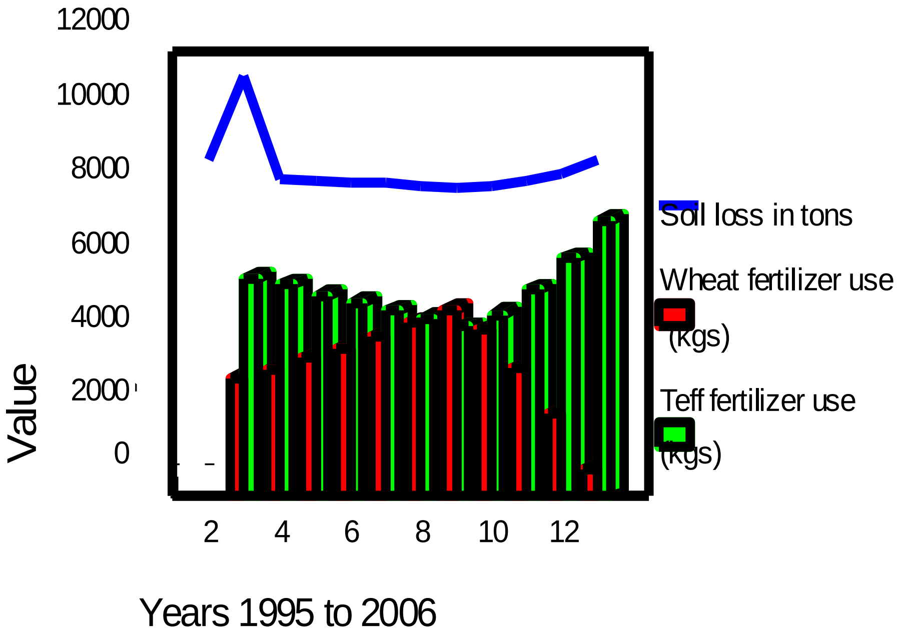
The model tentatively resolves this conflict by initially reducing teff cultivation and increasing its purchases by 52.6% between 1996- 2002 and adopts an income maximization strategy that promotes teff cultivation at the expense of wheat and maize thereafter. This change in strategy results in a 9% increase in soil erosion but enables a 70% reduction in teff purchases between 2002 and 2006. Soil conservation in the initial years thus pays off heftily towards the end of the 12 year plan. These results support existing literature which view soil conservation as a shift of extraction rates towards the future (Ciriacy- Wantrup,1968: Thampapillai and Sinden, 1979:Burt, 1981). It is however clear that incomes cannot be sustained at their current levels indefinitely with current technology.

Figure 1 below illustrates the relationship between fertilizer technology and soil erosion. Results indicate a 24% rise in soil loss in 1996 when farmers adopt a fertilizer use intensification strategy. During this year, most of the fertilizer is applied on teff (an erosive crop) and is aimed at generating higher incomes as well as ensuring self-sufficiency in teff supplies. The resulting sharp rise in soil loss impacts negatively on crop yields in the following years hence the model readjusts fertilizer allocation in subsequent years such that more and more of the available totals are applied on wheat (a less profitable but less erosive crop) at the expense of teff. This readjustment, coupled with better groundcover associated with fertilizer use, are the forces behind soil loss reductions between 1996 - 2002.

In 2003, the change in strategy as noted above reverses the process and more fertilizer is applied on teff in subsequent years. This explains the rise in erosion in these years.

Figure 1. Impact of fertilizer use on the natural resource base in Ginchi watershed

4.0 Conclusions



This study reveals a strong **trade-off** between attainment of food self-sufficiency and reduction in soil erosion with current technology. Improved extension services that encourage farmers to practice crop rotation and use more fertilizer appears to be the best policy option in the shortrun. This however, requires considerable dependence on the market to meet the resulting shortfalls. The study results also demonstrate the importance of a secure land tenure policy in natural resource conservation. Improvement of human welfare with limited natural resource degradation requires both technological and policy interventions. A commercial policy with sound input and output price incentives, good marketing channels and sound infrastructure is thus likely to facilitate improved technology adoption. Provision of short term credit may also impact positively on both land productivity and soil conservation. The effects of these technology and policy options on the watershed economy are being studied.

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