The dynamics of soil degradation and incentives for optimal management in the Central Highlands of Ethiopia

By

Chilot Yirga Tizale

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy: Environmental Economics in the Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences,
University of Pretoria

Supervisor: Prof. Rashid Mekki Hassan

February 2007

Dedication

To my mother, Zemamu Gebremedhin; my wife, Hiwot Hailu and my daughter, Lydia Chilot

Declaration

I, the under signed, hereby declare that this thesis, which I submit for the degree of PhD in Environmental Economics at the University of Pretoria is my own work and has not been previously submitted for a degree at another university.

ACKNOWLEDGEMENTS

This thesis would have not been completed had it not been to the support and contributions of many individuals and institutions. My special thanks go to my supervisor, Prof. Rashid Hassan for his guidance and relentless support. His persuasiveness, keen interest and challenges sharpened my thinking and I say once more thanks.

I am grateful to Drs. Ramos Mabugu, Alemu Mekonen and Kerk Hamilton for their advice and invaluable comments during the planning stage of the research. Thanks also due to Dr. James A. Benhin for reading part of the early drafts of the thesis and making valuable suggestions.

I would like to thank the Ethiopian Institute of Agricultural Research (EIAR) for supporting my study through a World Bank supported Agricultural Research and Training Project (ARTP). The financial support of CEEPA is also dully acknowledged. I also thank Professor Johan Kirsten, Head of Department for the administrative and moral support. The contributions of Mrs Zuna Botha and Dalene du Plesis in maintaining a pleasant working environment has immensely contributed to the completion of this study.

Thanks are also extended to my colleagues and friends at Holetta Research Center for the multifaceted assistance during the course of the data collection stage and beyond. Among others the assistance of Dr. Negussie Alemayehu, Center Director and the socio-economics staff, namely, Agagie Tesfaye, Aselef Teshome and Takle Mebratu were commendable. I am also grateful to Dr. Woldeysus Sinebo, Dr. Asgelil Debabe, W/o Workalem Berihun and W/o Missa Demise for the invaluable assistance provided to my family.

This thesis would have not bean realized without the unprecedented support, love and care of my wife Hiwot Hialu, my sisters, Raheal, Yeshi, Yabune, Belyanesh, Adina, Tiruembet and my brother Amsalu. Special thanks is due to my mother, Zemamu

Gebremedhin and my daughter, Lydia, who, despite being on the opposite side of the age spectrum raised same questions, had similar wishful thinking and difficulties of comprehending my extended absence. The motivation and encouragement of colleagues and friends at the University of Pretoria and its environs was instrumental for the completion of my thesis work. These are Patrick Birunji, Benjamin Banda, Jethro Zuwarimwe, Yamane Fesihaye, James Juana, Enid Katungi, Ameha Sebsibe, Tedie O. Nakhunma, Oyenuga Oyenike, Mampiti Elizabeth Matete, Glwadyes Gbetbouo, Hailu Beyene, Legesse Wolde, Amsal Tarekenge, Abebe Damte and many others.

Finally I thank my Lord, Jesus, who nurtured me through all the years and provided me the patience, strength and wisdom required for completing this study.

The dynamics of soil degradation and incentives for optimal management in the central highlands of Ethiopia

By

Chilot Yigra Tizale

Supervisor: Prof. Rashid Mekki Hassan

Department: Agricultural Economics, Extension and Rural Development

Degree: PhD (Environmental Economics)

ABSTRACT

In Ethiopia, as in the rest of sub-Saharan Africa, soil degradation (decline in soil quality due to topsoil loss and net nutrient extraction) has become the most important natural resource problem imposing on-site costs to individual farmers in terms of reduced yield and off-site costs to society as a result of externalities. Excessive soil loss rates reaching over 100 tons/ha on croplands are not uncommon. Much worse, the amount of nutrients extracted from the soil through cropping is estimated to be several folds the nutrient inputs added to the soil in the form of organic and inorganic nutrients. Consequently, per capita food production, income and savings have been falling.

Nonetheless, despite the seriousness of soil degradation problems and its negative consequences on food security and income to individual households and the nation at large, the magnitude of the threat that soil degradation poses on current as well as future income and how best to address the problem is not well known. The few available estimates based on static models that do not account for the inter-temporal use of the soil capital indicate the importance of the soil degradation problem but could not provide the full costs that continued soil degradation will have on the country's economic development. Furthermore, the attention provided to the analysis of soil conservation adoption and soil nutrient management practices to date is minimal. This thesis, therefore, using an inter-temporal optimisation framework analysed the tradeoffs of soil

use that smallholder farmers' face in their production decisions. Also, using econometric models that account for simultaneity of choices and plot level survey data, the thesis analysed the determinants of soil fertility and soil conservation adoption decision behaviour of smallholder farmers in the Central highlands of Ethiopia. For the former purpose, the study developed a dynamic analytical control model, derived optimality conditions, solved steady state dynamic and profit maximizing static solutions and then compared results with current average farmer practices. For the latter purpose, multinomial logit models for discrete dependent variables involving multiple choices, Heckman's two-step and Tobit regression models for the censored continuous dependent variables of intensity of inorganic fertilizer and stone/soil bunds, respectively, were employed.

Four major conclusions are drawn from the optimization results. First, steady state optimal output and input levels under the dynamic decision rule are found to be significantly higher than the static solutions signifying that the static decision rule is sub-optimal. Second, current farmer practices involve a net nutrient (N) extraction of 16.2 kg/ha from bottomlands and 56.7 kg/ha from slopping lands entailing a total soil user cost of Birr 255 per ha and Birr 928 per ha, respectively, suggesting smallholder farmers discount the future heavily (display a high rate of time preference) and hence over exploit the resource stock. Third, although current soil nutrient inputs and conservation efforts are lower than the dynamic steady state solutions it is well above the requirements of the static decision rule. Smallholder farmers, therefore, appears to have private incentives and hence consider some of the externalities of soil degradation. These findings suggest that the social gains from better utilization of soil resources are tremendous and government assistance that unlocks the private incentives and help smallholder farmers adjust input use levels towards the socially desirable steady state levels would be desirable to improve profitability of smallholder agriculture and attain sustainable use of the soil capital. Fourth, a comparison of steady state dynamic solutions where Nitrogen stock is the sole determinant of soil quality with a case where both Nitrogen stock and rooting depth impinge on soil quality confirm the main hypothesis that the socially

optimal path of soil use not only diverged from the private optimal path but also depends on the nature of soil degradation smallholder farmers face on their plots. In the highlands of Ethiopia where smallholder farmers manage multiple plots of heterogeneous soil quality and where perception of soil degradation is a function of plot characteristics, soil conservation projects and programs should consider plot heterogeneity in program design and implementation.

The sensitivity analysis of the steady state dynamic solutions showed that a rise in the discount rate lowered steady state optimal input levels, output and the resource stock whereas a lower discount rate have the opposite effect. Measures that raise the future worth of soil resources would, therefore, be crucial to induce smallholder farmers to adopt soil conserving farming techniques. Similarly a rise in output price and a fall in the price of inorganic N fertilizer would have the impact of raising steady state optimal input and output levels whereas a fall in output price and a rise in the price of inorganic N would have the opposite effect. Policies aimed at improving market access and efficiency of existing input and output markets that ensure the delivery of inorganic fertilizers at the right time, product mix and reasonable price, therefore, are likely to increase the use of inorganic fertilizers and soil conservation practices which ultimately contribute to a more sustainable use of soil resources.

The econometric analyses of soil fertility and soil conservation adoption behavior of smallholder farmers provided a number of findings of policy relevance. First, the study showed the importance of farmer education in raising the likelihood of using most of the soil fertility management (SFM) practices as well as intensity of use of inorganic fertilizer and stone/soil bunds suggesting investment in education are indispensable to reducing soil degradation and improve farm income. Second, livestock, a proxy for the wealth position of households, is positively and significantly related with the likelihood of using inorganic fertilizers and integrated soil fertility management (ISFM) practice. Livestock also has a positive and significant effect on the intensity of use of inorganic fertilizers and stone/soil bunds. Households with livestock (particularly oxen) utilize not

only their land more productively but also lease in additional land from fellow farmers, take the production and marketing risks associated with using inorganic fertilizers and stone/soil bunds. Improving smallholder farmers' access to better livestock husbandry techniques particularly veterinary services coupled with measures that increase oxen ownership (individually or collaborative) would be vital to enhance adoption of soil fertility and conservation practices. Third, project assistance in sharing the initial investment costs of soil and water conservation (SWC) structures and access to extension are found to be important determinants of the intensity of SWC and inorganic fertilizers as well as the likelihood of using ISFM technologies suggesting government assistance is vital in improving adoption and hence contribute to more sustainable use of soil resources. Fourth, the likelihood of using manure, ISFM and stone/soil bunds is found to be significantly higher on owned lands than rented in or sharecropped plots suggesting that improved tenure security is a precondition for households to engage in soil fertility management and soil conservation practices that have a long gestation period. Fifth, plot size and number of plots, a proxy for farm size, are positively and significantly related with the likelihood of using all types of SFM but animal manure. Land redistribution in the already degraded and land scarce highlands, therefore, not only contribute to land fragmentation but also by raising the fixed costs of operating micro (very small) and dispersed plots further undermine sustainable farming and increase nutrient mining. Sixth, while access to institutional credit for the purchase of inorganic fertilizers enhanced both incidence and intensity of inorganic fertilizers it has a detrimental effect on the use of stone/soil bunds. This is an important tradeoff that should be considered seriously in policy formulation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVATIONS

ACRU	Agricultural Catchement Research Unit
ADLI	Agricultural Development Led Industrialization
AGNPS	Agricultural Non-point Source Model
AM	Animal Manure
ANSWERS	Arial Non-Point Source Watershed Environment Response Simulation
CBH	Cost-Benefit Analysis
C-D	Cobb-Douglas
CLAD	Censored Least Absolute Deviations
CREAMS	Chemical Runoff and Erosion from Agricultural Management Systems
CSA	Central Statistical Authority, Ethiopia
DAP	Diamonium Phosphate
EI	Erodibility Index
EPID	Extension and Project Implementation Department
EPL	Erosion Productivity Loss
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
FFHC	Freedom from Hunger Campaign
FOCs	First Order Conditions
GDP	Gross Domestic Product
HARC	Holeta Agricultural Research Center
IGF	Inorganic Fertilizer
IIA	Independence of Irrelevant Alternatives
ISFM	Integrated Soil Fertility Management
LAD	Least Absolute Deviations
LP	Linear Programming
LR	Legume Rotations

MEDaC	Ministry of Economic Development and Cooperation
MFD	Ministry of Finance and Development, Imperial Ethiopian
MLE	Maximum Likelihood Estimates
MNL	Multinomial Logit
MNP	Multinomial Probit
MOA	Ministry of Agriculture, Ethiopia
MPP	Minimum Package Program
MUC	Marginal User Cost
N	Nitrogen
NGOs	Non-Governmental Organizations
OLS	Ordinary Least Square
PA	Peasant Association
PRA	Participatory Rural Appraisal
RSLE	Revised Soil Loss Equation
SCRP	Soil Conservation Research Project
SD	Soil Depth
SF	Seasonal Fallowing
SFM	Soil Fertility Management
SLEMSA	Soil Loss Estimation Model for Southern Africa
SSA	sub-Saharan Africa
SUEST	Seemingly Unrelated Estimation
SWC	Soil and Water Conservation
TGE	Transitional Government of Ethiopia
TLU	Tropical Livestock Unit
US	United States
USD	United States Dollar
USLE	Universal Soil Loss Equation
VCE	Variance-Covariance
WEPP	Water Erosion Prediction Project
WFP	World Food Program of the United Nations

Chilot Yirga Tizale was born at Woken, North Gonder Zone of Ethiopia in 1964. He earned a BSc degree in agricultural economics in 1986 from the Alemaya University of Agriculture (AUA). Soon after graduation, Chilot joined the then Institute of Agricultural Research (IAR) now the Ethiopian Institute of Agricultural Research (EIAR) as a junior researcher. After working for 4 years he rejoined the AUA and obtained MSc degree in the field of Agricultural Economics in 1994. Currently he is working in the same institution as a senior researcher.

In his thesis, the dynamics of soil degradation and incentives for optimal management in the central Highlands of Ethiopia, he addressed the very important problem of sustainability of current soil management practices and their long-term consequences for the welfare of rural people in the Ethiopian Highlands. Recognizing the inter-temporal nature and dynamic costs associated with the extraction of exhaustible natural resources such as soils, he modeled the dynamics of soil resource extraction and evaluated the consequences of ignoring this dimension for policy design and optimal land management decisions. In the modeling approach developed for dealing with the problem of exploiting non-renewable resource stocks he was able to extend earlier modeling attempts by incorporating innovative extensions to deal with the irreversible soil physical degradation through loss of topsoil as a result of erosion, which normally are ignored in the literature. The study also analyzed determinants of farmers' decisions to adopt soil conservation and fertility management techniques. The results of the study generated useful information for improved policy for optimal soil management and development for the promotion of appropriate smallholder farming technologies. So far one article in an accredited journal has been published and two manuscripts are under review for publication in international journals.