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Technology and policy impacts on nutrient flows, soil erosion and economic performance at watershed level: Application of a bio-economic model

B.N. Okumu,[a, b] *M.A. Jabbar,*[b] *D. Colman,*[a, b] *N. Russell,*[a, b] *M.A. Mohamed-Saleem*[b] *and J. Pender*[c]

a. University of Manchester, UK
b. International Livestock Research Institute, Ethiopia
c. International Food Policy Research Institute, USA

Background

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 soil nutrient balances arising from 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. The model is validated in the Ginchi watershed in the central highlands of Ethiopia. The current situation of limited technological and policy intervention in the watershed is compared with a situation involving single and multiple interventions. Given the current shift in focus from increasing agricultural production *per se* (through overcoming soil constraints to fit plant nutrient uptake by use of purchased inputs) to minimisation of external inputs use and maximisation of their efficiency, this study utilises a nutrient balance monitoring technique to gain insight on the effects of proposed technology and policy interventions on the gains and losses of major nutrients in the watershed. Hence judicious measures that manipulate nutrient flows to result in a reduction in nutrient losses or an increase in nutrient gains are explored.

Cross-sectional socio-economic and biophysical data from four land categories found in the Ginchi watershed, for the years 1995, 1996 and 1997, are used to test the model and are supplemented with on-station experimental data. Output from the validated dynamic model is then used to generate nutrient balances arising from the interactions and interrelationships between technological and policy interventions on one hand, and biophysical and human factors on the other.

Bio-economic model results

Two versions of the bio-economic model are generated; a static goal programming version; and a dynamic non-linear mathematical programming version. The static goal programming approach simultaneously optimises both environmental and economic goals of the watershed and its results are used to validate the dynamic model. The dynamic model optimises 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 chemical and dung fertiliser. Both versions of the model take into account seasonality 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 aspects of soil erosion and nutrient balances arising from these activities.

With limited technological intervention over a 12-year planning period, incomes increase by 50% from a very low base and average per hectare (ha) soil nutrient balances stand at −58 kg for nitrogen, −32 kg for phosphorous and −114 kg for potassium. Associated soil losses are 31 tonnes/ha. With a set of new technologies involving use of new high yielding crop varieties, agroforestry, organic (animal dung) and inorganic fertilisers, construction of a communal drain to reduce water logging and some limited land user rights, results show a 10-fold increase in incomes, 20% decline in aggregate erosion levels and an increase in the dependence on livestock for dung manure, oxen draft, milk and cash. Moreover, a minimum daily calorie intake of 2000 per adult equivalent is met from on-farm outputs and per ha nutrient losses after interventions are reduced to −25 kg nitrogen, −14 kg phosphorus and −68 kg potassium on average. There is hence a reduction in nutrient losses despite the higher reliance on the watershed for subsistence food requirements. The bias towards replenishment of nitrogen and phosphorous nutrients at the expense of potassium may, however, not be resolved. Emissions (leaching, gaseous losses and erosion) could be higher than imissions (atmospheric deposition and nitrogen fixation) in both situations.

Soil losses are also compared under three scenarios: only modest chemical fertiliser application to achieve a consumption target of 1500 calories/adult equivalent per day; multiple technology intervention to achieve a consumption target of 1500 calories/adult equivalent; and multiple technology intervention to achieve a consumption target of 2000 calories/adult equivalent. Security in land was assumed for the long-term. Results showed that with multiple technological and policy interventions and consumption targets of 2000 calories/adult equivalent per day, soil losses are likely to be higher than those generated under the multiple intervention situation with a minimum calorie intake of 1500/adult equivalent per day. With limited intervention and a similar calorie intake of 1500/adult equivalent per day, soil loss levels may be the highest. We may, therefore, conclude that when the set of multiple technologies are combined with a conducive policy environment such as a secure land policy, the result could be an outward shift of the watershed production possibility frontier that could enable higher outputs at lower biophysical and economic costs than before. The extent of this shift may, however, be reduced if self-reliance on food production for consumption at recommended levels is emphasised. Dependence on the market to meet some of the household food supplies, therefore, impacts positively on the sustainability of the watershed by enabling use of land based on land suitability and flow of outputs from surplus households to deficit ones through exchange. It also allows benefits related to the law of comparative advantage and the related economies of scale to be realised.

From a policy perspective, these results imply a need for a more secure land tenure policy than currently prevailing and provision of credit to ensure uptake of the above land management package. They also suggest a shift from a general approach to land management to a relatively more site-specific approach that emphasises spatial and inter-temporal variability in input use based on land quality. Such variable rate technology is known to be an efficient nutrient management strategy as it enables farmers to apply optimal rates of fertiliser for each field and in each period. Moreover, residual nutrient loading is simultaneously reduced. Implementation of such a strategy may be difficult in a developing country situation but an attempt to do so may yield results that are significantly better than at present.