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POLICY BRIEF

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THE INTERPLAY BETWEEN SMALLHOLDER FARMERS AND FRAGILE TROPICAL AGROECOSYSTEMS IN THE KENYAN HIGHLANDS

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LINKAGES BETWEEN THE SOCIO-ECONOMIC AND BIOPHYSICAL ENVIRONMENTS

Farmers obviously rely on the land for their livelihoods. The converse, that ecosystem services depend on farmers' behaviors, must also be recognized in order to improve agricultural productivity. Small farms in the central and western Kenyan highlands experiencing soil degradation provide an ideal context in which to investigate interactions between human behavior, natural capital stocks, and the flow of ecosystem services.

Small farmers routinely make decisions about land use and improvements, such as selection of crop varieties, livestock management strategies, soil nutrient amendments and labor allocations. These decisions fundamentally affect the growth of plants, production of livestock and functioning of soil micro- and macrofauna, which in turn affect soil structure and chemistry. To capture the complexity of Kenyan highlands agroecosystems, we are developing a dynamic, bioeconomic model under a project supported by the U.S. National Science Foundation, in close collaboration with the BASIS CRSP project. Our goal is to model the linkages between biophysical and economic processes and to calibrate the model to identify threshold levels of ecosystem services and their interlinkage with corresponding socio-economic thresholds defining wealth accumulation trajectories, following the economic concept of the poverty trap.

The existence of widespread persistent poverty raises the possibility of "poverty traps," states into which individuals, households, or even entire communities or nations might fall and from which escape is difficult. Nonlinear welfare dynamics with multiple equilibria (different steady states toward which households naturally gravitate at least one of which is below an appropriately defined poverty line) are characteristic of poverty traps. Capturing the economic aspects of poverty traps is complicated enough. But we aim also to link poverty dynamics with human responses and the impact that these have on the biophysical environment.

In order to capture poverty dynamics, measurements over time are required. Toward this end, we have collected panel data from households in two research sites in the Kenyan highlands, Madzuu (Vihiga District) and upper Embu District. We are exploring within- and between-site variation in assets, income and expenditures to unravel the causes of persistent poverty and to explore those poverty traps which emerge from soil biology and agronomy and economics of farm management.

Soil Degradation and Repletion

Soil degradation plays an important role in poverty in the Kenyan highlands, but the rates at which degradation occurs and at which lost nutrients can be repleted must be established. Critical to our understanding of these dynamics is determining whether irreversible thresholds exist. At what point, does soil become so degraded that rehabilitation is not practical? Our focus is on soil organic matter (SOM) because it is critical in maintaining the fertility of weathered, tropical soils. We also are studying N and P dynamics which are strongly related to SOM status in these soils.

To better understand the dynamics of N, P and organic matter depletion and repletion, we have collected data along a chronosequence in Nandi and Vihiga districts in Western Kenya with sites that were converted from forest to agriculture in 1900, 1930, 1950, 1970, 1985, 1995, and 2000. Samples from the forest provide the zero time points. When the sample blocks were selected, care was taken to ensure that the parent material of the soil, slope, and climatic conditions were similar for all conversions within a block. Four of the blocks emanating from the Kakamega and Nandi Forests consist of heavy textured soils while two blocks in the Kibiri-Tiriki area northeast of Madzuu contain sandier soils.

These chronosequence sites are being used for repletion experiments to determine soil and crop responses to the same N, P and OM inputs to compare soils with different levels of degradation. The goal of the chronosequence research is to determine the dynamics of long-term soil degradation and to relate the quantity and quality of SOM and soil nutrients in Embu and Madzuu to degradation states obtained from the chronosequence. We have collected detailed soils data from each of the plots in our Embu and Madzuu sites so as to link soil conditions and dynamics directly with socio-economic conditions and dynamics.

MODEL DEVELOPMENT

At the household level, we couple models of human and natural systems to identify emergent properties of the integrated agroecosystem. Events that occur beyond the farm boundaries that affect what happens to people, soils, crops and livestock are captured as exogenous variables. The general structure of our model is described in Figure 1. We have a biophysical model of soil dynamics in which state variables describe the soil. The dynamics are driven not just by the state variables, but also by external variables describing farmer decisions. Similarly, the state of the soil is an input into the crop and livestock production functions which, along with farmer decisions, determine the evolution of farmer wealth. For example, using the terminology in Figure 1, farmer's choices result in both biophysical and economic actions which in turn feed back into farmer's perceptions of their biophysical and economic status in the next time period (T+1). This structure permits us to examine discrepancies between the farmers' perceived realities and the conditions measured by the scientists involved in the project. Bearing in mind that both farmers and scientists filter out much of what is happening on the farm as they develop their perceptions, it will be interesting to see how close is the correspondence between the two.

EMPIRICAL RESULTS

Although our formal simulation model remains embryonic, we have sufficient soils and economic data to uncover some interesting relationships. The empirical social science findings, presented in a companion BASIS Policy Brief (#1), indicate that poverty traps indeed exist in Madzuu (analysis is ongoing in Embu). We seek now to establish whether these traps are linked, in either direction, to soils degradation.

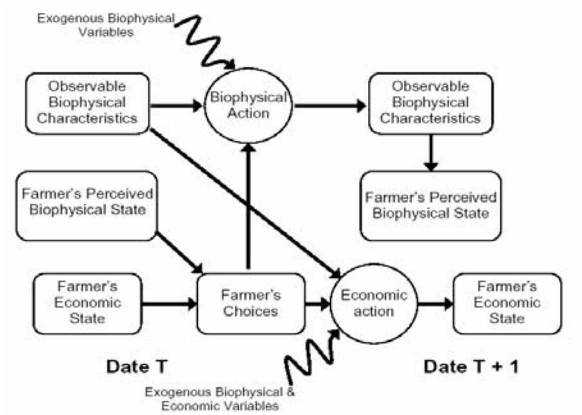
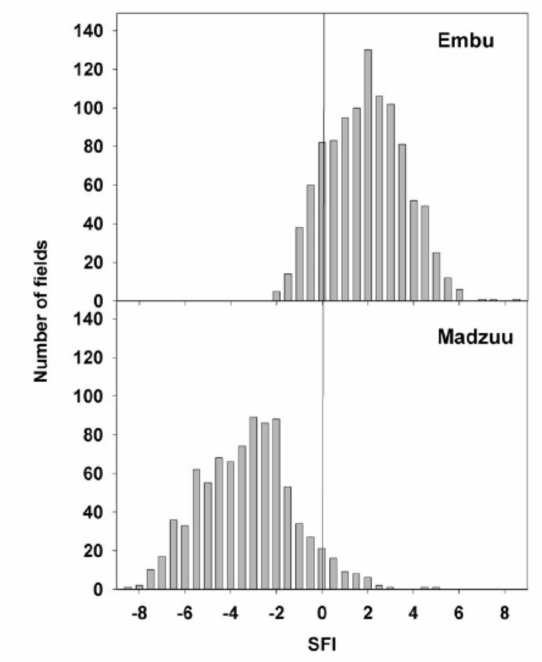


Figure 1. Conceptual diagram of bioeconomic model. The state variables are Observed Biophysical Characteristics, Farmer's Perceived Biophysical State and Farmer's Economic State. The circles represent equations that drive the two economic and biophysical modules.

Biophysical Results

The approximately 2000 soil samples collected from all plots of the participating farmers tell an interesting story about differences in soil fertility between Embu and Madzuu. Using a composite soil fertility index that includes five important soil attributes, we find that soils in Embu are more fertile than those in Madzuu, as shown in Figure 2. These data agree with farmers' perceptions. When the participating farmers were asked to evaluate whether their soils had improved or deteriorated over the past ten years using a 1 to 5 scale, the farmers from Embu were justifiably much more positive about the condition of their soils than were those from Madzuu.

We tested whether soil fertility varied by crop for the most common crops grown in each region. In Madzuu, soil fertility was highest in plots with home gardens, coffee and pasture while areas with napier grass, tea and fallow were the least fertile. The many maize fields were of intermediate fertility. These data confirm farmers' reports that, in Western Kenya, tea is a crop of last resort that is grown only when the soil cannot produce other crops.



Embu is similar to Madzuu in that there are significant differences in soil fertility among enterprises, but in Embu the most fertile fields are those with tea and pasture. The least fertile are those with maize and coffee, while bananas and fallow fields are of medium fertility. In Embu, milk and tea are the most important cash farm products and credit is available for fertilizer for tea from the local tea companies. Most of the cattle are improved dairy cattle which represent a significant investment and have the potential to yield a significant return. Embu maize yields are low because of acidic soils. Although people persist in growing maize for home consumption in this unfavorable environment, they **Figure 2. Distribution of soil fertility index from soil samples taken from all plots on all participat-ing farms in Embu and Madzuu.**

do not invest heavily in it. Historically, coffee has been an important cash crop, but marketing problems have meant that farmers have not been paid for the past several years.

The chronosequence study reveals that both carbon levels and enzyme activity decline very rapidly within 10 years of conversion from forest to agriculture, as shown in Figure 3. When we are able to couple these data with additional information on soil degradation, soil repletion, crop productivity and household economic status, we should be in a strong position to explore the complexity of the on-going conversations between farmers and their crops, soils and livestock.

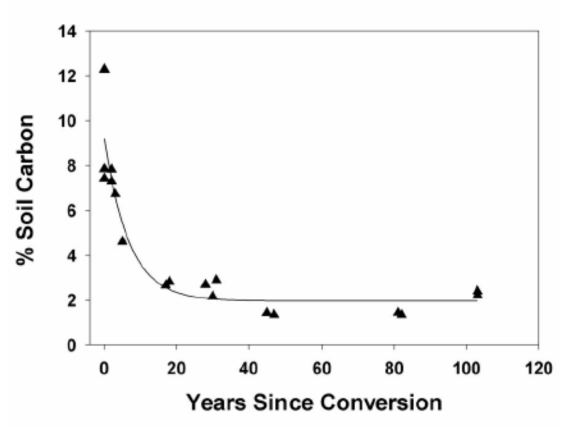


Figure 3. Percent of soil organic carbon in samples taken from one block of a chronosequence emanating from the Nandi Forest to Kapsengere.

SUMMARY

Considerable effort has been expended to determine how social and biophysical aspects of the agro-ecosystem might be linked in a dynamic model to explore the relationships between farmers' perceptions of their options and biophysical and economic processes. Preliminary data hint at linkages between socio-economic poverty traps and soil degradation. Longitudinal data from Madzuu indicate higher rates of farmer-reported and measured soil degradation than found in Embu, as well as generally lower crop and livestock productivity and standards of living. Our socio-economic panels have underscored the importance of off-farm earnings to investment in agricultural intensification and soil nutrient amendments in Madzuu. The chronosequence sites are providing useful information on the dynamics of soil depletion and repletion that will be used to parameterize our soils submodel. Most importantly, we have developed a model structure that permits us to monitor the exchanges between farmers and their biophysical environment.

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FURTHER READINGS

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