Land Degradation in the Sahel:

An Application of Biophysical Modeling

in the Optimal Control Setting

by

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Abstract

Low-input farming practices in many parts of the developing world have pushed cultivation onto marginal lands. Sustainability of already fragile ecosystems is threatened. Farmers place a high priority on satisfying subsistence food needs with on-farm production. Population pressure is high throughout much of Sub-Saharan Africa. Farmers in those regions are challenged by the need to put continually more food on their table over the coming years. An optimal control model was developed to investigate alternative farming practices within this setting. Namely, whether farmers would choose continued land expansion of if they would adopt crop intensive practices. The model included an environmental subcomponent to estimate the degradation costs from continued expansion onto marginal areas. The modeling activities from the Sahel of West African reinforce farmers' observed propensity to clear new land in lieu of crop intensification. Model activities suggest an important role for crop intensification under adequate policy conditions as well as the need to introduce new technology before degradation erodes its potential.

INTRODUCTION

Soil degradation has emerged as a primary concern for policy makers. Degradation can significantly reduce the soils capacity to produce food and sustain rural livelihoods (Lal 2001). Having subtle changes, soil degradation can be overlooked as a major problem to the agricultural sector. Yet noticeable declines in farm productivity, agricultural GDP, and global food losses from soil degradation have been reported. Over the past half-century, soil degradation has been estimated to account for about a 9 percent decline in yields, agricultural GDP losses from soil degradation have reached as high as 10 percent, and global food production losses due to soil degradation have been estimated to be about 9 percent of total world food production (Bishop and Allen, 1989;Stocking and Pain, 1983;Lal 2001). If soil degradation is not adequately addressed, it is likely to jeopardize future food security for many countries in the developing world (Scherr and Yadav, 2001).

The effects of soil degradation are of particular concern for Sub-Saharan Africa (SSA). Many areas have been identified as environmental "hot spots" for declining soil nutrients, soil erosion, and vegetative degradation (Scherr and Yadav, 2001). SSA countries are particularly susceptible to soil degradation. The hot and dry agro-climatic conditions that typify much of the sub-continent expose soils to extreme conditions; natural means of soil restoration are weakened. This explains, in part, why the region's food production losses from soil degradation are about 6 percent higher in SSA than the global average (Lal 2001). Globally speaking, degradation is afflicting most of its damage on countries that are least equipped to cope with it. SSA countries are highly dependent on agriculture with limited ability to satisfy food security concerns through imports.

In the Sahel of West Africa population pressure continues to strain already fragile agro-ecological systems. Farmers will have to sharply increase food production if there is any hope of reaching long-term food security benchmarks (Sanders et al., 1996). The traditional response of farmers to population pressure has been to clear more land. With increasing land scarcity farmers have pushed production onto marginal lands. In northern Burkina Faso, for example, the change in land use for a typical village between 1945 and 1995 showed an annual increase in land use roughly proportional to annual population growth, about 2.5 percent (Reenberg et al. 1998). In Mali, satellite imagery on cropland use intensity (CUI) reveals a significant number of areas in a high land-use intensity state, where active cropland constitutes over 90 percent of available land (FEWS 1997).

The move onto marginal lands is an initial strategy, adequate for the short run. Over time the associated environmental consequences are expected to grow large over time. Marginal lands serve an important role in these ecosystems as natural barriers to wind and water erosion through their vegetative covering; they protect the higher quality lands found lower on the toposequence (Vierich and Stoop, 1990). Once stripped of vegetation farmers fields are subjected to higher erosion rates and accelerated yield declines.

Factors have been identified that explain why farmers often employ poor land management practices: connections between poverty and soil degradation (Reardon and Vosti, 1995), the effect of poor agricultural polices on soil degradation (Heath and Binswanger, 1996; Lopez 1997), and the lack of private ownership in the traditional land tenure system (Larson and Bromley, 1990). The link between poverty and degradation[1] are primarily rooted in liquidity constraints. Agricultural investments are difficult to make and usually pushed aside by more immediate concerns. Food subsistence needs and income targets manifest into implicitly high discounting rates of future returns. In many countries, poor economic and agricultural policies have discriminated against domestic farmers and often the result has been depressed market prices and inadequate access to new technology. Hence, directing farmers toward improved land management requires an understanding of both the economic realities faced by farmers and the underlying bio-physical processes to soil degradation.

Proactive policy engagement is required to point farmers in more environmentally responsible directions. Poor land management at the farm and village level will eventually be felt by others. Spillover effects could bring large social costs: national food security goals could even be jeopardized. Developed countries have long been aware of environmental costs. Land conservation programs are firmly entrenched in their agricultural policies. They provide farmers with incentives to adopt more environmentally savvy land management practices. Programs have been successful in mitigating both on and off-site costs.

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[1] This paper will show that under existing socio-economic conditions, farmers have a strong incentive to clear new lands as opposed to intensifying production. The advantages of extensification in the short run are clear to the farmer: new lands bring forth an additional supply of soil nutrients at a lower cost than purchasing fertilizers to replenish soil nutrient stocks on already cultivated lands.

Land intensification and technical change have the potential to end cycles of poverty and to pull farmers out of environmental “downward spirals”. The shift in developed countries towards science driven agriculture, and away from resource based agriculture, has made a myth out of the “dismal economics” that had previously characterized population and land pressure. Science based agriculture is on the rise in SSA. New technologies have been developed to make more efficient use of water, increase soil fertility, and provide farmers with modern germplasm that better responds to the improved agronomic conditions. Advances have been made in both food and cash crops. Even in the drier areas where sorghum and millet are the staple foods, new technologies have been developed. Significant yield increases have been reported by experiment stations and farmers (Matlon 1990). The adoption of new technology in the traditional crops has been limited. It is believed that institutional factors and poor policies[2] explain the modest adoption. Reversing cheap food policies and giving farmers competitive prices would spurn technology adoption in the staple foods, increase food production, and give farmers higher incomes (Coulibaly et al. 1998).

Along with improved technology is the need for better market infrastructure. Expanding markets in the urban areas will bring higher prices and reduce the tendency for prices to fall when yields are good. It would also increase trade among the higher potential zones in the semi-humid areas and the drier semi-arid areas (Barbier 1998). The semi-humid areas of the Sahel have been one of the more successful regions for new technology introduction. Coupled with a longer and more reliable rainfall season, these regions have a strong potential to supply the areas prone to inadequate rainfall (Sanders et al., 1996). It is believed that farmers associate a fairly high cost with market participation; this motivates them to produce nearly all of their food on their farm. If cereal markets were improved, then farmers in the drier areas are likely to increase market participation. The reliance of food produced on the marginal lands[3] could be reduced as cereals purchased in the market could be used to supplement on-farm food production.

To investigate how farmers’ land use is likely to change over time as farmers respond to population pressure, this paper begins with a conceptual model of farmer’s decision making. The model includes soil degradation, and focuses on how the choice between continued land clearing and intensification is determined by the farmer. An empirical model is then constructed, and is used to test two factors thought to explain excessive land clearing: high future discount rates and lack of liquidity. The model is then used to

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[2] Three specific factors that have hindered efforts to intensify are the generally poor marketing infrastructure, the low profitability of mineral fertilizer applications, and weak off-farm income opportunities. The poor marketing posture results in depressed revenues in times of surplus, and high food prices when on-farm production falls below subsistence. The high food prices combined with low incomes places a particular burden on the household, which manifests in a strong preference towards producing subsistence food needs. This response to risk results in a crop portfolio that is geared towards food production in the below normal rainfall years, and in cases where farmers overcompensate the pressure on land is significantly increased. The weak off-farm income opportunities eliminates an alternative manner of generating liquidity for purchasing agricultural inputs.

[3] Production on the higher quality lands near the bottom of the topo-sequence would be maintained.

test the effectiveness of policies to mitigate poor land management practices through improved food markets.

The focus of this paper is on the Sudanian region of southern Mali, the country’s primary cereal producing region. The primary constraint to production is low soil moisture availability, as a large portion of the regions’ precipitation is lost to evapotranspiration and water runoff. This region is an appropriate case study for environmental degradation since population pressure and the lack of quality lands has significantly reduced fallow periods. Expansion onto marginal lands has already taken place in many areas, and the subsequent degradation and inherent low productivity of the marginal lands is likely to pose a threat to feeding a fast growing population over the coming few decades. The conditions found here also confront farmers in other countries of the West African Sahel.

CONCEPTUAL FRAMEWORK

The use of bio-economic modeling in studying environmental effects of land use change in smallholder farming has been established in a general framework (Beaumont and Walker, 1996), and applied to case studies in Mexico (Barbier 2000, 1); Mali (Ruben and van Ruijven, 1998); Ghana (Lopez 1997); Philippines (Shively 2001); and Senegal (Sankhayan and Ofsted, 2001). The modeling approach in this paper is similar to all of those previous works in the use of an integrated framework and a focus on how farmers internalize degradation costs.

An integrated framework is used to link crop choices made in the short-term with their emerging consequences on long-run natural resource management. Focus is placed on farmer’s choice between alternative farming practices: land extensification and crop intensification. Included are the effects and consequences of land clearing and soil degradation, how these effects accumulate over time, and the extent to which they can erode long-run benchmarks of agricultural performance.

Environmental Module: Land Degradation

Soil degradation is accelerated by the removal of vegetation that accompanies land extensification and other land clearing[4] activities. As plant leaf area and canopy cover is reduced, the quantity and speed of surface water runoff increases. Higher erosion rates emerge as soil particles are more easily dislodged and carried away from the soil surface. Off-site there is increased channeling of water to other portions of the watershed; the potential for flooding is increased. Soils harvest less of the water flowing over their surface; water percolation into the soil profile is reduced.

The removal of vegetation also affects conditions beneath the soil surface. Land clearing typically replaces woody species with standing crops; the root volume within the soil

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[4] This includes wood clearing for fuel wood, brush fires, and the removal of grasses and shrubs by foraging animals.

profile is reduced. This weakens the soil structure: soils are more prone to erosion, becoming unstable, and shifting. It also reduces the amount of water retained in root structures. Lateral flow hydrology within the soil profile is compromised. Water flow parallel to the soil surface is accelerated. There is increased channeling of water to adjacent fields and the watershed.

More subtle effects occur over the long-run: these create an additional, non-anthropogenic loss of vegetation. Land clearing creates harsher growing conditions for the plants left standing in its wake. Those plants have less water available for growth, a reduced supply of soil nutrients, and must contend with higher soil erosion rates. The health and long term survivability of those plants are compromised. As plants dwindle in size and number, the process of soil degradation is allowed to continue[5]. It proceeds in the same manner as the anthropogenic land clearing described above. Feedback between anthropogenic and non-anthropogenic land clearing accelerates land degration.

The extent of land degradation depends on the types of plant species removed as well as those left standing. Removing grasses reduces the basal coverage area. Water runoff is significantly increased, but there will be only minor impacts beneath the soil surface. Removing forbes and tress reduces canopy coverage and creates significant changes beneath the soil surface. Surface water flow is somewhat increased and wind erosion is . surface water flow reduces the soil's natural barrier from wind erosion, but the primary effect of trees will be on the changes beneath the soil surface.

The extent of the vegetation removal can be measured in terms of changes of leaf area index (LAI) and canopy cover. The LAI can be used as an input to base estimates on the changes in land and soil degradation that would occur with vegetation removal; this allows specific ecosystems to be evaluated on the basis of the species that exist within them.

The environmental module is based on SWAT, a land use/land change model. SWAT contains a comprehensive treatment of the changes in hydrology and vegetation that stem from land clearing.

Bio-Economic Module: Private Costs of Degradation

Smallholder farmers throughout SSA have been found to make decisions according to multiple-objectives (Barnet et al., 1982). Generally speaking, however, the most important objective to farmers is satisfying food subsistence needs. This can be viewed as an extension of Roy's safety-first method of risk analysis: subsistence needs are satisfied before profit motives are considered (Roy 1952). Preferences for natural resource management are revealed in farmer's willingness to trade-off income over time. Current income must be forgone to maximize long-run income streams. Formal estimates of

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[5] An additional effect that occurs over time is a change in the species composition. This could lead to a dominant species that would have undesirable effect on agriculture as a parasitic plant, through introducing a host pest, or through removal of more desirable species for animal forage.

farmers' preferences for natural resource management are still under study. It is widely believed that farmers discount future income.

The bio-economic module provides feedback between the economics of today's crop choices and the biophysics that explain long-term changes in natural resources. An optimal control model is used since degradation changes over time; a dynamic updating equation is required. The optimal control model includes farmers' lexicographic preferences for food subsistence requirements:

$$Max.\ e^{-\beta t}\int_0^T\int_0^F (P_t Y_{\phi At} - C_{\phi At})\,dA\,dt \qquad (1)$$

Subject to:

$$\int_0^F Y_{\phi At}\,dA + B_t \geq e^{rt} HH \qquad (2)$$

$$\frac{dY}{dt} = E_{\phi AF} Y_{\phi AF} \qquad (3)$$

There are two decision variables in the model, F and ϕ. F is the frontier of farming, the location where land clearing has ended. Crop intensification, ϕ, is an ideal index of inputs used in production. Crop yields, Y, are the flow variables. Yields are updated according to soil erosion E. Yield potential depends upon the frontier, F, intensification, and slope location, A.

Equation 1 states the farmer's objective: maximize the net present value from a stream of future incomes. The two decision variables in the model are the level of technology, ϕ, and the frontier, F. Farming is along an idealized slope that represents the change in soil quality that is associated with the topo-sequence's altitude, A. Yields, $Y_{\phi At}$, depend upon the location along the topo-sequence, A, as well as technology, ϕ. Profit is given as the sum of revenue (yield times price, P_t) less production costs ($C_{\phi At}$). Annual profit is obtained by integrating along the slope from 0 to the end of the frontier, F, and the present value of profits is obtained using the discount factor β.

Equation 2 is the food subsistence constraint: this assures that the farmer produces enough food to feed his family. One consequence of a fast growing population is increased food demand. Subsistence goals continue to grow over time in proportion to household size. Food production targets, as given by the right hand side of Equation 2, as e^{rt}HH. In principle the model permits buying food to satisfy subsistence requirements. Access to credit and off-farm income sources is typically weak in rural areas. Field surveys indicate that households purchase only limited quantities, even if the opportunity cost of producing food on-farm grows large.

Equation 3 is the flow equation; it describes how yields, Y, change over time in response to soil erosion, changing water availability, and nutrient depletion. Since farming takes place along an ideal slope yields also depend upon slope location, A. Farming proceeds up the slope and stops at the frontier, F. The consequences of land clearing induce yield degradation on soils that lie under the frontier. Yields decline according to E, an erosion parameter. Erosion increases as the frontier moves out and more land is cleared. More intensive practices better mitigate soil erosion. Location plays a critical role in determining yields. Productivity is highest along the lower portions of the slope, but falls off as soils get shallower and the slope grades steeper (Dalton 1996). Yield potential declines over time as the frontier is moved out.

The traditional land tenure system allocates farmers throughout the slope. By and large the distribution of the quality lands is equitable. So, as the village shifts the frontier upward, each farmer is affected in roughly the same manner[6]. Erosion and productivity losses from land clearing will be within the confines of a representative farmer's fields.

The actual preferences for managing yield degradation are not well documented. It is expected, however, that farmers internalize at some of the on-site degradation costs in their private decision making. The two factors included in this model that determine their preferences for internalizing degradation costs are the discount factor, β, and the planning horizon over which farmer's decisions are made, T.

Yield Degradation and Technology Choice

Optimal conditions support the well-observed propensity for land clearing. Consider for instance a sudden increase in household growth rate.). The key issue is how the farmer responds. Would he choose to intensify his production through increasing ϕ or by expanding the frontier F?

Comparative statics at any point in time t indicates that the net present value of the income stream, H, is more easily increased through pushing out the frontier than through intensification[7]:

$$\frac{\partial H}{\partial F} = P_t Y_{\phi AF} - C_{\phi AF} - \lambda_{1t} Y_{\phi AF} - \mu_t \frac{\partial E_{\phi AF}}{\partial F} Y_{\phi AF} - \mu_t \frac{\partial Y_{\phi AF}}{\partial F} E_{\phi AF} = 0 \tag{4}$$

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[6] The model presented here cannot capture the effects of externalities arising from the communal land tenure system. However, it is likely that within the extended family organization of the village, the farmer would internalize degradation costs imputed on fellow village members nearly to the same extent as he would his own. This paper also does not address village level decision making on land clearing; these decisions are presumed to be undertaken by village farmers acting as private agents.

[7] The concern here is optimality of decision variables, F and ϕ. Provided that Hamiltonian at those points is concave according to μ (co-state variable) , then the necessary optimality conditions are sufficient.

$$\frac{\partial H}{\partial \phi} = P_t \frac{\partial Y_{\phi AF}}{\partial \phi} - \frac{\partial C_{\phi AF}}{\partial \phi} - \lambda_{1t} \frac{\partial Y_{\phi AF}}{\partial \phi} - \mu_t \frac{\partial E_{\phi AF}}{\partial \phi} Y_{\phi AF} - \mu_t \frac{\partial Y_{\phi AF}}{\partial \phi} E_{\phi AF} = 0 \qquad (5)$$

Rewriting these equations the choice between continued land clearing, F, and intensification, ϕ, becomes more apparent[8]:

$$\lambda_{1,\mathrm{t}} = \frac{\partial \mathrm{C}_{\phi A\mathrm{t}}}{\partial \phi} \bigg/ \frac{\partial Y_{\phi A\mathrm{t}}}{\partial \phi} \qquad (6)$$

$$\lambda_{1,\mathrm{t}} = \frac{\mathrm{C}_{\phi A\mathrm{t}} + \mathrm{D}_{\mathrm{t}}}{Y_{\phi A\mathrm{t}}} \; . \qquad (7)$$

Equation 6 is the FOC associated with the frontier location, F: it equates the average cost of yields at the frontier plus the present value of increased food costs from degradation (D_t) to the marginal cost of satisfying home production, λ_{1t}. Equation 7 is the FOC for the intensification parameter, ϕ: it equates the marginal cost of increasing yields (through intensification) to λ_{1t}, the marginal cost of satisfying home production at time t.

Farmer's response to population pressure, hence, depends upon three factors: (1) the yield response to intensification efforts along the slope; (2) the cost of increasing yields from intensification relative to the absolute yields obtained more cheaply from extensification; and (3) the extent to which the farmer internalizes resource degradation costs into his decision making (through longer planning horizons and lower discount rates).

Intensification is only profitable at locations where the marginal cost of increasing productivity from intensification is lower than the average cost of production at the frontier. This is clearly a challenge to technology, since yields on the frontier are typically about one-third of the yields from intensification, yet the out-of-pocket costs from intensification are often ten to fifteen times as large (Coulibaly 1995; Dalton 1996). Thus, it reasonable to expect that intensification would be limited to small areas lower on the topo-sequence where the response to intensification is greatest. This suggests that extensification would be the farmer's primary response along other areas of the frontier.

The exception to this would be farmers with a long time horizon. Given the ideal slope, expansion onto marginal lands increases erosion run-off and degrades soil across the topo-sequence, reducing productivity (lower yields) on all of the farmer's fields. If these degradation costs, D_t, are large enough, then the costs of extension would grow large enough to make intensification more attractive and reduce land clearing.

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[8] For convenience the price, P, is set to zero. Food price is instead interpreted by the shadow value, λ_{1t}; this is the implicit value households place on food. Higher prices would make the argument even stronger that frontier expansion gives a higher income stream.

EMPIRICAL MODEL

The theoretical model presented above is the basis of an empirical model of farmers' decision making. The empirical model includes additional aspects of household decision making as well as a practical implementation of the idealized slope. The lack of formal credit institutions leaves households liquidity constrained; this affects farmers' ability to purchase food and inputs. Market purchases play an important role in satisfying food subsistence goals. Farmer's often-stated preference for using home production to satisfy subsistence indicates a certain degree of aversion to relying on markets. This preference can be explained by the uncertainty in cereal prices and cash availability. Farmer's are considered to plan for market purchases in a conservative manner, assuring that they can be financed even if cereal prices rose and their income fell. To capture this phenomenon, in the empirical model we include a cash constraint that limits the amount of food that can be purchased to 15 percent of the household's subsistence level.

A second liquidity constraint is included to limit the amount of cash available for purchased inputs. Observations indicate that about $150 would be available for purchased inputs (Coulibaly 1995). Households invest in purchased inputs provided that the returns are sufficiently large relative to returns from alternative uses.

Frontier expansion allows new land to be brought into production. Labor is the limiting factor in these regions; peak labor demands during critical periods of the growing season set upper limits on how much land can be farmed per household (DelGado 1990). Over time, household labor supply increases with population growth. This provides the additional labor required to farm the newly introduced lands. Labor constraints at critical periods of planting, weeding, and harvest are included in the model.

The empirical model is discrete in time, space, and technology; this representation allows for numeric solutions using computer software (GAMS). The idealized slope is approximated by dividing land into four types of varying quality: alluvial, low-slope, mid-slope, and marginal. This maintains consistency with the observed land tenure system that grants to each farmer a handful of plots. The higher quality plots are rationed to maintain a fair degree of equity among villagers. Using field observations, the prototypical farmer is taken to have 5 ha of the high quality land. Additional plots are more marginal; they are introduced through extending the frontier further up the slope.

Environmental Simulations

The transition of crop yields over time (Equation 3) was obtained[9] using SWAT. This is an environmental model that details interactions between land use patterns and watersheds. For agricultural purposes it is used to simulate changes in farm and land management practices on crop yields, hydrology, and off-site pollution.

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[9] The yield estimates in this paper are a first attempt at quantifying the long-run yield effects induced by land clearing. Next generation estimates will use SWAN, an updated version of EPIC that can more systematically handle changes in surface and sub-surface water flow along the topo-sequence.

A micro-watershed was developed in this study using SWAT. It was based upon the approximated version of the ideal slope. The micro-watershed details changes in slope hydrology as land clearing pushes out the frontier. Plant growth processes are included in SWAT. These are daily growth models based upon the method of limiting factors. Routines determine whether soil water, soil nutrients, or air temperature is the most limiting factor.

The plant growth modules contained within SWAT were used to estimate the dynamics of crop yields (Equation 3). SWAT's internal processes well simulate the types of yield degradation process discussed in the Conceptual Framework (see above). Crop yields are based upon several biotic factors that include: a detailed soil layer profile, macro-nutrient supply, soil moisture, temperature, and humidity. SWAT tracks soil erosion and the flow of soil nutrients over time.

Baseline yields for the first year of the simulation were calibrated to observed yields in southern Mali (Coulibaly 1995; Dalton 1996); calibration of the future yield was limited since data on long run erosion is scant. Thirty-five year simulations were run; SWAT's internal weather generator was used for rainfall, temperature, and wind. Data from a Mali weather station was used to seed the generator. Simulation results provided the input to develop crop yield meta-functions. The long-run effects of erosion and the changes in slope hydrology are contained in the crop yield meta-functions; this provided empirical estimates of Equation 3.

Model Data

The prototypical household has a size of 26 persons under baseline conditions. Typically about one-half of the household is available for agricultural labor throughout the growing season (Coulibaly 1995). During peak labor demand periods, planting and harvesting, the remainder of the household is made available. Household labor supply was increased at the same rate as the growth in household population (i.e. no urban migration). Annual growth rates are about 3 percent in this region. Travel time to the marginal fields was accounted for by increasing labor demand.

Data on the rate which farmers discount future income streams is not available. In its place the planning horizon, T, was varied from 5 to thirty-five years. Within each planning horizon future income streams were not discounted. Model results at the end of T years were used as initial conditions in year T+1; consecutive model runs were used to obtain a 35 year planning horizon.

Scenarios

The empirical optimal control model is used to analyze three scenarios: Baseline, New Technology, and Market. The scenarios encompass the range of conditions likely to be encountered by a typical farmer over the long-run from 2000 through 2035. In the

Baseline scenario, farmer’s per-capita income, food prices, and input prices are all held fixed at year 2000 levels. In the New Technology scenario changes in input costs are considered. This accounts for varying types and effectiveness of input distribution channels. In the model runs, all of the input costs required for intensification are increased at the start of the simulation in 2000; they remain fixed for the entire simulation period. Finally, in the Market scenarios the effects of lower long run food prices from improved market infrastructure are considered. In all three scenarios, per-capita income available for purchasing food and inputs remains constant.

RESULTS

With short planning horizons, as would be expected, land extensification is the more economically attractive alternative. Fresh stocks of nutrients appear to be “freely” available in the marginal lands; this is much cheaper than replenishing soil macro-nutrient stocks using chemical fertilizers on already cleared lands. In the Baseline scenarios, the model results indicate that a much faster conversion rate of marginal land occurs for farmers that plan over short horizons, such as 5, 10, 15, or 20 years (Figure 1). Over the first twenty years of the simulation period, land clearing corresponds to an average increase of about 5 percent for farmers with a planning horizon less than fifteen years. This is about two percent higher than the concurrent growth in population. It would appear to be an acceleration of land clearing compared to the field observations from Burkina Faso that was noted above.

The effects of degradation only become apparent when it is too late when degradation costs are ignored in the short-run. Degraded lands are much less responsive to intensification and would take many years to be restored back to any semblance of their original conditions.

When farmers plan over a longer horizon of at least thirty years, land clearing is significantly reduced. Land clearing would not even begin for the first ten years (Figure 1). Throughout the first twenty years, marginal land clearing would be less than one-half of the clearing that would take place for farmers with a shorter planning period. By comparison, the average increase in land clearing would be less than the growth in population.

Longer planning horizons include more of the future degradation costs that induce intensification early on in the planning horizon before degradation sets in. This occurs at the optimal time when new technology responds best to the agronomic conditions. With more intensive farming in the initial years, less degradation is encountered later in the planning period, and the need to clear additional land is reduced.

New Technology Scenarios

This scenario considers the effect of improved access to new technology. This change, modeled as a reduction in input costs, had only a slight impact on land clearing practices when the farmer's planning horizon was relatively short. Reductions in input costs of up to 50 percent from existing levels induced only a minor increase in intensification. The ineffectiveness of lower input prices in mitigating resource exploitation appears to be caused by the short planning horizon so that the prototypical farmer continues to view land clearing as the most profitable alternative, and fails to incorporate enough of the future degradation into present decision making. The reason that farmers with short planning horizons are unaffected by changes in input prices is that they utilize few purchased inputs.

With longer planning horizons such as thirty years, the effect of higher input prices is to greatly shift the farmer's food security strategy from self-sufficiency to one where food markets are used to satisfy subsistence (Figure 2). This shift in food security strategy would begin if input prices increased by at least 50 percent, and increases if input prices were to increase by 100 percent. The switch would occur at around the tenth year of the planning horizon, about one-third of the way to the 2030 benchmark.

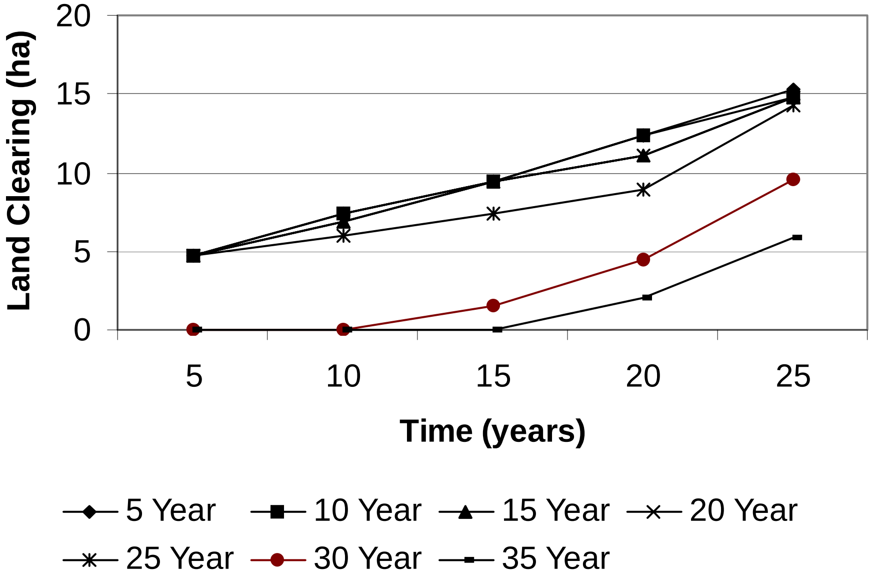

Figure 1 Land Clearing for Several Planning Horizons

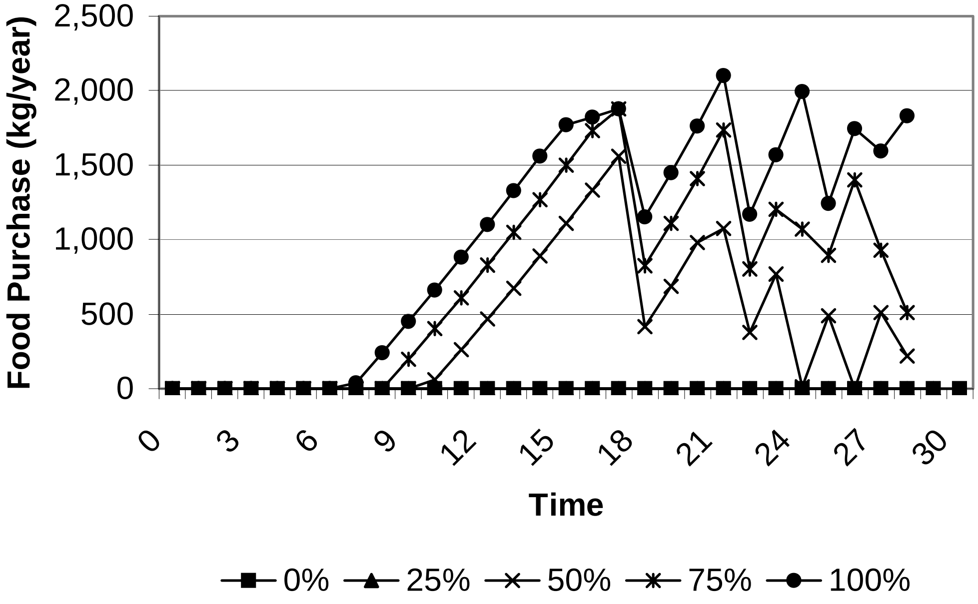

Figure 2 Food Purchases Under Influence of Higher Input Costs (35 Year Planning Horizon)

Market Scenario

When the prototypical farmer has future expectations of lower cereal prices, land clearing is only changed slightly[10]. This is explained since for the first 25 years of the planning period, farmers are self-sufficient, and do not rely on market purchases to satisfy food subsistence. As with the input prices, the effect of the short planning horizon appears to dominate farmer's decision making, and fails to realize the benefits from a strategy that uses food purchases to reduce home production and mitigate degradation from marginal land clearing.

Discussion

The results indicate three different land use patterns that might emerge. The most environmentally sound pattern would be if baseline input prices were maintained and farmers were able to have a sufficiently long planning period of about 30 years. Intensification would occur early on, marginal land clearing would be minimal, and farmers would remain self-sufficient throughout the simulation period. A slightly less environmentally sound land use pattern would result if input prices increased. In this case, farmers would need to purchase food to meet subsistence needs fairly early in the simulation period, although land clearing would only be slightly higher than when input costs do not increase. The third land use pattern is the least environmentally attractive case, and corresponds to farmers having a short planning period. This would result in substantial land clearing, food aid requirements by the year 2025 and degraded lands by the year 2030. Moreover, the short planning periods would not respond to policies aimed at mitigating land clearing through lowering input and food prices.

CONCLUSION

Our results indicate two aspects of the farmer's planning problem that policy makers might seek to influence to diminish soil degradation. First, they might seek to find innovative ways to extend the scope of farmer's planning to include future degradation costs. Second, they might work to create efficient input markets to provide farmers with new technology before significant soil degradation is encountered.

Extending farmers' planning horizon will not be easy, since farmers face immediate economic concerns and are likely to have rather high discount rates. Still, there will be a need to emphasize the importance of the need to switch to intensification early on before significant degradation has taken place, otherwise the productivity gains from intensification will be lost to degradation.

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[10] Model runs not reported in this paper showed less than a 5 percent change in land use among any of the planning horizons.

If input markets are not well developed, then policy makers would need to be aware that increased cereal flows into the drier areas from the higher potential zones would be required. The need for cereal flows to flow from the higher potential areas to the drier zones requires additional considerations for the policy makers. An important question is whether the supply response from the higher potential zone would maintain low food prices, affordable to consumers, while still being sufficiently high to provide incentives to producers. It might be the case that food exports could only be achievable with additional technology introduction in the semi-humid zones, which is likely to require complementary policies to assist development of the input supply channels. Also, consideration would need to be given to whether the higher potential zones would incur significant soil degradation as a result of their exports to the drier areas.

If planning periods are not extended, a second and much less desirable land use pattern would result. This pattern would leave the environment fairly well degraded by the year 2030, even though farmers appear able to meet the 2030 benchmarks. With short planning horizons, increasing population pressure does not coincide with higher levels of intensification that might have been expected. In this case, the falling costs of labor, coupled with the cheap stocks of nutrients contained in the marginal lands, are more profitable than intensification techniques, and the associated degradation costs from land extensification are not visible in the short run planning.

The short planning horizon appears to be the driving factor in farmer’s decision making. Policies to lower food prices to reduce pressure to home produce food, or lowering input prices to induce more intensification, would be ineffective in reducing farmer’s propensity to clear new land. The short-run profitability of the new lands are made very apparent to farmers with a narrow temporal view, and could only be overcome by very aggressive, and most likely unrealistic, input or food subsidies.

Policy makers should be aware that future expectations of greater cereal availability, such as the food aid, could increase land clearing from moral hazards. Farmers would have reduced incentives to conserve land resources since future food aid would be available after significant resource degradation has already taken place, which is likely to be a cheaper alternative to the farmers than mitigating degradation through proactive intensification. Ironically, the poverty trap is likely to provide some incentives to conserve, since limited future food purchasing power induces farmers to maintain home food production out into the future.

Clearly, one place for policy makers in the West African Sahel to look for optimism is the Machakos district of Eastern Kenya (Barbier 2000, 2). There the combination of market linkages, improved crop production practices, and adequate policy have been sufficient to counteract the effects of environmental degradation, and to maintain significant human carrying capacity. While the extent that this can be translated to different agro-ecological and socio-economic conditions remains to be studied, it points out the potential for appropriate incentives to move farmers to adopt more environmentally friendly production methods.

As for future research, it is suggested that next generation modeling activities include a more general set of land clearing activities, such as over-grazing marginal lands and deforestation associated with firewood. The social costs would also need to be expanded to include the negative impacts from lower village livestock populations and reduced land available for the nomadic pastoralists who rely on communal grazing lands during the dry season. Considerable feedback among the three activities is expected as they compete for a continually shrinking supply of land. Additional analysis could also consider how poor weather would factor into the farmers decision making, and if it would further aggravate land extensification through production risk.

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