

Promoting More Sustainable Land Use in the Semi-Arid Tropics Through Improved Market Infrastructure: A Malian Case Study¹

Jeffrey D. Vitale² and Richard Woodward³

ABSTRACT

This paper is concerned with the extent to which semi-arid regions should remain involved in food production. Current low-input farming practices in these drier areas have pushed cultivation onto the marginal lands, threatening the sustainability of their already fragile ecosystems. With higher productive zones available, such as the Sikasso region of Mali, increased food flows into the semi-arid areas could be used to relieve land pressure. Central to this question is the priority that farmers place on satisfying subsistence food needs with on-farm production, a strategy that avoids risk from high market prices should drought conditions ensue. To determine the feasibility of increased food flows, a farm model was developed that detailed the additional risk farmers would need to incur if they increased their reliance on food markets. The model included an environmental subcomponent (EPIC) to estimate the degradation costs from continued expansion onto marginal areas. Policies to improve market infrastructure resulted in a significant decrease in the use of marginal lands. The modeling activities suggest a reduced, but more sustainable, role for food production for the semi-arid areas.

INTRODUCTION

Soil degradation has emerged as a primary concern for policy makers since it can significantly reduce the soils capacity to produce food and sustain rural livelihoods (Lal 2001). Although the effects of soil degradation are subtle in the short run, and often appear to be overcome by technology or land expansion, noticeable declines in farm productivity, agricultural GDP, and global food losses have been reported due to soil degradation. 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).

Author Contact: Jeffrey D. Vitale, Email: jvitale@tamu.edu

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²Texas A&M University, ³Texas A&M University

The effects of soil degradation are of particular concern for Sub-Saharan Africa (SSA), as 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 susceptible to soil degradation due to their hot and dry agro-climatic conditions that prolong the natural means of soil restoration compared to more temperate regions. 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). The impact of potential losses in agricultural GDP is more severe in these countries since their economies are highly dependent on agriculture, and they have limited ability to enhance food security through imports.

In the Sahel of West Africa, population pressure is expected to aggravate the problems associated with soil degradation, and to place additional strain on already fragile agro-ecological systems. The resulting increased food demand means farmers will have to sharply increase food production if there is any hope of reaching long-term food security benchmarks, such as year 2020 scenarios (Sanders et al., 1996). So far, the response of farmers to population pressure has for the most part been to increase production through area expansion 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 (2.5 percent), with a dramatic increase in land clearing beginning in the mid 1980's (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).

While the move onto marginal lands may be an optimal strategy for farmers in the short run, the environmental consequences of this practice may grow large over time: marginal lands serve an important role in these eco-systems as natural barriers to wind and water erosion through their vegetative covering (Vierich and Stoop, 1990). Higher quality lands lower on the toposequence are subjected to higher erosion rates and yields from soil degradation are expected to fall faster as more marginal land is brought into production.

When viewed from a broader societal perspective, therefore, choices made by farmers might result in large social costs and reduced food security. However, with proactive policy engagement, the corresponding social costs from increased land pressure can be reduced. This would amount to enacting mitigation policies that would provide incentives to farmers to adopt more environmentally savvy land management practices.

Important socio-economic factors have been identified that explain why farmers often employ poor land management practices that, over time, accelerate environmental degradation. These factors include the connections between poverty and soil degradation (Reardon and Vosti, 1995), the effect of poor agricultural policies 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 degradation¹ are primarily rooted in liquidity constraints that make agricultural investments difficult and pressing concerns to satisfy food subsistence needs and income targets that manifest into high discounting rates. In many countries, poor economic and agricultural policies have in way or another 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.

Although the literature associated with population and land pressure has long been associated with “dismal economics”, and more recently with “downward spirals” and “tragedy of the commons”, there are policy options available to mitigate resource degradation. Intensification and technological change have the potential to end cycles of poverty and to pull farmers out of the “downward spiral”. Even in the drier sorghum and millet areas, new technologies have been developed that have shown significant yield increases (Matlon 1990).

Although their use has been limited, it is likely that institutional factors and poor policies² explain the low adoption. With a reversal in pricing policies in favor of farmers the impacts of these technologies on food production and incomes could be large (Coulibaly et al. 1998).

A second policy alternative to mitigate soil degradation is to improve market infrastructure and increase cereal flows from the higher potential zones in the semi-humid areas to 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, and that 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, and substitute the food produced on the marginal lands³ with cereals purchased in the market.

[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.

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.

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 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 and land use change in smallholder farming effects 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). While the approach in this paper is similar to all of those, it most closely resembles Beaumont and Walker, and Lopez in that the focus is on how individual farmers make decisions, and the extent to which degradation costs are internalized.

This section establishes the links that are likely to exist between farmer's decision making and natural resource management. The focus is limited to the choice between land clearing and intensification, and how this is likely to be made from the present through the 2030 benchmark.

Private Costs

Although smallholder farmers throughout SSA have been found to make decisions according to multiple-objectives (Barnet et al., 1982), the most important objective to farmers is generally satisfying food subsistence needs. This is an extension of the safety-first method of risk analysis (Roy 1952), since household subsistence needs are satisfied before profit motives are considered. Although the priority farmers give to natural resource management objectives is less well understood, farmers that choose to satisfy food subsistence objectives over a long planning horizon implicitly assign a strong weight to resource management.

This simplified version of farmer's decision making, limited to food subsistence and profit maximizing objectives, is formalized in the following equations.

$$\text{Max.} \quad e^{-\beta t} \int_0^T \int_0^F (P_t Y_{\phi A t} - C_{\phi A t}) dA \quad (1)$$

$$\text{S.T.} \quad \int_0^F Y_{\phi A t} dA + B_t \geq e^{-\tau} HH \quad (2)$$

$$\frac{dY_{\phi A t}}{dt} = \alpha(F_{1-\tau}, E_{\phi A t}) Y_{\phi A t} \quad (3)$$

Equation 1 states that the farmer's objective is to maximize the present value of profits. The two decision variables in the model are the level of technology, ϕ , and the frontier, F . Production is assumed to be along an idealized slope that represents the change in soil quality that is associated with the topo-sequence's altitude, A . Yields, $Y_{\phi A t}$, 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 ($C_{\phi A t}$). Total profit is obtained by integrating along the slope from 0 to the end of the frontier, F .

Equation 2 is the food subsistence constraint, which requires that the farmer produce enough food to feed his family for an annual food demand, HH . One consequence of a fast growing population is the increased demand for food production. Since food demand is proportional to household size, its growth rate over time is taken to be r , the household growth rate.

Equation 3 describes how yields, Y , change over the course of time in response to erosion and nutrient depletion. The general form of this equation allows soil erosion caused by marginal land clearing to induce degradation on soils lower on the topo-sequence, since erosion at time t is given by the history of frontier expansion, $F(t-\tau)$. Yields depend on altitude (A) and technology (ϕ). An erosion vector (E) captures changes in soil depth and soil nutrient levels. Productivity is highest at the lowest end of the toposequence ($A=0$) where the heavier, alluvial soils are located, and along the slope soil quality declines as the altitude, A , is increased (Dalton 1996).

Degradation and Technology Choices

The idealized slope assumption contains all of the erosion costs within the confines⁴ of the farmer's own fields. Farmers are likely to internalize at least 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).

⁴ 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.

The influence of soil degradation on crop technology choices is apparent from the optimality conditions of the decision-making model:

Equation 4 is the FOC for the intensification parameter, f , which equates the marginal cost of increasing yields (through intensification) to $l_{1,t}$, the marginal cost of satisfying home production at time t . Equation 5 is the FOC associated with extensification, F , which equates the average cost of yields at the frontier plus the present value of increased food costs from degradation (D_t) to $l_{1,t}$, the marginal cost of satisfying home production.

As time progresses, the increase in household size places a larger demand on food subsistence requirements as stated by Equation (2). Here, the key issue is how the farmer responds, and whether he would choose to intensify his production through increasing f , or through expanding the frontier F . The farmer's response to population pressure depends upon three factors: (1) the yield response along the slope to intensification, (2) the cost of increasing yields from intensification relative to the absolute yields 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).

When these factors are considered, there is good reason to suspect that extensification would be the farmer's primary response. Intuitively, Equations 4 and 5 state that 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 is reasonable to expect that intensification would be limited to small areas lower on the topo-sequence where the response to intensification is greatest, and for production increases to be achieved by continued frontier expansion.

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.

EMPIRICAL MODEL/DATA

The theoretical model presented in the previous section is used as a basis for an empirical model of farmers' decision making, which includes additional socio-economic realities confronting farmers. One is the role that market purchases play in satisfying food subsistence. 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. Based upon this, the empirical model includes a cash constraint that limits the amount of food that can be purchased to 15 percent of the households subsistence level.

A second 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. In addition, land and labor constraints are also included in the empirical 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 operationalized 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, with the higher quality plots rationed to maintain some degree of equity. Using field observations, the prototypical farmer is taken to have three plots of the relatively high quality land (3 ha in each plot), with additional plots of marginal land (of size 3 ha) that can be introduced into his cropping system.

The transition of yields over time, as indicated by Equation 3, was obtained⁵ using EPIC, a biophysical crop production model. EPIC estimates yields based upon several biotic factors that include: soil layer profile, nutrient availability, soil moisture, temperature, and humidity. EPIC tracks soil erosion and the flow of soil nutrients over time. Erosion estimates were obtained for a thirty-five year period from 2000 to 2035. 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.

The prototypical household has a size of 26 persons in the base line, with an annual growth rate of 3 percent. 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). Travel time to the marginal fields was accounted for by increasing labor demand.

⁵ 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.

RESULTS

The empirical model is used to analyze three scenarios that encompass a thirty-five year simulation period (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. The planning period that is used by the prototypical farmer is varied⁶ from one to thirty-five years. The New Technology scenario considers changes in input costs to account for varying degrees of success in developing input distribution channels. In the model, all input costs required for intensification are increased at the start of the simulation, and then held there for the entire simulation period. The Market scenario considers the effect of lower long run food prices from improved market infrastructure. In all three scenarios, per-capita income available for food purchases and per-capita liquidity available for purchasing inputs remain constant⁷.

Baseline

In the Baseline scenario, 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, and would appear to be an acceleration of land clearing compared to the field observations from Burkina Faso that were noted above.

When farmers plan over a longer horizon of at least thirty years, land clearing is significantly reduced, and 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, and average increase in land clearing would be less than the growth in population.

With short planning horizons, therefore, extensification is more profitable since fresh stocks of nutrients appear to be “freely” available in the marginal lands, and much cheaper than replenishing nutrient stocks using chemical fertilizers on already cleared lands. Without considering future degradation costs, the effects of degradation only become apparent when it is too late, since degraded lands are much less responsive to intensification and take many years to be restored back to any semblance of their original conditions. Longer planning horizons include more of the future degradation costs that induce intensification early on in the planning horizon before degradation sets in, and at a time when new technology responds best. 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.

⁶ For instance, a five year planning period would be run consecutively seven times.

⁷ The discount rate, β , was found to have little effect on model outcomes since it was the food subsistence constraint that was the driving factor. For completeness, a discount rate of 10 percent was chosen.

New Technology Scenario

When the prototypical farmer has future expectations of increased access to new technology through lower input costs, land clearing practices were found to change only slightly. 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 by the short planning horizon that continues to view land clearing as the most profitable alternative, and fails to incorporate enough of the future degradation into present decision making.

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. For farmers with short planning horizons less than thirty years, the higher input prices would have little effect since these types of farmers hardly utilize purchased inputs.

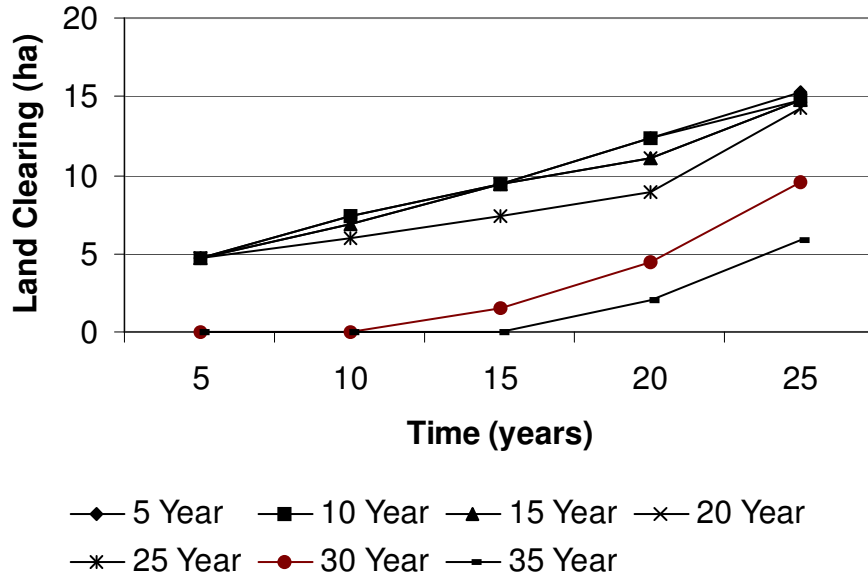


Figure 1 Land Clearing for Several Planning Horizons

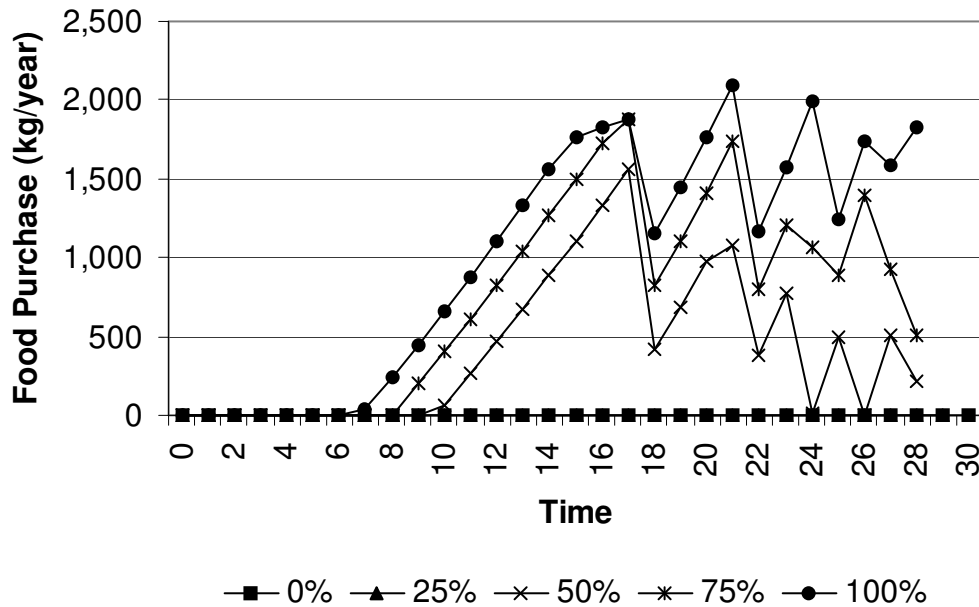


Figure 2 Food Purchases Under Influence of Higher Input Costs (35 Year Planning Horizon)

Market Scenario

When the prototypical farmer has future expectations of lower cereal prices, land clearing is only changed slightly⁸. 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 could 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,

⁸Model runs not reported in this paper showed less than a 65 percent change in land use among any of the planning horizons.

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.

CONCLUSIONS

The two major implications for policy makers is to find innovative ways to extend the scope of farmer's planning to include future degradation costs, as well as to provide efficient input markets to provide farmers with new technology before significant soil degradation is encountered. Extending farmers planning horizon won't 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.

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. One would be whether the supply response from the higher potential zone would maintain low food prices, affordable to consumers, and yet sufficiently high enough 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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